Deformation Analysis of the Holcim Ltd. Cement Factory Objects

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INTRODUCTION

- Determination of movements and deformations of construction objects
  - one of the most demanding geodetic tasks.
- What causes movements and deformations?
  - geologic and hydrological changes, the change of atmospheric conditions (temperature, pressure and humidity), and various loads causes the change of mechanical properties of the material that the objects are made of.
- Movement is a spatial change of the position of some point on the object or the ground between two or more measurements series.

INTRODUCTION

- Movements can be monitored by observing the positions of individual points on the objects from the points outside of the object, and we determine the deformation on the basis of the results of movements of a series of points.
- What is the main problem during the movement measurement?
  - ***The main problem is to determine which points remain stable between more measurement series?***
- The deformation analysis deals with the problem of determining stable points in the network, i.e. of localizing unstable points.

THEORETICAL BASES OF DEFORMATION ANALYSES

- Larger number of research centers dealt with methods of deformation analysis.
  - Which method is the most practical and optimal method?
- FIG Commission 6 concluded that it is very difficult to choose the best one!
  - ***The final selection of deformation analysis model is left therefore to users.***
- We will represent you the application of two deformation analysis models: *Hannover and Karlsruhe model*.

Deformation analysis according to Hannover model

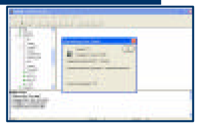
- Consists of five phases:
  1. adjustment of individual measurement series,
  2. testing of measurements homogeneity between the series,
  3. determination of global movements between two series (*zero and i-th*) of measurements,
  4. movement localization, i.e. identifying unstable points outside of objects, and
  5. movement localization, i.e. identifying unstable points on object.

The analysis of deformations according to the Karlsruhe model

- The essence of this method is in independent adjustment of *zero* and *i-th* measurement series, and in their mutual adjustment.
- In the first phase, the observations in single measurement series are adjusted using the method of least squares, and in the second phase the mutual adjustment of *zero* and *i-th* measurement series is made.
- Mutual adjustment of two series is carried out providing as follows:
  - that the points are stable (the same coordinates) in two series,
  - that the network scale is the same in both series and
  - that the measurement accuracy is homogeneous in both series.

PRACTICAL APPLICATION OF DEFORMATION MODELS

- The analysis of the deformations using the *Hannover* model has been made by means of the software ***Panda*** that uses this model as a theoretical base.

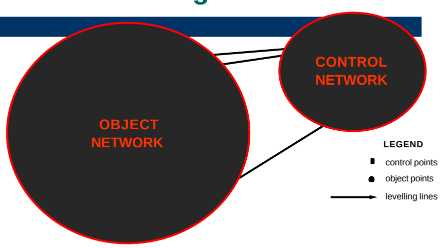


- The analysis of deformations using *Karlsruhe* model was made by applying the software ***Matlab***. We made an algorithm for the analysis of deformations using Karlsruhe model.

THE RESULTS OF COMPARING DEFORMATION MODELS

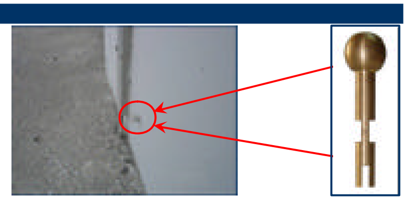
The comparison of deformation models was made on the leveling network stabilized on the objects of the concrete factory *Holcim Ltd.* in Koromacno - Croatia, needed in monitoring vertical movements of the silos for concrete storage.

Network configuration



The measuring spots on the object- bench marks were placed on the positions according to the “Project of founding and securing the slope”.

Point stabilization



- The points are stabilized in the object fundament.
- They are made of brass material, so that they are resistant to various atmospheric conditions.

Measurements

- 2 independent measurements of all points made in two directions.
- 15 elevation differences were measured in all series.
- The measurements were made by using the precise level WILD NA2 with parallel-plate micrometer.

Elevation difference		*Measurement series*			
From	***To***	***I series***	***II series***	***IIIseries***	***D(m)***
RI	*RII*	0,5157	0,5156	0,5156	26
RII	*RIII*	0,5071	0,5071	0,5070	46
RI	*RIII*	1,0228	1,0229	1,0229	69
1	*RI*	0,4945	0,4948	0,4951	40
4	*RII*	1,0008	1,0009	1,0012	70
2	*1*	0,0178	0,0178	0,0177	4,8
2	*4*	0,0275	0,0275	0,0275	12,8
5	*4*	0,0283	0,0284	0,0282	8,9
5	*6*	0,0369	0,0368	0,0368	8,9
7	*6*	0,0128	0,0126	0,0142	5,4
8	*7*	0,0130	0,0130	0,0116	7,3
8	*9*	0,0243	0,0243	0,0240	5,3
10	*9*	0,0161	0,0164	0,0161	8,9
1	*10*	0,0008	0,0007	0,0008	8,9
RI	*9*	0,4777	0,4779	0,4783	57,8

Hannover method

Analysis of the series 1 - 2

Homogeneity testing

$F = 2.24$

$F_{1-a,f1,f2} = 6.4$

$F = F_{1-a,f1,f2}$

Measurements are homogeneous.

Global movement analysis

$F = 3.01$

$F_{1-a,h,f} = 3.35$

$F = F_{1-a,h,f}$

No movement in the second series, all points are stable.

Analysis of the series 1 - 3

Homogeneity testing

$F = 3.03$

$F_{1-a,f1,f2} = 6.4$

$F = F_{1-a,f1,f2}$

Measurements are homogeneous.

Global movement analysis

$F = 68.85$

$F_{1-a,h,f} = 3.35$

$F = F_{1-a,h,f}$

There are movements in the third series, there are unstable points.

Hannover method

Point	$?_i^2$	$\max ?_i^2$
1	$1,85 \cdot 10^{-9}$	
2	$7,57 \cdot 10^{-10}$	
4	$7,01 \cdot 10^{-10}$	
5	$1,12 \cdot 10^{-9}$	
6	$1,03 \cdot 10^{-7}$	
7	$3,15 \cdot 10^{-7}$	max
8	$9,47 \cdot 10^{-8}$	
9	$7,10 \cdot 10^{-9}$	
10	$8,25 \cdot 10^{-41}$	

The movement of the point 7 has been detected. After removing the point 7 from the set of points, we determine by means of test statistics whether there are any more unstable points.

$F = 3.94$

$F_{1-a,h,f} = 3.31$

$F = F_{1-a,h,f}$

There are still some movements in the third series, there are unstable points.

Hannover method

Point	$?_i^2$	$\max ?_i^2$
1	$1,85 \cdot 10^{-9}$	
2	$7,57 \cdot 10^{-10}$	
4	$7,01 \cdot 10^{-10}$	
5	$1,12 \cdot 10^{-9}$	
6	$9,84 \cdot 10^{-11}$	
8	$7,64 \cdot 10^{-9}$	max
9	$7,10 \cdot 10^{-9}$	
10	$8,25 \cdot 10^{-9}$	

The movement of the point 8 has been detected. After removing the point 8 from the set of points, we determine by means of test statistics whether there are any more unstable points.

$F = 2.98$

$F_{1-a,h,f} = 3.31$

$F = F_{1-a,h,f}$

There are no more movements in the third series, all other points are stable.

By means of Hannover method the movements have been defined in the points 7 and 8 with 95% probability.

Karlsruhe method

The testing of the measurements homogeneity according to Karlsruhe method in two different series is made in the same way as with the Hannover model. So, the measurements are homogeneous.

Analysis of the series 1 - 2

Global movement analysis

$T = 3.06$

$F_{1-a,f,b} = 4.05$

$T = F_{1-a,f,b}$

No movement in the second series, all points are stable.

Analysis of the series 1 - 3

Global movement analysis

$T = 68.85$

$F_{1-a,f,b} = 4.05$

$T = F_{f,b,1-a}$

There are movements in the third series, there are unstable points.

Karlsruhe method

Point	Ω_Z	Ω_Z min
1	$3,31 \cdot 10^{-7}$	
2	$3,37 \cdot 10^{-7}$	
4	$3,34 \cdot 10^{-7}$	
5	$3,35 \cdot 10^{-7}$	
6	$1,54 \cdot 10^{-7}$	
7	$2,11 \cdot 10^{-8}$	min
8	$1,94 \cdot 10^{-7}$	
9	$3,11 \cdot 10^{-7}$	
10	$3,37 \cdot 10^{-7}$	

The movement of the point 7 has been detected. After the first iteration we remove the point 7. Using test statistics we test whether there are more unstable points left.

$T = 5.23$

$F_{1-a,f,b} = 4.05$

$T = F_{1-a,f,b}$

There are still some movements in the third series, there are unstable points.

Further analysis of the deformations using Karlsruhe model was not possible due to the lack of redundant measurements! The lack of redundant measurement has appeared because of the specific position of the silos. The points 5,6,7 and 8 are placed in the cutting, and it was not possible to connect them with additional measurements.

CONCLUSIONS

- **The aim of this two deformations analysis was to determine:**
  - *if there were some movements in leveling network, and*
  - *whether these methods yield the same results.*
- **The analysis showed:**
  - according to both model the measurements of all series were homogeneous,
  - global movement test had to be done for the second and third series, and it showed that in the third measurement series according to both models some movements appear,
  - finally the movement needed to be localized, and both models have localized the point no. 7 as an unstable point, Hannover model has shown the movement of point 8 as well. All other points remained stable.

CONCLUSIONS

- In general, both deformation models are practical for discovering the movements of objects.
- The presented example has shown that Hannover model has proven to be more acceptable, due to the configuration of the test network stipulated by terrain circumstances.
- The deformation analysis using Karlsruhe model was not as efficient as the one using Hannover model, for this network.

THANK YOU FOR YOUR ATTENTION!