New Methods of Precision Stabilisation of Geodetic Points for Displacement Observation

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Bei der Deformationsbestimmung ist die Konstanz der geodätischen Festpunkte entscheidend. Die Stabilität der Punkte ist den erwarteten Verschiebungen anzupassen. Es werden sowohl die herkömmliche Art der Punktfestlegung als auch neue Verfahren präsentiert. Eine Qualitätsanalyse der im präzisen Mikronetz der Stadt Libna verwendeten Punktvermarkungen weist deren Zuverlässigkeit nach.

1 Introduction

When establishing ground stability and the stability of man-made objects, the 0.1 mm scale displacements have to be defined frequently. Apart from precision measurements and adjustments, the inherent stability of the points for describing displacements is of utmost importance when trying to determine small-scale displacements with the highest degree of certainty possible – with relevance to points stabilized in stable grounds as well as for object points of the terrain observed. In practice, there is an abundance of methods regarding stabilisation of geodetic points, ranging from methods of fairly low complexity to methods including massive structures, such as concrete pillars and devices enabling forced-centring. Each stabilisation method has its strengths and weaknesses. From each stabilisation method the following is expected:

- securing its inherent (local) stability,
- the possibility of forced-centring,
- low level of physical and visual intrusion in its surroundings and object respectively, and
- lowest possible building costs.

All the conditions mentioned are met in few cases only. Accordingly, for applying optimal solutions in a given situation one resorts to making commpromise.

2 Stabilisation by means of concrete pillars

This is classic method of stabilisation (Fig. 1). Typically, round reinforced concrete pillars of 30–40 cm in diameter and 130–150 cm high (measured above ground mark) will be employed. The pillar is additionally protected by a concrete tube and with the empty space between, filled up by temperature insulation. This provides a high level of temperature resistance functioning as a shield against external influences, i.e. mainly against the sun causing temperature oscillation. The pillar base can be a rock providing an anchor. A system enabling forced-centring is built into the upper plane, this typically being a centred metal plate with a built-in screw, onto which a tripod base of an instrument of a chosen manufacturer is set up. The adaptation of forced-centring to the use of special adapting devices for instruments of different manufacturers is optional.

There are at least two advantages of this stabilisation method:

- high level of stability in qualitatively performed stabilisation, and
- assured accuracy of forced-centring (errors under 0.1mm).

The disadvantages include:

- a large mass, thus inducing a possibililty of local displacements,
- tilting possibility and the consequent point displacements,
- environmental intrusion, i.e. physical obstructions and visual intrusion,
- fixed height, unadjustable to the observer's height, and
- high material costs and costs of stabilisation implementation.

As shown above, the stabilisation method has its advantages and disadvantages, respectively.

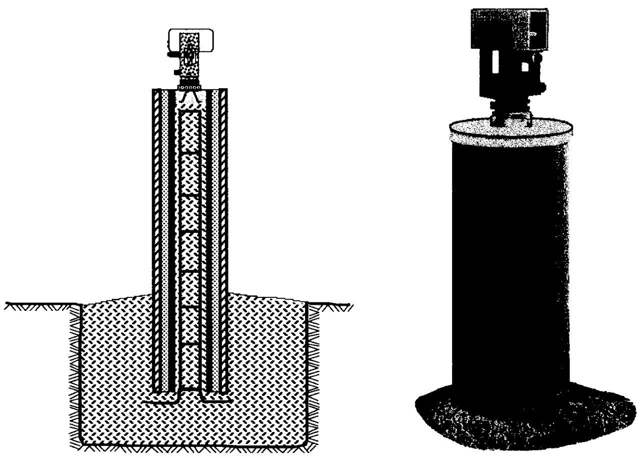

Fig. 1: Stabilisation by means of concrete pillars

3 Ground stabilisation by means of portable metal pillars

Fig. 2 shows a different system demonstrating some of the advantages and disadvantages of the previos stabilisation method. The basis is the conventionally established Swiss method optimized by Prof. Manzon. A point is presented by way of a base ground stabilisation of a disctinctively smaller scale than in the method employing concrete pillars. The ground stabilisation exhibits a system for forced-centring of the tripod and of a rigid precision plumb. A metal stud of approx. 150 cm in height is fixed to the ground stabilisation with screws, and levelled up by a tubular level vial. The instrument is fixed onto the tribrach plaque by way of forced-centring. The tripod stand of the instrument is attached to the rigid precision plumb that is forced-centred to the ground stabilisation centre. The plumb has a precise tubular level vial instead of the usual bull's eye bubble.

The advantages are:

- point stability, and
- forced-centring that is admittedly less accurate than that of concrete pillars.

This stabilisation method bridged most of the weaknesses of the classic stabilisation by means of concrete pillars, as follows:

- the point is considerably less massive, the costs are lower (leaving the manufacture of special tripods aside),
- the tilting possibilities are ruled out due to repeated levelling-up of the pillars,
- the stabilisation is not environmentally intrusive,
- however, there remains the question of fixed instrument height.

The stabilisation method under scrutiny boasts many advantages over the classic pillar, however the centring accuracy is lower.

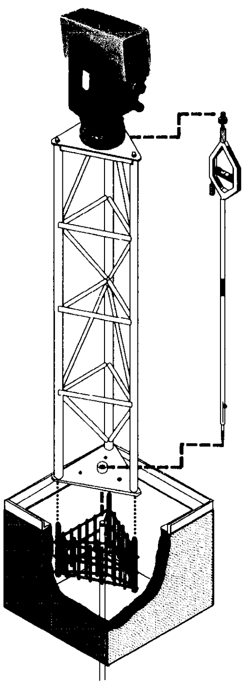

Fig. 2: Ground stabilisation by means of portable metal pillars

4 The new stabilisation method

When setting up a triangulation-trilateration network for recent tectonic movement determination, one has aimed to keep the advantages of both methods discussed.

Fig. 3 shows the basic stabilisation principle. As shown, the measuring points are determined by a set of two physically stabilised points. The measuring points, onto which the reflector is forced-centred, present the points monitored for displacements. All the measurements are carried out on the points that are – according to the reference measuring points – set up ex-centrally. The term ex-central stand is introduced. The distance from the ex-centre to the centre point is 10–20 m.

The reference points were stabilised by combining the methods described above, however, the implementation is simplified and the costs are lower. A mass-produced concrete tube with $\Theta = 0.25$ m in diameter and 1 m length was used. A hole of the same diameter was drilled into the pillar, and a concrete tube was put into the hole. The tube was filled in with concrete and a device for forced-centring was built in. The cylinder top is covered with a mass-produced cover the full protection.

The instrument stand is stabilised with the usual ground stabilisation by means of a concrete square stone with a built-in plug. Above the instrument stand, the tripod is set-up, centred and levelled. The centring accuracy does not influence the end results, since the co-ordinates of the measuring point onto which the reflector is forced-centred are of crucial importance, not the co-ordinates of the instrument stand. However, the tripod's stability during the measurements is essential.

The network is a combined triangulation-trilateration micro-network. The directions and lengths are measured according to a programme. At each stand the directions and distance from the reference point (point centre) are measured. Therefore, the centre and the ex-centre are connected with a minimum number of measurements. The adjustment procedure includes the reference points as well as the ex-central stands.

4.1 Centring errors

The reflector is accurately centred by ways of precision centring. The end result is influenced by the error in determining the co-ordinate difference between the instrument placement and reference points. With the precision laser distance meter Kern Mekometer ME 5000 and the Promeko programme the distance with the accuracy of 0.01 mm is measured. On the basis of many years of experience of using the distance meter and the practical results achieved, it can be established that the usual ex-centricity is that of 10–20 m with the accuracy of 0.03 mm, i.e. in good weather conditions. By means of the second theodolite the direction is repeatedly measured with sufficient accuracy.

The orientation accuracy is determined on the basis of adjustment results. Following the adjustments, corrections v of the calculated orientation angles are calculated. These are the basis for calculating the standard deviation σ_o of

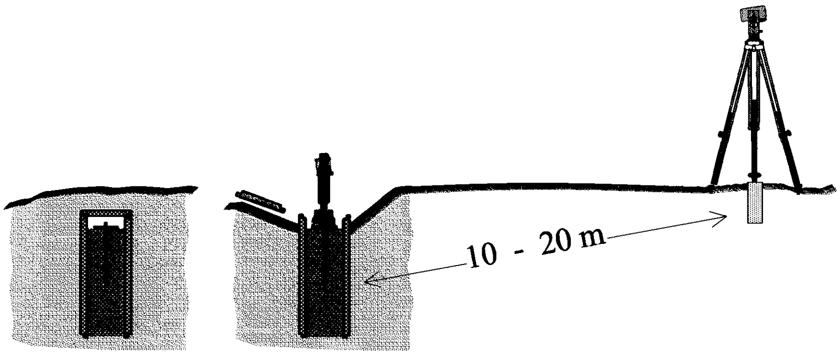

Fig. 3: Ground stabilisation of the centre and the ex-central stand

the average orientation angle – orientation as given in the equation:

$$\sigma_o = \sqrt{\frac{[vv]}{n(n-1)}}$$

On the basis of the orientation error, side error and the centre-ex-centre length, the influence of ex-centricity error stabilisation is calculated.
The accuracy in determining the centre position needs to be examined. As an illustration, the numerical values of the network of Libna in the vicinity of Krško are analysed.

Case study

The network of the town of Libna in the vicinity of Krško was set up to determine point stability at the Orlica fault. The network's shape is that of an irregular pentangle with five circumferential points, where Point 6 is a linking point amplifying network reliability. The points represent the geometrical basis for determining the positions of ground points A, B, C and D defined on the basis of geologic situation. Basically, the ground points are ex-centre of points 1, 2, 3 and 4. Network form is shown in Fig. 4. The network size is described by indicating the area of the circumferential points of a polygon, amounting approx. to 4.27 ha. The longest length in the network is 2–4, i.e. 385 m, the shortest length is 5–6, amounting to 40 m. The ex-central distances are between 10 and 19 m.
For determination of point positions in the horizontal plane the network was measured as a triangulation-trilateration network:

- The horizontal directions were measured with the theodolite Kern E2 on all bounded network points by way of the sets of angles' method in six sets.
- The lengths were measured with the precision distance meter Kern Mekometer ME 5000, in both ways among all bounded network points and to ground points, i.e. in two sets at two different epochs.

By utilizing the precision thermometer, barometer and psyschrometer the metoerological parameters were accurately measured during the angle and length measurements.
The accuracy of the angle and length measurement sets was determined by the a posteriori method of weight estimation according to Ebner. The network was adjusted as a free network, ground points were excluded from the adjustments. Table 1 illustrates the accuracy achieved in the measurements so far.

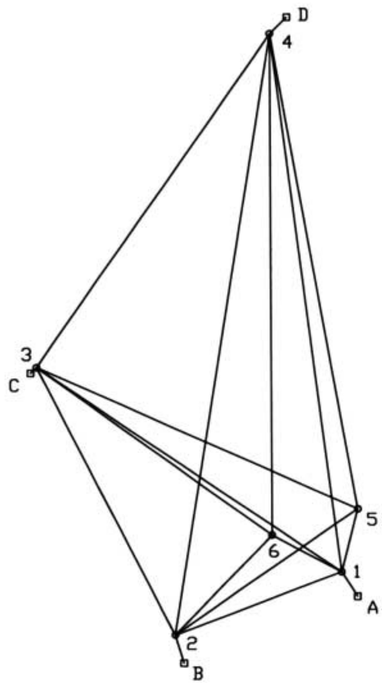

Fig. 4: The micro-network of Libna

Tab. 1: Standard deviation (σ) of the angle and length measurements in the network

measurement		σ_s [mm]	σ_α [″]
null	Set 1	0.40	0.72
	Set 2	0.29	1.00
second		0.23	0.53
third		0.52	0.62

The network measurements are carried out with the highest degree of accuracy possible. The form of the network provides the possibility of determining point positions with outstanding accuracy. The elements of standard ellipses of ex-centricity errors (instrument stands) confirm the latter.
The elements of error ellipses of ex-centre positions a_c, b_c, Θ_c and the ex-centricity error (transverse $S \cdot \sigma_\varphi$ and longitudinal errors σ_S) are the input data for calculating the accuracy in position determination of a ground stabilised point – ellipses of the centre a_z, b_z, Θ_z. Regarding the elements of error ellipses the following equations were used:

$$a_z = \sqrt{\frac{a_c^2 + b_c^2 + (S \cdot \sigma_\varphi)^2 + \sigma_s^2 + \sqrt{((a_c^2 - b_c^2) \cdot \cos 2\Theta_c + ((S \cdot \sigma_\varphi)^2 - \sigma_S^2) \cdot \cos 2\Theta_e)^2 + ((a_c^2 - b_c^2) \cdot \sin 2\Theta_c + ((S \cdot \sigma_\varphi)^2 - \sigma_S^2) \cdot \sin 2\Theta_e)^2}}{2}}$$

$$b_z = \sqrt{\frac{a_c^2 + a_c^2 + (S \cdot \sigma_\varphi)^2 + \sigma_S^2 - \sqrt{((a_c^2 - b_c^2) \cdot \cos 2\Theta_c + ((S \cdot \sigma_\varphi)^2 - \sigma_S^2) \cdot \cos 2\Theta_e)^2 + ((a_c^2 - b_c^2) \cdot \sin 2\Theta_c + ((S \cdot \sigma_\varphi)^2 - \sigma_S^2) \cdot \sin 2\Theta_e)^2}}{2}}$$

$$tg\ 2\Theta_z = \frac{(a_c^2 - b_c^2) \cdot \sin 2\Theta_c + ((S \cdot \sigma_\varphi)^2 - \sigma_S^2) \cdot \sin 2\Theta_e}{(a_c^2 - b_c^2) \cdot \cos 2\Theta_c + ((S \cdot \sigma_\varphi)^2 - \sigma_S^2) \cdot \cos 2\Theta_e}$$

In Table 2 data regarding accuracy in determining ex-centre positions and ex-centricity errors are collected, as a follow-up, basing on the data provided, accuracy of identifying centre position is calculated.

5 Conclusion

Each method of stabilisation discussed in this article has its strengths and weaknesses respectively. The main features of the disadvantages and advantages are summed up in Table 3.
The classic stabilisation method is – when carried out carefully – a highly recommended choice. A quality implementation depends on the type of grounds where the point is being set up – rocky grounds are most appropriate. Forced-centring is another advantageous feature. Accordingly, point setting-up can be highly demanding in inaccessible terrains. However, this stabilisation method may come out as possibly disruptive in its urban and agricultural environments, additionally, another disadvantage is the fixed instrument height.

By means of ground stabilisation and with the use of metal tripod stands some disadvantages of the classic method can be bridged. The manufacture is substantially simpler and less expensive, presuming that there are special metal tripod stands available. Owing to the removal of the tripod stand after the measurements, the point is not environmentally challenging. The disadvantage is the fixed stand height and only partial forced-centring, by means of the rigid precision plumb.
By introducing the division between the signal-reflector stand as the centre point and the instrument point as the associated ex-centre, the disadvantages of the other two ways were neutralized. The stabilisation is quick and simple – a concrete tube is put into a borehole and filled with concrete. The point is not environmentally disruptive. Forced-centring is ensured as well as the possibility of height adjustment. The only additional demand is the high accuracy in measuring the ex-central elements. Theoretically, the accuracy of "centring" may be of lower degree.

Table 2: Comparison of centring accuracy at centre and ex-centre points

Point	Standard error ellipses Ex-centre (tripod stand)			Ex-centricity error				Total error ellipses Centre (ground stabilisation)		
	a_c [mm]	b_c [mm]	Θ_c [°]	σ_φ [″]	$S \cdot \sigma_\varphi$ [mm]	σ_S [mm]	Θ_e [°]	a_z [mm]	b_z [mm]	Θ_z [°]
A	0.07	0.06	156	0.40	0.04	0.03	146	0.08	0.07	152
B	0.09	0.07	153	0.20	0.02	0.03	163	0.09	0.08	151
C	0.11	0.08	32	0.26	0.03	0.03	354	0.11	0.09	32
D	0.09	0.07	67	0.12	0.01	0.03	43	0.09	0.08	73

Table 3: Stabilisation features of the methods discussed

	Concrete pillars	Swiss method	New method
Centring	forced	rigid plumb with a tubular vial	forced
Stability	o.k.	o.k.	o.k.
Complexity of manufacture	high	low	low
Local displacement possibility	yes	no	no
Environmentally disruptive	yes	no	no
Additional demands	none	metal tripod stand	ex-centre stand

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Abstract

An optimal stabilisation of geodetic points is undeniably an important factor when determining displacements. According to the size of the anticipated displacements a proper stabilisation accuracy must be provided. Traditional ways of stabilisation are discussed as well as a new method for measuring tectonic movement is proposed. Accordingly, a quality analysis of the new stabilisation method used in the precision micro-network of Libna in the vicinity of Krško is given.