PHOTOGRAMMETRIC MEASUREMENT OF DEFORMATIONS OF THE GABČÍKOVO LOCK GATE

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ABSTRACT:

The paper presents application of photogrammetric measurements of lock gate deformations.Spatial lock gate deformations are measured by means of the analytical intersection method utilizing the ORIENT software (ORIENT,1991).Deformations are caused by lock filling with parameters changing due to the water level elevation in the lock. The achieved accuracy, given by the mean true error m_ε = 1-3 mm, is sufficient to express the expected maximum deformations of about 45 mm. This method can be used during full operation of the lock to enable regular monitoring of the lock´s safety parameters.

1. INTRODUCTION

Locks of the Hydro-electric system Gabčíkovo are by their dimensions unique not only in the Slovak Republic but also in Europe and we can say all over the world.Therefore it is natural that construction of such work requires the cooperation of a wide group of specialists.That concerns not only the complete work but also individual tasks as well as activities during the construction of such work.

After the crush of the left gate of the left lock in March 1994 it was necessary to replace the construction of the gate.The left lock gate crushed just before reaching the maximum water level in the lock and the outflowing water below the gate caused big backward wave which damaged the gate of the right lock.To accelerate navigable conditions of the Danube it was necessary to repair immediately the right gate.The result of specific conditions was to accept such technological procedure of the repair that could be considered as temporary solution.The complete exchange of this gate is planned within a short time.

High rate of hydrostatic pressure on the gate makes it as exposed construction.Naturally before starting to work this kind of construction,the complex quality check as well as reliable functioning of gate was performed.

Assembling of the construction of the left lock gate was performed in so called "dry dock",that means a section of a lock closed off with upper and lower temporary steel barriers and after pumping off the water assembling takes place in dry environment.The dry dock is suitable for loading test of the gate by onesided pressure of water after removal the upper barrier.In the case of loading test without dry dock it is not possible to test gate under maximum pressure designed.

Loading test of the left gate was performed within 15. Jan. to 18 Jan. 1995 to determine its deformations using more measuring methods.Tensiometric measurements were performed by Technical and Testing Institute for Civil Engineering in Bratislava and simultaneous geodetic and photogrammetric measurements by Department of Surveying,Slovak Technical University in Bratislava.

Presented paper is devoted to problems of photogrammetric measurements of 3-D deformations of the gate during the loading test.

2. PHOTOGRAMMETRIC MEASUREMENTS OF LOCK GATE DEFORMATIONS

The loading test on the left gate of the Gabčíkovo lock arised the question, whether the lock filling process may cause the deformation, eventually deflection of the gate to a greater extent than permitted by the given project.

The method applied to solve this problem should determine the spatial position of observed points, marked by targets on the tested gate in very short time intervals (stages). The single stages depend on the water level in the lock.

The photogrammetric intersection method utilizing the analytic software ORIENT is a convenient method for the solution of this problem with sufficient accuracy.This software has been developed at the Vienna Technical University, in the Institute for Photogrammetry and Remote Sensing .

ORIENT is a modular program system consisting of individual computation modules, where the adjustment module (ADJUST) is the main one. It is based on the principle of projective transformation (collinearity condition) of single photographs into the reference system, where they are mutually (in a block) adjusted by means of the bundle method. This results in adjusted co-ordinates of projection centers, determined points and rotations parameters of the single photographs, with their corresponding mean errors.

The projective transformation is given by the following equations (Figure 1):

$$(\mathbf{p}-\mathbf{p}_0)=\lambda\mathbf{R}^T(\mathbf{P}-\mathbf{P}_0) \qquad (1)$$

eventually

$$(\mathbf{P}-\mathbf{P}_0)=\frac{1}{\lambda}\mathbf{R}(\mathbf{p}-\mathbf{p}_0) \qquad (2)$$

whereby R is the orthogonal rotation matrix

λ - scale coefficient.

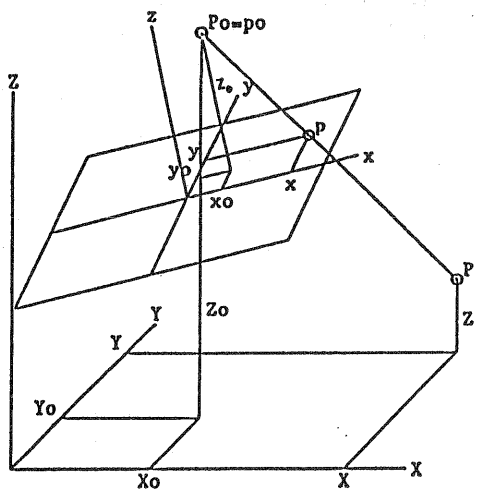

Figure 1 Coordinate system

Photogrametric measurements of spatial shifts of observed targets,which were glued on he gate,were performed simultaneously with geodetic measurements in two sets.

First set of measurements (15. - 17. Jan. 1995) were performed in the dry dock near onesided pressure of water,after removal the upper barrier.The water level elevation "above" the gate was lifted from 0,0 m to 23,0 m and the water level elevation "under" the gate was constantly 0,0 m (table1).

Second set of measurements (18. Jan. 1995).The water level elevation "above" and "under" the lock gate was levelled on 8,0 m and the water level elevation "above" the gate was lifted from 8,0 m to 29,5 m (table1).

Geodetic measurements of spatial shifts of observed points were performed by line of sight method.The theodolites (THEO 010B) stations have been located on the left and right side of the lock (the stations A,B, figure 2).The 0,6 m long rulers with milimeter division were fastened on the observed points and observed vertical plane passed through stations of theodolites A,B (figure 2).

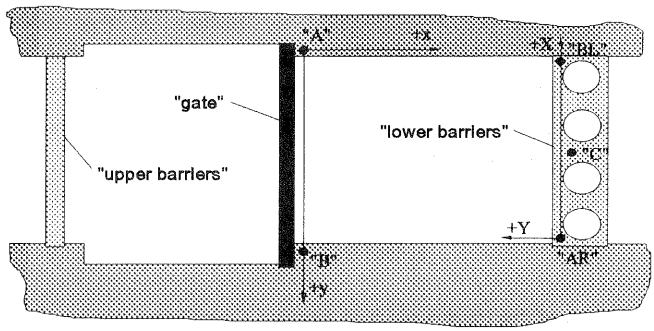

Figure 2 Geodetic and photogrammetric coordinate system

3 LAYOUT AND TARGETING OF CONTROL AND OBSERVED POINTS

The control points (1 - 8,figure3) have been laid out in places, where the stability remained the same during the whole experiment.

The observed points (L1 - L19,P1 - P19, Figure 4) have been positioned on the surface of the observed lock gate.Marking of the control as well as observed points has been secured by diagonal targets that have been glued to the required positions.

The spatial coordinates of control points in the local coordinate system have been determined by geodetical means, applying the spatial intersection method from the given geodetical base line equal to the photogrammetric base.Two second theodolites THEO 010 Zeiss Jena and a subtense bar have been used for the geodetic measurements.

The accuracy of the determined spatial position of control points is given by the mean coordinate error 1.0 mm < m_{xyz} < 1.5 mm.

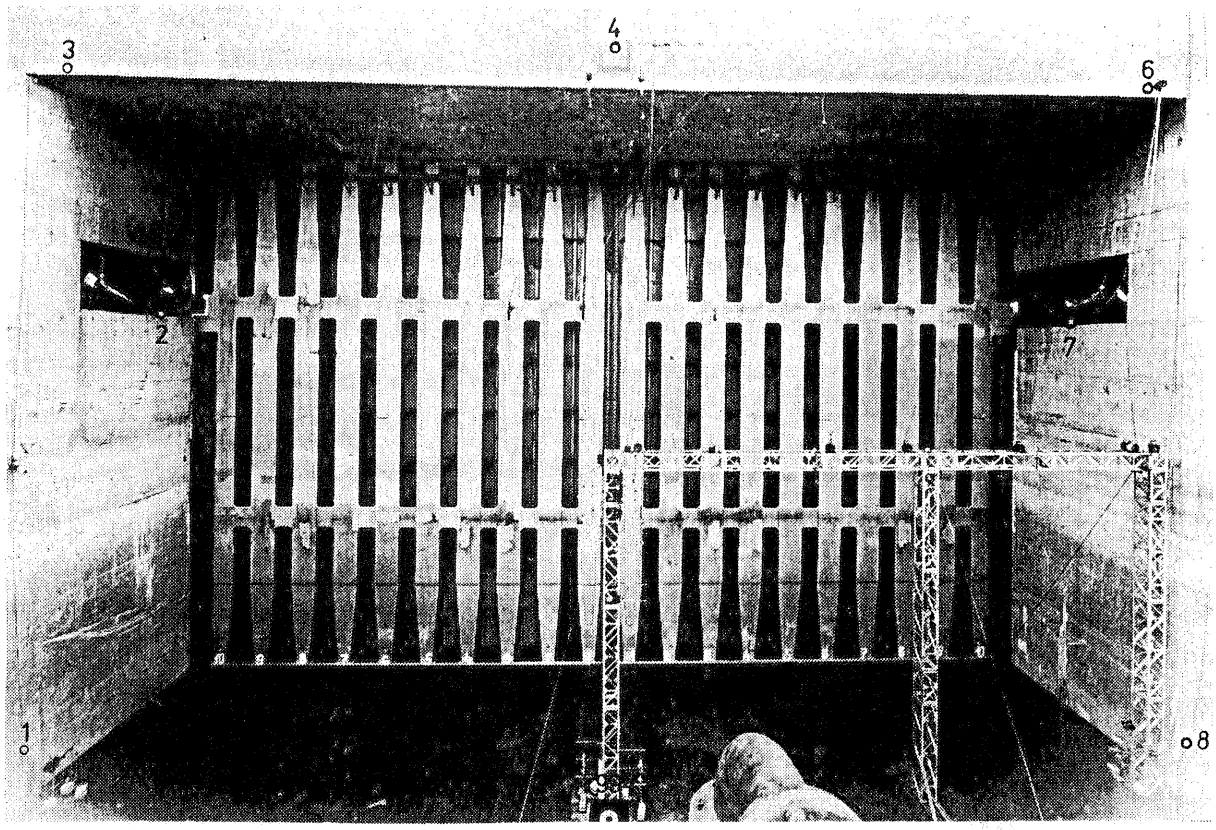

Figure 3 Distribution of control points

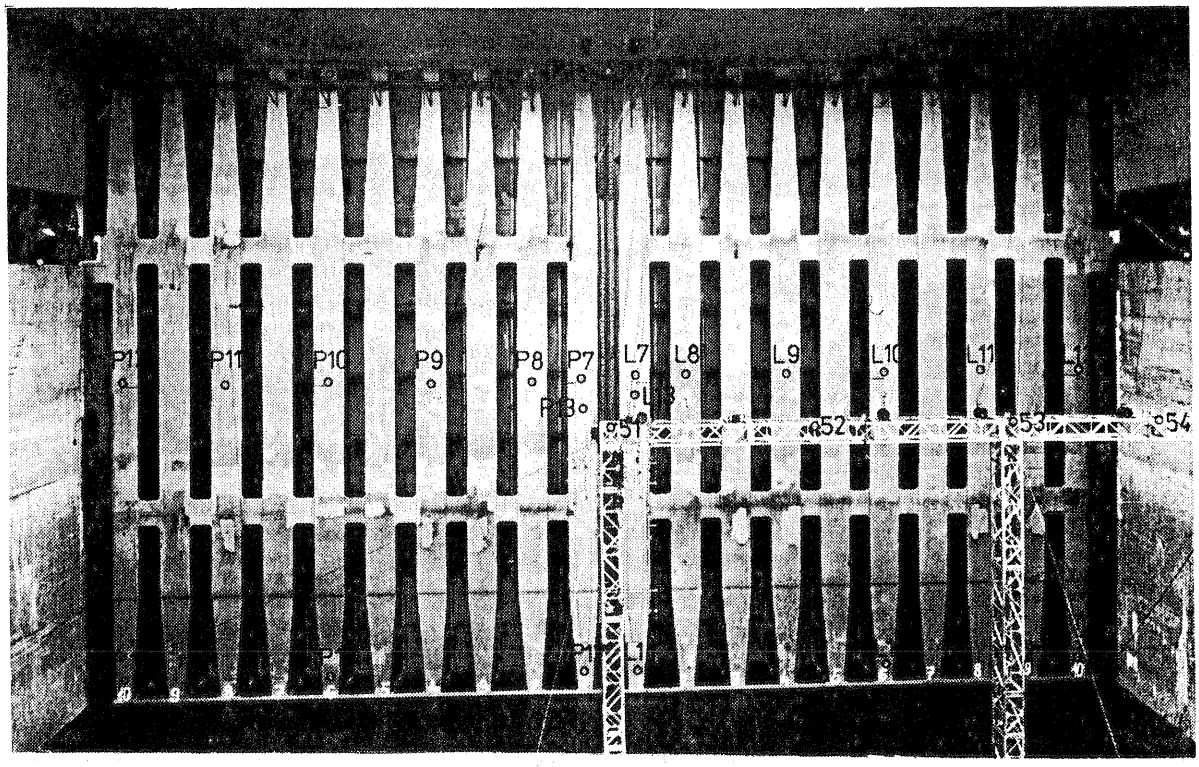

Figure 4 Distribution of obderved points

4. PHOTOGRAPHY

We used two wide angle universal measuring cameras UMK 10/1318 A and one superwide angle universal measuring camera UMK 6,5 /1318 Zeiss Jena in order to take the terrestrial photogrammetric photographs. Photographic glass plates TOPO ORWO having dimensions of 130/180 mm and sensitivity of 6 to 9 DIN have been used.

Tab.1

Number of point		1.MEASUREMENT ΔY (mm)				2.MEASUREMENT ΔY (mm)					
		15.1. 1995	15.1.1 1995	16.1. 1995	16.1. 1995	15.1. 1995	18.1. 1995	18.1. 1995	18.1. 1995	18.1. 1995	18.1. 1995
		7.45	15.55	12.20	18.30	7.45	12.15	12.35	13.00	13.15	13.30
		0/0	8/0	14/0	23/0	0/0	8/8	19/8	29.5/8	20/8	8/8
P 12	G	0	+1.0	+8.0		0	-6.8		+20.7		-10.4
	F	0	+3.0	+6.0	+15.0	0	-8.0	+14.0	+19.0	+13.0	-13.0
P 11	G										
	F	0	+4.0	+6.0	+24.0	0	-13.0	+14.0	+30.0	+15.0	-23.0
P 10	G	0	0	+5.0		0	-19.1		+34.7		-29.1
	F	0	+2.0	+6.0	+25.0	0	-19.0	+14.0	+32.0	+17.0	-33.0
P 9	G										
	F	0	+2.0	+8.0	+32.0	0	-28.0	+17.0	+37.0	+18.0	-45.0
P 8	G										
	F	0	+2.0	+7.0	+29.0	0	-36.0	+18.0	+40.0	+19.0	-55.0
P 7	G	0	+0.7	+5.9		0	-39.3		+40.2		-57.7
	F	0	+3.0	+6.0	+33.0	0	-39.0	+19.0	+43.0	+21.0	-58.0
L 7	G	0	+1.6	+7.3		0	+4.1		+42.9		+2.6
	F	0	+4.0	+5.0	+34.0	0	+5.0	+20.0	+45.0	+21.0	+2.0
L 8	G										
	F	0	+3.0	+9.0	+32.0	0	+3.0	+21.0	+44.0	+22.0	+4.0
L 9	G										
	F	0	+3.0	+7.0	+31.0	0	+2.0	+18.0	+41.0	+17.0	-1.0
L 10	G	0	+2.1	+7.6		0	+2.6		+35.6		+1.4
	F	0	+2.0	+7.0	+25.0	0	+2.0	+14.0	+35.0	+17.0	-1.0
L 11	G										
	F	0	-1.0	+4.0	+22.0	0	+2.0	+15.0	+32.0	+14.0	-1.0
L 12	G	0	+0.9	+5.4		0	+2.0		+24.1		+1.5
	F	0	+3.0	+6.0	+20.0	0	+7.0	+19.0	+29.0	+18.0	+7.0
P 13	G										
	F	0	+5.0	+8.0	+35.0	0	-38.0	+21.0	+43.0	+21.0	-59.0
L 13	G										
	F	0	+1.0	+6.0	+31.0	0	+1.0	+19.0	+42.0	+23.0	0

The camera stations (UMK 10/1318) have been located on the left and right side of the lock (built-in platforms,stations AR,BL, figure 2).They were identical with the theodolites stations during the geodetic measurement of control points.The camera station (UMK 6,5/1318) has been located on the lower barrier (station C,figure 2).Photographs have been taken simultaneously at both stations in the single stages.

5. DATA REDUCTION

The photograph coordinates of control as well as determined points create the basic input data for the analytical calculation of the observed points spatial position in the single stages.

The spatial shifts of observed targets ΔX,ΔY,ΔZ were determined as differences between spatial reference coordinates of observed points X,Y,Z in separate stages of loading test.

The photograph coordinates have been measured monocularly on a precise Dicometer Zeiss Jena stereocomparator, achieving an accuracy of photograph co-ordinates of 2 μm. The photograph coordinates have been simultaneously recorded as input data for further processing and computer calculations, applying the universal analytic ORIENT software.

The calculations resulted in spatial reference coordinates X,Y,Z of observed points determined in the single stages, accurate to 1.0 mm < m_Y < 2.0 mm (observed points L7 - L13,P7 - P13) and 2.0 mm < m_Y < 3.0 mm of remaining observed points.

The mean errors m_X, m_Y, m_Z is a priori estimate by law of error propagation by the following equations:

$$m_X = \frac{d}{2f}(\cos\varphi + tg\alpha'.\sin\varphi)^2 m'$$

$$m_Y = \frac{d}{2ftg\alpha'}(\cos\varphi + tg\alpha'.\sin\varphi)^2 m' \qquad (3)$$

$$m_X = \frac{d}{2f}(\cos\varphi + tg\alpha'.\sin\varphi)^2 m'$$

whereby (figure 5)

φ is the convergence angle of camera axes,

α' - the maximum image space angle,

d - distance of lock gate from photogrammetric base b,

m' - mean error of image coordinates.

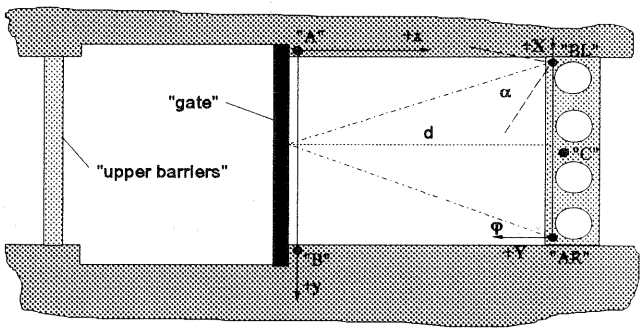

Figure 5 Camera axes

If photograps ere taken with universal metric camera UMK 10/1318,m'=0.005 mm,d=30 m,φ=42^g and α'=46.5^g,there are mean coordinates errors $m_X = m_Z$ = 1.3 mm and m_Y = 1.5 mm.

6. RESULTS AND EVALUATION

The horizontal shifts ΔY of chosen observed points in separate stages of loading test are in tab.1..Graphical presentation of deformation of the lock gate in separate stages are in figure 6 (dashed line - geodetic measurements,full line - photogrammetric measurements).

The differences of determined horizontal shift ΔY of observed points between "geodetic" minus "photogrammetric" measurements as the true errors,are in average ε = 2.0 mm for points L7 - L13 and P7 - P13.The differences of remaining observed points are the largest ones.The geodetic measurement was considered

as a standard.This is caused with worse measuring of photograph coordinates of observed points (contrast of targets) and no synchronization between geodetic and photogrammetric measurements.Observed time of geodetic measurements in one stage is cca 30 min and for photogrammetric measurements is 1 - 10 second (exposure time).

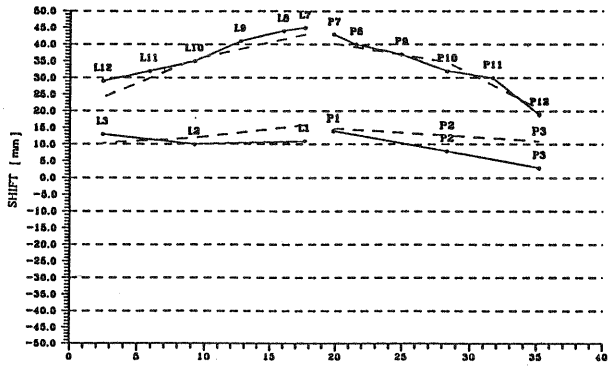

Figure 6 Graphical presentation of deformation

The value of the true errors ε is an accuracy estimate of the horizontal shifts ΔY.A priori accuracy of measurement of ΔY is given by the mean error m

$$m = \frac{1}{15}s \qquad (4)$$

whereby s is expected total horizontal shift of the lock gate in mm

The expected maximum horizontal shift of observed points located on the centre of surface of the observed lock gate is 45 mm.According to the equation (4) is the mean error of measurement of ΔY, m = 3 mm.The horizontal uncertainty characterized by the mean error m_ε = 1.5 - 3 mm is sufficient for the determination of the displacements of observed points assumed by the project.

The analytical photogrammetric method utilizing ORIENT software is the most convenient method for measuring spatial deformations of the observed points in short time intervals, as it was in the case of check measurements on the left lock gate of the Gabčíkovo waterworks.The given method can be used during full lock operation, what would enable regular monitoring of the lock safety parameters.

7. REFERENCES

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