THE DETERMINATION OF GRAVITY ZONE FOR WEIGHING INSTRUMENTS IN SLOVENIA

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ABSTRACT

Several derivations from the WELMEC gravity concept concerning non-automatic weighing instruments that are sensitive to the gravity were developed and analyzed. Apart from that, the gravity field model was developed for a territory of the Republic of Slovenia based on the geographical data and empirical gravity formula. It was established that some simplifications comparing to the WELMEC gravity zone concept could be introduced regarding free movement of weighing instruments across Slovenia. Limitations were set up concerning instruments' characteristics that have to be regarded when the simplifications are used.

1. INTRODUCTION

Membership in the EU enables free movement of non-automatic weighing instruments (NAWI) between EU member states. A special attention is required if the instrument is sensitive to gravity variations. For this reason some EU countries have established gravity zones and in parallel, WELMEC gravity concept exists [1]. Slovenia is a new member of the EU and has not regulated this field so far. Therefore it is necessary to make a study of gravity conditions valid for Slovenia and propose an establishment of gravity zone suitable for initial (EC verification) and periodic verifications.

2. GRAVITY MODEL OF SLOVENIA

The "standardised" gravity formula according to [1], which depends on latitude φ (°) and altitude a (m), is used to calculate the value of gravity g:

$$g = 9{,}780318 \cdot \left(1 + 0{,}0053025 \cdot \sin^2 \varphi - 0{,}0000028 \cdot \sin^2 2\varphi\right) - 0{,}000003085 \cdot a . \qquad (1)$$

According to [2], there are no free air gravity anomalies on territory of Slovenia, which would significantly influence the value of gravity according to (1).

Slovenia expands from latitude 45°25'18'' to 46°52'38'' and from altitude 0 m to 2864 m [3]. Bigger cities are settled up to the altitude of 600 m whereas smaller settlements up to 900 m. Table 1 shows geographical data and gravity values for some bigger cities, which are important in a view of this research.

Table 1: Geographical data [3] and gravity values for Slovene cities

City	Altitude a (m)	Latitude φ	Gravity g (m/s^2)	Note
Ljubljana (LJ)	298	46°03'25''	9,8062	Capital city
Koper (KP)	2	45°32'55''	9,8067	Min a and φ
Jesenice (JE)	574	46°25'45''	9,8057	Max a
Murska Sobota (MS)	190	46°39'30''	9,8071	Max φ and g
Postojna (PO)	550	45°46'30''	9,8052	Min g

The relief of the Republic of Slovenia is represented on Figure 1 where whole country is divided into five regions with a respect to the altitude. The graduation of the partition is 200 m and all places over 800 m are marked as the same region.

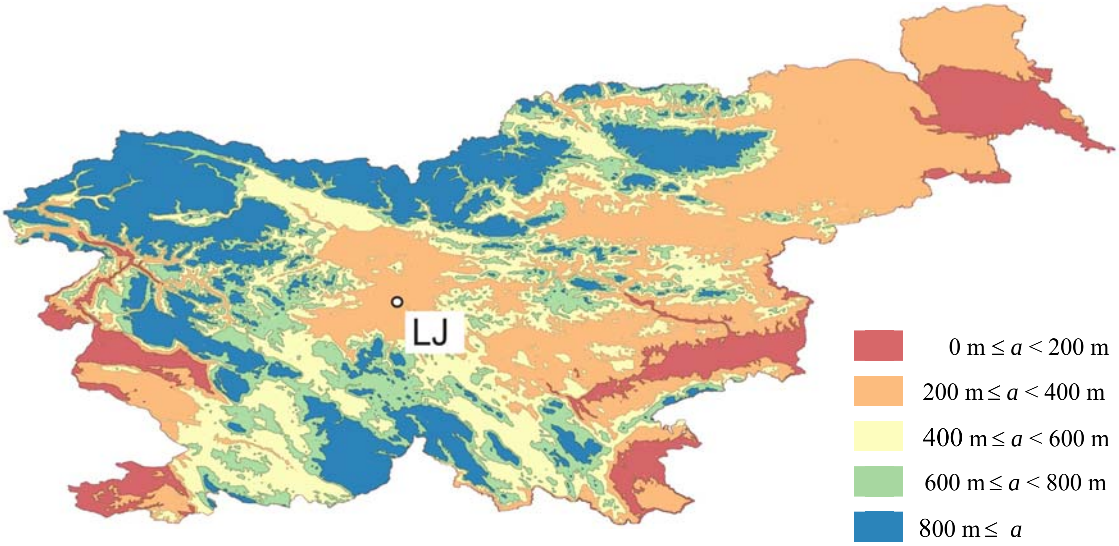

Figure 1: Relief of the Republic of Slovenia

The best way to present gravity field is to apply (1) to digital elevation model (DEM). For gravity field calculation a DEM with 100 m resolution is used. The DEM is interpolated by a linear interpolation from the 25 m interferometric radar digital elevation model and reprojected from a state plane coordinate system to a spherical longitude – latitude coordinate system based on the WGS84 geodetic datum. The reprojection allows direct usage of DEM in "standardized" gravity formula (1).

The result of calculation is continuous gravity field with 100 m resolution that is, for visualization purpose, categorized into 5 categories. For interpolation, reprojection, calculation and categorization process Erdas Imagine 8.7 is used. The results are shown on Figure 2.

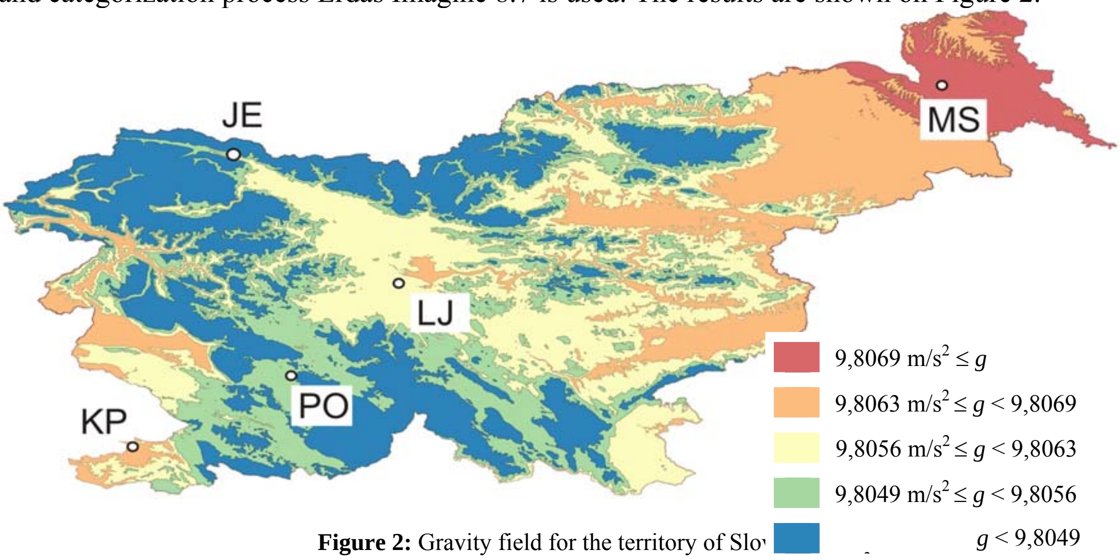

Figure 2: Gravity field for the territory of Slo

Applying WELMEC gravity zone concept on field some practical disadvantages were noticed. The information concerning geographical altitude and latitude are usually not readily available when metrological activities (verification or supervision) are performed on site. However, because of the geographical characteristics of Slovenia (geographically small country, oriented in direction East – West) there is despite stir terrene a good possibility to consider the whole country as one zone considering some limitations. Those limitations are established trough the analysis in the next section.

3. ANALYSIS AND RESULTS

The main object of the present work is to simplify procedures when moving the instruments across the territory of the Republic of Slovenia. This simplification should be applied on the most widely used group of the instruments. Through the analysis it was established that the instruments of the accuracy class (I) and (II) may be used only at the place of the verification and that the instruments of the class (IIII) may be moved freely across the country after the verification. Then the analysis was focused on a group of the instruments of the accuracy class (III). For this group it was necessary to find the limit considering a number of the verification scale intervals, which would divide those instruments into a group that can be freely moved across the country and into a group that may only be used at the place of the verification.

If it is presumed that Slovenia represents a single gravity zone, then it is necessary to limit the maximum number n of verification scale intervals e for NAWI, which can be freely moved across the whole country. This value can be determined through adapted WELMEC condition [1]:

$$n \cdot e \cdot \Delta g / g_{ref} \leq mpe \cdot f \ , \qquad (2)$$

where g_{ref} represents the reference gravity value of the territory, *mpe* the maximum permissible error on EC verification and f the fraction of *mpe*.

In addition, two modifications of (2) are necessary, because there is a nonlinear changes of *mpe* for the instruments of the accuracy class (III) at $n = 500$ and $n = 2000$. Therefore we get for $500 \leq n \leq 1000$:

$$500 \cdot e \cdot \Delta g / g_{ref} \leq mpe \cdot f \Leftrightarrow \Delta g / g_{ref} \leq 1/3000 \qquad (3)$$

and for $2000 \leq n \leq 3000$:

$$2000 \cdot e \cdot \Delta g / g_{ref} \leq mpe \cdot f \Leftrightarrow \Delta g / g_{ref} \leq 1/6000 \qquad (4)$$

Regarding the calculation of the difference in gravity Δg the following (sub)cases are dealt with:

1. $\Delta g = \Delta g_{\varphi} + \Delta g_{\mathrm{a}}$, where Δg_{φ} and Δg_{a} are calculated as it is defined in [1], and the instrument is adjusted to g_{ref}. For calculation of Δg different geographical boundaries can be discussed:

   a) in the first case the widest boundaries of the Republic of Slovenia are considered. The latitude φ ranges from 45°25'18'' to 46°52'38'' and the altitude a ranges from 0 m to 900 m. Actual highest altitude in country is 2864 m, but the areas over 900 m are not populated,
   b) the boundaries of the country rounded to the permitted values according to [1] are considered in the second case. The range of latitude φ is then between 45°30'00'' and

47°00’00’’ and the range of altitude a is between 0 m and 600 m. This boundaries actually cover most of the country and its population, and

c) in the third case boundary values for latitude are the extremes taken from values for 8 biggest cities in Slovenia, all of them are settled up to the altitude of 600 m. This extremes are cities of Koper (KP) and Murska Sobota (MS): φ_{KP} = 45°32’55’’ $\leq \varphi \leq \varphi_{MS}$ = 46°39’30’’, 0 m $\leq a \leq$ 600 m.

2. $\Delta g = g_{max} - g_{min}$, where g_{max} and g_{min} are values for the cities with extreme gravity conditions (that are Murska Sobota (MS) and Postojna (PO), respectively). The instrument can be adjusted:

   a) to g_{ref} and used between g_{max} and g_{min} ($\Delta g = (g_{max} - g_{min})/2$ in this case). This cases arise mostly after EC verifications that are conducted outside Slovenia and where the instrument is adjusted to the reference gravity value of Slovenia, or

   b) at g_{max} but used at g_{min} and vice versa, what can be the case after the periodic verification, when the instrument is verified at one place and used somewhere else.

While cases from 1a to 2a are mostly relevant for the initial (EC) verification, where instruments are adjusted to g_{ref}, the case 2b is relevant for the periodic verification.

Taking into account (2), (3) and (4) Figure 2 can be developed, which represents a relation between the relative difference of gravity $\Delta g/g_{ref}$ and permissible maximum number of verification scale intervals n of the instrument, which is moved across a certain territory and exposed to changes in gravity. This dependence is presented for the factor f taking values 1/3, 1/2 and 1.

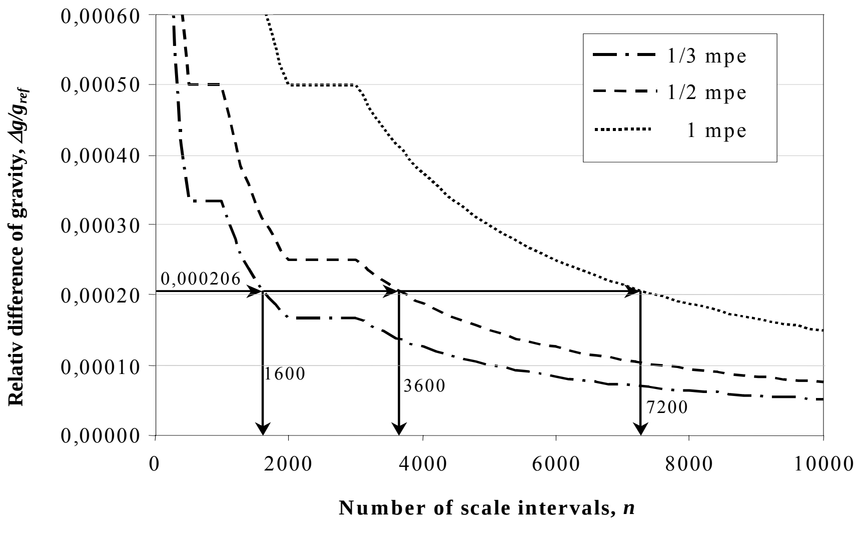

Figure 2: Relation between relative difference of gravity $\Delta g/g_{ref}$ and number of verification scale intervals n

Table 2 shows the maximum values of number of the verification scale intervals n according to (2), (3) and (4) for the cases from 1a to 2b treated above. Table 2 was finalised with the aid of Figure 2. The $\Delta g/g_{ref}$ values according to conditions 1a to 2b are marked on y-axis and the acceptable maximum number of the verification scale intervals at these values are read out on the x-axis. There are three different conditions concerning the allowed magnitude of error that is introduced through gravity changes. These errors are equal 1/3, 1/2 and 1 *mpe* (f = 1, 1/2 and 1/3, respectively).

Table 2: Results of investigation for class (III) instruments

Case	$\Delta g/g_{ref}$	g_{ref} m/s^2	n		
			mpe	1/2 *mpe*	1/3 *mpe*
1a	0,000206	9,8059	7200	3600	1600
1b	0,000164	9,8064	9200	4600	3100
1c	0,000141	9,8063	10000	5400	3500
2a	0,000097	9,8062	10000	7800	5200
2b	0,000195	9,8062	7600	3800	1700

4. CONCLUSIONS

The greatest influence on changes in value of local gravity acceleration in Slovenia has a relief of the country. Because of the combination of low altitude and the biggest latitude in the country the North – East part of Slovenia has the largest value of the gravity acceleration. Areas with the smallest value of acceleration are mostly unpopulated. Because of the relatively small territory of the country some simplifications can be made regarding free movement of the balances considering some limitations.

From Table 2 it can be seen that maximum value of n of NAWI, which can be moved across Slovenia, depends on severity of boundary conditions defined in the article. If the instrument with n = 5000 is adjusted to g_{ref} and used anywhere in Slovenia, only in a few cases the error due to the gravity variation close to *mpe* is introduced. The calculation of Δg according to [1] also shows higher gravity variations than actually exist in Slovenia.

On the basis of the analysis of the results it can be established that, apart from the accepted WELMEC gravity zones system, all instruments of the accuracy class (III) with 5000 verification scale intervals or less that have been adjusted to g_{ref} according outside Slovenia or adjusted on the territory of Slovenia can be moved freely across the country.

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