Long Terme Photogrammetric Measuremend of Rockfill Dam

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ISPRS Commission V , Working Group 3

KEY WORDS :Bundle, Adjustment, Analytical, Monitoring, Network, Comparison, Parameters, Accuracy

ABSTRACT

Two photogrammetric methods the SAS method and ORIENT software were used for the photogrammetric measurement of the rockfill dam. The results of these both methods were compared with a ground control survey in one epoch of the measurement. The stability of the monitoring network was established by concrete pillars with forced centering for the theodolit, terrestrial camera and targets. The required accuracy has been kept in the range of 1-2" for the angle measurement and 1-2 μm for the photocoordinate measurement. The results show that the achieved accuracy of 2-3 mm in spatial displacement of a rockfill dam determinated by the SAS method and by ORIENT software were comparable to the ground survey.

1. Introduction

Since 1977 we have determined the spatial displacements of the rockfill dam Bukovec (East Slovakia) using the analytical photogrammetric method called: Separate Analytical Solution method - SAS method. This method was presented at the Congress ISPRS in Rio de Janeiro 1984 and at the Conference Optical 3D-Measurement Techniques III in Viena 1995, (Cernansky, J., 1995).

The SAS method has been applied in 23 epochs of the photogrammetric displacement measurements carried 1 - 2 times per year. The method use the horizontal and vertical angles measured by a theodolit with forced centering directly on the photogrammetric stations. The coordinates of the projection centers were determined by ground survey with the eccentricity of the camera entrance pupil and its bearing.

For the spatial displacements of that rockfill dam was utilising also the ORIENT analytical adjustment software (ORIENT, 1991). It was possible to compare the spatial coordinates determined by the SAS method and by the ORIENT with ground survey in 1994.

2. Determination of the spatial coordinates by analytical intersection using the SAS method.

For the displacement measurements of the dam, a monitoring network with reference, control and detail (observed) points was established (Fig. 1). The reference points were situated around the body of the dam and served as ground survey = theodolite stations. Some of them were the camera stations. The detail points were placed directly on the body of the dam. All these points were constructed as concrete pillars. The ground survey coordinate system XY is visible from Fig. 1, Z-axis directed to the zenith.

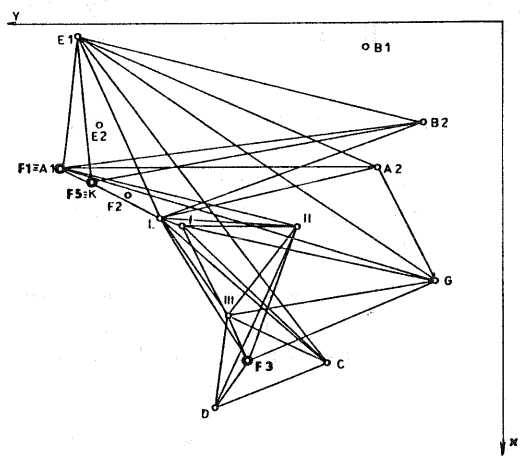


Fig.1 Monitoring network of the dam

Ground survey

The ground survey angles of reference points, control and detail one were measured by precise theodolit Wild T3 in three sets with an achieved accuracy:

$$m\,\alpha = 0{,}7'' \qquad m\,\beta = 1{,}1'' \qquad (1)$$

All those points were marked by the special circular targets both for the ground survey and photography. The camera stations F1, F3, F5 (Fig. 1) are identical to the reference points of monitoring network.

Photography and photocoordinate measurement

The normal angle metric terrestrial camera Photheo 19/1318 Zeiss Jena with horizontal photograph was used for the photography. The distribution of control and detail points is shown in Fig. 2.

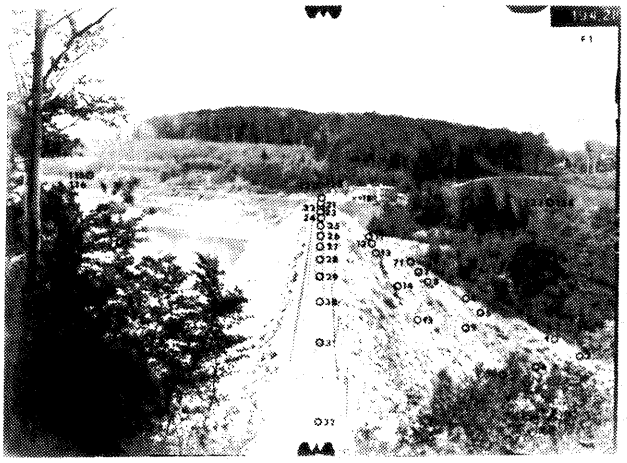


Fig.2 Distribution of control and detail points - F1

The comparator coordinates of control and detail points were measured on 3 or 4 photographs by the precise monocomparator Komess 3030 Zeiss Jena with an achieved accuracy:

$$m_{x'} = 1{,}2\ \mu m \qquad m_{y'} = 1{,}1\ \mu m \qquad (2)$$

The x, y, z ground coordinates of control and detail points were determined by a spatial survey intersection from F1, F3, F5 three stations (Fig. 1).

The x, y, z photogrammetric spatial coordinates of detail points placed on the air side of the dam were determined by the spatial analytical intersection where the photograph parameters were computed by the SAS method.

The x, z photogrammetric plane coordinates of detail points placed on the top side of the dam were determined by the analytical time base method where the photograph parameters were also computed by the SAS method too.

Graphic presentation of displacements

The displacements of the air side of the dam in dx resp. dz direction during the period 20 - 23 epochs are illustrated in Fig. 3 resp. Fig. 4.

The displacements of the top side of the dam in dx resp. dz direction during the same period are illustrated in Fig. 5 resp. Fig. 6.

Fig. 3 Air side of the Bukovec dam "90-94

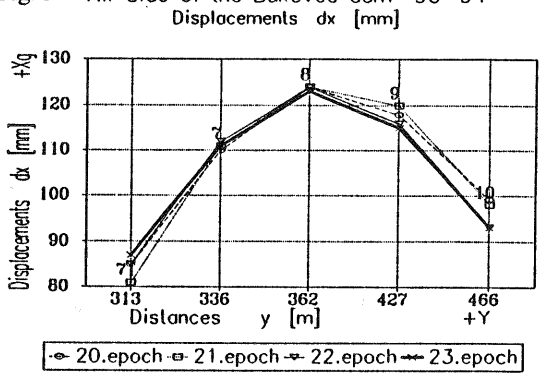


Fig. 4 Air side of the Bukovec dam "90-94

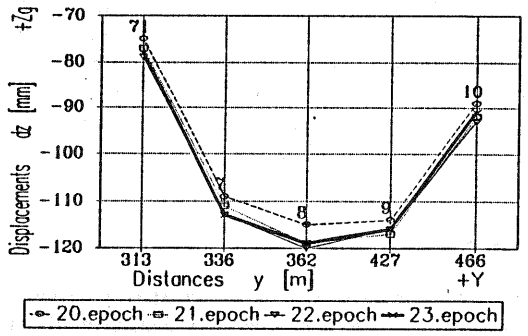


Fig. 5 Top side of the Bukovec dam "90-94

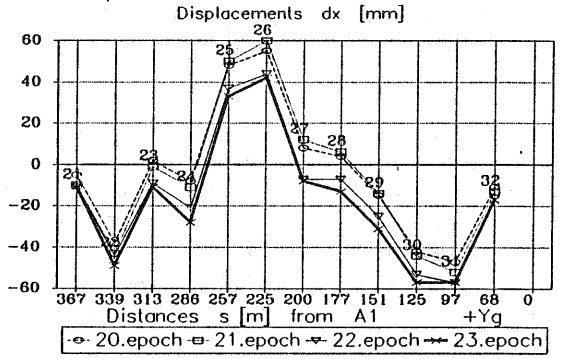
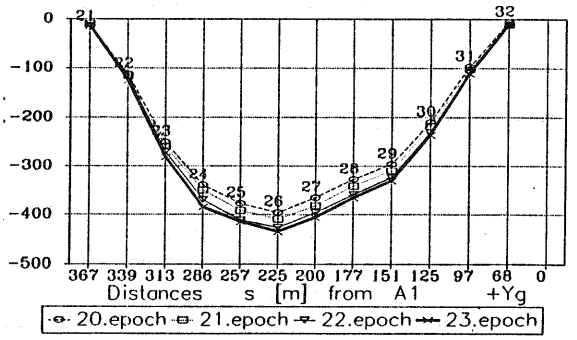


Fig. 6 Top side of the Bukovec dam "90-94



The projection center coordinates determined by bundle adjustment were compared with ground survey. The dxo, dyo, dzo differences are presented in Table 3:

The dxo, dyo differences can be neglected, but the dzo differences are the significant systematic errors. These dzo differences influence essentially the accuracy of control and observed points in heights.

Table 3: Differences dxo, dyo, dzo between projection centers determined by ground survey and by the ORIENT - OR 1

Projection center	dxo mm	dyo mm	dzo mm
F1	1	0	-15
F3	2	-1	-11
F5	0	3	-9

Achieved accuracy of the ORIENT - OR 1

From the dx_1, dy_1, dz_1 differences between ground survey and photogrammetric coordinates of the control and observed points for the OR 1 variant we obtain these RMS values:

$m_{x1} = 1{,}2$ mm $m_{y1} = 2{,}0$ mm $m_{z1} = 8{,}6$ mm (6)

RMS m_{z1} according to (6) and its systematic error $c_z = 7{,}1$ were over the allowable values. It was probably caused by unfavourable distribution of control points in the image planes and mainly by the height differences between individual camera stations (Table 2).

Under these conditions a linear dependence between the elements of inner orientation (especially y'_h) and the coordinates of projection centers (especially z_o) and the rotations (especially ω = ZE in ORIENT)can arise.

3.2 Determination of photograph parameters and spatial coordinates by the ORIENT - variant OR 2

The problems shown above have been solved by
- increasing the number of control points to 6 for the F3 station and to 8 for the F1 and F5 station
- the elements of inner orientation were determined individually for the station F1 and together for stations F3 and F5 by bundle adjustment.

The x_o, y_o, z_o projection center coordinates were compared with ground coordinates again.

The dxo, dyo, dzo differences are given in Table 4:

Table 4: Differences dxo, dyo, dzo between projection centers determined by ground survey and by the ORIENT - OR 2

Projection center	dxo mm	dyo mm	dzo mm
F1	0	-1	-5
F3	2	-1	-6
F5	-1	3	-2

From Table 4 it follows that the differences of the dxo, dyo projection centers computed from the OR 2 variant were practically equal with the differences from the variant OR 1 (Table 3). But the dzo differences (Table 6) were essentially smaller then the dzo differences (Table 3).

Achieved accuracy of the ORIENT - OR 2

The dx_2, dy_2, dz_2 differences between ground survey and photogrammetric coordinates of the variant OR 2 are presented in Table 5.

Table 5: Differences dx2, dy2, dz2 between ground and photogrammetric coordinates determined by the ORIENT - variant OR 2

Control point	dx2 mm	dy2 mm	dz2 mm
1	0	0	3
5	2	1	2
6	0	-3	1
10	-2	-1	0
11	1	3	2
15	-1	-3	-1
115	-2	1	3
32	4	2	-5
AVG	-0.2	0.0	0.6
RMS	1.9	2.1	2.5
Detail point	**dx2 mm**	**dy2 mm**	**dz2 mm**
4	4	2	3
7	1	-3	4
8	0	2	2
9	0	-4	-1
12	-1	-5	3
13	-3	0	1
14	-1	-4	-3
AVG	0.0	-1.7	1.3
RMS	2.0	2.8	2.3
Control and detail points together :			
AVG	0.1	-0.8	0.9
RMS	2.0	2.7	2.6

Achieved accuracy of the SAS method

The dxa, dya, dza differences between the ground coordinates of observed points and the photogrammetric coordinates determinated by the SAS method are presented in Table 1.

Table 1: Differences dxa, dya, dza between ground and photogrammetric coordinates determined by the SAS method

Detail point	dxa mm	dya mm	dza mm
1	-5	3	1
4	-4	5	3
5	-5	-1	2
6	-6	-2	2
7	0	1	4
8	0	-1	4
9	-3	0	-1
10	-7	3	1
11	1	-2	0
12	0	-2	3
13	2	-2	4
14	1	-3	-3
15	-2	1	0
AVG	-2.2	0.2	1.5
RMS	3.6	2.4	2.6

The achieved accuracy of SAS method was characterized by the following RMS :

$m_{xa} = 3{,}6$ mm $\quad m_{ya} = 2{,}4$ mm $\quad m_{za} = 2{,}6$ mm (3)

with these systematic errors :

$c_{xa} = -2{,}2$ mm $\quad c_{ya} = 0{,}2$ mm $\quad c_{za} = 1{,}5$ mm (4)

Advantage of these experiment was as follows :

1. The ground survey of control points and the photography were carried out from the same stations and were synchronized in one day.

2. Achieved accuracy of the surveying angle measurement according to (2) and photocoordinates measurements according to (3) were optimal

3. Stability of the atmosphere was characterised by temperature within 5 ° to 6 °C.

3. Determination of the spatial coordinates by the analytical intersection using the ORIENT system of bundle adjustment

ORIENT is an universal photogrammetric system of bundle adjustment which was developed at the Institute for Photogrammetry and Remote Sensing of the Vienna Technical University by Dr. Kager

. The ground spatial coordinates and photocoordinates of the control points were used for the determination of parameters.The parameters included the following unknowns: The inner orientation, the coordinates of the projection centers and the rotations.

Variants of the experiment

In our experiment we determined the inner orientation and remaining parameters in two variants :

1. Variant OR 1 - ORIENT: The inner orientation was determined for each photograph, from 5 control points placed on the border of the dam.This way was used as principal by the SAS method too.

2. Variant OR 2 - ORIENT: The inner orientation was determined together for 9 photographs from the stations F3 and F5 and for 3 photographs from the station F1 (with different $z'_h = -20$ mm). 6 - 8 control points were placed in the border of the photograph.

Determination of the spatial coordinates of control and detail points was carried out by bundle adjustment for all the measured points and for 12 photographs.

The height differences between the camera stations are given in Table 2.

Table 2: Heights and their differences between the camera stations

Camera station	z m	dz m
F1	444.5	73.7
F3	370.8	0
F5	425.8	55.0

3.1. Determination of photograph parameters and spatial coordinates by the ORIENT - variant OR 1

For the parameters determination of variant OR 1 were used 5 control points placed on the border of the dam only. Because the height differences between the station F1 and F3 is 74 m, the body of the dam covered only 1/4 of the photograph from the station F1 (Fig . 2). The similar situation is also for the station F5.

Photograph parameters

RMS of inner orientation parameters were determined by bundle adjustment as follows :

$m_{x'h} = 0{,}02$ m $\quad m_{y'h} = 0{,}005$ m $\quad m_f = 0{,}012$ m (5)

For the control and observed points together we reached these values of RMS:

$m_{x2} = 2,0$ mm $\quad m_{y2} = 2,7$ mm $\quad m_{z2} = 2,6$ mm $\quad$ (7)

4. Comparison of the analytical spatial intersection using theSAS method and ORIENT system with ground survey.

The basis for the comparison of the photogrammetric methods (SAS and ORIENT) were the results summarized in Table 1 and Table 5. Through the RMS and their systematic errors (AVG) we attempted to evaluate the reliability of the photograph parameters determination

Systematic errors of theSAS method

The single SAS method at present use the average of the photogrammetric angles from 3 or 4 photographs and spatial photogrammetric intersection from the stations F1, F3, F5 (Fig 1).

The photogrammetric angles are calculated from corrected photocoordinates as a function of photograph parameters (inner orientation and rotations). Differences between ground and photogrammetric coordinates in Table 1 show these systematic errors (AVG):

$c_{xa} = -2,2$ mm $\quad c_{ya} = 0,2$ mm $\quad c_{za} = 1,5$ mm $\quad$ (8)

Systematic errors of the ORIENT - OR 2

Differences between bundle adjustment of the variant OR 2 and ground survey have shown the systematic errors (AVG in Table 5) less than 1 mm:

$c_{x2} = 0,1$ mm $\quad c_{y2} = -0,8$ mm $\quad c_{z2} = 0,9$ mm $\quad$ (9)

The systematic errors according to (9) show that the ORIENT system compensates the systematic errors of the photograph parameters very good. In the opposite of them the necessity of 6 - 8 control points were too large.

Projection centers "zo" - the main problem

The main problem consist in the determination of projection center in zo direction. When the control points were placed in a quarter of the photograph only (Table 3) dz_o were within -9 to -15 mm. On the other hand when the control points were placed optimal (Table 4) dz_o were within -2 to -6 mm.

5. Conclusion

The results archieved by two photogrammetric methods the SAS and the ORIENT have shown that both methods can be used for the periodical measurements of the rockfill dam displacements.

The SAS method is simplier compare with ORIENT but at present it doesn't have an adjustment program. The photograph parameters are computed from ground angles measured from camera stations on the control points. The spatial coordinates are determined by analytical intersection.

The ORIENT is a bundle adjustment software. The photograph parameters and spatial coordinates are computed from ground coordinates and photocoordinates of control and detail points by bundle adjustment. The accuracy of both method is comparable.

The application of both methods requires the following conditions:
- the accuracy of the horizontal and vertical angle measurements must be approx. 1" to 2"
- the accuracy of the photocoordinate measurements have to be approx. 1 to 2 μm
- the ground coordinates of the projection centers by SAS method or the ground coordinates of control points by ORIENT system must be determined with accuracy within 1 to 2 mm in monitoring network of the rockfill dam

Acknowledgement: Author thanks Mrs. Ing. Michaela Ragalová for the processing of data by the ORIENT and dr. H. Kager for consulting of the ORIENT application.

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