**EUROMET Supplementary Comparison, Project 677**

# Steel tape measures

# Final report

Wabern, Dezember 2004, R. Thalmann

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# 1 Introduction

The metrological equivalence of national measurement standards and of calibration certificates issued by national metrology institutes is established by a set of key and supplementary comparisons chosen and organized by the Consultative Committees of the CIPM and by the regional metrology organizations, respectively.

At its meeting in October 2002, the EUROMET TC Length decided to carry out a comparison for steel tape measurements, with the Swiss Federal Office of Metrology and Accreditation (METAS) as the pilot laboratory. The results of this international comparison will support the Calibration and Measurement Capabilities (CMCs) declared by the NMIs in the CIPM Mutual Recognition Arrangement (MRA).

# 2 Organisation

## 2.1 Conditions for participation

The participating laboratories were NMIs and required to fulfil the following conditions:

- signatory (or applicant) of the CIPM MRA;
- having submitted CMCs for steel tape calibration (or intending to do so soon);
- calibrating steel tapes for their customers as a regular service;
- being well trained in handling steel tapes without the risk to damage the tapes;
- being capable to measure at least the shortest tape (10 m) in one setting.

## 2.2 Participants

| Institute | Adress | Contact |
|---|---|---|
| METAS<br>**Coordinator** | Swiss Federal Office of Metrology and Accr.<br>Lindenweg 50<br>CH-3003 Bern-Wabern<br>Switzerland | Ruedi Thalmann<br>Tel. +41 31 323 33 85<br>Fax +41 31 323 3210<br>rudolf.thalmann@metas.ch |
| BEV | Bundesamt für Eich- und Vermessungswesen<br>Arltgasse 35<br>A-1160 Wien<br>Austria | Michael Matus<br>Tel. +43 1 49 110 540<br>Fax. +43 1 49 20 875<br>m.matus@metrologie.at |
| CEM | Centro Español de Metrologia<br>C/del Alfar ,2<br>28760 Tres Cantos, Madrid<br>Spain | Javier Bisbal<br>Tel. +34 91 807 4793<br>Fax. +34 91 807 4807<br>jbisbal@cem.es |
| CMI-VUGTK | Research Institute of Geodesy, Topography and Cartography (VUGTK), associated to Czech Metrology Institute<br>V botanice 4<br>15072 Praha 5<br>Czech Republic | Petr Balling<br>Tel. +420 2 5732 3089<br>Fax. +420 2 5732 8077<br>pballing@cmi.cz |
| GUM | Central Office of Measures<br>ul. Elektoralna 2<br>P.O. Box 10<br>00-950 Warszawa<br>Poland | Zbigniew Ramotowski<br>Tel. +48 22 620 54 38<br>Fax. +48 22 620 83 78<br>length@gum.gov.pl |
| INM - BRML | Institutul National de Metrologie<br>Sos. Vitan Barzesti 11<br>75669 Bucuresti<br>Romania | Gabriela Raissa Mocanu<br>Tel. +40 1 334 50 60/int.154<br>Fax. +40 1 334 53 45<br>mocanu@inm.ro |

| | | |
|---|---|---|
| JV | Justervesenet<br>Norwegian Metrology and Accreditation Ser-vice<br>Fetveien 99<br>N-2007 Kjeller<br>Norway | Helge Karlsson<br>Tel. +47 64 84 84 84<br>Fax. +47 64 84 84 85<br>helge.karlsson@justervesenet.no |
| LNMC | Latvian National Metrology Centre<br>157, K. Valdemara Str<br>LV - 1013 Riga<br>Latvia | Edite Turka<br>Tel. +371 7 362 086<br>Fax. +371 7 362 805<br>edite@lnmc.lv |
| MIKES | Centre for Metrology and Accreditation<br>Lönnrotinkatu 37<br>P.O. Box 239<br>FIN-00181 Helsinki | Antti Lassila<br>Tel. +358 9 6167 521<br>Fax. +358 9 6167 467<br>antti.lassila@mikes.fi |
| MIRS | Metrology Institute of Republic of Slovenia<br>Univ. of Maribor<br>Faculty of Mech. Engineering<br>Smetanova 17<br>2000 Maribor<br>Slovenia | Bojan Acko<br>Tel. +386 2 220 7581<br>Fax. +386 2 220 7990<br>bojan.acko@uni-mb.si |
| NMIA | National Measurement Institute<br>Bradfield Road, West Lindfield<br>PO Box 218<br>NSW 2070 Lindfield<br>Australia | Nick Brown<br>Tel. +612 8467 3509<br>Fax. +612 8467 3655<br>nick.brown@nmi.gov.au |
| NCM | National Centre of Metrology<br>52B G.M.Dimitrov Blvd<br>1797 Sofia<br>Bulgaria | Veselin Gavaljugov<br>Tel. +359 2 71 03 07<br>Fax. +359 2 71 70 50<br>ncm@sasm.orbitel.bg |
| OMH | Országos Mérésügyi Hivatal<br>XII Németvölgyi ut 37-39<br>H – 1535 Budapest, Pf.919<br>Hungary | Edit Bánréti<br>Tel. +36 1 4585 997<br>Fax. +36 1 4585 927<br>e.banreti@omh.hu |
| PTB | Physikalisch-Technische Bundesanstalt<br>Section 5.21<br>Bundesallee 100<br>D-38116 Braunschweig<br>Germany | Karl Meiners-Hagen<br>Tel. +49 531 592 5230<br>Fax. +49 531 592 5277<br>Karl.Meiners-Hagen@ptb.de |
| SMD | Metrologische Dienst<br>Koning Albert II laan 16<br>B-1000 Bruxelles<br>Belgium | Hugo Pirée<br>Tel. +32-2-206 4960<br>Fax. +32-2-206 57 45<br>hugo.piree@mineco.fgov.be |
| SP | Sveriges Provnings- och Forskningsinstitut<br>Box 857<br>S-50115 Borås<br>Sweden | Mikael Frennberg<br>Tel. +46 33 16 5486<br>Fax. +46 33 10 6973<br>mikael.frennberg@sp.se |

One more laboratory (VMT/VMC from Lithuania) was originally in the list of participants and performed also the measurements. Shortly after the measurements the laboratory has with-drawn its participation in this comparison due to technical reasons (wrong adjustment of the microscope).

### 2.3 Time schedule

The comparison was carried out in the form of a circulation. The tapes were measured at the beginning, in the middle and at the end of the circulation by the pilot laboratory in order to monitor the stability of the tapes.

With the exception of one change in order between two laboratories, the schedule could be kept exactly as planned in the protocol.

| Laboratory | Country | Date | |
|---|---|---|---|
| METAS | CH | Feb. 2003 | |
| SP | SE | 1.-25.March 2003 | 1st loop (old EU) |
| JV | NO | 26. March - 20. April 2003 | |
| MIKES | FI | 21. April – 15. May 2003 | |
| PTB | DE | 16. May – 10. June 2003 | |
| SMD | BE | 11. June – 5. July 2003 | |
| CEM | ES | August 2003 | |
| BEV | AT | September 2003 | |
| METAS | CH | October 2003 | |
| CMI-VUGTK | CZ | November 2003 | 2nd loop |
| GUM | PL | December 2003 | |
| LNMC | LV | January 2004 | |
| MIRS | SI | March 2004 | |
| NCM | BG | April 2004 | |
| OMH | HU | May 2004 | |
| INM - BRML | RO | June 2004 | |
| NMIA | AU | July 2004 | |
| METAS | CH | August 2004 | |

### 2.4 Transportation

The transportation of the devices was not critical. In most cases fast courier services were used. The ATA carnet, which was issued for the 2nd loop outside EU was handled correctly in all cases.

## 3 Description of the Standards

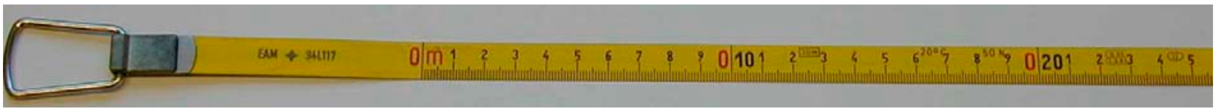
The package contained 3 steel tapes:

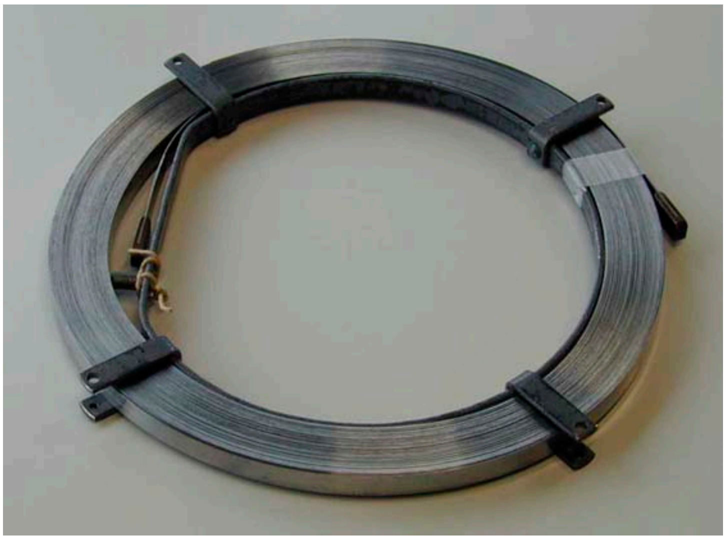
| Length | Width | Nominal load, therm. expansion | Identification | Material | Manufacturer, year | Line marks |
|---|---|---|---|---|---|---|
| 10 m | 13 mm | 50 N<br>$(11.5 \pm 1) \cdot 10^{-6}\ K^{-1}$ | EAM+94L195.4 | stainless steel | Richter, 1994 | etched |
| 30 m | 13 mm | 50 N<br>$(11.5 \pm 1) \cdot 10^{-6}\ K^{-1}$ | EAM+94L117 | steel, yellow painted | Richter, 1994 | painted |
| 50 m | 12 mm | **100 N**<br>$(11.7 \pm 1) \cdot 10^{-6}\ K^{-1}$ | 252 PTB 55 | steel | ?, 1955(?) | engraved |

Any further details may be taken from the photographs below:

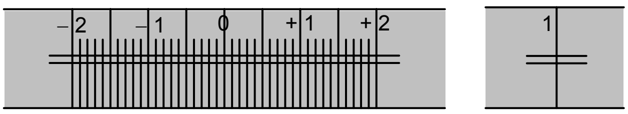

10 m tape


30 m tape





50 m tape


Drawing of line marks at 0 m and at 1 m

## 4 Measurement instructions

Each tape had to be calibrated in 10 regularly spaced intervals, i.e. in intervals of 1 m, 3 m, and 5 m for the tapes 10 m, 30 m, and 50 m, respectively. All the results were to be given starting from the origin (zero). For the 10 m and the 30 m tape, the lines had to be localized at nominally the border of the scale (usually taking into account the first approx. 3 mm of the lines). For the 50 m tape, the lines had to be localized in the middle of the tape, between the two longitudinal lines.

The tapes had to be calibrated in horizontal position, loaded by the nominal force (50 N or 100 N, respectively). Any deviation of this position or force had to be appropriately corrected. The measurement results had to be corrected to the reference temperature of 20°C using the thermal expansion coefficients indicated in chapter 3.

The measurement results, instrument descriptions and a detailed evaluation of the uncertainty of measurement have to be reported using forms given in the protocol. All results were transmitted electronically and – in addition – as a signed paper report.

## 5 Measurement equipment and methods used by the participants

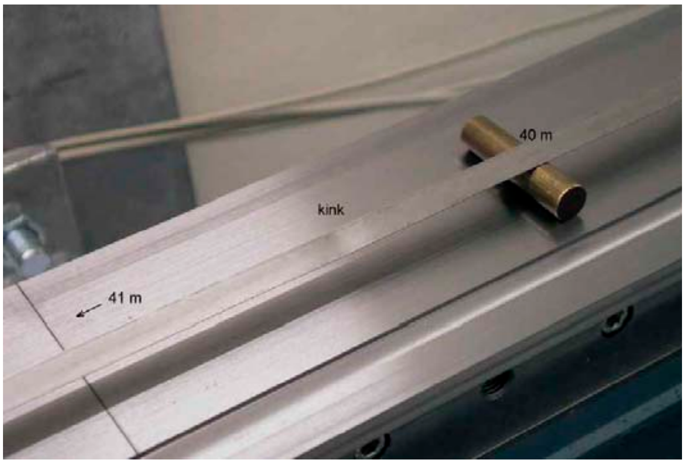
The participating laboratories gave a short description in their measurement report about the equipment and method used for tape calibration. These reports are given in Appendix 1. All laboratories used horizontal measurement benches, mostly built in house, of lengths varying between 3 m and 50 m. Most of the labs used a laser interferometer system for the length measurement, some use a reference tape. In the table below, the most important points are summarized:

| Lab | Bench length | Reference | Tape support | Scale mark localisation |
|---|---|---|---|---|
| BEV | 30 m | Laser interferometer | Multiple catenary on uniformly spaced (0.5 m) rollers | Visual microscope |
| CEM | 25 m | Laser interferometer | On flat granite surface | Video microscope |
| CMI-VUGTK | 30 m | Laser interferometer | Multiple catenary on uniformly spaced (1 m) cylinders | Microscope |
| GUM | 50 m | Laser interferometer | Multiple catenary on uniformly spaced (0.21 m) rollers | Video microscope |
| INM | 50 m | Laser interferometer | Flat on steel surface | Visual microscope |
| JV | 50 m | Laser interferometer | Flat aluminium profile with low friction, high slip, Teflon tape | Video microscope |
| LNMC | 20 m | 20 m steel tape | Flat | Visual microscope |
| METAS | 50 m | Laser interferometer | Flat aluminium profile with low friction, high slip, Teflon tape | Visual and photo-electric microscope |
| MIKES | 30 m | Laser interferometer | Multiple catenary on uniformly spaced (0.5 m) rollers | Video microscope |
| MIRS | 3 m | Laser interferometer | Multiple catenary on uniformly spaced (0.25 m) rollers | Video microscope |
| NCM | 24 m | Laser interferometer | Multiple catenary on uniformly spaced (0.5 m) rollers | Video microscope |

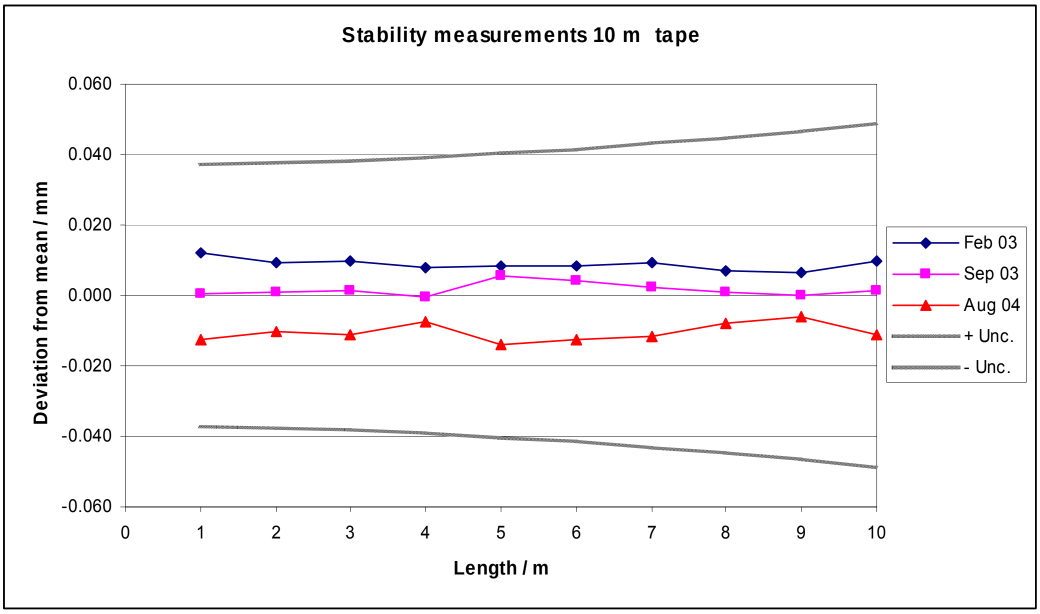
| | | | | |
|---|---|---|---|---|
| NMIA | 70 m | Laser interferometer | catenary at the measurement points | Video microscope |
| OMH | 15.5 m | Laser interferometer | Flat plastic plates, width 80 mm, spacing 100 mm | Video microscope |
| PTB | 50 m | Laser interferometer | Multiple catenary on uniformly spaced (0.4 m) rollers | Visual and photo-electric microscope |
| SMD | 10 m | Laser interferometer | Flat aluminum plates; rollers for relieving friction | Video microscope |
| SP | 50 m | reference steel tape | Multiple catenary on uniformly spaced (0.5 m) rollers | Visual microscope |

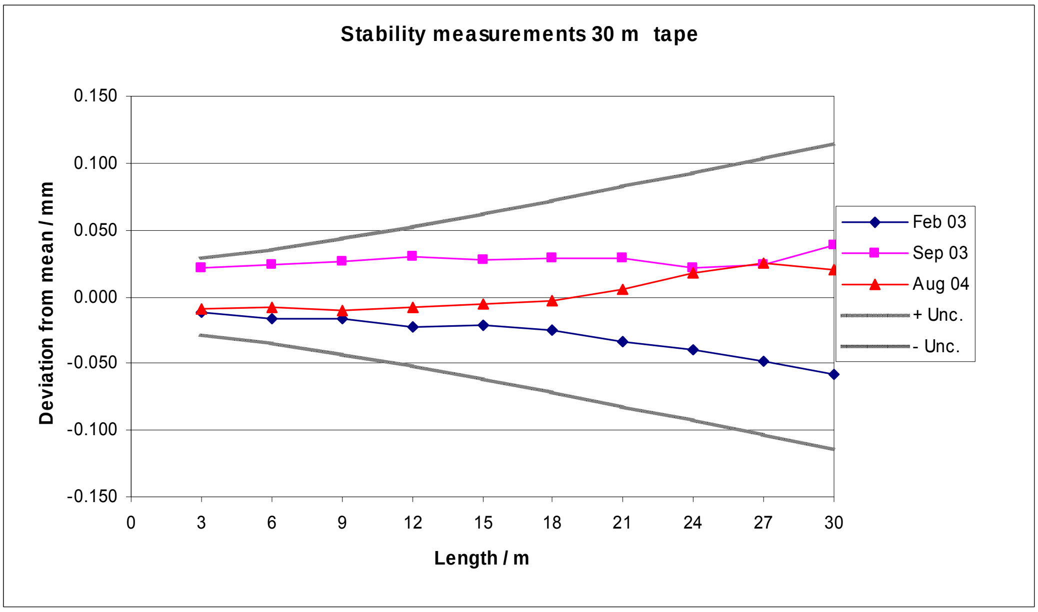
## 6 Stability of the measurement tapes

The stability of the three tapes has been monitored by the pilot laboratory with an initial, intermediate and final calibration. As can be seen from the graphs below (Figure 1), the measurements of the 50 m tape show variations larger than the expanded uncertainty, whereas the two shorter tapes seem to be perfectly stable. Of course, the pilot measurements are no proof of instability of the 50 m tape, however, the graphs with the measurements of the other labs show also a similar trend (see Apepndix 2). Possibly, the tape has been damaged (bent) somewhere before BEV's participation. BEV reported in September 2003 a kink in the tape between 40 m and 41 m (see Photo).




*Kink in the 50 m tape, as reported by BEV.*





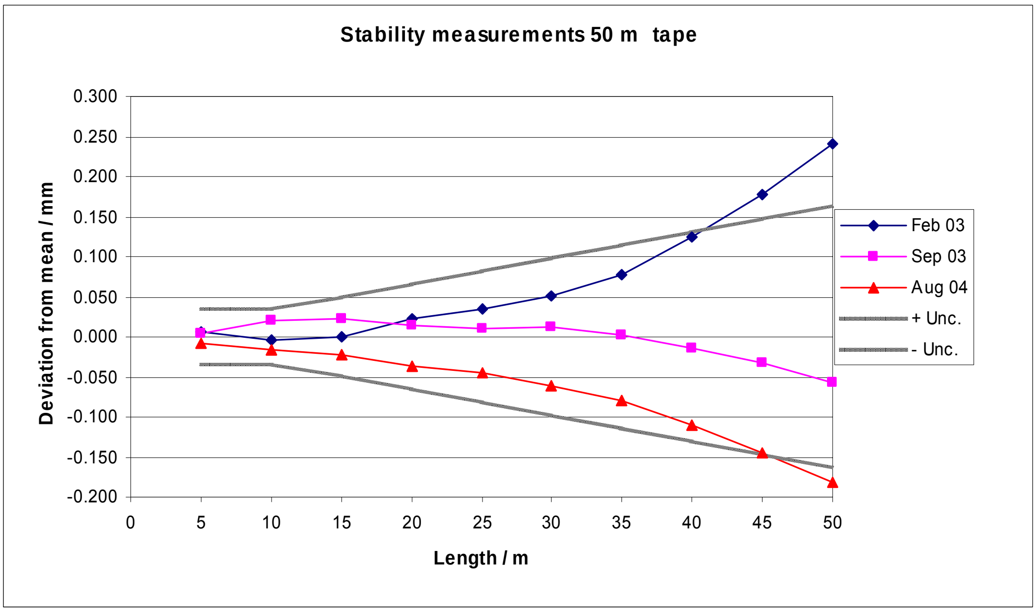




*Figure 1. Measurements of the pilot laboratory monitoring the stability of the 10 m, 30 m and 50 m tapes bound by the expanded measurement uncertainty of the initial calibration (Feb 2003). The curves represent deviations from the arithmetic mean of the three measurements.*

## 7 Measurement results

In the tables below, the measurement results and the expanded measurement uncertainties are given for all laboratories and the three tapes.

| NMI | Country | Calibration | 1 m | | 2 m | | 3 m | | 4 m | | 5 m | | 6 m | | 7 m | | 8 m | | 9 m | | 10 m | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | date | L / mm | U / mm | L / mm | U / mm | L / mm | U / mm | L / mm | U / mm | L / mm | U / mm | L / mm | U / mm | L / mm | U / mm | L / mm | U / mm | L / mm | U / mm | L / mm | U / mm |
| METAS | CH | 17.02.2003 | 1000.0576 | 0.037 | 2000.0141 | 0.038 | 2999.9654 | 0.038 | 3999.9083 | 0.039 | 4999.8748 | 0.040 | 5999.8709 | 0.042 | 6999.728 | 0.043 | 7999.7129 | 0.045 | 8999.6435 | 0.047 | 9999.6412 | 0.049 |
| SP | SE | 01.03.2003 | 1000.05 | 0.120 | 2000.01 | 0.121 | 2999.96 | 0.122 | 3999.91 | 0.124 | 4999.88 | 0.126 | 5999.9 | 0.129 | 6999.75 | 0.132 | 7999.73 | 0.136 | 8999.66 | 0.140 | 9999.68 | 0.144 |
| JV | NO | 27.03.2003 | 1000.014 | 0.045 | 1999.977 | 0.050 | 2999.933 | 0.055 | 3999.866 | 0.060 | 4999.833 | 0.065 | 5999.823 | 0.070 | 6999.687 | 0.075 | 7999.664 | 0.080 | 8999.597 | 0.085 | 9999.581 | 0.090 |
| MIKES | FI | 30.04.2003 | 1000.033 | 0.023 | 2000.003 | 0.023 | 2999.950 | 0.023 | 3999.899 | 0.023 | 4999.867 | 0.023 | 5999.871 | 0.023 | 6999.726 | 0.024 | 7999.713 | 0.024 | 8999.657 | 0.024 | 9999.653 | 0.024 |
| PTB | DE | 30.05.2003 | 1000.035 | 0.035 | 1999.994 | 0.035 | 2999.945 | 0.036 | 3999.887 | 0.036 | 4999.855 | 0.037 | 5999.846 | 0.038 | 6999.711 | 0.039 | 7999.691 | 0.040 | 8999.628 | 0.042 | 9999.622 | 0.043 |
| SMD | BE | 30.06.2003 | 1000.054 | 0.053 | 2000.046 | 0.053 | 2999.949 | 0.053 | 3999.916 | 0.054 | 4999.887 | 0.054 | 5999.918 | 0.054 | 6999.781 | 0.055 | 7999.729 | 0.056 | 8999.675 | 0.056 | 9999.672 | 0.057 |
| CEM | ES | 15.08.2003 | 1000.014 | 0.035 | 1999.961 | 0.035 | 2999.924 | 0.035 | 3999.854 | 0.036 | 4999.831 | 0.036 | 5999.819 | 0.036 | 6999.676 | 0.037 | 7999.666 | 0.037 | 8999.596 | 0.038 | 9999.582 | 0.038 |
| BEV | AT | 07.10.2003 | 1000.050 | 0.049 | 2000.007 | 0.049 | 2999.964 | 0.050 | 3999.912 | 0.050 | 4999.878 | 0.051 | 5999.875 | 0.052 | 6999.741 | 0.053 | 7999.730 | 0.054 | 8999.668 | 0.055 | 9999.681 | 0.057 |
| METAS 2 | CH | 29.09.2003 | 1000.046 | 0.034 | 2000.006 | 0.034 | 2999.957 | 0.035 | 3999.9 | 0.036 | 4999.872 | 0.037 | 5999.867 | 0.038 | 6999.721 | 0.039 | 7999.707 | 0.041 | 8999.637 | 0.042 | 9999.633 | 0.044 |
| CMI | CZ | 10.12.2003 | 1000.064 | 0.019 | 2'000.026 | 0.021 | 2'999.992 | 0.023 | 3'999.931 | 0.026 | 4'999.896 | 0.028 | 5'999.892 | 0.031 | 6'999.749 | 0.033 | 7'999.726 | 0.036 | 8'999.658 | 0.038 | 9'999.631 | 0.041 |
| GUM | PL | 10.01.2004 | 1000.033 | 0.026 | 1'999.986 | 0.027 | 2'999.942 | 0.029 | 3'999.882 | 0.031 | 4'999.854 | 0.033 | 5'999.851 | 0.035 | 6'999.713 | 0.038 | 7'999.700 | 0.041 | 8'999.637 | 0.044 | 9999.636 | 0.048 |
| LNMC | LV | 23.01.2004 | 999.998 | 0.087 | 1999.967 | 0.088 | 2999.929 | 0.091 | 3999.875 | 0.094 | 4999.844 | 0.098 | 5999.854 | 0.104 | 6999.691 | 0.109 | 7999.69 | 0.115 | 8999.642 | 0.122 | 9999.704 | 0.129 |
| MIRS | SI | 16.03.2004 | 1000.042 | 0.035 | 1999.992 | 0.042 | 2999.932 | 0.049 | 3999.876 | 0.056 | 4999.833 | 0.063 | 5999.809 | 0.070 | 6999.668 | 0.077 | 7999.645 | 0.084 | 8999.576 | 0.091 | 9999.559 | 0.098 |
| NCM | BG | 15.04.2004 | 1000.071 | 0.068 | 2000.025 | 0.069 | 2999.974 | 0.070 | 3999.926 | 0.072 | 4999.899 | 0.074 | 5999.882 | 0.077 | 6999.747 | 0.080 | 7999.737 | 0.083 | 8999.692 | 0.087 | 9999.684 | 0.091 |
| OMH | HU | 15.05.2004 | 1000.06 | 0.084 | 1999.98 | 0.093 | 2999.94 | 0.108 | 3999.86 | 0.125 | 4999.82 | 0.144 | 5999.82 | 0.165 | 6999.66 | 0.186 | 7999.7 | 0.208 | 8999.62 | 0.230 | 9999.59 | 0.253 |
| INM - BRML | RO | 15.06.2004 | 1000.05 | 0.061 | 1999.97 | 0.064 | 2999.94 | 0.068 | 3999.87 | 0.074 | 4999.82 | 0.081 | 5999.82 | 0.089 | 6999.67 | 0.098 | 7999.65 | 0.107 | 8999.61 | 0.116 | 9999.59 | 0.125 |
| NMIA | AU | 15.07.2004 | 1000.021 | 0.014 | 1999.974 | 0.014 | 2999.925 | 0.015 | 3999.867 | 0.016 | 4999.835 | 0.017 | 5999.827 | 0.018 | 6999.694 | 0.019 | 7999.677 | 0.020 | 8999.621 | 0.021 | 9999.611 | 0.023 |
| METAS 3 | CH | 01.09.2004 | 1000.0327 | 0.034 | 1999.9949 | 0.034 | 2999.9442 | 0.035 | 3999.8931 | 0.035 | 4999.8524 | 0.036 | 5999.8502 | 0.037 | 6999.7069 | 0.038 | 7999.6978 | 0.039 | 8999.6311 | 0.040 | 9999.6202 | 0.042 |

*Table 1. Measurement results for 10 m stainless steel tape and expanded measurement uncertainties (k = 2), as reported by the laboratories.*

| NMI | Country | Calibration | 3 m | | 6 m | | 9 m | | 12 m | | 15 m | | 18 m | | 21 m | | 24 m | | 27 m | | 30 m | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | date | L / mm | U / mm | L / mm | U / mm | L / mm | U / mm | L / mm | U / mm | L / mm | U / mm | L / mm | U / mm | L / mm | U / mm | L / mm | U / mm | L / mm | U / mm | L / mm | U / mm |
| METAS | CH | 11.02.2003 | 3000.6876 | 0.029 | 6000.9728 | 0.035 | 9001.347 | 0.043 | 12001.813 | 0.052 | 15002.192 | 0.062 | 18002.599 | 0.072 | 21003.012 | 0.082 | 24003.427 | 0.093 | 27003.807 | 0.103 | 30004.151 | 0.114 |
| SP | SE | 01.03.2003 | 3000.67 | 0.122 | 6001.01 | 0.129 | 9001.37 | 0.140 | 12001.86 | 0.154 | 15002.25 | 0.170 | 18002.68 | 0.187 | 21003.1 | 0.206 | 24003.56 | 0.226 | 27003.95 | 0.247 | 30004.28 | 0.268 |
| JV | NO | 28.03.2003 | 3000.67 | 0.055 | 6000.956 | 0.070 | 9001.332 | 0.085 | 12001.793 | 0.100 | 15002.157 | 0.115 | 18002.547 | 0.130 | 21002.954 | 0.145 | 24003.381 | 0.160 | 27003.761 | 0.175 | 30004.112 | 0.190 |
| MIKES | FI | 30.04.2003 | 3000.708 | 0.047 | 6001.011 | 0.049 | 9001.398 | 0.052 | 12001.873 | 0.056 | 15002.27 | 0.061 | 18002.689 | 0.067 | 21003.11 | 0.073 | 24003.551 | 0.079 | 27003.941 | 0.086 | 30004.308 | 0.093 |
| PTB | DE | 30.05.2003 | 3000.669 | 0.047 | 6000.963 | 0.049 | 9001.341 | 0.053 | 12001.824 | 0.058 | 15002.204 | 0.064 | 18002.622 | 0.071 | 21003.041 | 0.078 | 24003.474 | 0.085 | 27003.869 | 0.093 | 30004.223 | 0.101 |
| SMD | BE | 30.06.2003 | 3000.655 | 0.054 | 6001.014 | 0.055 | 9001.386 | 0.056 | 12001.878 | 0.079 | 15002.235 | 0.082 | 18002.665 | 0.087 | 21003.061 | 0.103 | 24003.506 | 0.105 | 27003.924 | 0.108 | 30004.26 | 0.113 |
| CEM | ES | 15.08.2003 | 3000.662 | 0.045 | 6000.938 | 0.045 | 9001.314 | 0.047 | 12001.782 | 0.048 | 15002.137 | 0.050 | 18002.545 | 0.052 | 21002.943 | 0.055 | 24003.359 | 0.057 | 27003.733 | 0.073 | 30004.054 | 0.073 |
| BEV | AT | 07.10.2003 | 3000.693 | 0.050 | 6000.975 | 0.052 | 9001.355 | 0.055 | 12001.831 | 0.060 | 15002.203 | 0.065 | 18002.619 | 0.071 | 21003.035 | 0.077 | 24003.462 | 0.084 | 27003.847 | 0.091 | 30004.201 | 0.098 |
| METAS 2 | CH | 01.10.2003 | 3000.721 | 0.033 | 6001.014 | 0.037 | 9001.39 | 0.043 | 12001.866 | 0.050 | 15002.241 | 0.057 | 18002.652 | 0.065 | 21003.074 | 0.073 | 24003.488 | 0.082 | 27003.879 | 0.091 | 30004.248 | 0.100 |
| CMI | CZ | 10.12.2003 | 3'000.683 | 0.022 | 6'000.970 | 0.029 | 9'001.316 | 0.037 | 12'001.764 | 0.044 | 15'002.105 | 0.052 | 18'002.510 | 0.059 | 21'002.922 | 0.067 | 24'003.320 | 0.074 | 27'003.703 | 0.082 | 30'004.013 | 0.089 |
| GUM | PL | 10.01.2004 | 3'000.674 | 0.030 | 6'000.957 | 0.039 | 9'001.348 | 0.050 | 12'001.815 | 0.063 | 15'002.194 | 0.077 | 18'002.599 | 0.090 | 21'003.013 | 0.104 | 24'003.439 | 0.118 | 27003.812 | 0.132 | 30004.181 | 0.146 |
| LNMC | LV | 23.01.2004 | 3000.639 | 0.091 | 6000.964 | 0.104 | 9001.354 | 0.122 | 12001.842 | 0.144 | 15002.228 | 0.168 | 18002.643 | 0.193 | 21002.921 | 0.219 | 24003.358 | 0.246 | 27003.756 | 0.273 | 30004.202 | 0.301 |
| MIRS | SI | 16.03.2004 | 3000.682 | 0.036 | 6000.95 | 0.051 | 9001.317 | 0.067 | 12001.772 | 0.082 | 15002.118 | 0.098 | 18002.515 | 0.114 | 21002.917 | 0.129 | 24003.315 | 0.145 | 27003.668 | 0.160 | 30004.058 | 0.176 |
| NCM | BG | 15.04.2004 | 3000.664 | 0.070 | 6000.967 | 0.077 | 9001.387 | 0.087 | 12001.902 | 0.099 | 15002.285 | 0.113 | 18002.703 | 0.128 | 21003.118 | 0.143 | 24003.576 | 0.159 | 27003.99 | 0.176 | 30004.346 | 0.192 |
| OMH | HU | 15.05.2004 | 3000.69 | 0.108 | 6000.96 | 0.165 | 9001.34 | 0.230 | 12001.84 | 0.299 | 15002.14 | 0.369 | 18002.49 | 0.367 | 21002.94 | 0.388 | 24003.26 | 0.420 | 27003.64 | 0.461 | 30003.88 | 0.509 |
| INM - BRML | RO | 15.06.2004 | 3000.69 | 0.068 | 6000.98 | 0.089 | 9001.38 | 0.116 | 12001.87 | 0.145 | 15002.22 | 0.176 | 18002.66 | 0.207 | 21003.05 | 0.239 | 24003.48 | 0.271 | 27003.91 | 0.303 | 30004.25 | 0.335 |
| NMIA | AU | 15.07.2004 | 3000.682 | 0.016 | 6000.966 | 0.020 | 9001.358 | 0.025 | 12001.836 | 0.031 | 15002.203 | 0.037 | 18002.63 | 0.044 | 21003.046 | 0.050 | 24003.476 | 0.057 | 27003.872 | 0.064 | 30004.224 | 0.070 |
| METAS 3 | CH | 01.09.2004 | 3000.691 | 0.028 | 6000.9822 | 0.031 | 9001.3538 | 0.036 | 12001.828 | 0.042 | 15002.208 | 0.048 | 18002.62 | 0.055 | 21003.051 | 0.062 | 24003.484 | 0.069 | 27003.88 | 0.076 | 30004.229 | 0.084 |

*Table 2. Measurement results for 30 m steel tape and expanded measurement uncertainties (k = 2), as reported by the laboratories.*

| NMI | Country | Calibration date | 5 m | | 10 m | | 15 m | | 20 m | | 25 m | | 30 m | | 35 m | | 40 m | | 45 m | | 50 m | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $L$ / mm | $U$ / mm | $L$ / mm | $U$ / mm | $L$ / mm | $U$ / mm | $L$ / mm | $U$ / mm | $L$ / mm | $U$ / mm | $L$ / mm | $U$ / mm | $L$ / mm | $U$ / mm | $L$ / mm | $U$ / mm | $L$ / mm | $U$ / mm | $L$ / mm | $U$ / mm |
| METAS | CH | 14.02.2003 | 5000.04 | 0.034 | 10000.045 | 0.034 | 15000.036 | 0.050 | 20000.072 | 0.066 | 25000.098 | 0.082 | 30000.062 | 0.098 | 35000.069 | 0.114 | 40000.101 | 0.130 | 45000.091 | 0.147 | 50000.158 | 0.163 |
| SP | SE | 01.03.2003 | 5000.05 | 0.126 | 10000.08 | 0.144 | 15000.05 | 0.170 | 20000.09 | 0.200 | 25000.16 | 0.233 | 30000.09 | 0.268 | 35000.13 | 0.305 | 40000.16 | 0.342 | 45000.1 | 0.379 | 50000.18 | 0.418 |
| JV | NO | 30.03.2003 | 5000.048 | 0.039 | 10000.087 | 0.057 | 15000.083 | 0.079 | 20000.146 | 0.102 | 25000.172 | 0.126 | 30000.171 | 0.150 | 35000.187 | 0.174 | 40000.204 | 0.198 | 45000.205 | 0.223 | 50000.203 | 0.247 |
| MIKES | FI | 30.04.2003 | 5000.037 | 0.015 | 10000.059 | 0.017 | 15000.051 | 0.019 | 20000.109 | 0.021 | 25000.143 | 0.024 | 30000.127 | 0.027 | 35000.123 | 0.030 | 40000.144 | 0.034 | 45000.146 | 0.037 | 50000.147 | 0.041 |
| PTB | DE | 30.05.2003 | 5000.029 | 0.021 | 10000.054 | 0.030 | 15000.045 | 0.041 | 20000.106 | 0.053 | 25000.147 | 0.065 | 30000.136 | 0.077 | 35000.136 | 0.089 | 40000.151 | 0.101 | 45000.163 | 0.114 | 50000.171 | 0.126 |
| SMD | BE | 30.06.2003 | 4999.978 | 0.053 | 10000.02 | 0.058 | 14999.968 | 0.086 | 19999.966 | 0.094 | 24999.911 | 0.113 | 29999.858 | 0.121 | 34999.788 | 0.141 | 39999.743 | 0.147 | 44999.646 | 0.17 | 49999.551 | 0.18 |
| CEM | ES | 15.08.2003 | 4999.983 | 0.040 | 9999.995 | 0.042 | 14999.95 | 0.045 | 19999.932 | 0.050 | 24999.91 | 0.054 | 29999.804 | 0.067 | 34999.735 | 0.068 | 39999.671 | 0.070 | 44999.559 | 0.073 | 49999.431 | 0.077 |
| BEV | AT | 07.10.2003 | 5000.021 | 0.027 | 10000.045 | 0.037 | 15000.024 | 0.049 | 20000.024 | 0.061 | 25000.024 | 0.075 | 29999.957 | 0.088 | 34999.898 | 0.104 | 39999.851 | 0.118 | 44999.750 | 0.131 | 49999.636 | 0.145 |
| METAS 2 | CH | 03.10.2003 | 5000.038 | 0.037 | 10000.068 | 0.062 | 15000.059 | 0.090 | 20000.064 | 0.118 | 25000.074 | 0.147 | 30000.023 | 0.176 | 34999.992 | 0.204 | 39999.963 | 0.233 | 44999.88 | 0.262 | 49999.86 | 0.291 |
| CMI | CZ | 10.12.2003 | 5'000.001 | 0.019 | 9'999.986 | 0.032 | 14'999.910 | 0.045 | 19'999.900 | 0.058 | 24'999.834 | 0.071 | 29'999.749 | 0.084 | 34'999.659 | 0.097 | 39'999.581 | 0.110 | 44'999.428 | 0.123 | 49'999.328 | 0.136 |
| GUM | PL | 10.01.2004 | 5'000.012 | 0.057 | 10'000.017 | 0.072 | 14'999.992 | 0.092 | 19'999.949 | 0.114 | 24'999.956 | 0.137 | 29'999.883 | 0.161 | 34'999.820 | 0.186 | 39'999.765 | 0.210 | 44'999.620 | 0.235 | 49'999.507 | 0.260 |
| LNMC | LV | 23.01.2004 | 4999.999 | 0.098 | 9999.974 | 0.129 | 14999.883 | 0.168 | 19999.808 | 0.210 | 24999.827 | 0.255 | 29999.762 | 0.301 | 34999.641 | 0.347 | 39999.526 | 0.394 | 44999.365 | 0.440 | 49999.31 | 0.488 |
| MIRS | SI | 16.03.2004 | 4999.998 | 0.035 | 9999.98 | 0.060 | 14999.917 | 0.085 | 19999.856 | 0.110 | 24999.808 | 0.135 | 29999.693 | 0.160 | 34999.585 | 0.185 | 39999.476 | 0.210 | 44999.326 | 0.235 | 49999.191 | 0.260 |
| NCM | BG | 15.04.2004 | 5000.051 | 0.055 | 10000.109 | 0.076 | 15000.109 | 0.101 | 20000.165 | 0.129 | 25000.149 | 0.157 | 30000.075 | 0.186 | 35000.01 | 0.215 | 39999.972 | 0.244 | 44999.87 | 0.274 | 49999.807 | 0.304 |
| OMH | HU | 15.05.2004 | 4999.92 | 0.144 | 9999.84 | 0.253 | 14999.71 | 0.369 | 19999.43 | 0.379 | 24999.37 | 0.433 | 29999.28 | 0.509 | 34999.23 | 0.524 | 39999.13 | 0.564 | 44998.99 | 0.624 | 49998.83 | 0.632 |
| INM - BRML | RO | 15.06.2004 | 4999.94 | 0.081 | 9999.96 | 0.125 | 14999.88 | 0.176 | 19999.84 | 0.228 | 24999.87 | 0.281 | 29999.77 | 0.335 | 34999.65 | 0.390 | 39999.63 | 0.444 | 44999.51 | 0.499 | 49999.42 | 0.553 |
| NMIA | AU | 15.07.2004 | 5000.007 | 0.017 | 10000.006 | 0.024 | 14999.968 | 0.032 | 19999.957 | 0.040 | 24999.94 | 0.050 | 29999.862 | 0.059 | 34999.803 | 0.068 | 39999.74 | 0.077 | 44999.63 | 0.087 | 49999.517 | 0.096 |
| METAS 3 | CH | 01.09.2004 | 5000.0253 | 0.030 | 10000.033 | 0.062 | 15000.013 | 0.090 | 20000.012 | 0.118 | 25000.018 | 0.147 | 29999.949 | 0.176 | 34999.911 | 0.204 | 39999.867 | 0.233 | 44999.768 | 0.262 | 49999.735 | 0.291 |

*Table 3. Measurement results for 50 m steel tape and expanded measurement uncertainties (k = 2), as reported by the laboratories.*

## 7.1 Corrected results from JV

After an informal discussion between the pilot laboratory and JV in October 2003 concerning possible problems in JV's results, JV has submitted a new report with the following comment:

*I send you enclosed a new copy of the same report that I have sent you before. As you can see, I explained in detail under item Additional remarks what was the problem with the 30 m tape.*
*I also enclose in this e-mail my second measurement results for the 30 m tape, which I carried out the following day after the tape had been exposed to 5 kg weight for ca 26 hours.*
*The large discrepancy between these results on the 30 m tape, I expected was due to a permanent change in the tape because it was not stable. However, from the results from other labs that you showed to me at the Euromet meeting, JV is the only lab who had not complete control of this problem.*
*This means that we need to look more closely into the problem of such tapes. This problem might be connected to the fact that we have a flat teflon measurement surface, but it could also be that this particular type of tape just needs a long time for reaching a stable length when exposed to 5 kg force. In that case we would need to change our measurement procedure and let the tape relax for longer time than 1 hour. We will carry out this work before the end of this year, and I will send you our conclusions to this problem.*
*Regarding the friction to the flat teflon surface, this has been investigated earlier to not have any significant influence. We have measured that the force of 5 kg weight is transferred along the entire length of the tape.*
*What we will do in near future is to carry out an investigation for each type of tape we calibrate how much does this tape change with time under exposure of the required force. For our customers who use such low quality tapes, we will probably use a similar procedure with a short relaxation time, and rather quote a much higher uncertainty than our best measurement uncertainty. For this very low quality tape, the relaxation time will probably become the largest uncertainty component.*

The 2nd report of JV contains new values for the 30 m tape and modified uncertainties:

| old results | | new results | |
|---|---|---|---|
| *L* / mm | *U* / mm | *L* / mm | *U* / mm |
| 3000.607 | 0.033 | 3000.67 | 0.055 |
| 6000.843 | 0.042 | 6000.956 | 0.070 |
| 9001.18 | 0.053 | 9001.332 | 0.085 |
| 12001.612 | 0.066 | 12001.793 | 0.100 |
| 15001.957 | 0.079 | 15002.157 | 0.115 |
| 18002.331 | 0.093 | 18002.547 | 0.130 |
| 21002.691 | 0.107 | 21002.954 | 0.145 |
| 24003.082 | 0.121 | 24003.381 | 0.160 |
| 27003.439 | 0.136 | 27003.761 | 0.175 |
| 30003.724 | 0.150 | 30004.112 | 0.190 |

In the draft B report, the new results are used.

Comment from JV after draft A report:

*Our results clearly show that we have a problem with friction for low quality tapes, but for the high quality tape (see results for 50 m tape) our quite low uncertainties are well balanced. From this ILC we have learned that we need to have a better relaxation of the friction of lower quality tapes, and we will also increase uncertainty for lower quality tapes, which means most of our regular calibration work on tapes.*

*Prior to the measurements at JV, SP oiled all three tapes, in contradiction with the measurement instructions, which clearly states that tapes shall not be oiled or greased. All tapes were cleaned at JV, but it is likely that the 30 m tape had some residual oil on the tape which gave unusual high friction to the teflon surface of the measurement table. Residual oil on the tapes can occur when doing regular calibration work as well. We now use cylinders to raise the tape up from the table to avoid contact with the table when applying the measurement force to the tape.*

## 7.2 Corrected results from LNMC

After receipt of the draft A report, LNMC sent corrected results to the pilot together with the explanation, that at the time of the measurements, the existing calibration values for the reference tape were outdated and not reliable, and that for this reason no correction values for the reference tape had been used. In the meantime, the reference tape of LNMC was calibrated at METAS and it was therefore possible to apply these corrections to the measurement data of the comparison. The pilot has checked the original recordings of LNMC, the calibration certificates for the reference tapes and the corrections applied by LNMC for consistency. EUROMET TC Length agreed with the procedure to introduce the new values of LNMC in the results tables, as long as full transparency is given and the old values be reproduced in the report as well. The correlation between the new results of LNMC and the results of METAS, from where LNMC gets the traceability, was regarded to be a minor problem in view of the relatively large uncertainty stated by LNMC. In the table below, the old and new values as well as the calibration results of the reference tape of LNMC are given.

| | **old** | **new** | **corrections** |
|---|---|---|---|
| **10 m tape** | 999.98 | 999.998 | 0.013 |
| | 1999.97 | 1999.967 | -0.003 |
| | 2999.95 | 2999.929 | -0.021 |
| | 3999.91 | 3999.875 | -0.04 |
| | 4999.89 | 4999.844 | -0.051 |
| | 5999.93 | 5999.859 | -0.076 |
| | 6999.77 | 6999.691 | -0.082 |
| | 7999.78 | 7999.69 | -0.09 |
| | 8999.74 | 8999.642 | -0.096 |
| | 9999.79 | 9999.704 | -0.086 |
| **30 m tape** | 3000.66 | 3000.639 | -0.021 |
| | 6001.04 | 6000.964 | -0.076 |
| | 9001.45 | 9001.354 | -0.096 |
| | 12001.93 | 12001.842 | -0.088 |
| | 15002.31 | 15002.228 | -0.082 |
| | 18002.7 | 18002.643 | -0.057 |
| | 21002.94 | 21002.921 | -0.019 |
| | 24003.43 | 24003.358 | -0.072 |
| | 27003.87 | 27003.756 | -0.114 |
| | 30004.32 | 30004.202 | -0.118 |
| **50 m tape** | 5000.05 | 4999.999 | -0.051 |
| | 10000.06 | 9999.974 | -0.086 |
| | 15000.02 | 14999.883 | -0.137 |
| | 19999.98 | 19999.808 | -0.172 |
| | 25000.05 | 24999.827 | -0.223 |
| | 30000.02 | 29999.762 | -0.258 |
| | 34999.95 | 34999.641 | -0.309 |
| | 39999.87 | 39999.526 | -0.344 |
| | 44999.76 | 44999.365 | -0.395 |
| | 49999.74 | 49999.31 | -0.43 |

| **METAS certificate** |
|---|
| 1000.013 |
| 1999.997 |
| 2999.979 |
| 3999.96 |
| 4999.949 |
| 5999.924 |
| 6999.918 |
| 7999.91 |
| 8999.904 |
| 9999.914 |
| 10999.915 |
| 11999.912 |
| 12999.928 |
| 13999.907 |
| 14999.918 |
| 15999.921 |
| 16999.929 |
| 17999.943 |
| 18999.96 |
| 19999.968 |

*Original and revised results reported by LNMC as well as corrections applied to the originally reported results based on the new calibration values of the reference tape according to the METAS certificated of May 2004.*

### 7.3 Revised measurement uncertainty of MIKES for 30 m tape

After a first evaluation of the reference values in the draft A report, the results of MIKES showed for the 30 m tape En-values which were much larger than 1, mainly due to the small measurement uncertainties stated by MIKES. Due to the fact, that MIKES' uncertainties were considerably smaller than those of the other laboratories, their weight in the weighted mean reference values for the 30 m tape was considered to be too large. Consequently MIKES submitted a revised uncertainty budget (see comment below).
In draft B report, the revised uncertainty was thus used.

Originally stated uncertainty for 30 m tape: $U = [(17.1)^2 + (0.82\,L)^2]^{½}$ µm, $L$ in m
Revised uncertainty for 30 m tape: $U = [(46)^2 + (2.7\,L)^2]^{½}$ µm, $L$ in m

Comment from MIKES*:*
*The uncertainty of 30 m tape was increased from initial estimation. The reason was that it seems evident that uncertainty contributions of line quality and effects of friction were underestimated for this low quality tape.The tape had painted lines and surface. The contrast with MIKES' microscope with axial lightning was very bad. An auxiliary lamp was needed for line detection. The friction properties of the tape differ from typical steel tape. Different methods for supporting the tape change the detected line distance since tension is altered by varying friction forces.*

Comment from MIKES after draft B:
*Reference and En values for 30 m tape:*
*… The tension affects greatly the measured line distance. It is easy to have correct weight to do tension. The rest of the problem is to manage friction forces. Ideal case is zero friction at supports. In case of larger friction the result will always be shorter. This means that probability distribution is one-sided ie. biased. … CMI and CEM have relatively small uncertainties and short result for 30 m tape.*

*My conclusion is that the deviation of JV (initially), CMI and CEM with 30 m tape most likely -at least partially- come from worse friction properties of the tape i.e. their setup is more sensitive for friction of tape surface. This error component has also one-sided nature so it biases the reference value only to one direction. In order to have best possible reference value I propose that En criteria is used with 30 m tape.*
*First CMI, they had largest En for 30 m 1.88 and they have 3rd smallest uncertainty. It is justified to omit these results from reference value calculation (or ask them to reanalyse their uncertainty). They actually had problems with all tapes which might indicate that they also had some other systematic length dependent errors. Then CEM: they have flat support as JV which had problems with 30 m tape. After omitting CMI, En value of CEM approaches 2 and they actually have smallest uncertainty together with NMIA. So it is also justified to omit these results from reference value calculation (or ask them to reanalyse their uncertainty).*

*…After these changes I believe the reference values for 30 m are more correct.*

The pilot laboratory thinks that the arguments brought up by MIKES are to some extent reasonable and that indeed the reference value might improve. There is, however, no statistical nor physical argument to exclude just two labs for one of the tapes, without applying this procedure to the whole comparison. This in turn would be in contradiction to what has been decided at the EUROMET TC meeting. The pilot therefore decided to keep the reference value calculation as already presented in draft B, but to add the above comment from MIKES to make aware of any remaining problems which might be taken into account when reviewing CMCs based on the evidence given by this comparison.

## 8 Measurement uncertainties

The participants were asked to report detailed measurement uncertainty budgets evaluated according to the ISO Guide. In table 4, the majority of the contributions are summarized, as they have been reported by the participants for the 30 m tape.

| Description \ Laboratory | BEV | CEM | CMI | NMIA | GUM | INM | JV | LNMC | METAS | MIKES | MIRS | NCM | OMH | PTB | SMD | SP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Laser interf. fixed part / µm | 5.5 | 0.004 | 0.013 | | 0.03 | | | 5 | | | 0.01 | | | | 0.3 | 40 |
| LI prop. part / $10^{-6} \cdot l$ | 0.32 | 0.08 | 0.13 | 0.15 | 0.34 | 0.27 | 1 | 2.1 | 0.2 | 0.11 | 0.14 | 0.22 | 1 | 0.13 | 0.18 | 1 |
| Alignment / $10^{-6} \cdot l$ | | | | | 0.018 | 3 | | | 0.003 | | | | | | | |
| tape temperature / $10^{-6} \cdot l$ | 1.35 | 0.7 | 1.2 | 0.7 | 1.97 | 4 | 1.7 | 1.15 | 1.33 | 0.23 | 2.3 | 3 | 11.6 | 1.4 | 1 | 3.6 |
| CTE. / $10^{-6} \cdot l$ | 0.29 | 0.06 | 0.11 | 0.3 | 0.1 | 1 | 0.58 | 4.2 | 0.17 | 0.1 | 0.3 | 0.2 | 1 | 0.35 | 0.66 | 0.3 |
| Load / $10^{-6} \cdot l$ | 0.11 | 0.18 | 0.003 | 0.43 | | 1.6 | 1.15 | | 1.3 | 1.35 | | | 0.005 | | | 1.7 |
| Abbe error / µm | 5 | 11 | | | 1.2 | | 25 | | 9.5 | 3 | 0.13 | 15 | 8 | 1.5 | | |
| catenary correc. / $10^{-6} \cdot$ l | 0.02 | | | 0.5 | | | | | | 0.034 | | | | 0.27 | | |
| line mark definition / µm | 23 | 19.3 | 7 | 7 | 13 | 29 | 32 | 43 | 10 | 23 | 10 | 31 | 40 | 23 | 5.8 | 40 |
| $u_c$ fixed part /µm | 24 | 22 | 7 | 7 | 13 | 29 | 20 | 43 | 14 | 23 | 10 | 34 | 40 | 23 | 27 | 60 |
| $u_c$ prop. part / $10^{-6} \cdot l$ | 1.42 | 0.7 | 1.2 | 1.1 | 2.4 | 5.3 | 2.5 | 4.8 | 1.9 | 1.35 | 2.6 | 3.1 | 12 | 1.47 | 1 | 4 |

*Table 4: Summary of the most frequently reported measurement uncertainty contributions, taken from the uncertainty budgets reported by the participating laboratories for the 30 m tape. The gray lines contain fixed contributions in units of µm, the white lines contain length dependent contributions.*

| | |
|---|---|
| Laser interf. fixed part / µm | mainly resolution of reading. Contains also the fixed part of the reference tape calibration for those laboratories referring their measurements to a reference tape. |
| LI prop. part / $10^{-6} \cdot l$ | length dependent part, including frequency, index of refraction, dead path. Contains also the proportional part of the reference tape calibration for those laboratories referring their measurements to a reference tape. |
| Alignment / $10^{-6} \cdot l$ | cosine error |
| tape temperature / $10^{-6} \cdot l$ | calibration of temperature sensors, uncertainty of tape temperature measurement, temperature gradients in the tape. |
| CTE. / $10^{-6} \cdot l$ | uncertainty of the coefficient of thermal expansion of the tape used for correction to reference temperature. |
| Load / $10^{-6} \cdot l$ | Uncertainty of load force, friction of tape on support. |
| Abbe error / µm | uncompensated correction of Abbe errors of the measurement bench. |
| catenary correc. / $10^{-6} \cdot$ l | correction due to elongation of the tape when supported on catenary. |
| line mark definition / µm | reading scale marks with microscope, positioning, zero point setting, includes also type A evaluated repeatability. |
| $u_c$ | combined standard uncertainty, fixed and proportional part, as reported by the laboratories. Does not necessarily result from combining the contributions stated in the column above, since further contributions might be missing. |

## 9 Conclusions

This was the first international comparison of tape measures at a large scale. The agreement of the results was in general satisfactory. For most of the laboratories it was an important opportunity to validate their measurement instrumentation and procedure. It allowed to become aware of potential problems and to take corrective actions in changing the procedure. In particular the influence of friction of the tape on its support and thus an unpredictable contribution in the tape elongation due to the applied force was underestimated.

In spite of the good agreement of the measurement results, the consistency with the stated uncertainties was not satisfactory, which showed up in a relatively large number of En-values larger that 1, in most cases probably rather due to underestimated measurement uncertainties than avoidable errors of measurement. Therefore some laboratories might need to reconsider their uncertainty budget and try to get a better estimate of the influence quantities.

For the evaluation of the reference value, the weighted mean approach has been chosen, although the consistency check according to the procedure A of Ref. [1] failed in many cases. It was, however, estimated by the experts, that another – much more complicated – procedure for the evaluation of the reference value would not significantly change the reference value and thus not provide any additional information.

The author would like to thank Michel Degoumois from METAS for performing the initial and the subsequent calibrations of the tapes, PTB for giving the high quality 50 m tape for this comparison, and all the participants for the excellent cooperation and the valuable comments.

## 10 References

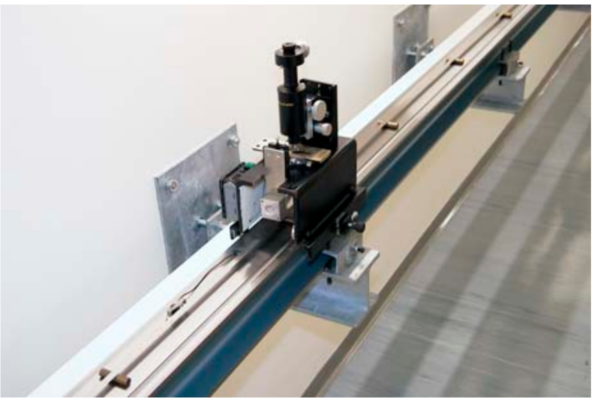
[1] M. G. Cox, The evaluation of key comparison data, *Metrologia* **39**, 589 – 595 (2002).

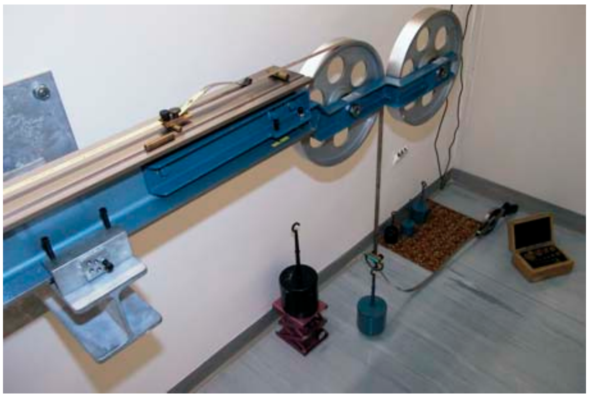
# 11 Appendix 1: Description of the laboratories' measurement equipment

## 11.1 BEV, Austria

### Short description of measurement bench

The bench is constructed of out of standard IPB120 steel beams with a flatness deviation of less than 0.1 mm (for each of the 5 m sections). They are mounted via adjustable corbels to the wall. The trolley carrying the microscope and the retroreflector is rolling on three ball bearings on the bench. The laser axis is 50 mm above the tape (Abbe principle not fulfilled). The whole instrument is located in an air conditioned room. The load is generated via weighing pieces.





### Length measurement instrument

HP 5529A Laser interferometer system with standard linear interferometer and Agilent 10751D air sensor.

### Principle of tape support

Multiple catenary on uniformly spaced (0.5 m) rollers. The correction to the reference condition (tape in horizontal position) were performed according to: C. B. Rosenberg et al., OIML Bulletin, **38**, Number 2, pp 25–29. This correction is virtually insignificant.

### Microscope for localization of scale marks

Visual microscope with a magnification of 20×. The ocular is equipped with a graticule of 2 parallel lines, the distance of which can be adjusted for the artifact to be measured. The scale marks are aligned between this two lines by eye in a symmetrical manner. The tapes are illuminated by a ring light made of white LEDs. This illumination is virtually shadow free.

**Temperature measurement system, number and location of sensors**

Three surface temperature sensors (Agilent 10757F) are evenly distributed on the bench near (but not touching) the tape. The temperature distribution has been analyzed by 8 additional surface sensors (TEMP12 by JENAer Messtechnik). It was found that the tape temperature is 0.04 °C higher than that measured by the Agilent-sensors, a correction of this amount was performed on all results. Moreover there are significant deviations from the mean temperature along the bench, this effect was not corrected but treated as an additional uncertainty component.

**Additional remarks**

To obtain an estimate for the definition of the scale marks, each tape was measured by three different observers, the standard deviation of this readings (assuming a Student's distribution) is taken for the corresponding standard uncertainty.

Each tape was mounted at least four times (reproducibility), both in normal and in inverted orientation (kind of averaging the temperature distribution).

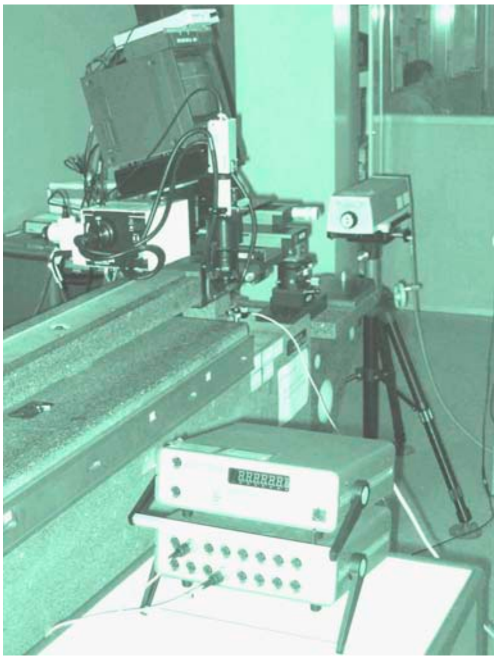
The 50 m tape had to be treated in two steps: first the intervals between the 0 m mark and the marks up to 30 m were determined, then the same procedure starting from the 20 m mark up to 50 m has been performed. This way three marks (20 m, 25 m, and 30 m) were treated twice. This two results are now joined in a way to minimize the joining errors. The mean error (10 µm in this case) is used as a constant uncertainty contribution for distances greater 30 m.

## 11.2 CEM, Spain

**Short description of measurement bench**

The granite measurement bench has a capacity of 25 metres. It has an upper railway on which a mobile device slips along. It also has a plane surface to extend the tape.

The mobile device has an illumination system through optical fiber, a CCD camera with zoom in order to vary the magnification, the interferometric corner cube and an XY displacement cross table with coarse and fine movements, to align the marks while moving corner cube.



**Length measurement instrument**

HP 5508A laser interferometer with fixed interferometer and movable corner cube.
Selected resolution: 1 µm.

**Principle of tape support**

Free standing of the tape on a flat granite surface. Fixing of the tape near the origin and applying of a mass or dynamometer in the opposite end.

**Microscope for localisation of scale marks**

The image appears on a monitor on which a digital reticle is electronically generated in order to make a good alignment of the line marks. Magnification used was: 25 X for the 10 m tape, 29 X for the 30 m tape and 30 X for the 50 m tape.

**Temperature measurement system, number and location of sensors**

Electronic thermometer manufactured by ASL (resolution 0,01 ºC) with three Pt 100 sensors. Measuring of the air temperature in three points located at the beginning, the middle and the end of the tape. Just in the middle of the tape, there was a Pt 100 contact sensor in order to measure the temperature of the tape.

## 11.3 CMI-VUGTK, Czech Republic

**Short description of measurement bench**

30 meter long measurement bench in the air-conditioned laboratory.

**Length measurement instrument**
laser interferometer HP 5519 A SN 3627A00792

**Princle of tape support**

Tape supports are in 1 meter (distance betwen tape supports)
Cylindrical head of tape support with ø = 35 mm

**Microscope for localisation of scale marks**

Microscope with double variability line. Microscope magnification = 10 x

**Temperature measurement system, number and location of sensors**

Digital thermometer TESTOTERM 5500 with probe 9955/611 (standard uncertainty 0,105°K)
Temperature measurement in distance 5 meter

## 11.4 NMIA, Australia

**Short description of measurement bench**

Described in an article in the Australian Surveyor, "A 70 metre Laser Interferometer for the calibration of survey tapes and EDM equipment" by P.E. Ciddor. K.H. Edensor, K.J. Loughry and H.M.P. Stock. June 1987, Vol 33, No.6. (Can send a pdf). Since this publication it has been automated.

Novel cube-corner reflectors place the measurement point at the apex of the reflector to avoid Abbe errors. The carriages are computer controlled and can be moved in 5 µm steps or driven as fast as the interferometer will allow.

**Length measurement instrument**
Comparison with laser interferometer

**Princle of tape support**

Supported in catenary at the measurement points with weights at each end

**Microscope for localisation of scale marks**

Video equipped microscopes are mounted on remote controlled carriages

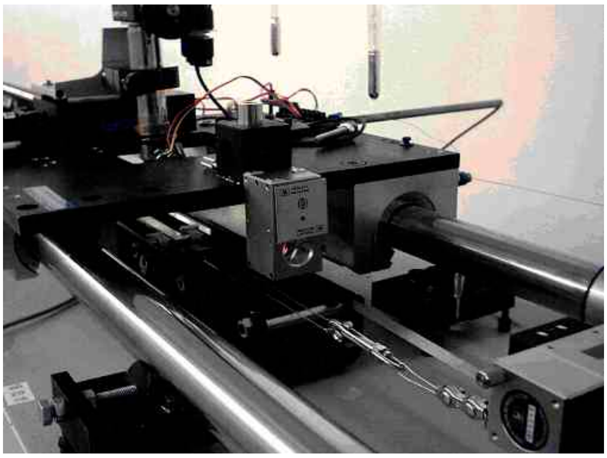
**Temperature measurement system, number and location of sensors**

Three thermometers for the 10 m tape, four thermometers for the 30 m tape and seven for the 50 m tape. They were mounted just below the tapes and spaced evenly along the tape. ..

## 11.5 GUM, Poland

**Short description of measurement bench**

The 50 m bench is housed in the corridor laboratory located in the basement and has its own air conditioning system. The base of the bench is made from steel channel bars each 3 m long and 400 mm wide. These are supported by 51 concrete piers. The rails are mounted on the top of channel bars. There are made from 3-metre length stainless steel rods about 40 mm in diameter. There are spaced 250 mm apart and are supported in saddles positioned every 500 mm which are adjustable laterally, in height and for lateral tilt. Between the rails there are a channel bars each 420 mm long and 80 mm wide running the length of the bench. This channel is used for mounting steel rods about 12 mm in diameter and spaced 212 mm apart on which tapes can be supported. Two ends of the tape are connected to a hanging weights by a wire. The wire passes over 300 mm diameter pulley wheels. The measuring carriage is carried microscope with CCD camera and the optics associated with



the interferometer. The carriage is driven using belt-transmission and electrical engine with remote – controlled variable speed drive.

**Length measurement instrument**

Laser interferometer HP 5529A with long-range option laser head HP 5519A

**Principle of tape support**

steel rods about 12 mm in diameter and spaced 212 mm apart

**Microscope for localisation of scale marks:**

optical microscopes with CCD camera; magnify of the observed line 110x

**Temperature measurement system, number and location of sensors:**

- five material temperature sensors type YSI with KEITHLEY multimeter; they are placed very close to the tape along its length,
- eleven mercury thermometers made by THERMOSCHNEIDER Karl Schneider & Sohn for air temperature are placed as close as possible to the laser beam in every measuring point
- $CO_2$ content was measured with analyser made by Intelli Charge, type SPN 4462A

## 11.6 INM-BRML, Roumania

**Short description of measurement bench**

The measurement bench is housed in a special room, located in the basement, with air conditioning system. The maximum spatial variation of the temperature along the bench is 1 ºC. The length of the bench is 50 m.

The base of the bench is a continuous ferroconcrete structure, equiped with steel horizontal flat surfaces, in steps of 2 m length, in which are incapsulated steel plates with lines measures of (-10... +10) mm, placed in steps of 0.5 m.

A carriage with an optical microscope and a He-Ne laser retroreflector is moving along two rails.

**Length measurement instrument**
Laser interferometer type Hewlett – Packard, model 5526 A.

**Principle of tape support**

A steel continuous baselines of the bench (surface contact on steel).

**Microscope for localisation of scale marks**

Optical microscope.

**Temperature measurement system, number and location of sensors**

For temperature measurement a system of six temperature sensors was used. The Hg thermometers with 0.2 ºC resolution there are placed at equal distances along the measuring tape length.

**Additional remarks**

The capture of the marks was realized as follows:

- according to the technical requirements protocol for 50 m long tape, namely in the middle of the mark (between the longitudinal lines scratched on the tape);
- in the aproximate middle of the long marks for 30 m long tape (tangential to the upper level of short marks);
- at 3 mm distance roughly from the base of marks for 10 m long tape.

We used the following values for math calculation:

- friction coefficient $\nu$ = 0.2
- cross section of tapes A = 2.766 mm$^2$ ( for 10 m long tape);
  A = 3.433 mm$^2$ (for 30 m long tape);
  A = 4.914 mm$^2$ (for 50 m long tape);
- Young's modululus E = 2,1.10$^5$ N / mm $^2$
- mass per unit length $\sigma$ = 2.12 ·10$^{-4}$ N/mm (for 10 m long tape);
  $\sigma$ = 1.98 ·10$^{-4}$ N/mm (for 30 m long tape);
  $\sigma$ = 3.78 ·10$^{-4}$ N/mm (for 50 m long tape);

During the measurements the maximum gradient of temperature (at the ends of tape) was 0,5 $^0$C.

## 11.7 JV, Norway

**Short description of measurement bench**

50 m bench. Low friction, high slip, Teflon tape. 5 kg mass gives 49,09 N stretching force on the tape.

**Length measurement instrument**
HP 5529 B laser interferometer, range 80 m.

**Princle of tape support**

Flat aluminium profile measurement table with low friction, high slip, Teflon tape.

**Microscope for localisation of scale marks**

Magnification 20 x. Manual micrometer localization of cross hairs on top of center of scale mark. Small lamp enlightens the scale marks from similar angle at all readings.

**Temperature measurement system, number and location of sensors**

HP integrated system, 3 Pt 100 sensors. Magnetic holders on the tape, localized at positions ca 1 m, ca 10 m and ca 21 m.

**Additional remarks**

U = Q[0,03; 0,0049 L] mm, L in m, is our best measurement capability expressed in quadratic form. For ordinary calibration service for customers, we quote a linear relationship for expanded measurement uncertainty: U = (0,04 + 0,005 L) mm, L in m.

The uncertainty of the measurements for 10 m and 30 m have been encreased to what is usually quoted for customers. The reason for this is that we have applied the same measurement procedure as for customers tapes. Only 50 m tape is a very high quality tape, so only this tape have been quoted to the best measurement uncertainty.

## 11.8 LNMC, Latvia

**Short description of measurement bench**

Made by wooden plate, 20 m long (see photo).

**Length measurement instrument**

The comparison is done with Reference standard steel tape 20 m long. It has engraved scale marks.

**Princle of tape support**

Manually on the bench with system of zero setting and equipment for force of tension.

**Microscope for localisation of scale marks**

The measuring device is microscope type MPB[cyrillic] with scale resolution 0,05 mm and magnification 24x.

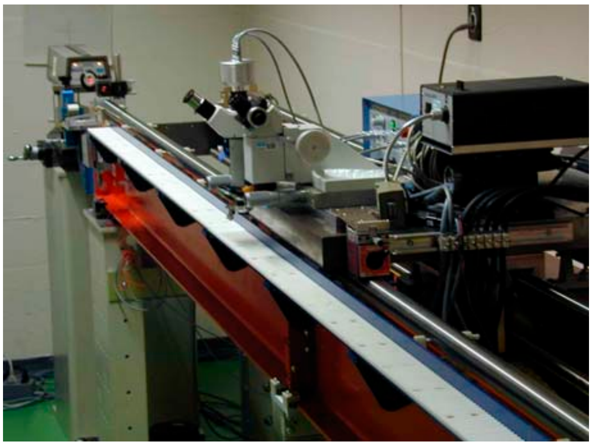
**Temperature measurement system, number and location of sensors**

There are enviromental conditional system in room. Temperature are measured by mercury termometers with scale resolution 0,1°C , located on the tapes near 2, 5, 9 meters

## 11.9 METAS, Switzerland

**Short description of measurement bench**

50 m bench with laser interferometer (see photo, detailed description in: Michel Degoumois, *Un Long laboratoire de mesure*, OFMETinfo Vol.5, No 2, 1998).



**Length measurement instrument**

HP 5529 B laser interferometer, range 80 m.

**Princle of tape support**

Flat aluminium profile measurement table with low friction, high slip, Teflon tape.

**Microscope for localisation of scale marks**

Photoelectric microscope (with double photo diode as detecting element) for good quality scale marks. Visual microscope for low contrast scale marks.

**Temperature measurement system, number and location of sensors**

10 thermistors regularly spaced along the measurement bench. For thermal expansion correction, the average temperature is used.

## 11.10 MIKES, Finland

**Short description of measurement bench**

MIKES has 30 m long interferometric measurement rail. It is situated in a temperature controlled laboratory room. Linear rail is based on two precision round guide bars. Microscope is attached at a carriage with bearings. Straightness of the bench is calibrated annually. Abbé offset is normally 28 mm. Abbé error is compensated with calibrated straightness data.

**Length measurement instrument**

As a reference we have a linear laser interferometer HP-5529A. Temperature of air is measured with 6 pt100 sensors and Systemteknik S1220 temperature meter. Air pressure and humidity are measured with Vaisala PTU200. Updated Edlén equation by Bönsch & Potulski is used for calculation of refractive index of air.

**Principle of tape support**

Steel rolls with bearings support the tape at 0,5 m intervals.

**Microscope for localisation of scale marks**

Microscope is UHL & objective 2,5/0,07 with CCD camera and monitor.  Light source is halogen lamb with coaxial lightning geometry. Line marks are centred with aid of a visible alignment line on monitor and micrometer driven fine position control. Then position of the microscope is recorded.

**Temperature measurement system, number and location of sensors**

Temperature is measured with 3-6 Pt100 sensors near the tape. Systemteknik 1220 with 4-wire scanner measures the temperatures and program calculates the corrections.

## 11.11 MIRS, Slovenia

### Short description of measurement bench

Zeiss ULM 3000 (3 m segments can be measured)

### Length measurement instrument

Laser interferometer Hewlet Packard HP 5528 A

### Principle of tape support

Tape was fixed at one end, at the other end stretched with a weight over a pulley; the tape was supported by cylinders of diameter 10 mm, which are 250 mm apart from each other

### Microscope for localisation of scale marks

Video system Renishaw VP 2 with co-ordinate cross generator (measured line is positioned between two adjustable reference lines an a monitor)

### Temperature measurement system, number and location of sensors

Provided with LI; 2 material sensors, put on the tape at both ends of the measured segment of the tape, 1 LI air sensor

## 11.12 NCM, Bulgaria

### Short description of measurement bench

24-meter comparator, moving carriage with mounted cube– corner retroreflector and CCD camera; Laser measuring system and measuring software.

### Length measurement instrument

HP 5528A laser interferometer, He-Ne laser at 633 nm.

### Principle of tape support

The tape under tension is placed horizontally and supported on cylindrical rollers $\phi$7 mm with distance between rollers 0,5 m.

### Microscope for localisation of scale marks

CCD camera for location of scale marks

### Temperature measurement system, number and location of sensors

3 Hg-thermometers with 0,2 °C resolution, regularly located over all tape length for measuring of tape temperature. 3 digital thermometers with 0,01 °C resolution, regularly located over all tape length for measuring of air temperature;

Hg pressure meter with resolution 0,1 mmHg; 2 digital hygrometers.

## 11.13 OMH, Hungary

### Short description of measurement bench


The bench length is 16,5 m and the measuring range is 15,5 m (photo).

The carriage consists of 2 parts, one of them is a motorised so called “big” carriage with adjustable velocity (done by a frequency changer) and a so called fine adjustable “little” carriage also motorised. The camera system is mounted on the little carriage.

### Length measurement instrument

Laser interferometer system with a type of IT40, made by a Hungarian firm called Optometria Ltd. You can see 2 laser-interferometers on the photo. One which is on the top is an older one and the second is a brand new that is the normal operating laser. This second was used in the EUROMET measurements.

### Princle of tape support

The “table” consists of plastic plates with a width of 80 mm and with a distance of 100 mm between. The material of these plates is sliding bearing plastic with good sliding feature.

There are 7 aligning parts – so called bumpers - on the whole distance fixed in aluminium profiles. These parts can be moved perpendicularly to the tape axis in order to align the tape.

### Microscope for localisation of scale marks

A CCD TV camera is used for the positioning. The camera system has an electronic unit having 2 parallel vertical lines on the display. These lines can be moved horizontally according to the width of the scale marks. There are 2 horizontal lines to help the alignment. The picture can be switched in to analog or digital picture.

### Temperature measurement system, number and location of sensors

Pt 100 sensors, 4 pieces for measuring of the material temperature (0; 5; 10 and 15 m) and 4 pieces for air temperature (0; 5; 10 and 15 m).
The uncertainty is 0,02 K (k=2).

**Additional remarks:** Standard tapes have to be measured 3 times according to the normal calibration procedure.

## 11.14 PTB, Germany

### Short description of measurement bench

50 m bench with He-Ne laser interferometer in nearly Abbe free configuration. Tape support on rollers with a distance of about 0,4 m. Refractive index of air is determined using the Edlen equation. The air temperature is measured by 21 sensors along the bench, the air pressure and humidity are measured at one position. The material temperature is measured with up to 21 sensors with are attached magnetically at the tape typically with a distance of

2,5 m. The lines can be detected either with a photoelectric microscope (automatic measurement) or with an optical microscope manually.

**Length measurement instrument**

He-Ne laser interferometer

**Princle of tape support**

Rollers with a distance of about 0,4 m

**Microscope for localisation of scale marks**

Photoelectric microscope for automatic measurement. Optical microscope for manual measurement.

**Temperature measurement system, number and location of sensors**

21 PT 100 sensors for air temperature along the bench, 2,5 m distance, 4 additional sensors for free placement.

21 PT 100 sensors for material temperature, magnetically attached to the tape in 2,5 m distance, 4 additional sensors for free placement.

**Additional remarks:**

The lines of the 30 m tape were detected manually with the optical microscope. The contrast of the black lines on the yellow tape was not enough for our photoelectric microscope. The 10 m and 50 m tape were measured automatically with the photoelectric microscope.

## 11.15 SMD, Belgium

**Short description of measurement bench**

The measuring system is based on a horizontal " ┌──┐ " shaped steel profile with a height of 70 mm, a width of 180 mm and a length of 14 m. This steel profile is aligned for straightness on adjustable supports every metre. The maximal measurable length is 10 m. Tapes with longer lengths are measured is steps of 10 m. At the left end, the laserinterferometer is mounted on this profile. At about 2,5 m from the left end, the necessary accessories are mounted on the steel profile for attaching or clamping the tape and for winding up the measured parts of tapes longer than 10 m. At the right end the necessary accessories are mounted on the steel profile for attaching or clamping the tape, for (un)winding parts of tape to be measured and for applying the measuring force. The measured part of the tape rests on an aluminium profile that is mounted and aligned on the steel profile. The bench is equipped with a laserinterferometer. The lines of the tapes are probed with a camera, mounted on a carriage that moves over the tape. The bench is installed in a laboratory that is specially dedicated to and climatised (temperature and relative humidity) for this application.

**Length measurement instrument**

Measurements are made with a Hewlett Packard laserinterferometer. The retroreflector is mounted on the part of the moving carriage that supports the camera. The measuring laser beam is as close as possible to the tape and protected against air turbulence. The refractive index of air, as calculated with Edlèns formula (Metrologia 31, 1994, 315-316), is taken into account. Air temperature and air pressure are measured. Air humidity can be selected with a switch (25 %, 50 % and 75 %) in function of the measured relative humidity in the laboratory. The environmental sensor of the laserinterferometer is mounted half way the bench as close as possible to the laser beam and at about the same height as the laser beam.

**Principle of tape support**

The tape is supported over its whole measured length on a L shaped aluminium profile that is mounted and aligned on the steel profile. The side of the tape is aligned against the vertical part of the aluminium profile with micrometerscrews. When moving the tape over the aluminium support, free turning rollers, mounted every metre (starting at 0,5 m), can be pneumatically put just above the aluminium profile in order to support the tape and minimise friction.

**Microscope for localisation of scale marks**

A camera with macro vision is mounted on the upper part of the carriage. The upper part of the carriage can be fine adjusted to the lower part with a joystick on the command console. The carriage itself is moving over the measuring bench with special cylindrical rollers on long bars. These bars are aligned with the aluminium profile that supports the tape and is moved with an electrical motor.

The image of the camera is displayed on a monitor. On this monitor are supplementary reference lines for exact positioning of the camera on the measured line. The image on the monitor can be inverted (positive - negative image) to get the optimal image. Once the type of image is selected, this has to be used for all the measurements on a tape.

**Temperature measurement system, number and location of sensors**

Every meter (starting at 0,5 m) PT100 sensors are mounted in the aluminium profile, on which rests the tape, to measure the tape temperature. At every measurement, the temperature of the measured part of tape is taken into account for the correction for the measured part of the tape. The PT100 sensors are connected to a Keithley system and temperatures are read from this system by the software.

## 11.16 SP, Sweden

**Short description of measurement bench**

The bench consists of a simple aluminium U−shaped profile with polished steel pins acting as supports for the tape. The bench is a little over 50 m long, and works as support for the reference tape and the calibrated tape simultaneously.

**Length measurement instrument**

Comparison with reference steel tape.

**Principle of tape support**

The tapes rests on polished steel pins placed at 0,5m distances.

**Microscope for localisation of scale marks**

Handheld microscope 10x.

**Temperature measurement system, number and location of sensors**

The air temperature of the laboratory is continuously registered in 5 points equally distributed along the bench.

# 12 Appendix 2: Reference values

Due to the large differences in the stated uncertainties, it is proposed to use the weighted mean for determining the reference value $x_{ref}$. This is calculated by the mean of all measurement values $x_i$ weighted by the inverse square of the standard uncertainties $u(x_i)$ associated with the measurements.

$$x_{ref} = \frac{\sum_{i=1}^{n} u^{-2}(x_i) \cdot x_i}{\sum_{i=1}^{n} u^{-2}(x_i)} \tag{1}$$

The weighted mean approach requires the individual uncertainties from the laboratories be estimated according to a common approach (which should be the case, since all participants were requested to estimate the uncertainties according to the *ISO Guide*).

The standard uncertainty $u(x_{ref})$ of the reference value is calculated by combining the individual uncertainties (Eq. 2):

$$u(x_{ref}) = \left( \sum_{i=1}^{n} u^{-2}(x_i) \right)^{-1/2} \tag{2}$$

The pilot laboratory contributed only by its first measurement to the reference values.

As mentioned in Section 6, the 50 m tape showed a possibly unstable behaviour. This is confirmed by looking at the graphs below, which show clearly a “jump” in the values between PTB and SMD. For this reason, two sets of reference values have been calculated, a first based on the weighted mean of the laboratories between METAS and PTB, a second involving the other labs including the values of METAS2.

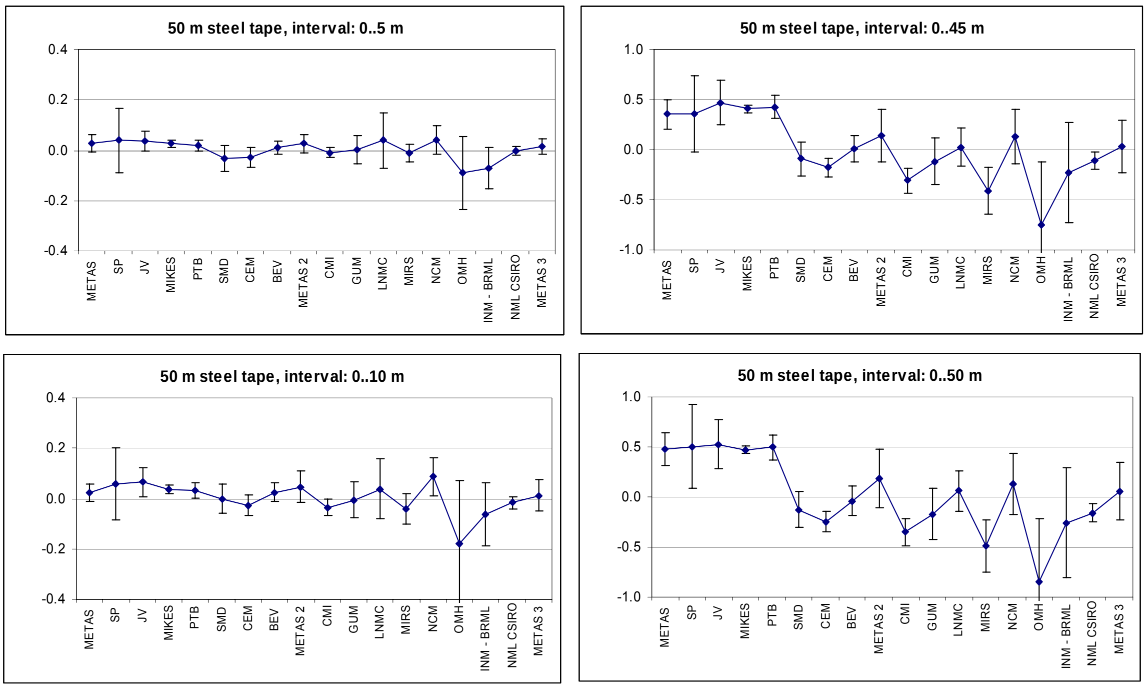



*Figure 2. Deviation from weighted mean for the 50 m tape, first two and last two intervals, showing a possible length change occurred between PTB and SMD.*

Table 5 contains the reference values and their associated uncertainties calculated according to Eq. (1) and (2) using the weighted mean. For the 50 m tape, two values are given, (I) based on the first 5 participants, (II) based on the other participants.

| 10 m tape | | 30 m tape | | 50 m tape I | | 50 m tape II | | 50 m (I – II) | |
|---|---|---|---|---|---|---|---|---|---|
| $x_{ref}$ | $U(x_{ref})$ | $x_{ref}$ | $U(x_{ref})$ | $x_{ref}$ | $U(x_{ref})$ | $x_{ref}$ | $U(x_{ref})$ | $Dx_{ref}$ | $U(\Delta x_{ref})$ |
| 1000.037 | 0.008 | 3000.680 | 0.009 | 5000.036 | 0.011 | 5000.006 | 0.010 | 0.030 | 0.015 |
| 1999.993 | 0.008 | 6000.969 | 0.011 | 10000.058 | 0.013 | 10000.011 | 0.014 | 0.046 | 0.019 |
| 2999.945 | 0.009 | 9001.349 | 0.013 | 15000.050 | 0.016 | 14999.968 | 0.018 | 0.082 | 0.024 |
| 3999.887 | 0.009 | 12001.820 | 0.016 | 20000.107 | 0.018 | 19999.954 | 0.022 | 0.153 | 0.029 |
| 4999.855 | 0.009 | 15002.188 | 0.018 | 25000.141 | 0.021 | 24999.929 | 0.026 | 0.212 | 0.034 |
| 5999.852 | 0.010 | 18002.603 | 0.020 | 30000.125 | 0.024 | 29999.847 | 0.031 | 0.278 | 0.040 |
| 6999.713 | 0.010 | 21003.011 | 0.022 | 35000.123 | 0.027 | 34999.774 | 0.035 | 0.349 | 0.045 |
| 7999.697 | 0.011 | 24003.435 | 0.024 | 40000.144 | 0.031 | 39999.710 | 0.039 | 0.434 | 0.049 |
| 8999.637 | 0.011 | 27003.828 | 0.027 | 45000.146 | 0.034 | 44999.591 | 0.042 | 0.554 | 0.054 |
| 9999.630 | 0.012 | 30004.171 | 0.029 | 50000.151 | 0.037 | 49999.477 | 0.046 | 0.674 | 0.059 |

*Table 5. Reference values and associated expanded uncertainties based on weighted mean. The last column is the difference between (I) and (II).*

### 12.1 Artefact uncertainty

After the apparent change in length of the 50 m tape, which has been taken into account by allowing for a change in the reference value as documented in table 5, the stability of the tape length could no longer be assured at the same level as before. It was therefore decided to introduce an additional artefact uncertainty to be taken into account when calculating the degree of equivalence , i.e. the uncertainty of the difference of the laboratories results from the reference value. This artefact uncertainty, which was applied only to the second series of laboratories, was estimated to be the uncertainty of the difference between the reference value I and II and thus calculated from a linear fit through the values of the last column of table 5: $U_{art}$ = 9 µm + $1 \cdot 10^{-6} L$.

### 12.2 Consistency check

According to the procedure A outlined in Ref. [1] for the weighted mean, the consistency of the results together with their uncertainties may be checked by a $\chi^2$-Test:

$$\Pr \{ \chi^2(\nu) - \chi^2(x_i) \} < 0.05, \tag{3}$$

where Pr {..} means the probability and $\nu = N - 1$ is the degree of freedom with $N$ equal to the number of participating laboratories. The above condition is equivalent to

$\chi^2(0.05, \nu) > \chi^2(x_i)$. Note that $\chi^2(\Pr, \nu)$ is a standard function available in Excel. Table 6 shows in the first column $\chi^2(0.05, \nu)$ and in the subsequent columns $\chi^2(x_i)$ evaluated for each interval of the three tapes. It can be seen that in many cases the consistency criterion is not fulfilled, which means that the uncertainties are not consistent with the spread of the results. In spite of this lack of consistency, no other method for evaluating the comparison reference values has been applied, since procedure B of Ref.[1] is much more complicated and would not lead to significantly different values.

| tape | $\chi^2(0.05, \nu)$ | $\chi^2(x_i)$ for all 10 intervals | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 m | 25.0 | 21.3 | 29.6 | 28.3 | 28.8 | 24.5 | 32.9 | 26.1 | 19.0 | 19.0 | 25.6 |
| 30 m | 25.0 | 11.3 | 15.2 | 17.4 | 24.6 | 33.9 | 35.0 | 34.1 | 40.8 | 40.7 | 47.8 |
| 50 m I | 9.5 | 0.9 | 1.8 | 1.1 | 1.8 | 1.4 | 2.2 | 1.5 | 0.8 | 1.0 | 0.3 |
| 50 m II | 19.7 | 14.0 | 20.8 | 30.2 | 37.5 | 37.0 | 33.0 | 32.5 | 33.1 | 33.9 | 33.7 |

*Table 6. $\chi^2(0.05, \nu)$ and $\chi^2(x_i)$ for all measured intervals of the three tapes. For the yellow shaded numbers the consistency according to Eq.(3) is not fulfilled.*

### 12.3 Degrees of equivalence

The deviations from reference values are calculated by $\Delta x_i = x_i - x_{ref}$. For calculating the uncertainty of these deviations, the corresponding uncertainties $u(x_i)$ and $u(x_{ref})$ cannot simply be geometrically added, because the values $x_i$ and $x_{ref}$ are correlated. It can be shown [1], that for the weighted mean with an uncertainty $u(x_{ref})$, the expanded uncertainty $U(\Delta x)$ is given by

$$U(\Delta x) = 2\sqrt{u^2(x_i) - u^2(x_{ref})} \,. \tag{4}$$

In case where an additional artefact uncertainty had to be taken into account, eq.(4) was replaced by

$$U(\Delta x) = 2\sqrt{u^2(x_i) - u^2(x_{ref}) + (U_{art}/2)^2} \,. \tag{5}$$

The En-values as shown in tables 10 to 12 were calculated by

$$En = \Delta x_i / U(\Delta x_i) \,. \tag{6}$$

## 13 Appendix 3: Deviations from reference values

In the following, the deviations from the reference values are given in various tables and figures. The uncertainty bars in the figures correspond to the expanded uncertainties ($k$ = 2) as reported by the participants.

| | 1 m | | 2 m | | 3 m | | 4 m | | 5 m | | 6 m | | 7 m | | 8 m | | 9 m | | 10 m | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | U(D) / mm | 2 | U(D) / mm | 3 | U(D) / mm | 4 | U(D) / mm | 5 | U(D) / mm | 6 | U(D) / mm | 7 | U(D) / mm | 8 | U(D) / mm | 9 | U(D) / mm | 10 | U(D) / mm |
| METAS | 0.021 | 0.036 | 0.021 | 0.037 | 0.020 | 0.037 | 0.021 | 0.038 | 0.020 | 0.039 | 0.019 | 0.040 | 0.015 | 0.042 | 0.016 | 0.044 | 0.007 | 0.045 | 0.011 | 0.047 |
| SP | 0.013 | 0.120 | 0.017 | 0.121 | 0.015 | 0.122 | 0.023 | 0.124 | 0.025 | 0.126 | 0.048 | 0.129 | 0.037 | 0.132 | 0.033 | 0.136 | 0.023 | 0.139 | 0.050 | 0.144 |
| JV | -0.023 | 0.044 | -0.016 | 0.049 | -0.012 | 0.054 | -0.021 | 0.059 | -0.022 | 0.064 | -0.029 | 0.069 | -0.026 | 0.074 | -0.033 | 0.079 | -0.040 | 0.084 | -0.049 | 0.089 |
| MIKES | -0.004 | 0.021 | 0.010 | 0.021 | 0.005 | 0.021 | 0.012 | 0.021 | 0.012 | 0.021 | 0.019 | 0.021 | 0.013 | 0.021 | 0.016 | 0.021 | 0.020 | 0.021 | 0.023 | 0.021 |
| PTB | -0.002 | 0.034 | 0.001 | 0.034 | 0.000 | 0.035 | 0.000 | 0.035 | 0.000 | 0.036 | -0.006 | 0.037 | -0.002 | 0.038 | -0.006 | 0.039 | -0.009 | 0.040 | -0.008 | 0.041 |
| SMD | 0.017 | 0.052 | 0.053 | 0.053 | 0.004 | 0.053 | 0.029 | 0.053 | 0.032 | 0.053 | 0.066 | 0.054 | 0.068 | 0.054 | 0.032 | 0.055 | 0.038 | 0.055 | 0.042 | 0.056 |
| CEM | -0.023 | 0.034 | -0.032 | 0.034 | -0.021 | 0.034 | -0.033 | 0.034 | -0.024 | 0.035 | -0.033 | 0.035 | -0.037 | 0.035 | -0.031 | 0.035 | -0.041 | 0.036 | -0.048 | 0.036 |
| BEV | 0.013 | 0.048 | 0.014 | 0.049 | 0.019 | 0.049 | 0.025 | 0.050 | 0.023 | 0.050 | 0.023 | 0.051 | 0.028 | 0.052 | 0.033 | 0.053 | 0.031 | 0.054 | 0.051 | 0.055 |
| METAS 2 | 0.009 | 0.033 | 0.013 | 0.033 | 0.012 | 0.034 | 0.013 | 0.035 | 0.017 | 0.036 | 0.015 | 0.037 | 0.008 | 0.038 | 0.010 | 0.039 | 0.000 | 0.041 | 0.003 | 0.042 |
| CMI-VUGTK | 0.027 | 0.017 | 0.033 | 0.019 | 0.047 | 0.022 | 0.044 | 0.024 | 0.041 | 0.027 | 0.040 | 0.029 | 0.036 | 0.032 | 0.029 | 0.034 | 0.021 | 0.037 | 0.001 | 0.039 |
| GUM | -0.004 | 0.025 | -0.007 | 0.026 | -0.003 | 0.027 | -0.005 | 0.029 | -0.001 | 0.031 | -0.001 | 0.034 | 0.000 | 0.037 | 0.003 | 0.040 | 0.000 | 0.043 | 0.006 | 0.046 |
| LNMC | -0.039 | 0.086 | -0.026 | 0.088 | -0.016 | 0.090 | -0.012 | 0.094 | -0.011 | 0.098 | 0.002 | 0.103 | -0.022 | 0.109 | -0.007 | 0.115 | 0.005 | 0.121 | 0.074 | 0.128 |
| MIRS | 0.005 | 0.034 | -0.001 | 0.041 | -0.013 | 0.048 | -0.011 | 0.055 | -0.022 | 0.062 | -0.043 | 0.069 | -0.045 | 0.076 | -0.052 | 0.083 | -0.061 | 0.090 | -0.071 | 0.097 |
| NCM | 0.034 | 0.068 | 0.032 | 0.069 | 0.029 | 0.070 | 0.039 | 0.072 | 0.044 | 0.074 | 0.030 | 0.076 | 0.034 | 0.079 | 0.040 | 0.083 | 0.055 | 0.086 | 0.054 | 0.090 |
| OMH | 0.023 | 0.083 | -0.013 | 0.093 | -0.005 | 0.107 | -0.027 | 0.125 | -0.035 | 0.144 | -0.032 | 0.164 | -0.053 | 0.186 | 0.003 | 0.208 | -0.017 | 0.230 | -0.040 | 0.253 |
| INM - BRML | 0.013 | 0.061 | -0.023 | 0.063 | -0.005 | 0.068 | -0.017 | 0.074 | -0.035 | 0.081 | -0.032 | 0.089 | -0.043 | 0.097 | -0.047 | 0.106 | -0.027 | 0.115 | -0.040 | 0.125 |
| NMIA | -0.016 | 0.012 | -0.019 | 0.012 | -0.020 | 0.012 | -0.020 | 0.013 | -0.020 | 0.014 | -0.025 | 0.015 | -0.019 | 0.016 | -0.020 | 0.017 | -0.016 | 0.018 | -0.019 | 0.020 |
| METAS 3 | -0.004 | 0.033 | 0.002 | 0.033 | -0.001 | 0.034 | 0.006 | 0.034 | -0.003 | 0.035 | -0.001 | 0.036 | -0.006 | 0.037 | 0.001 | 0.038 | -0.006 | 0.039 | -0.010 | 0.040 |

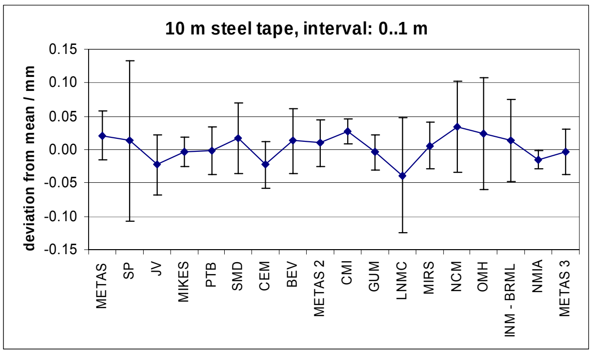
*Table 7. Deviation from reference value and expanded uncertainty of theses deviations for 10 m stainless steel tape.*

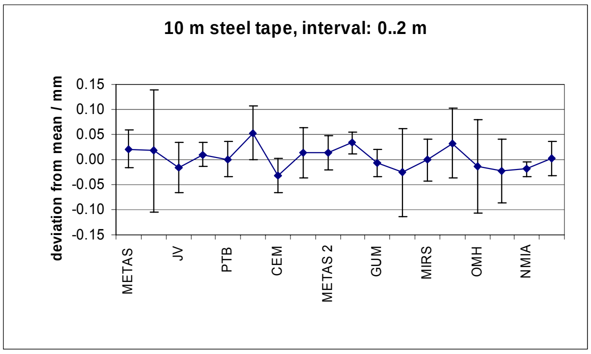
| | 3 m | | 6 m | | 9 m | | 12 m | | 15 m | | 18 m | | 21 m | | 24 m | | 27 m | | 30 m | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 3 | U(D) / mm | 6 | U(D) / mm | 9 | U(D) / mm | 12 | U(D) / mm | 15 | U(D) / mm | 18 | U(D) / mm | 21 | U(D) / mm | 24 | U(D) / mm | 27 | U(D) / mm | 30 | U(D) / mm |
| METAS | 0.007 | 0.028 | 0.004 | 0.033 | -0.002 | 0.041 | -0.007 | 0.050 | 0.004 | 0.059 | -0.004 | 0.069 | 0.000 | 0.079 | -0.008 | 0.090 | -0.020 | 0.100 | -0.020 | 0.110 |
| SP | -0.010 | 0.122 | 0.041 | 0.129 | 0.021 | 0.139 | 0.040 | 0.153 | 0.062 | 0.169 | 0.077 | 0.186 | 0.089 | 0.205 | 0.125 | 0.225 | 0.122 | 0.246 | 0.109 | 0.267 |
| JV | -0.010 | 0.054 | -0.013 | 0.069 | -0.017 | 0.084 | -0.027 | 0.099 | -0.031 | 0.114 | -0.056 | 0.128 | -0.057 | 0.143 | -0.054 | 0.158 | -0.067 | 0.173 | -0.059 | 0.188 |
| MIKES | 0.028 | 0.046 | 0.042 | 0.048 | 0.049 | 0.050 | 0.053 | 0.054 | 0.082 | 0.059 | 0.086 | 0.064 | 0.099 | 0.070 | 0.116 | 0.076 | 0.113 | 0.082 | 0.137 | 0.088 |
| PTB | -0.011 | 0.046 | -0.006 | 0.048 | -0.008 | 0.052 | 0.004 | 0.056 | 0.016 | 0.062 | 0.019 | 0.068 | 0.030 | 0.075 | 0.039 | 0.082 | 0.041 | 0.089 | 0.052 | 0.097 |
| SMD | -0.025 | 0.053 | 0.045 | 0.054 | 0.037 | 0.054 | 0.058 | 0.077 | 0.047 | 0.080 | 0.062 | 0.085 | 0.050 | 0.101 | 0.071 | 0.102 | 0.096 | 0.104 | 0.089 | 0.109 |
| CEM | -0.018 | 0.044 | -0.031 | 0.044 | -0.035 | 0.045 | -0.038 | 0.046 | -0.051 | 0.047 | -0.058 | 0.048 | -0.068 | 0.050 | -0.076 | 0.052 | -0.095 | 0.068 | -0.117 | 0.067 |
| BEV | 0.013 | 0.049 | 0.006 | 0.051 | 0.006 | 0.054 | 0.010 | 0.058 | 0.016 | 0.062 | 0.017 | 0.068 | 0.024 | 0.074 | 0.026 | 0.080 | 0.019 | 0.087 | 0.031 | 0.094 |
| METAS 2 | 0.041 | 0.032 | 0.045 | 0.036 | 0.041 | 0.041 | 0.046 | 0.047 | 0.053 | 0.054 | 0.049 | 0.062 | 0.063 | 0.070 | 0.053 | 0.078 | 0.051 | 0.087 | 0.077 | 0.095 |
| CMI-VUGTK | 0.003 | 0.020 | 0.001 | 0.027 | -0.033 | 0.034 | -0.056 | 0.041 | -0.083 | 0.048 | -0.093 | 0.056 | -0.089 | 0.063 | -0.115 | 0.070 | -0.125 | 0.077 | -0.158 | 0.084 |
| GUM | -0.006 | 0.028 | -0.012 | 0.037 | -0.001 | 0.049 | -0.005 | 0.061 | 0.006 | 0.074 | -0.004 | 0.088 | 0.002 | 0.102 | 0.004 | 0.116 | -0.016 | 0.129 | 0.010 | 0.143 |
| LNMC | -0.041 | 0.090 | -0.005 | 0.103 | 0.005 | 0.121 | 0.022 | 0.143 | 0.040 | 0.167 | 0.040 | 0.192 | -0.090 | 0.218 | -0.077 | 0.245 | -0.072 | 0.272 | 0.031 | 0.299 |
| MIRS | 0.002 | 0.034 | -0.019 | 0.050 | -0.032 | 0.066 | -0.048 | 0.081 | -0.070 | 0.096 | -0.088 | 0.112 | -0.094 | 0.127 | -0.120 | 0.143 | -0.160 | 0.158 | -0.113 | 0.174 |
| NCM | -0.016 | 0.070 | -0.002 | 0.076 | 0.038 | 0.086 | 0.082 | 0.098 | 0.097 | 0.111 | 0.100 | 0.126 | 0.107 | 0.141 | 0.141 | 0.157 | 0.162 | 0.174 | 0.175 | 0.190 |
| OMH | 0.010 | 0.107 | -0.009 | 0.164 | -0.009 | 0.230 | 0.020 | 0.299 | -0.048 | 0.368 | -0.113 | 0.367 | -0.071 | 0.387 | -0.175 | 0.419 | -0.188 | 0.460 | -0.291 | 0.508 |
| INM - BRML | 0.010 | 0.068 | 0.011 | 0.089 | 0.031 | 0.115 | 0.050 | 0.144 | 0.032 | 0.175 | 0.057 | 0.206 | 0.039 | 0.238 | 0.045 | 0.270 | 0.082 | 0.302 | 0.079 | 0.334 |
| NMIA | 0.002 | 0.013 | -0.003 | 0.016 | 0.009 | 0.021 | 0.016 | 0.027 | 0.015 | 0.033 | 0.027 | 0.039 | 0.035 | 0.045 | 0.041 | 0.052 | 0.044 | 0.058 | 0.053 | 0.064 |
| METAS 3 | 0.011 | 0.027 | 0.013 | 0.029 | 0.005 | 0.033 | 0.008 | 0.039 | 0.020 | 0.045 | 0.018 | 0.051 | 0.040 | 0.058 | 0.049 | 0.064 | 0.053 | 0.071 | 0.058 | 0.078 |

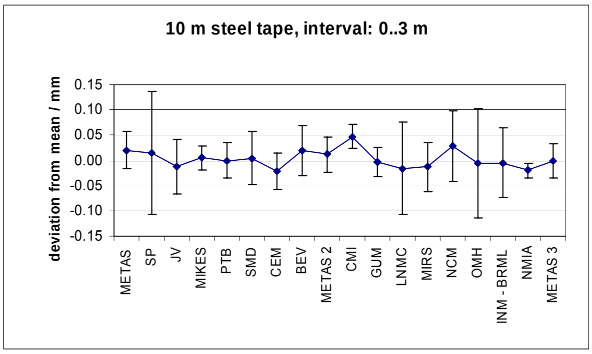
*Table 8. Deviation from reference value and expanded uncertainty of theses deviations for 30 m stainless steel tape.*

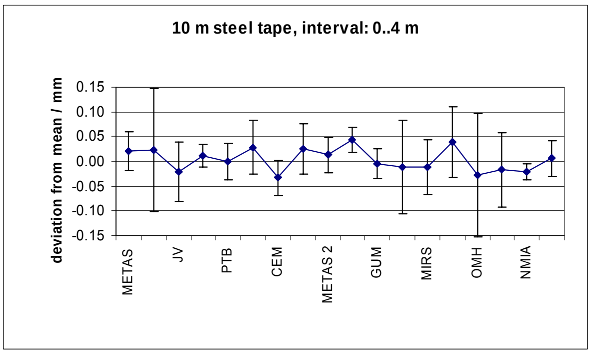
| | 5 m | | 10 m | | 15 m | | 20 m | | 25 m | | 30 m | | 35 m | | 40 m | | 45 m | | 50 m | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *5* | *U(D) / mm* | *10* | *U(D) / mm* | *15* | *U(D) / mm* | *20* | *U(D) / mm* | *25* | *U(D) / mm* | *30* | *U(D) / mm* | *35* | *U(D) / mm* | *40* | *U(D) / mm* | *45* | *U(D) / mm* | *50* | *U(D) / mm* |
| METAS | 0.004 | 0.032 | -0.013 | 0.031 | -0.014 | 0.047 | -0.035 | 0.063 | -0.043 | 0.079 | -0.063 | 0.095 | -0.054 | 0.111 | -0.043 | 0.127 | -0.055 | 0.143 | 0.007 | 0.159 |
| SP | 0.014 | 0.126 | 0.022 | 0.144 | 0.000 | 0.169 | -0.017 | 0.199 | 0.019 | 0.232 | -0.035 | 0.267 | 0.007 | 0.303 | 0.016 | 0.340 | -0.046 | 0.378 | 0.029 | 0.416 |
| JV | 0.012 | 0.037 | 0.029 | 0.056 | 0.033 | 0.078 | 0.039 | 0.101 | 0.031 | 0.124 | 0.046 | 0.148 | 0.064 | 0.172 | 0.060 | 0.196 | 0.059 | 0.220 | 0.052 | 0.244 |
| MIKES | 0.001 | 0.010 | 0.001 | 0.010 | 0.001 | 0.010 | 0.002 | 0.010 | 0.002 | 0.011 | 0.002 | 0.012 | 0.000 | 0.013 | 0.000 | 0.014 | 0.000 | 0.015 | -0.004 | 0.017 |
| PTB | -0.007 | 0.018 | -0.004 | 0.027 | -0.005 | 0.038 | -0.001 | 0.049 | 0.006 | 0.061 | 0.011 | 0.073 | 0.013 | 0.085 | 0.007 | 0.097 | 0.017 | 0.109 | 0.020 | 0.121 |
| SMD | -0.028 | 0.053 | 0.009 | 0.058 | 0.000 | 0.086 | 0.012 | 0.094 | -0.018 | 0.113 | 0.011 | 0.121 | 0.014 | 0.141 | 0.033 | 0.148 | 0.055 | 0.171 | 0.074 | 0.181 |
| CEM | -0.023 | 0.040 | -0.016 | 0.042 | -0.018 | 0.045 | -0.022 | 0.049 | -0.019 | 0.055 | -0.043 | 0.067 | -0.039 | 0.069 | -0.039 | 0.072 | -0.032 | 0.075 | -0.046 | 0.080 |
| BEV | 0.015 | 0.028 | 0.034 | 0.037 | 0.056 | 0.048 | 0.070 | 0.061 | 0.095 | 0.075 | 0.111 | 0.088 | 0.124 | 0.104 | 0.142 | 0.118 | 0.159 | 0.133 | 0.159 | 0.147 |
| METAS 2 | 0.032 | 0.037 | 0.057 | 0.062 | 0.091 | 0.090 | 0.110 | 0.118 | 0.145 | 0.147 | 0.176 | 0.175 | 0.218 | 0.204 | 0.253 | 0.234 | 0.288 | 0.263 | 0.383 | 0.292 |
| CMI-VUGTK | -0.005 | 0.019 | -0.025 | 0.032 | -0.058 | 0.045 | -0.054 | 0.058 | -0.095 | 0.071 | -0.098 | 0.084 | -0.115 | 0.097 | -0.129 | 0.111 | -0.163 | 0.124 | -0.149 | 0.138 |
| GUM | 0.006 | 0.057 | 0.006 | 0.072 | 0.024 | 0.092 | -0.005 | 0.114 | 0.027 | 0.137 | 0.036 | 0.161 | 0.046 | 0.186 | 0.055 | 0.211 | 0.029 | 0.236 | 0.030 | 0.261 |
| LNMC | -0.007 | 0.099 | -0.037 | 0.129 | -0.085 | 0.168 | -0.146 | 0.210 | -0.102 | 0.255 | -0.085 | 0.301 | -0.133 | 0.347 | -0.184 | 0.394 | -0.226 | 0.441 | -0.167 | 0.488 |
| MIRS | -0.008 | 0.035 | -0.031 | 0.060 | -0.051 | 0.085 | -0.098 | 0.110 | -0.121 | 0.135 | -0.154 | 0.160 | -0.189 | 0.185 | -0.234 | 0.210 | -0.265 | 0.236 | -0.286 | 0.261 |
| NCM | 0.045 | 0.055 | 0.098 | 0.076 | 0.141 | 0.101 | 0.211 | 0.128 | 0.220 | 0.157 | 0.228 | 0.186 | 0.236 | 0.215 | 0.262 | 0.245 | 0.279 | 0.274 | 0.330 | 0.304 |
| OMH | -0.086 | 0.144 | -0.171 | 0.253 | -0.258 | 0.369 | -0.524 | 0.379 | -0.559 | 0.433 | -0.567 | 0.509 | -0.544 | 0.524 | -0.580 | 0.564 | -0.601 | 0.624 | -0.647 | 0.632 |
| INM - BRML | -0.066 | 0.081 | -0.051 | 0.125 | -0.088 | 0.176 | -0.114 | 0.228 | -0.059 | 0.281 | -0.077 | 0.335 | -0.124 | 0.390 | -0.080 | 0.444 | -0.081 | 0.499 | -0.057 | 0.554 |
| NMIA | 0.001 | 0.017 | -0.005 | 0.024 | 0.000 | 0.031 | 0.003 | 0.040 | 0.011 | 0.050 | 0.015 | 0.059 | 0.029 | 0.068 | 0.030 | 0.078 | 0.039 | 0.088 | 0.040 | 0.098 |
| METAS 3 | 0.019 | 0.031 | 0.021 | 0.062 | 0.045 | 0.090 | 0.058 | 0.118 | 0.089 | 0.147 | 0.103 | 0.175 | 0.137 | 0.204 | 0.157 | 0.234 | 0.177 | 0.263 | 0.258 | 0.292 |

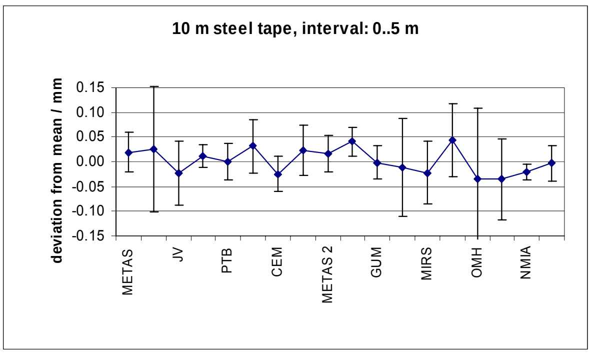
*Table 9. Deviation from reference value and expanded uncertainty of theses deviations for 50 m steel tape.*

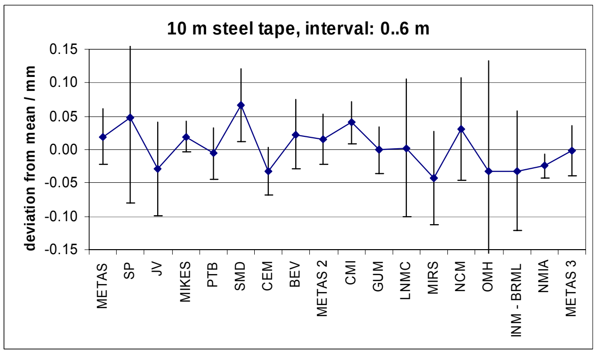

10 m steel tape, interval: 0..1 m
deviation from mean / mm
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
METAS
SP
JV
MIKES
PTB
SMD
CEM
BEV
METAS 2
CMI
GUM
LNMC
MIRS
NCM
OMH
INM - BRML
NMIA
METAS 3

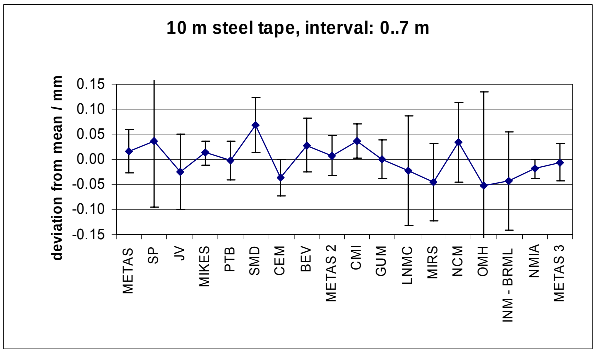

10 m steel tape, interval: 0..2 m
deviation from mean / mm
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
METAS
JV
PTB
CEM
METAS 2
GUM
MIRS
OMH
NMIA

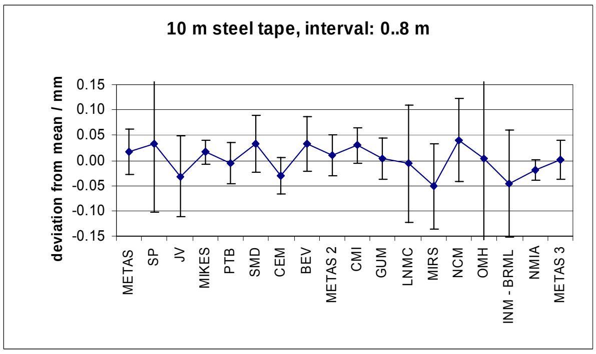

10 m steel tape, interval: 0..3 m
deviation from mean / mm
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
METAS
SP
JV
MIKES
PTB
SMD
CEM
BEV
METAS 2
CMI
GUM
LNMC
MIRS
NCM
OMH
INM - BRML
NMIA
METAS 3

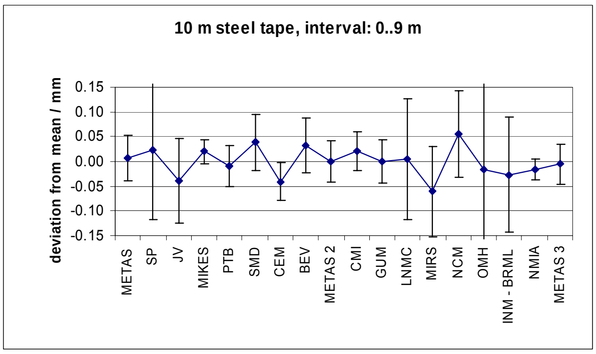

10 m steel tape, interval: 0..4 m
deviation from mean / mm
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
METAS
JV
PTB
CEM
METAS 2
GUM
MIRS
OMH
NMIA

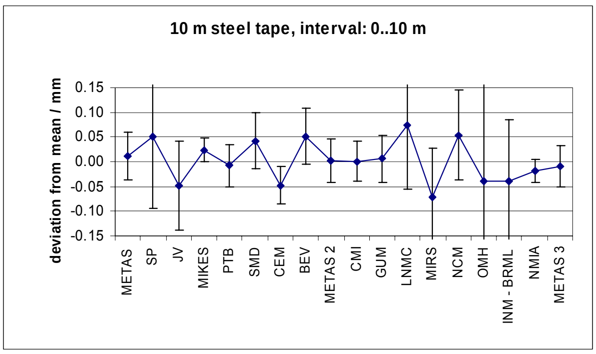

10 m steel tape, interval: 0..5 m
deviation from mean / mm
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
METAS
JV
PTB
CEM
METAS 2
GUM
MIRS
OMH
NMIA

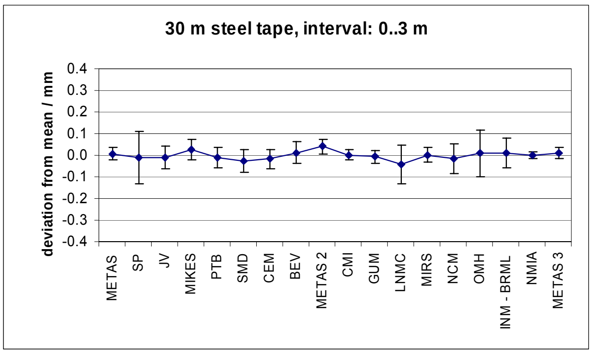

10 m steel tape, interval: 0..6 m
deviation from mean / mm
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
METAS
SP
JV
MIKES
PTB
SMD
CEM
BEV
METAS 2
CMI
GUM
LNMC
MIRS
NCM
OMH
INM - BRML
NMIA
METAS 3

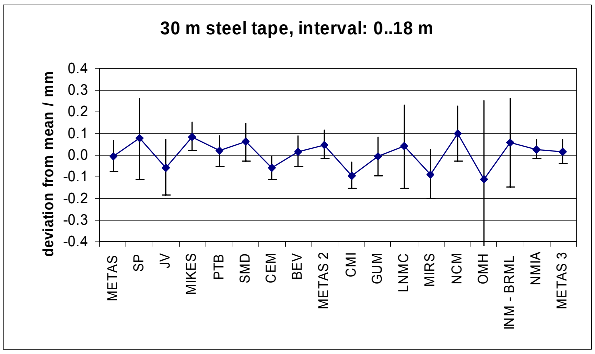

10 m steel tape, interval: 0..7 m
deviation from mean / mm
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
METAS
SP
JV
MIKES
PTB
SMD
CEM
BEV
METAS 2
CMI
GUM
LNMC
MIRS
NCM
OMH
INM - BRML
NMIA
METAS 3

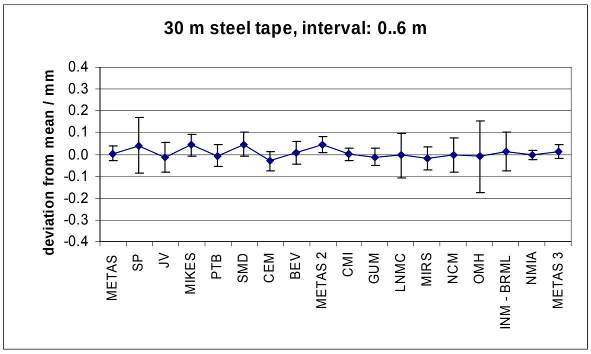

10 m steel tape, interval: 0..8 m
deviation from mean / mm
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
METAS
SP
JV
MIKES
PTB
SMD
CEM
BEV
METAS 2
CMI
GUM
LNMC
MIRS
NCM
OMH
INM - BRML
NMIA
METAS 3

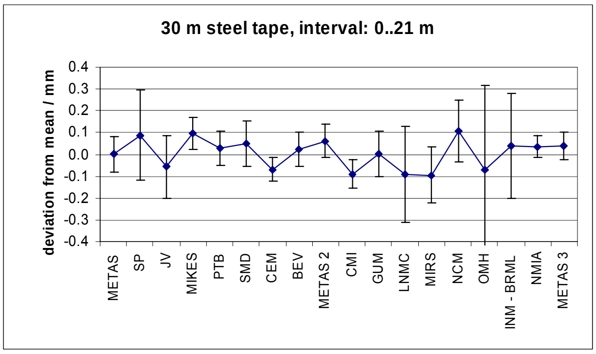

10 m steel tape, interval: 0..9 m
deviation from mean / mm
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
METAS
SP
JV
MIKES
PTB
SMD
CEM
BEV
METAS 2
CMI
GUM
LNMC
MIRS
NCM
OMH
INM - BRML
NMIA
METAS 3

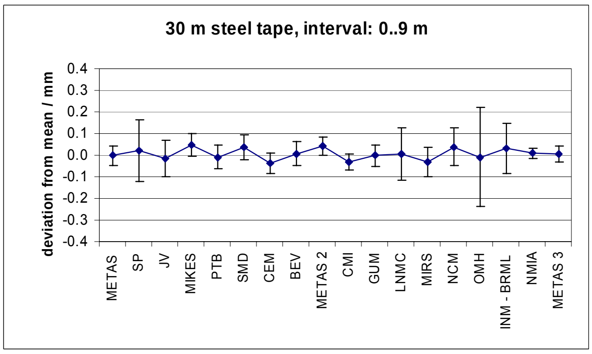

10 m steel tape, interval: 0..10 m
deviation from mean / mm
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
METAS
SP
JV
MIKES
PTB
SMD
CEM
BEV
METAS 2
CMI
GUM
LNMC
MIRS
NCM
OMH
INM - BRML
NMIA
METAS 3

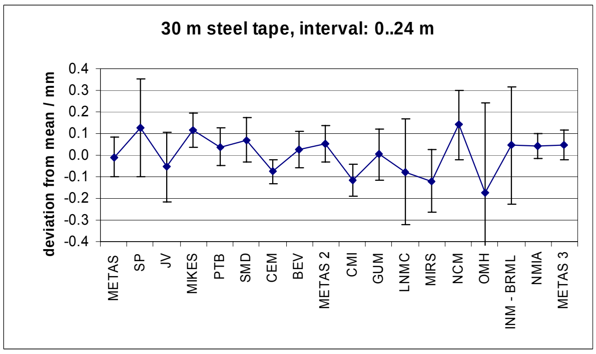

30 m steel tape, interval: 0..3 m
deviation from mean / mm
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
METAS
SP
JV
MIKES
PTB
SMD
CEM
BEV
METAS 2
CMI
GUM
LNMC
MIRS
NCM
OMH
INM - BRML
NMIA
METAS 3

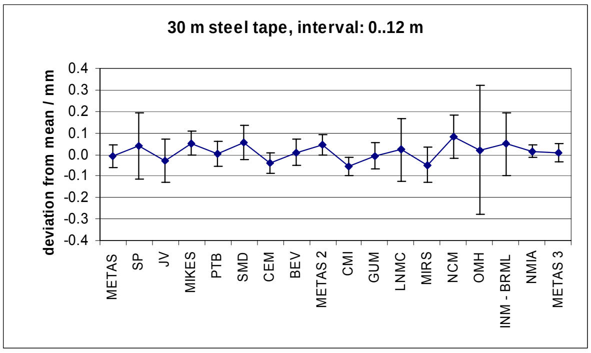

30 m steel tape, interval: 0..18 m
deviation from mean / mm
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
METAS
SP
JV
MIKES
PTB
SMD
CEM
BEV
METAS 2
CMI
GUM
LNMC
MIRS
NCM
OMH
INM - BRML
NMIA
METAS 3

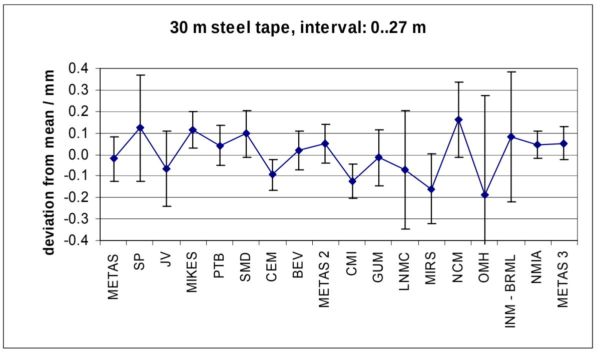

30 m steel tape, interval: 0..6 m
deviation from mean / mm
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
METAS
SP
JV
MIKES
PTB
SMD
CEM
BEV
METAS 2
CMI
GUM
LNMC
MIRS
NCM
OMH
INM - BRML
NMIA
METAS 3

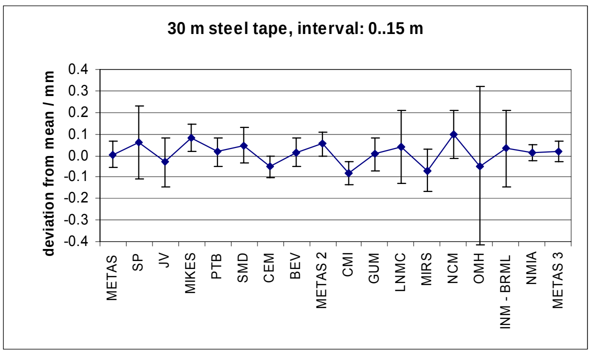

30 m steel tape, interval: 0..21 m
deviation from mean / mm
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
METAS
SP
JV
MIKES
PTB
SMD
CEM
BEV
METAS 2
CMI
GUM
LNMC
MIRS
NCM
OMH
INM - BRML
NMIA
METAS 3

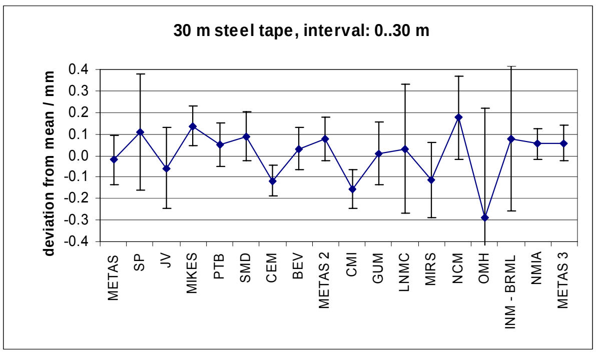

30 m steel tape, interval: 0..9 m
deviation from mean / mm
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
METAS
SP
JV
MIKES
PTB
SMD
CEM
BEV
METAS 2
CMI
GUM
LNMC
MIRS
NCM
OMH
INM - BRML
NMIA
METAS 3

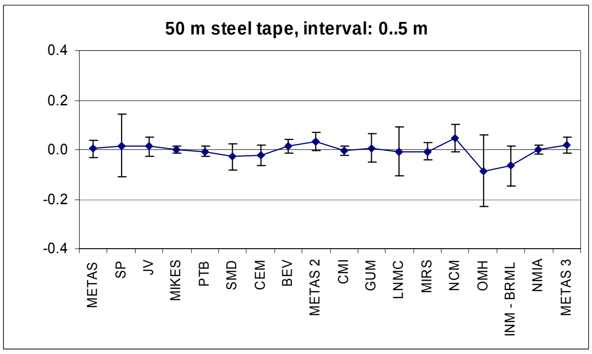

30 m steel tape, interval: 0..24 m
deviation from mean / mm
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
METAS
SP
JV
MIKES
PTB
SMD
CEM
BEV
METAS 2
CMI
GUM
LNMC
MIRS
NCM
OMH
INM - BRML
NMIA
METAS 3

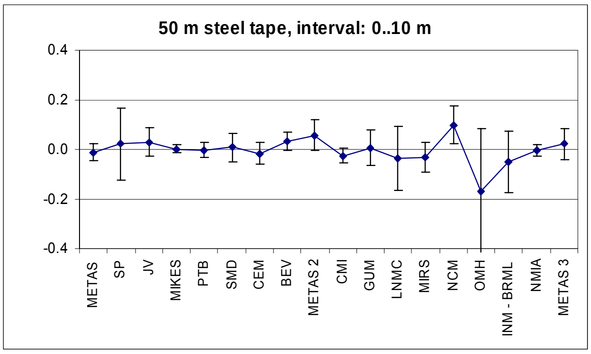

30 m steel tape, interval: 0..12 m
deviation from mean / mm
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
METAS
SP
JV
MIKES
PTB
SMD
CEM
BEV
METAS 2
CMI
GUM
LNMC
MIRS
NCM
OMH
INM - BRML
NMIA
METAS 3

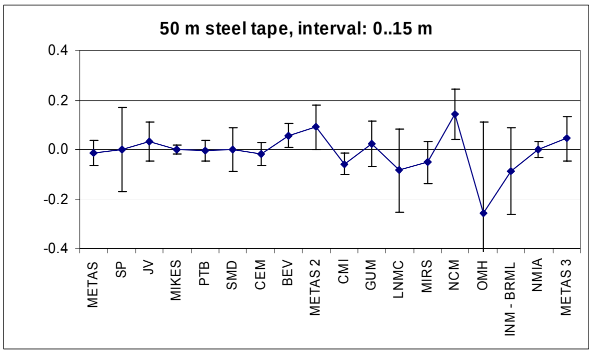

30 m steel tape, interval: 0..27 m
deviation from mean / mm
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
METAS
SP
JV
MIKES
PTB
SMD
CEM
BEV
METAS 2
CMI
GUM
LNMC
MIRS
NCM
OMH
INM - BRML
NMIA
METAS 3

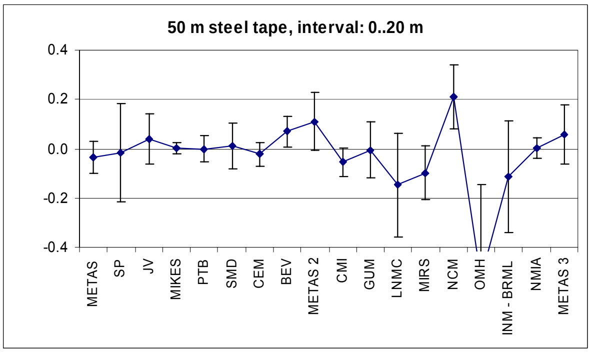

30 m steel tape, interval: 0..15 m
deviation from mean / mm
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
METAS
SP
JV
MIKES
PTB
SMD
CEM
BEV
METAS 2
CMI
GUM
LNMC
MIRS
NCM
OMH
INM - BRML
NMIA
METAS 3

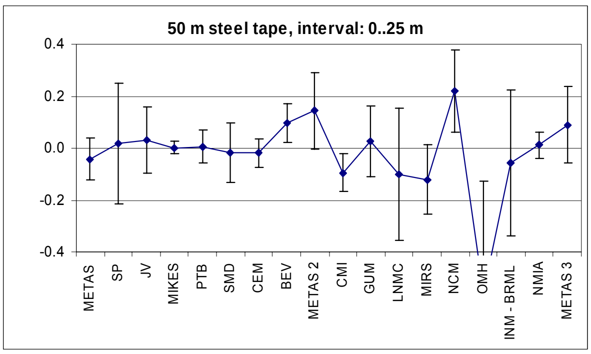

30 m steel tape, interval: 0..30 m
deviation from mean / mm
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
METAS
SP
JV
MIKES
PTB
SMD
CEM
BEV
METAS 2
CMI
GUM
LNMC
MIRS
NCM
OMH
INM - BRML
NMIA
METAS 3

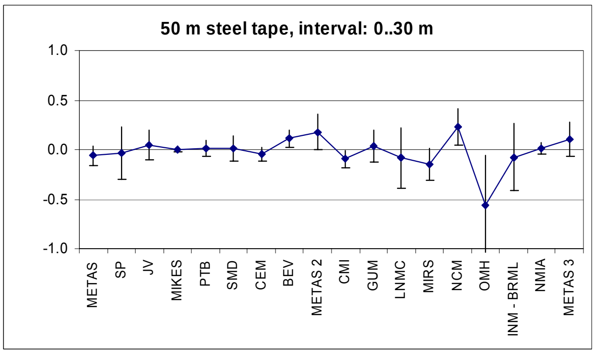

50 m steel tape, interval: 0..5 m
0.4
0.2
0.0
-0.2
-0.4
METAS
SP
JV
MIKES
PTB
SMD
CEM
BEV
METAS 2
CMI
GUM
LNMC
MIRS
NCM
OMH
INM - BRML
NMIA
METAS 3

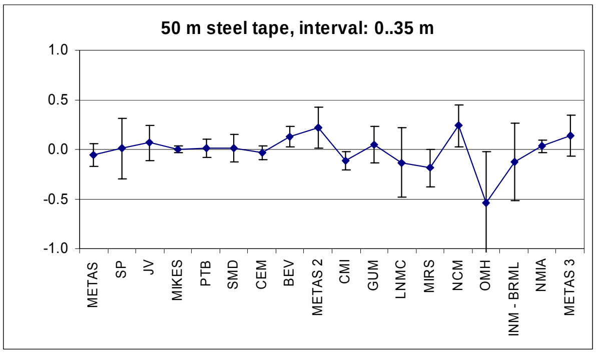

50 m steel tape, interval: 0..10 m
0.4
0.2
0.0
-0.2
-0.4
METAS
SP
JV
MIKES
PTB
SMD
CEM
BEV
METAS 2
CMI
GUM
LNMC
MIRS
NCM
OMH
INM - BRML
NMIA
METAS 3

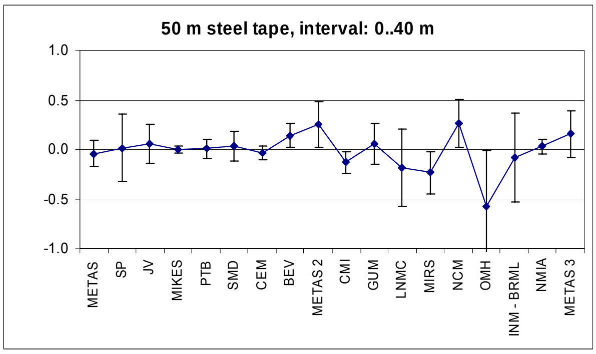

50 m steel tape, interval: 0..15 m
0.4
0.2
0.0
-0.2
-0.4
METAS
SP
JV
MIKES
PTB
SMD
CEM
BEV
METAS 2
CMI
GUM
LNMC
MIRS
NCM
OMH
INM - BRML
NMIA
METAS 3

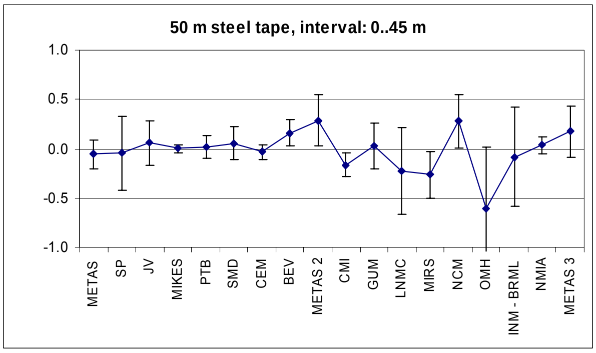

50 m steel tape, interval: 0..20 m
0.4
0.2
0.0
-0.2
-0.4
METAS
SP
JV
MIKES
PTB
SMD
CEM
BEV
METAS 2
CMI
GUM
LNMC
MIRS
NCM
OMH
INM - BRML
NMIA
METAS 3

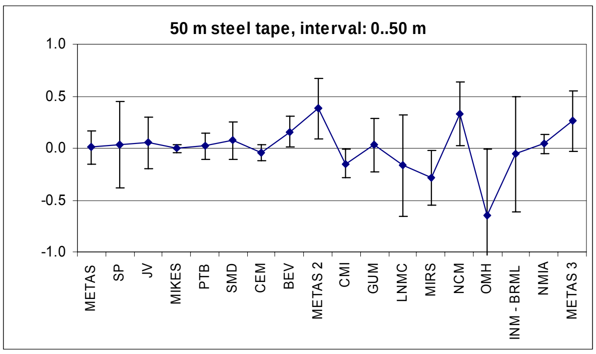

50 m steel tape, interval: 0..25 m
0.4
0.2
0.0
-0.2
-0.4
METAS
SP
JV
MIKES
PTB
SMD
CEM
BEV
METAS 2
CMI
GUM
LNMC
MIRS
NCM
OMH
INM - BRML
NMIA
METAS 3

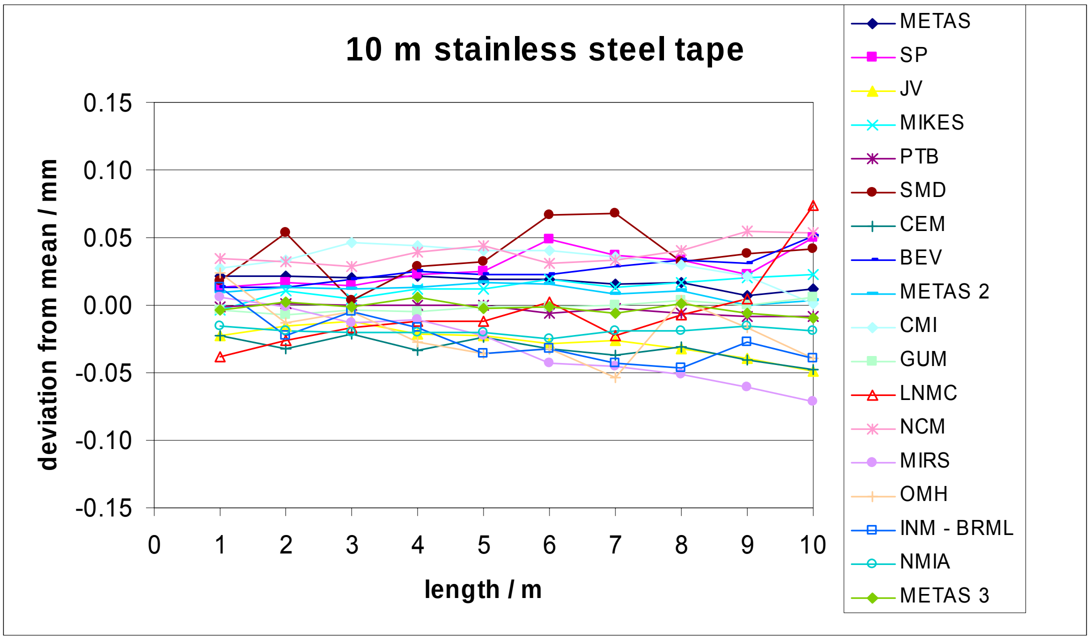

50 m steel tape, interval: 0..30 m
1.0
0.5
0.0
-0.5
-1.0
METAS
SP
JV
MIKES
PTB
SMD
CEM
BEV
METAS 2
CMI
GUM
LNMC
MIRS
NCM
OMH
INM - BRML
NMIA
METAS 3

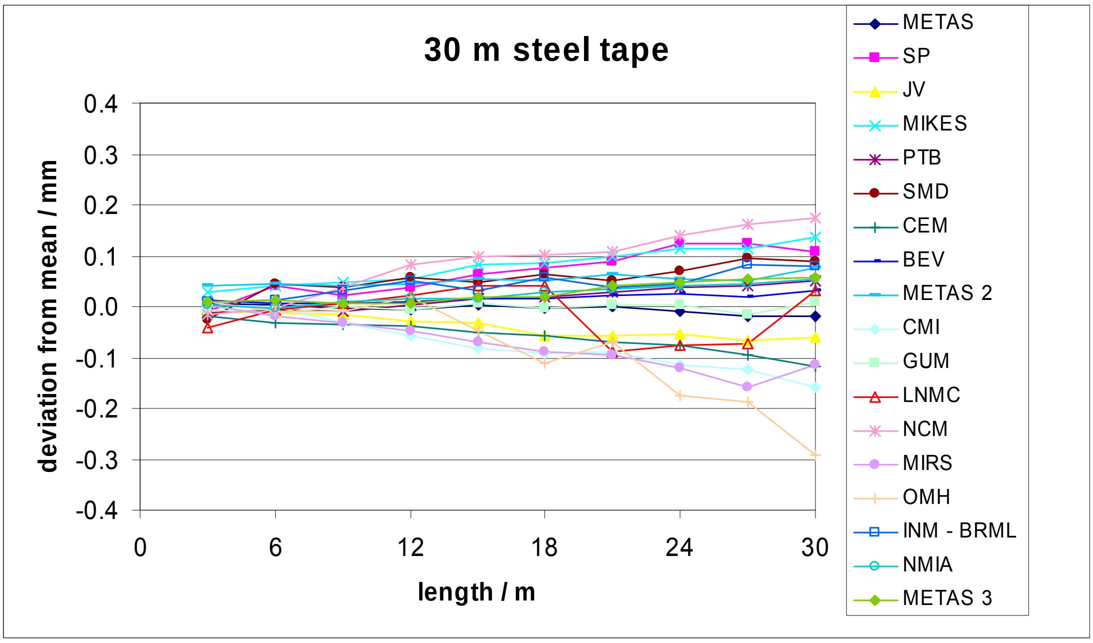

50 m steel tape, interval: 0..35 m
1.0
0.5
0.0
-0.5
-1.0
METAS
SP
JV
MIKES
PTB
SMD
CEM
BEV
METAS 2
CMI
GUM
LNMC
MIRS
NCM
OMH
INM - BRML
NMIA
METAS 3

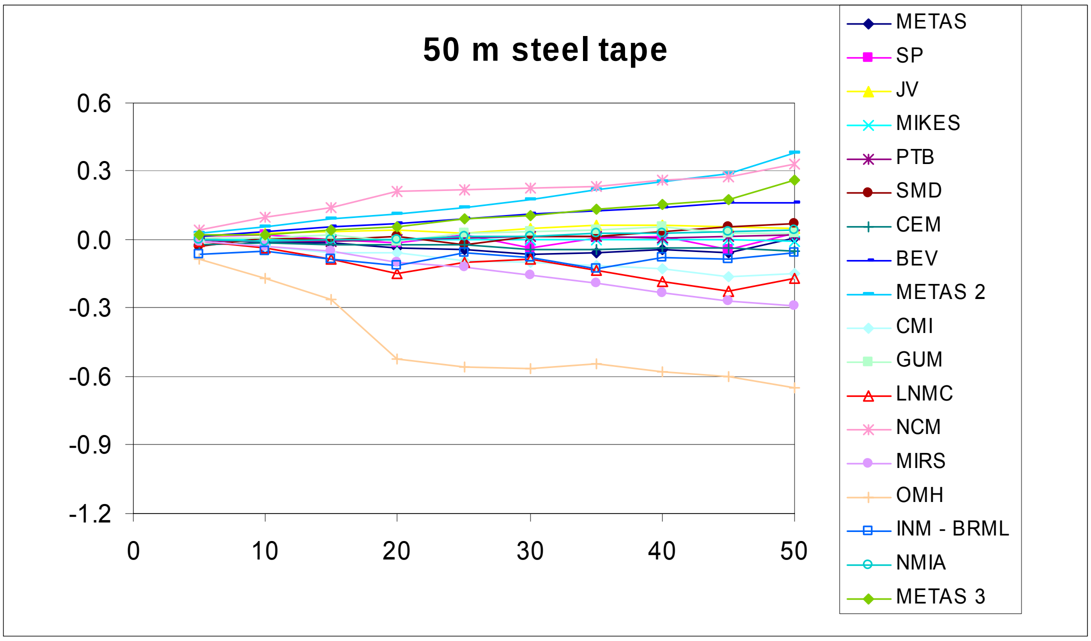

50 m steel tape, interval: 0..40 m
1.0
0.5
0.0
-0.5
-1.0
METAS
SP
JV
MIKES
PTB
SMD
CEM
BEV
METAS 2
CMI
GUM
LNMC
MIRS
NCM
OMH
INM - BRML
NMIA
METAS 3


50 m steel tape, interval: 0..45 m
1.0
0.5
0.0
-0.5
-1.0
METAS
SP
JV
MIKES
PTB
SMD
CEM
BEV
METAS 2
CMI
GUM
LNMC
MIRS
NCM
OMH
INM - BRML
NMIA
METAS 3


50 m steel tape, interval: 0..50 m
1.0
0.5
0.0
-0.5
-1.0
METAS
SP
JV
MIKES
PTB
SMD
CEM
BEV
METAS 2
CMI
GUM
LNMC
MIRS
NCM
OMH
INM - BRML
NMIA
METAS 3


10 m stainless steel tape
deviation from mean / mm
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
0 1 2 3 4 5 6 7 8 9 10
length / m
METAS
SP
JV
MIKES
PTB
SMD
CEM
BEV
METAS 2
CMI
GUM
LNMC
NCM
MIRS
OMH
INM - BRML
NMIA
METAS 3


30 m steel tape
deviation from mean / mm
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
0 6 12 18 24 30
length / m
METAS
SP
JV
MIKES
PTB
SMD
CEM
BEV
METAS 2
CMI
GUM
LNMC
NCM
MIRS
OMH
INM - BRML
NMIA
METAS 3


50 m steel tape
0.6
0.3
0.0
-0.3
-0.6
-0.9
-1.2
0 10 20 30 40 50
METAS
SP
JV
MIKES
PTB
SMD
CEM
BEV
METAS 2
CMI
GUM
LNMC
NCM
MIRS
OMH
INM - BRML
NMIA
METAS 3

| | 1 m | 2 m | 3 m | 4 m | 5 m | 6 m | 7 m | 8 m | 9 m | 10 m | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| METAS | 0.58 | 0.58 | 0.54 | 0.55 | 0.50 | 0.48 | 0.36 | 0.37 | 0.15 | 0.24 | |
| SP | 0.11 | 0.14 | 0.12 | 0.18 | 0.20 | 0.38 | 0.28 | 0.25 | 0.17 | 0.35 | |
| JV | 0.51 | 0.32 | 0.22 | 0.36 | 0.35 | 0.41 | 0.35 | 0.41 | 0.47 | 0.55 | |
| MIKES | 0.17 | 0.47 | 0.23 | 0.55 | 0.55 | 0.91 | 0.61 | 0.77 | 0.95 | 1.09 | |
| PTB | 0.05 | 0.03 | 0.01 | 0.01 | 0.01 | 0.15 | 0.06 | 0.14 | 0.22 | 0.19 | |
| SMD | 0.33 | 1.01 | 0.07 | 0.54 | 0.60 | 1.24 | 1.26 | 0.59 | 0.69 | 0.76 | |
| CEM | 0.66 | 0.93 | 0.62 | 0.97 | 0.70 | 0.94 | 1.06 | 0.86 | 1.14 | 1.32 | |
| BEV | 0.27 | 0.28 | 0.39 | 0.50 | 0.45 | 0.45 | 0.54 | 0.63 | 0.58 | 0.93 | |
| CMI | 1.63 | 1.71 | 2.14 | 1.79 | 1.51 | 1.37 | 1.12 | 0.85 | 0.57 | 0.03 | |
| GUM | 0.14 | 0.27 | 0.12 | 0.18 | 0.04 | 0.02 | 0.00 | 0.08 | 0.00 | 0.13 | |
| LNMC | 0.45 | 0.29 | 0.18 | 0.13 | 0.12 | 0.02 | 0.20 | 0.06 | 0.04 | 0.58 | |
| MIRS | 0.16 | 0.02 | 0.27 | 0.20 | 0.36 | 0.62 | 0.59 | 0.62 | 0.67 | 0.73 | |
| NCM | 0.51 | 0.47 | 0.41 | 0.54 | 0.59 | 0.40 | 0.43 | 0.49 | 0.64 | 0.60 | |
| OMH | 0.28 | 0.14 | 0.05 | 0.22 | 0.25 | 0.19 | 0.29 | 0.02 | 0.07 | 0.16 | |
| INM - BRML | 0.22 | 0.36 | 0.08 | 0.23 | 0.44 | 0.36 | 0.44 | 0.44 | 0.23 | 0.32 | |
| NMIA | 1.32 | 1.58 | 1.63 | 1.56 | 1.47 | 1.67 | 1.21 | 1.15 | 0.86 | 0.96 | |

*Table 10. En-values for 10 m tape.*

| | 3 m | 6 m | 9 m | 12 m | 15 m | 18 m | 21 m | 24 m | 27 m | 30 m | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| METAS | 0.26 | 0.12 | 0.05 | 0.15 | 0.07 | 0.06 | 0.00 | 0.09 | 0.20 | 0.18 | |
| SP | 0.09 | 0.32 | 0.15 | 0.26 | 0.37 | 0.42 | 0.43 | 0.55 | 0.50 | 0.41 | |
| JV | 0.19 | 0.19 | 0.20 | 0.28 | 0.27 | 0.43 | 0.40 | 0.34 | 0.39 | 0.31 | |
| MIKES | 0.60 | 0.89 | 0.97 | 0.97 | 1.40 | 1.35 | 1.42 | 1.53 | 1.38 | 1.55 | |
| PTB | 0.25 | 0.12 | 0.16 | 0.06 | 0.26 | 0.29 | 0.40 | 0.47 | 0.46 | 0.54 | |
| SMD | 0.48 | 0.84 | 0.68 | 0.74 | 0.59 | 0.74 | 0.49 | 0.69 | 0.92 | 0.82 | |
| CEM | 0.42 | 0.70 | 0.78 | 0.84 | 1.09 | 1.19 | 1.37 | 1.47 | 1.40 | 1.74 | |
| BEV | 0.26 | 0.12 | 0.12 | 0.18 | 0.25 | 0.25 | 0.32 | 0.33 | 0.22 | 0.33 | |
| CMI | 0.13 | 0.04 | 0.97 | 1.37 | 1.71 | 1.67 | 1.43 | 1.65 | 1.62 | 1.88 | |
| GUM | 0.23 | 0.32 | 0.02 | 0.09 | 0.08 | 0.04 | 0.02 | 0.03 | 0.12 | 0.07 | |
| LNMC | 0.46 | 0.05 | 0.04 | 0.15 | 0.24 | 0.21 | 0.41 | 0.32 | 0.26 | 0.10 | |
| MIRS | 0.05 | 0.38 | 0.49 | 0.60 | 0.73 | 0.78 | 0.74 | 0.84 | 1.01 | 0.65 | |
| NCM | 0.23 | 0.02 | 0.44 | 0.83 | 0.87 | 0.80 | 0.75 | 0.89 | 0.93 | 0.92 | |
| OMH | 0.09 | 0.05 | 0.04 | 0.07 | 0.13 | 0.31 | 0.18 | 0.42 | 0.41 | 0.57 | |
| INM - BRML | 0.14 | 0.13 | 0.27 | 0.34 | 0.18 | 0.28 | 0.16 | 0.17 | 0.27 | 0.24 | |
| NMIA | 0.13 | 0.17 | 0.42 | 0.58 | 0.46 | 0.70 | 0.77 | 0.79 | 0.77 | 0.83 | |

*Table 11. En-values for 30 m tape.*

| | 5 m | 10 m | 15 m | 20 m | 25 m | 30 m | 35 m | 40 m | 45 m | 50 m | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| METAS | 0.12 | 0.40 | 0.29 | 0.55 | 0.55 | 0.66 | 0.49 | 0.34 | 0.38 | 0.04 | |
| SP | 0.11 | 0.16 | 0.00 | 0.08 | 0.08 | 0.13 | 0.02 | 0.05 | 0.12 | 0.07 | |
| JV | 0.32 | 0.52 | 0.43 | 0.39 | 0.25 | 0.31 | 0.37 | 0.31 | 0.27 | 0.21 | |
| MIKES | 0.09 | 0.13 | 0.11 | 0.22 | 0.15 | 0.19 | 0.02 | 0.01 | 0.03 | 0.25 | |
| PTB | 0.40 | 0.13 | 0.13 | 0.02 | 0.09 | 0.15 | 0.16 | 0.07 | 0.16 | 0.16 | |
| SMD | 0.53 | 0.15 | 0.00 | 0.13 | 0.16 | 0.09 | 0.10 | 0.23 | 0.32 | 0.41 | |
| CEM | 0.58 | 0.39 | 0.39 | 0.44 | 0.35 | 0.64 | 0.57 | 0.54 | 0.43 | 0.58 | |
| BEV | 0.54 | 0.93 | 1.17 | 1.14 | 1.27 | 1.25 | 1.19 | 1.20 | 1.20 | 1.08 | |
| METAS 2 | 0.85 | 0.91 | 1.01 | 0.93 | 0.98 | 1.00 | 1.07 | 1.08 | 1.10 | 1.31 | |
| CMI | 0.28 | 0.79 | 1.29 | 0.93 | 1.34 | 1.16 | 1.18 | 1.16 | 1.32 | 1.08 | |
| GUM | 0.10 | 0.08 | 0.26 | 0.04 | 0.20 | 0.23 | 0.25 | 0.26 | 0.12 | 0.11 | |
| LNMC | 0.08 | 0.29 | 0.51 | 0.69 | 0.40 | 0.28 | 0.38 | 0.47 | 0.51 | 0.34 | |
| MIRS | 0.24 | 0.52 | 0.60 | 0.89 | 0.90 | 0.96 | 1.02 | 1.11 | 1.13 | 1.10 | |
| NCM | 0.81 | 1.29 | 1.40 | 1.64 | 1.40 | 1.23 | 1.10 | 1.07 | 1.02 | 1.08 | |
| OMH | 0.60 | 0.68 | 0.70 | 1.38 | 1.29 | 1.11 | 1.04 | 1.03 | 0.96 | 1.02 | |
| INM - BRML | 0.82 | 0.41 | 0.50 | 0.50 | 0.21 | 0.23 | 0.32 | 0.18 | 0.16 | 0.10 | |
| NMIA | 0.03 | 0.23 | 0.00 | 0.08 | 0.22 | 0.26 | 0.42 | 0.39 | 0.44 | 0.40 | |

*Table 12. En-values for 50 m tape.*