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CONVERSION OF UNITS OF LENGTH FROM THE CZECH STATE STANDARD TO THE GEODETIC BASELINE JAVORIV

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Abstract.

Modern society cannot do without high quality geospatial data. This need constantly strengthens with the growth of the information society and the emerging cyber society. Validity and quality of geospatial data is strongly connected to the level of its metrological service. It is necessary to conduct National metrological comparisons, in order to maintain an effective measuring infrastructure both inside a single country and in the whole Europe. The main result of such a comparison is a validation of actual values of key parameters of state standards.

The article presents results of a conversion of unit of length of the state standard of the Czech Republic to the geodetic baseline Javoriv (Ukraine), as performed by the staff of the Research Institute of Geodesy, Topography and Cartography (RIGTC). The conversion was realised in cooperation with Lviv Polytechnic National University (Ukraine). High-precision measuring equipment used during the conversion includes: the Leica AT401 laser tracker and the Leica Nova MS50 electronic total station.

A comparison of the measured length sections of the geodetic baseline Javoriv, performed by VUGTK employees, with the measurement results performed on a geodetic baseline Javoriv by specialists of the National Science Center (NSC) Institute of Metrology, gave a very good consistency. This is a sign of high quality results of comparative international measurement. It is planned to continue with the common efforts in the field of comparative international measurements between the Czech Republic and Ukraine in order to determine the actual values of the length sections of the geodetic baseline Javoriv.

Keywords: The geodetic baseline Koštice, the geodetic baseline Javoriv, the state standard of the Czech Republic, conversion of unit of length.

1. Introduction

Geospatial industry is a key factor of global economy and social sphere development [1]. This is due to the general trend of the post-industrial era, which implies strengthening of the virtual component of the emerging hybrid world, a significant part of which is geospatial data [2]. Active integration of European countries is being ensured thanks to geospatial data, and a single European research and development space is being created in this area [3].

As a result of constant integration, there is a pressing need for high-precision geospatial support for a whole range of tasks in the field of geodesy, cartography, construction, cadastre and many others [4–6]. At the same time, obtaining reliable high-precision geospatial data is directly related to the level of their metrological service. The quality and objectivity of which is established with the help of national metrological services, as well as responsible organizations conducting a metrological comparison of measuring instruments used for these purposes [7, 8].

To date, in the field of geodetic instrumentation technology, there is an obvious tendency associated with the increase in the production of new measuring instruments. In this regard, there is an obvious need for constant modernisation of reference complexes to ensure the uniformity of length measurement as well as for constant international metrological comparisons. To achieve this, the European Association of National Metrology Institutes (EURAMET) was established in 2007 within the European Union. This association develops and distributes an integrated, cost-effective, and internationally competitive measuring infrastructure for Europe [9].

The EURAMET development strategy until 2030 presents the main directions for the modernisation of Europe's measuring infrastructure, the key tasks that the organization solves, and the main mission of the organisation, which includes the following four key points [10]:

- to develop and maintain an appropriate, integrated, and cost-effective measurement infrastructure for

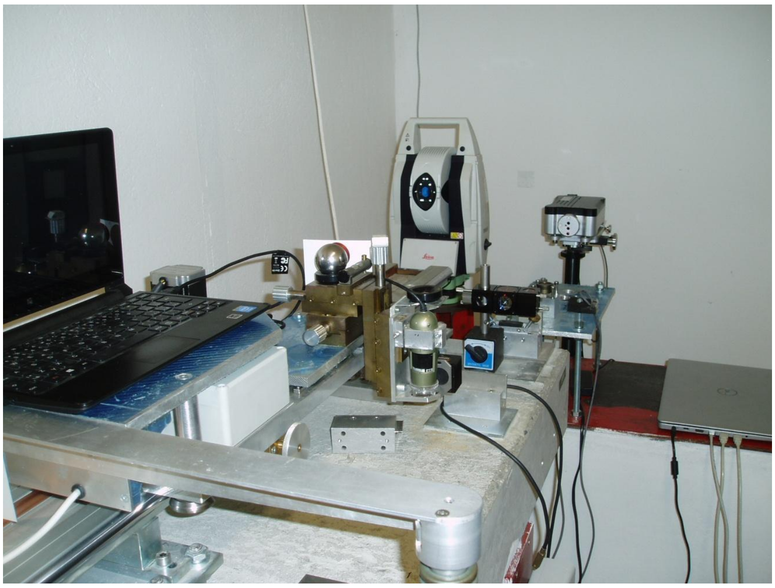

FIGURE 1. The laser interference comparator RIGTC.

Europe aligned to the needs of the society and industry;

- to ensure that the European measurement infrastructure is internationally competitive and recognised, and is based on a world-class R&D;
- to support policy and decision makers where metrology is the key;
- to support members of EURAMET in meeting their national requirements through collaboration and a balanced European measurement infrastructure.

EURAMET also includes RIGTC as a laboratory of the Czech Metrological Institute (CMI). Since 2006, RIGTC has been actively participating in length comparisons both inside and outside the Czech Republic. In April 2019, in the framework of a cooperation agreement with the National Lviv Polytechnic University (Ukraine), the first measurement for the conversion of unit of length of the State Standard to the Czech Republic on the geodetic baseline Javoriv (Ukraine) was performed. The measurements were completed in October 2021. This article presents the results of the conversion of unit of length of the state standard of the Czech Republic to the geodetic baseline Javoriv (Ukraine). The conversion was performed by employees of the RIGTK.

2. Materials and methods

2.1. Reference complex for ensuring the uniformity of length's measurements RIGTC

The reference complex for ensuring the uniformity of length's measurement consists of a thirty-meter laser interference comparator and the geodetic baseline Koštice [10]. The laser interference comparator is located in a separate air-conditioned laboratory; it is protected from noise, vibrations, and electromagnetic interference. The laboratory is equipped with a system maintaining a constant temperature and atmospheric pressure monitoring system. The comparator is equipped with a laser interferometer Renishaw XL-80, which allows calibrating geodetic measuring instruments with an error of $\pm(22 + 6 \cdot L\,(\mathrm{m}))$ (Figure 1).

The laser interferometer is the main standard of RIGTC and the main measuring and calibration equipment of the Institute.

2.2. The geodetic baseline Koštice (Czech Republic)

The geodetic baseline Koštice is located along the road Koštice – Libčeves. It was built between 1979 and 1980 near the Koštice village in Louny district (Figure 2). The geodetic baseline Koštice consists of 12 pillars established to the depth from 5 to 9 m, situated at distances from 25 to 1450 meters. The pillars are equipped with devices for forced centring. The standard uncertainty of determining the length sections ranges from ±0.3 mm to ±3.4 mm [11]. From 2008, the geodetic baseline Koštice is the Czech State Long Distances Measuring Standard.

2.3. The geodetic baseline Javoriv (Ukraine)

At present, the geodetic baseline Javoriv consists of 19 tubular metal pillars with a diameter of 200 mm established to the depth of up to 4 m. The total length of the baseline is approximately 2260 m. The pillars of the baseline protrude above the ground surface up to 1.3 m and end with a horizontal plate with a screw hole and a side oval cut-out in the pipe for an easy access to it. The precision of centring geodetic instruments is not less than 0.2 mm. The design of the construction is unique – it consists of a 10-meter phase section,

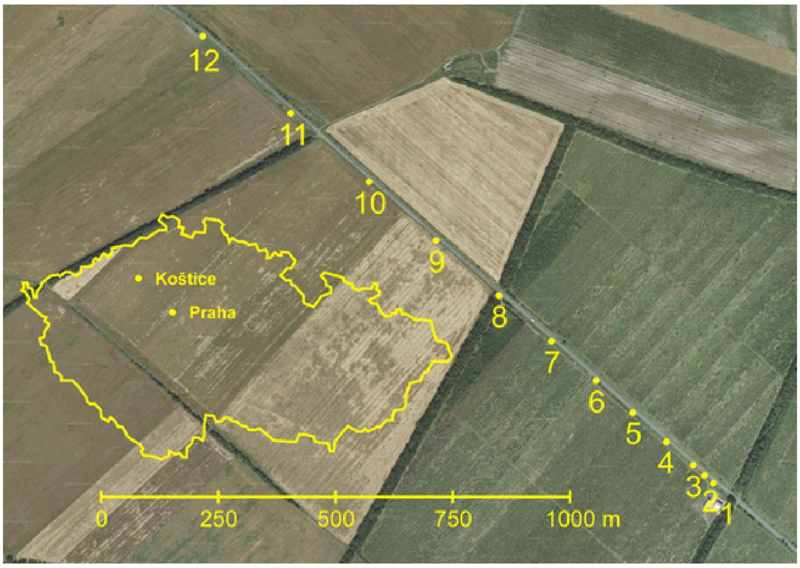

Figure 2. The schematic of the geodetic baseline Koštice.

fixed with points 1 m from pillar No. 4 to pillar No. 14. It allows us to determine the additive constant of any laser rangefinder, electronic total station, etc [12]. The general view of the geodetic baseline Javoriv is shown in Figure 3.

Metrological certification of the geodetic baseline Javoriv has been performed since 2003. The first metrological certification was carried out with a PLD-1M laser rangefinder (of an increased accuracy), and the subsequent ones were conducted with the help of precise electronic total stations and GNSS technologies (Table 1). The length sections of the geodetic baseline Javoriv were measured with a RMSE from 0.2 mm to 0.5 mm [13].

3. Results

In April 2019, on the geodetic baseline Javoriv, employees of the RIGTC performed measurements according to the program in all combinations from pillar 1 to pillar 14 using Leica AT401 laser tracker [14]. These measurements were performed in accordance with a cooperation agreement with the National Lviv Polytechnic University (Ukraine). Each baseline section was measured no less than 10 times. From ten measurements, the average value was calculated.

Before performing the measurements, the additive constants of the Leica AT401 laser tracker and the Leica RRR 1.5 spherical prism in the accredited metrological laboratory RIGTC were determined (Figure 4). It is necessary to determine the additive constant of the tracker-prism measuring system because this value is of the time-varying nature of this correction, in addition, depending on the spherical prism chosen, the additive constant of the tracker-prism measuring system will be different [15, 16].

The difference of the additive constant of the Leica AT401 laser tracker and the Leica RRR 1.5 spherical prism in the period between June 2011 and August

Figure 3. The General view of geodetic baseline Javoriv.

2021 is shown in Figure 5. The magnitude of the additive constant change, in micrometres along the y-axis, is shown.

No	Year of measurements	Instrument
1	2003	PLD-1M (laser rangefinder)
2	2006	Trimble 5700 (receivers GPS)
3	2006	Trimble 5601 DR-Standard (electronic total station)
4	2007	Trimble 5601 DR-Standard (electronic total station)
5	2009	Leica TCR1201+R400 (electronic total station)
6	2009	Trimble 5700 (receivers GPS)
7	2010	Trimble 5700 and Leica GX1230GG (receivers GNSS)
8	2011	Leica TM 30R (electronic total station) and Trimble S8 (electronic total station)
9	2011	Trimble 5700, Leica GX1230GG and Novatel DL-V3 (receivers GNSS)
10	2012	Leica TM 30R (electronic total station) and ET Trimble S8 (electronic total station)
11	2012	Trimble 5700 and Leica GX1230GG (receivers GNSS)
12	2013	Leica TCR1201 (electronic total station) and Trimble S8 (electronic total station)
13	2014	Trimble 5700, Trimble R7, Leica GX1230GG and South S82T (receivers GNSS)
14	2015	Trimble S8 (electronic total station)
15	2017	Trimble S8 (electronic total station)
16	2018	Trimble S8 (electronic total station)

Table 1. Metrological certification of the geodetic baseline Javoriv.

Figure 4. The accredited metrological laboratory RIGTC.

The contractual measurements were continued in October 2021 using the Leica Nova MS50 electronic total station. The measurements were performed according to the program in all combinations from pillar No. 1 to pillar No. 19. During the measurements, the temperature, pressure and relative humidity of the air at all pillars of the baseline using two different devices were recorded. After the measurements, atmospheric corrections and a constant of the Leica Nova MS50 electronic total station were added into each length section of the baseline.

The line lengths made by the Leica Nova MS50 electronic total station and the Leica AT401 laser tracker were compared at the accredited metrological laboratory RIGTC before the measurements. According to the results of the comparison, the RMSE in determining the differences was 0.19 mm.

The length sections of the geodetic baseline Javoriv collected from measurements of the Leica AT401 laser tracker, the Leica Nova MS50 electronic total station, and an assessment of their accuracy are shown in Table 2.

Measurements were not performed on the baseline section 1–4, because pillar No. 4 is damaged. In addition, it is necessary to additionally conduct control measurements with the Leica Nova MS50 electronic total station on the baseline sections 1–5 and 1–13 due to the problems with the centring of the reflector on the pillars No. 5 and No. 13.

The standard uncertainties given in Table 2 were calculated as follows

$$u_i = Q\left[a;\, b \cdot L_i(m)\right], \tag{1}$$

where:

- a standard uncertainty of the additive constant of the Leica AT 401 laser tracker or the Leica Nova MS50 electronic total station (type A uncertainty);
- b standard uncertainty of the multiplicative constant of the Leica AT401 laser tracker or the

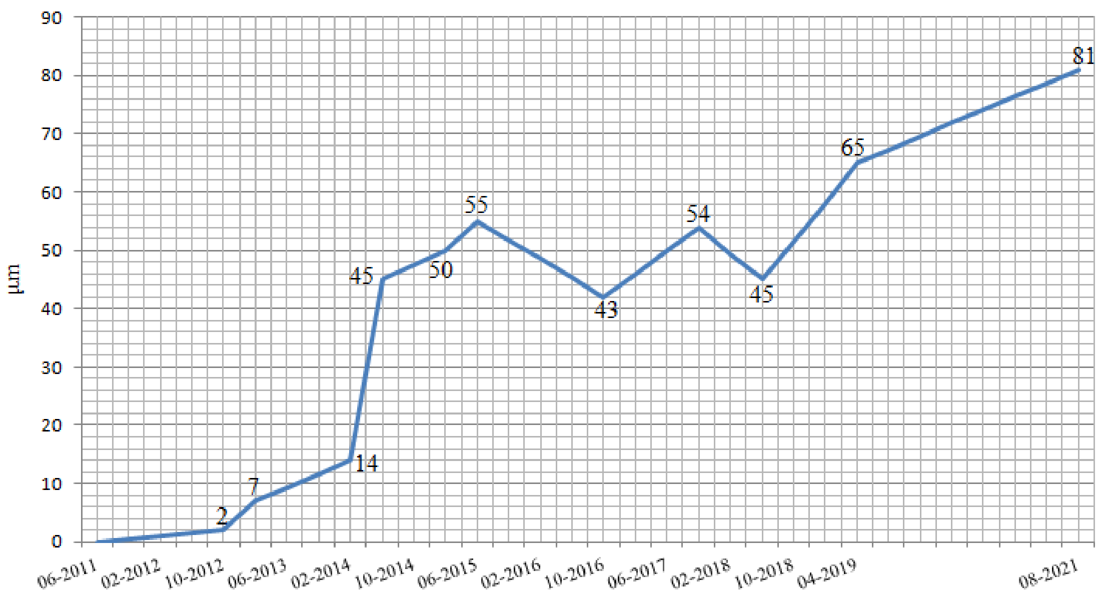

Figure 5. The difference of the additive constant of the Leica AT401 laser tracker and the Leica RRR 1.5 spherical prism in the period between June 2011 and August 2021.

Pillars	Length sections [m]		Standard uncertainty Leica AT401 [μm]	Standard uncertainty Leica Nova MS50 [mm]
	Leica AT401	Leica Nova MS50		
1–2	4.9822	4.9823	99	0.21
1–3	10.5331	10.5332	104	0.22
1–4	15.0297	–	108	–
1–5	16.0349	–	108	–
1–6	17.0345	17.0350	109	0.23
1–7	18.0298	18.0299	110	0.23
1–8	19.0254	19.0252	111	0.23
1–9	20.0284	20.0286	112	0.23
1–10	21.0212	21.0209	112	0.24
1–11	22.0232	22.0230	113	0.24
1–12	23.0208	23.0205	114	0.24
1–13	24.0203	–	115	–
1–14	25.0294	25.0292	116	0.24
1–15	–	129.6616	–	0.42
1–16	–	239.9904	–	0.61
1–17	–	589.3688	–	1.20
1–21	–	977.6581	–	1.86
1–20	–	2259.8946	–	4.04

Table 2. The length sections of the geodetic baseline Javoriv and their accuracy.

Leica Nova MS50 electronic total station (type B uncertainty);

L_i the measured length sections of the baseline (in meters);

Q quadratic sum of all partial uncertainties.

Standard uncertainties for the Leica AT401 laser tracker and the Leica Nova MS50 electronic total station were calculated based on the following documents [17–19]. The obtained values are given in Tables 3 and 4.

Quantity	Standard uncertainty	Unit	Probability distribution	Sensitivity coefficient	Uncertainty contribution $u_i(y)$	
					Additive constant	Scale correction
X_i	$u(x_i)$		i	c_i	[μm]	[μm/m]
Additive part of the uncertainty of the laser interferometer standard	0.01	μm	normal	1	0	–
Additive part of the uncertainty of the AT401	65.00	μm	normal	1	65	-
Multiplicative part of the uncertainty of the laser interferometer	0.22	μm/m	normal	1	–	0.22
Multiplicative part of the uncertainty of the AT401	0.70	μm/m	normal	1	–	0.70
Measurement uncertainty for temperature measurement accuracy	0.10	°C	normal	0.924	–	0.09
Air temperature change in the path of the air measuring beam	0.30	°C	normal	0.924	–	0.28
Measurement uncertainty for the accuracy of atmospheric pressure measurement	0.25	hPa	normal	0.271	–	0.07
Measurement uncertainty for determining of atmospheric pressure	0.50	hPa	normal	0.271	–	0.13
Measurement uncertainty for determining of the air humidity	5.00	%	normal	0.015	–	0.00
Effect of centering and horizontality of the CMM and RRR prism	50.00	μm	normal	1.4	70	–
Effect of uncertainty of cant determination	0.0471	μm/m	logarithmically normal	1	–	0.00
Uncertainty for straightening lengths to a straight line	0.00845	μm	logarithmically normal	1	0	–
Overall uncertainty u					**96**	**0.80**

Table 3. The uncertainty of the geodetic baseline Koštice in connection with Leica AT 401.

After, the length sections of the geodetic baseline Javoriv measured by the Leica AT401 laser tracker and the Leica Nova MS50 electronic total station were compared with the measurement results performed by specialists of the NSC Institute of Metrology (Ukraine) in 2003 using the PLD-1M laser rangefinder of increased accuracy (Table 5).

Based on the results of the comparison, the following conclusions can be drawn. The measured length sections of the geodetic baseline Javoriv using the Leica AT401 laser tracker and the Leica Nova MS50 electronic total station are generally consistent with the measurement results performed on the geodetic baseline Javoriv by specialists of the NSC Institute of Metrology (Ukraine), in 2003 using the PLD-1M laser rangefinder of increased accuracy.

In baseline section 1–3, measurement results contained differences that exceed the permissible values of the accuracy of determining the characteristics of the geodetic baseline Javoriv. This may be due to the fact that there may be individual shifts, which are most likely periodic in nature. In the baseline section 1–20, the maximum deviation from the measurement results performed by specialists of the NSC Institute of Metrology on a geodetic baseline Javoriv was obtained, which is 15.3 mm. It can be explained by the difficult observation conditions of this length section, namely the maximum temperature drop on the path of propagation of the electromagnetic signal, the high atmospheric turbulence at the time of the measurement and the influence of lateral refraction. In addition, this may be due to the instability

Quantity	Standard uncertainty	Unit	Probability distribution	Sensitivity coefficient	Uncertainty contribution $u_i(y)$	
					Additive constant	Scale correction
X_i	$u(x_i)$		i	c_i	[μm]	[μm/m]
Additive part of the uncertainty of the AT 401 standard	65	μm	normal	1	65	-
Additive part of the uncertainty of the MS 50 standard	170	μm	normal	1	170	-
Multiplicative part of the uncertainty of the AT401	0.75	μm/M	normal	1	-	0.75
Multiplicative part of the uncertainty of the MS50	2	μm/M	normal	1	-	2.00
Measurement uncertainty for temperature measurement accuracy	0.1	°C	normal	0.924	-	0.09
Air temperature change in the path of the air measuring beam	0.3	°C	normal	0.924	-	0.28
Measurement uncertainty for the accuracy of atmospheric pressure measurement	0.5	hPa	normal	0.271	-	0.13
Measurement uncertainty for determining of the air humidity	5	%	normal	0.015	-	0.08
Effect of centering and horizontality of the CMM and RRR prism	50	μm	normal	1.4	70	-
Effect of uncertainty of cant determination	0.0471	μm/m	logarithmically normal	1	-	0.00
Uncertainty for straightening lengths to a straight line	0.00845	μm	logarithmically normal	1	0.0	-
Overall uncertainty u					**195**	**1.70**

Table 4. The uncertainty of the geodetic baseline Koštice in connection with Leica MS 50.

of pillar No. 20, therefore, it is planned to repeat the measurement of baseline section 1–20.

4. Conclusion

A developing modern society cannot do without high-quality geospatial data. This need constantly strengthens with the growth of the information society and the emerging cyber society. As noted above, the reliability and quality of geospatial data is inextricably connected with the level of its metrological support. It is necessary to conduct National metrological comparisons, in order to maintain an effective measuring infrastructure both inside a single country and in the whole Europe. The main result of such a comparison is a validation of actual values of key parameters of state standards.

As part of the comparisons, the staff of the RIGTC conducted work on the conversion of unit of length of the state standard of the Czech Republic to the geodetic baseline Javoriv (Ukraine). When transmitting a unit of length, a high-precision measuring equipment was used: the Leica AT401 laser tracker and the Leica Nova MS50 electronic total station. As the result of comparing the measured length sections of the geodetic baseline Javoriv, performed by RIGTC employees, with the measurement results performed on a geodetic baseline Javoriv by specialists of the NSC Institute of Metrology, a good consistency of the measured data was obtained. This testifies the high quality of the international comparison and the stability of the baseline pillars.

The maximum deviations in the comparison results are obtained only for baselines 1–3 and 1–20. In baseline section 1–3, measurement results contained differences that exceed the permissible values of the accuracy of determining the characteristics of the geodetic baseline Javoriv. This may be due to the fact that there may be individual shifts, which are

Pillars	Length sections [m]			Difference [mm]		
	Leica MS50	Leica AT401	PLD-1M			
1	**2**	**3**	**4**	**2-3**	**3-4**	**4-2**
1–2	4.9823	4.9822	4.9816	-0.1	-0.6	-0.7
1–3	10.5332	10.5331	10.5285	-0.1	**-4.6**	**-4.7**
1–4	–	15.0297	15.0316	–	1.9	–
1–5	–	16.0349	16.0362	–	1.3	–
1–6	17.0350	17.0345	17.0344	-0.5	-0.1	-0.6
1–7	18.0299	18.0298	18.0287	-0.1	-1.1	-1.2
1–8	19.0252	19.0254	19.0241	0.2	-1.3	-1.1
1–9	20.0286	20.0284	20.0277	-0.2	-0.7	-0.9
1–10	21.0209	21.0212	21.0222	0.3	1.0	1.3
1–11	22.0230	22.0232	22.0215	0.2	-1.7	-1.5
1–12	23.0205	23.0208	23.0211	0.3	0.1	0.4
1–13	–	24.0203	24.0211	–	0.8	–
1–14	25.0292	25.0294	25.0294	0.2	0.0	0.2
1–15	129.6616	–	129.6612	–	–	-0.4
1–16	239.9904	–	239.9903	–	–	-0.1
1–17	589.3688	–	589.3680	–	–	-0.8
1–21	977.6581	–	977.6590	–	–	0.9
1–20	2259.8946	–	2259.9100	–	–	**15.3**

TABLE 5. The results of the comparison.

most likely periodic in nature. In the baseline section 1–20, the maximum deviation from the measurement results performed by specialists of the NSC Institute of Metrology on a geodetic baseline Javoriv was obtained, which is 15.3 mm. It can be explained by the difficult observation conditions of this length section, namely the maximum temperature drop on the path of propagation of the electromagnetic signal, the high atmospheric turbulence at the time of the measurement and the influence of lateral refraction. In addition, this may be due to the instability of pillar No. 20, therefore, it is planned to repeat the measurement of baseline section 1–20.

In the future, it is planned to continue the joint work in the field of comparative international measurements between the Czech Republic and Ukraine in order to determine the actual values of the length sections of the geodetic baseline Javoriv.

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