Terrestrial Laser Scanning for the Fire Test on Experimental Building in Mokrsko

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Key words: deformation measurement, engineering survey, laser scanning, fire test

SUMMARY

A fire test on experimental object v Mokrsko took place. The main goal of the fire test was to verify total behavior of the construction exposed to fire, which cannot be observed only on the separate elements. Geodetic measurements were also carried out among others within this test. Laser scanning method was used in two of three stages of geodetic works. In the first stage it was scanning of the whole interior of the object approximately 14 days before fire, when construction of the object had been finished, but other elements necessary for monitoring of the fire test had not been installed. The second stage was measurement of the construction after the fire test. This scanning took place approximately one week after fire, when the construction became cold and when there was minimum danger of its breakdown. There were observed and evaluated individual construction elements of the object, cellular beams and beams with corrugated webs, columns, wall construction from monolithic concrete, wall construction created by sandwich panels and wall construction created by linear trays, mineral wool and external corrugated sheets. Values of vertical and horizontal shifts for beams were found out. Difference models of wall constructions characterizing their deformation after the fire test were created. The gained results serve for analysis of behavior of experimental construction simulating administration building.

SUMMARY

Požární zkouška, která proběhla na experimentálním objektu v Mokrsku, si kladla za cíl ověřit celkové chování konstrukce vystavené požáru, což nelze uskutečnit pouze na jednotlivých prvcích. Mimo jiné proběhla v rámci této zkoušky také geodetická měření. Metoda laserového skenování byla využita ve dvou ze tří fází geodetických prací. V první fázi se jednalo o naskenování celého interiéru objektu v době cca 14 dní před požárem po dokončení stavebních úprav objektu, ale před instalováním ostatních prvků potřebných pro sledování požární zkoušky. Druhou fází bylo zaměření konstrukce zhruba týden po požární zkoušce, kdy byla konstrukce již zcela vychladlá a nebezpečí jejího zhroucení bylo minimální. Byly sledovány a vyhodnoceny jednotlivé konstrukční prvky objektu, prolamované nosníky a nosníky s vlnitou stojinou, sloupy, stěnová konstrukce z monolitického železobetonu, stěnová konstrukce tvořená sendvičovými panely a stěnová konstrukce tvořená nosnými kazetami, minerální vlnou a vnějšími trapézovými plechy. Pro nosníky byly zjištěny hodnoty vertikálních a příčných posunů. Pro stěnové konstrukce byly vytvořeny rozdílové modely, které charakterizují jejich přetvoření po požární zkoušce. Získané výsledky slouží pro analýzu chování experimentální konstrukce simulující administrativní budovu.

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1. INTRODUCTION

Workers of the Department of Special Geodesy, CTU in Prague were asked to carry out geodetic measurement during fire test on the experimental object in Mokrsko (Wald, 2008), solved within VZ 04 MSM 6840770005 „Sustainable Construction“. The concrete goal was to carry out geodetic measurement of the building construction, its displacement during fire and change of shape of the building construction after fire in comparison with its state before fire (Pospíšil, 2008).

Geodetic measurement of the experimental object se consisted of two main parts. In the first part we observed dynamic behaviour of the object during fire by means of trigonometric measurement by classical methods with total station and with using automatic pointing. In the second part we observed deformation of the building construction after fire in comparison with its state before fire. We chose the laser scanning method with HDS 3000 as the most suitable method so that we can measure the observed object in as complex way as possible. At first we scanned the whole interior of the object approximately 14 days before fire, when all the construction works of the object had been finished, but elements necessary for monitoring of the fire test had not been installed. For the second time we scanned the object approximately one week after fire, when the construction had been cold and when there was minimum danger of its breakdown.

2. MEASUREMENT WITH HDS 3000

The zero stage of measurement of the experimental object in Mokrsko with the HDS 3000 scanning system took place on 5. 9. 2008. In the course of this measurement we completely scanned interior of the building. The strongest emphasis was put on measurement of the ceiling and the wall constructions. Interior space was measured from four standpoints (fig 1). Total measuring time was approximately 8 hours. The standpoints were chosen near walls and corners of the objects that it were possible to scan as much of interior as possible from each standpoint with using spherical sector defining scanning range with the smallest possible horizontal angle range, which contributed to significant acceleration of measurement.

The first stage of measurement was carried out on 25. 9. 2008. It was scanning of not collapsed constructions – approximately ½ of the wall constructions and ¼ of the ceiling constructions. The scanned territory in picture 2 is drawn in yellow colour. Measurement was carried out from three standpoints and it took approximately 6 hours.

Demands on placing the standpoints in the first stage were similar as in the zero stage, but their selection was significantly influenced by large amount of rubble situated in space of the object after collapse of the construction.

An important criterion for selection of standpoints in both stages was the highest possible number of control points that were possible to measure from the individual standpoints. The control points were signalized by means of plane HDS targets inside and outside the observed construction. Control points inside the object were stabilized temporarily, whereas control points outside the object were stabilized permanently. Inner and outer control points were used to create the whole cloud within one stage. Total clouds from the zero and the first stage were placed into one system of coordinates by means of outside photogrammetric points.

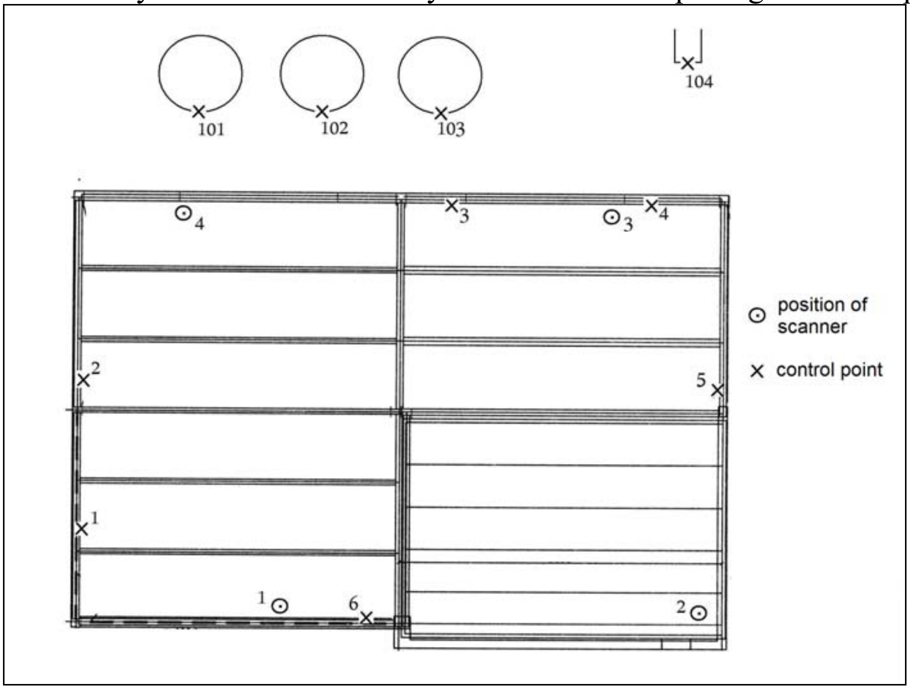

Figure 1 Position of scanner and control points scheme in zero stage

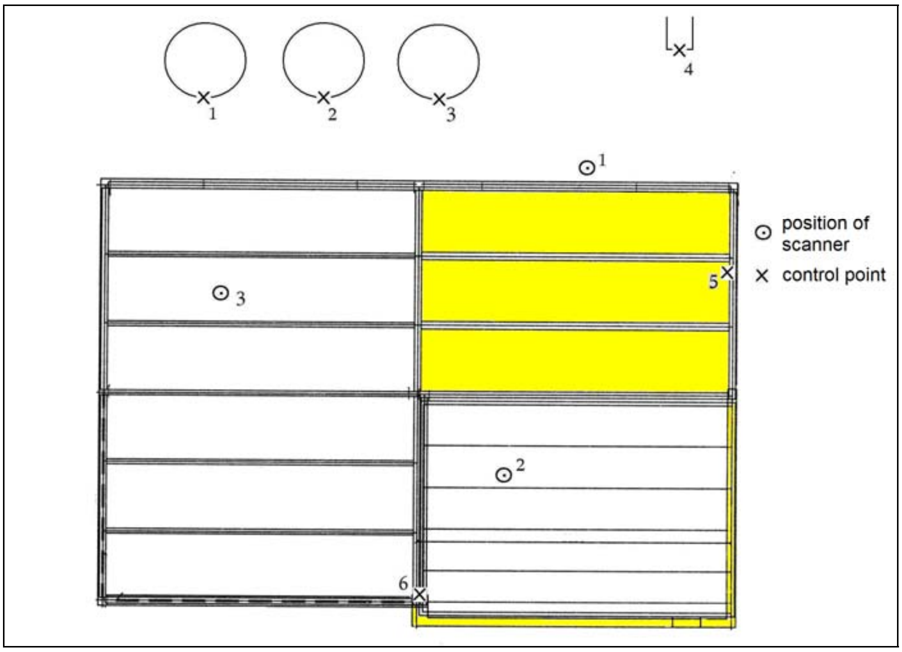

Figure 2 Position of scanner and control points scheme in first stage

The scanning process on each standpoint can be divided into two parts. At first we scanned the scene (on the basis of the set parametres – scanning density, range of the scanned field of view) and then we scanned photogrammetric points.
The time of the individual scanning parts was variable. The time of the scanning of the scene was influenced by size of the measured territory and by scanning density. Operating period was approximately 60 minutes for mostly used scanning setting one quarter of sphere. The second part of scanning works on the standpoints – measuring the photogrammetric points – took approximately 30 minutes, but even this information is only approximate and it changed in dependence on number of control points and on speed of localization of these points in the cloud. In some cases it was necessary to carry out some additional measurements of the nearest surroundings of the control point, so that it is possible to localize the target correctly, which caused extension of measuring period again.

3. PROCESSING AND RESULTS

3.1 Registration and cleaning

The first step when processing the measured data was registration of clouds from the individual standpoints and their placing into the selected system of coordinates. The resulting system of coordinates was defined by the coordinates of the outside photogrammetric points in the system of coordinates of the first standpoint of the zero stage. Registration was carried out for each stage separately in the Cyclone program. Registration mean absolute error of the zero stage was 0,9 mm and registration mean absolute error of the first stage was 0,8 mm. Check of transformation accuracy of both stages was carried out by comparison of intersection of two planes, which arose by fitting of point clouds measured on the concrete wall in the zero stage with corresponding intersection in the first stage. Only upper section of the intersections was compared for reasons of damage of the construction during fire. Achieved difference in position of the upper point of intersections is 16 mm. Size of this difference is caused by damage of construction during fire (flaking off of walls reaches up to 20 mm in the observed corner) and by error in transformation. Accuracy of the accomplished transformation was therefore taken for sufficient.
In the second step it was necessary to clean the resulting cloud from each stage from points that were not desirable for our needs (fig. 3). The cleaned cloud was further segmented into parts from which we consequently prepared the individual construction components for which we were finding out their deformation after fire. These components were ceiling beams, construction of the side walls and the central column. Evaluation of deformation of processes and procedures of these construction components are described in the following part.

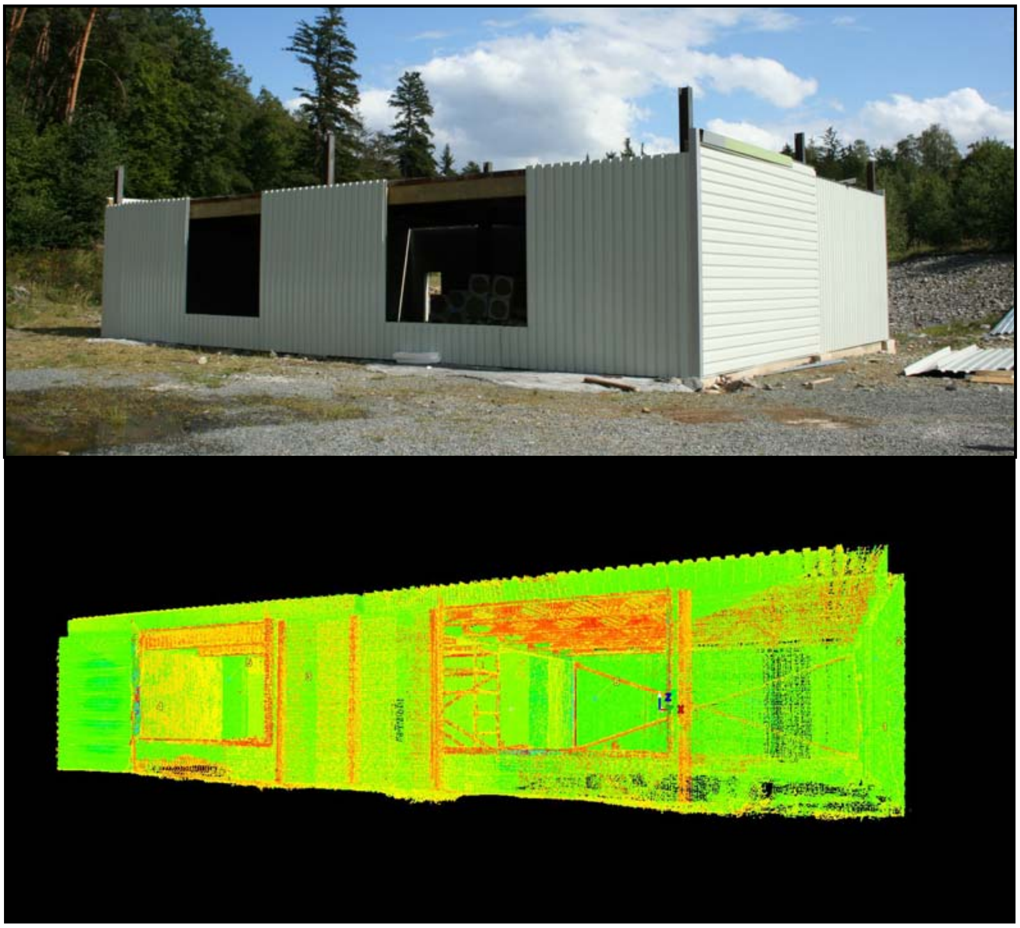

Figure 3 Final point clouds from zero stage and its comparison with photo

3.2 Processing and evaluation of beams

We evaluated three ceiling beams, two beams WTB 500 with corrugated web and one IPE 400 beam. For evaluating beams we used method of cross cuts. The first step of this processing was insertion of the cleaned beams from both stages in one model (fig. 4). In this model we created a new system of coordinates that was related to one of the beams in the zero stage (to the second WTB 500 beam calculated from the window). X axis was inserted into the longitudinal axis, Y axis was inserted upright to X axis into the horizontal plane and Z axis was inserted into the vertical. Consequently we created cross sections perpendicular to the horizontal axis with step 100 mm, by which we gained profiles of all beams in both measuring stages. From these profiles we consequently subtracted coordinates of corner points of the individual beams. We determined height and cross shifts (buckling) of beams between stages from differences in position of these points. These values were placed into graphs. Figure 5 shows graph of horizontal shift. Description of the beam corners in the graph is taken from view of an observer standing with his back towards the wall and having the window holes at his right hand.

Stationing of the individual beams is illustrated on X axis of the graph. This stationing grows in positive direction of X axis. Zero value of stationing corresponds to the beam edge adjoining to the enclosure wall. Cross or vertical shifts in the individual stationing are illustrated on axis Y.

Relatively strong dispersion between the individual values of shifts appeared in some graphs. That is why the calculated values in all graphs showing cross shifts were interlaid with regression polynomial second degree curve. These curves were inserted into graphs, so that the trend of the individual buckling was more apparent. Similar curves were also inserted into the graphs of vertical shifts for IPE 400 beam. These dispersions were caused by selection of width of cross sections in the Cyclone program (50 mm) and by scanning density, when position of subtracted end points did not always have to be identical to the real beam edge.

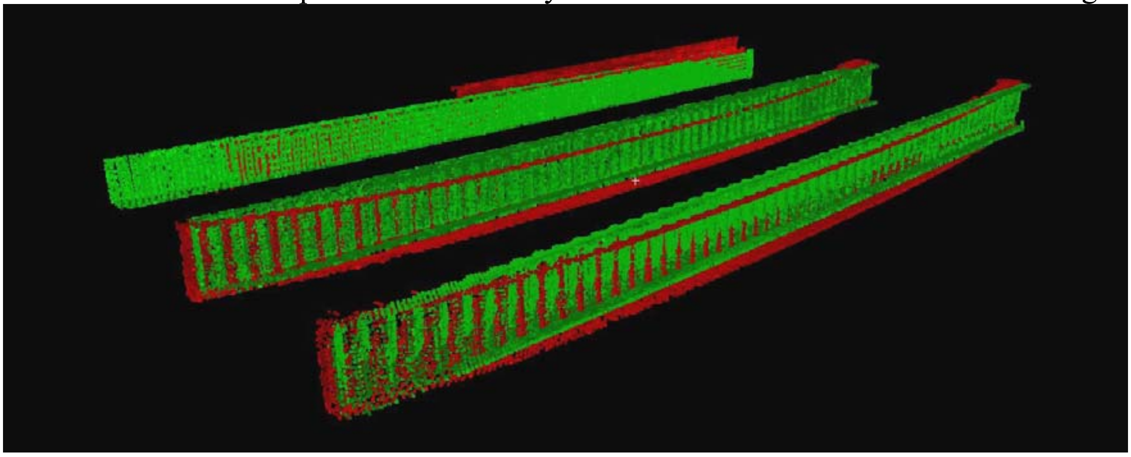

Figure 4 Beams from both stages joint into one model

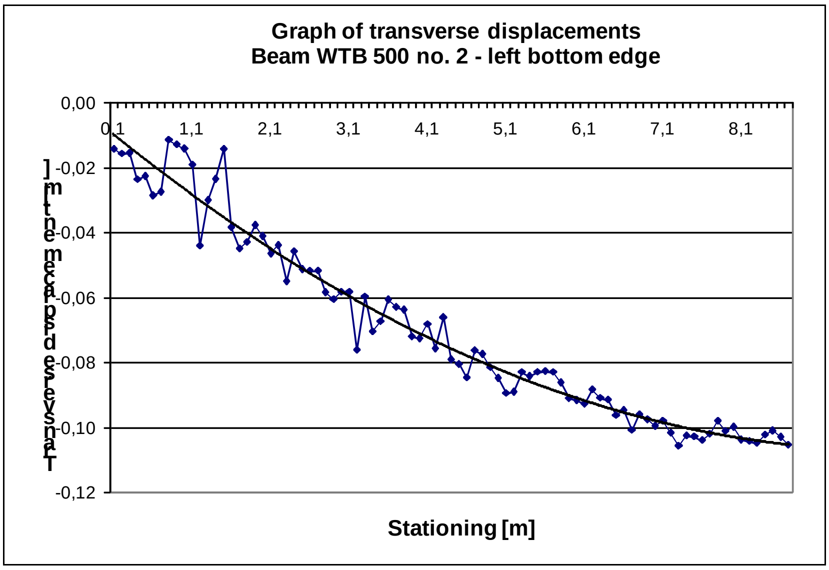

Figure 5 Graph of transverse displacements

3.3 Processing and evaluation of wall constructions

Deformation of wall constructions was found out in comparison with beams by another method. This method consists in creation of a difference model characterizing divergences in the wall construction between the zero and the first stage. The measured data from the individual stages enter into the calculation in the form of triangular nets (concretely the TIN nets) that were created in the first processing step. Then we created a reference plane that is approximately parallel the observed walls. In our case the reference plane was inserted into the wall plane in the zero stage. Perpendicular distances to the reference plane were found out to the individual triangular nets in discrete points in regular spacing 20 mm. Differences of perpendicular distances of nets were calculated. The calculated values of differences were assigned as height coordinates (taken from the reference plane) to discrete points. A triangular net was created from points calculated in this way in the final version of processing. This triangular net represents difference model of wall deformation between the stages. Difference models of two evaluated walls are shown in fig. 6 and fig. 7. Found differences are expressed by means of hypsometric scale.

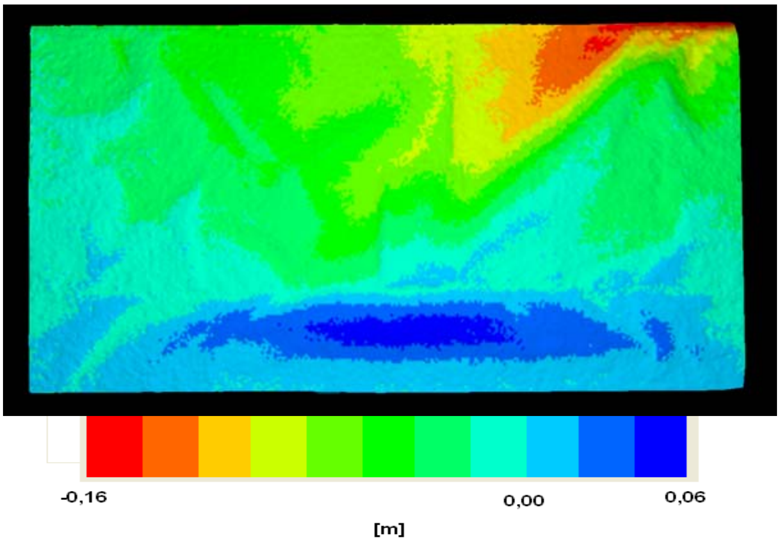

Figure 6 Difference model of the wall created by the Kingspan sandwich panels

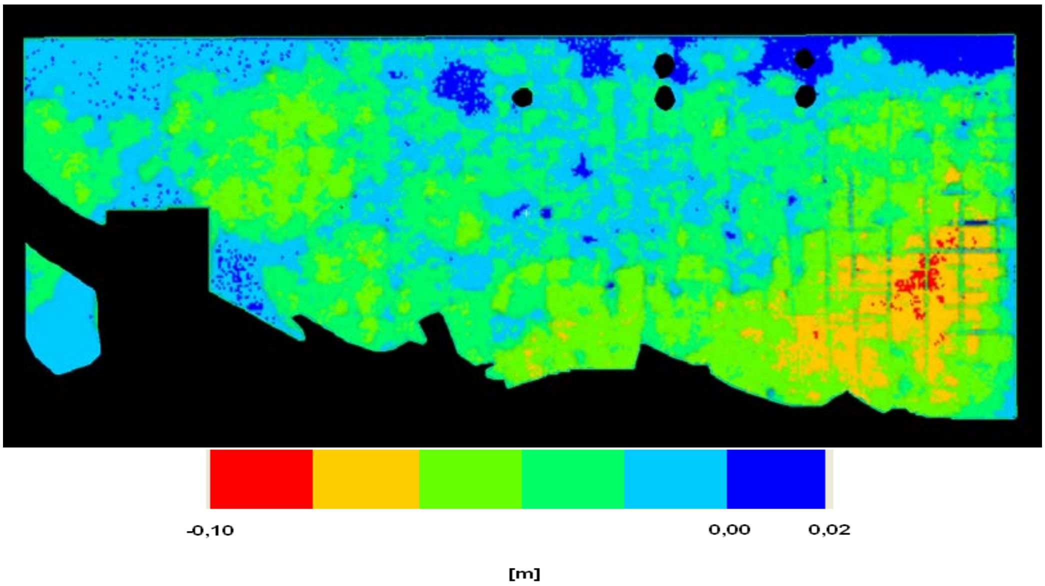

Figure 7 Difference model of the monolithic concrete wall (opposite the window)

3.4 Processing and evaluation of the central column

Evaluation of the central column produced from HEB 280 profile was carried out in a similar way as evaluation of the ceiling beams. Coordinates of point of the central column were subtracted by means of the cross sections in both stages. System of coordinates was selected so that Z axis was inserted into vertical edge of the central column, X axis was inserted into the edge of the column base parallel to window plane and Y axis was inserted into the edge of the column base upright to window plane. Beginning of the coordinate system was inserted into the left lower column corner from view of an observer standing with his back to the wall with the window holes. Shifts in direction of X and Y axes were calculated from the subtracted coordinates. Values of the calculated shifts were put into graphs in dependence on column stationing. Description of beam corners in the graphs is considered with respect to the same observer as the system of coordinates. Calculated values in all graphs were interlaid with regression polynomic second degree curve, so that the trend of the individual buckling is more apparent.

In fig. 7 we can see buckling of the HEB 280 column very well in direction from the wall with the window holes. The column measured in the zero stage is illustrated in green and the column measured in the first stage is illustrated in red.

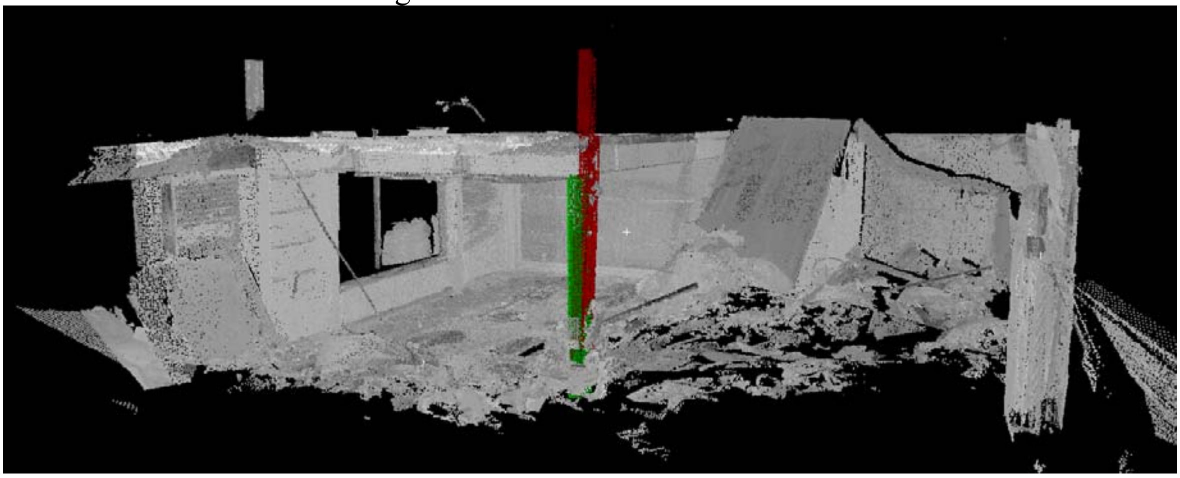

Figure 8 Connection of the column from the zero and first stage into one model

4. CONCLUSION

We evaluated deformation of the experimental building object after the fire test by means of the terrestrial laser scanning. We observed two WTB 500 beams with the corrugated web and the IPE 400 beam, the HEB 280 central column, the wall construction from monolithic concrete, the wall construction created by the Kingspan sandwich panels and the wall construction created by the linear trays, mineral wool and external corrugated sheets.

When evaluating beams we found out vertical shifts and cross shifts (buckling). As for beams with corrugated web, we found out maximum vertical shift 160 mm and maximum cross buckling 110 mm. As for the IPE 400 beam, maximum vertical shift was 15 mm and maximum buckling was 110 mm. Vertical shift of this beam is about 10 times smaller than for the WTB 500 beams. This could be caused by its covering with mineral wave and plasterboard, which protected it from fire action. Cross buckling of beams was caused by deformation of the central column that arose owing to fire and owing to collapse of part of the construction. The individual constructions at the end of all beams (in the middle of the object) were lifted above the position in which they were before the fire test (approximately 40 mm). This phenomenon can be put down to the fact that the zero stage was measured with loading placed on the ceiling of the object (sacks of gravel), whereas the first stage was measured after the loading had been removed. Values of deformation of the beams and of the column we gained will be compared with the data gained by another team during construction reconnaissance next day after the fire within the total evaluation of the fire test.

Difference models characterizing deformation of all the wall constructions after the fire test were created for all types of the wall constructions. Strong concrete falling off (up to 100 mm) is apparently visible in the hypsometric plan of the monolithic concrete wall. This concrete falling off arose during fire in consequence of transformation of water present in the wall construction into water vapour. When watching the wall created by the sandwich panels it is apparent that it came to bulge of the panel inwards into the object (up to 60 mm) in the lower part of the object, whereas in space near the ceiling (in place with the highest temperature) it came to bulge of the panel outwards from the object (up to 160 mm). The difference model of the wall which was created by the linear trays, mineral wool and external corrugated sheets shows that it came to deformation of all the bearing cassettes in a similar way. It always came to bulge of the cover trapezoidal sheet of each cassette in the middle of the cassette construction (up to 80 mm). Hypsometric expressions of deformation of the wall constructions were evaluated positively, because these deformations were not observed by any other method and therefore they provide unique information about behaviour of the building construction.

The gained results will serve for analysis of behaviour of the experimental construction simulating administration building. The up to now used calculation procedures and formulas used in fire prevention of buildings should be judged on the basis of this analysis.

Using the HDS 3000 scanning system for evaluation of static deformation of the building construction after the fire test turns out to be a suitable method. Suitability of using TLSS showed itself especially in the complex recording of deformation of the building construction after the fire test. This recording enabled to carry out evaluation of deformation of some construction elements that were not in the original observation setting. When using classical measurement with the total station, when it is possible to record changes only in limited number of discrete points and only in places that were determined in advance, this additional evaluation is not possible.

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BIOGRAPHICAL NOTES

Dr. Tomáš Křemen is assistant professor at the department of Special geodesy at Faculty of Civil Engineering CTU in Prague. Terrestrial laser scanning systems and their applications are his specialization. He has 4 monography and more than 40 original papers. He is member of the group "Engineering survey". He is the Czech Republic national delegate to FIG commission 6.

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