Experience with a Long-term Monitoring of Natural Gas Leakage During Transportation Tunnels Construction

Radovan Hajovsky, Stepan Ozana, Martin Pies, and Jaroslav Lossmann

Abstract— **In the field of modern construction engineering, the monitoring of various physical and mechanical quantities is an integral part of almost all sophisticated construction sites. The main objective of so called geotechnical monitoring is to eliminate as much as possible the hazards resulting from realization of constructional projects together with mutual interference of the construction and surrounding rock pillar. In the case of realization of the projects in built up areas, it is mostly impossible to avoid negative affection of the surrounding estate. The paper gives a description of the monitoring system of methane presence and the long-term experience with its use for the objects above the newly constructed tunnels of Kralovo pole which are parts of Brno big town circuit. It contains the specification of measurement chain including particular components. The monitoring system is based on sending alarm SMS by GSM technology.**

Index Terms — **Gas monitoring, measurement system, monitoring system, GSM communication, gas detector**

I. Introduction

In January 2008, there was a dedication of the construction of the tunnels of Kralovo pole which are parts of Brno big town circuit. The official name of the project is "Silnice I/42, VMO, Dobrovskeho B" and after its completion it will significantly decrease the congestion of traffic within Brno city and improve the quality and comfort of travel. The construction is funded by Road and Motorway Directorate of the Czech Republic and Brno city.

The Kralovopolsky tunnel I is 1237 m long and its route has been designed mainly under Dobrovskeho street. 1019 m of drilled tunnel parts are connected to excavated parts built within cased holes, 168m of them in Zabovresky and 50 m in Kralovo pole. The Kralovopolsky tunnel II has a total length of 1258 m and parallels the first tunnel, shifted southerly by approx. 70 m. Drilled tunnel parts have a total length of 1060 m and ditching parts are located in Zabovresky (149 m) and Kralovo Pole (49 m).

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At the beginning of construction of the tunnel, there arose a demand for continuous measurement of methane presence in the objects located above the current drilling places. Experts from Department of Measurement and Control by VSB-Ostrava together with colleagues from GEOtest Brno Inc. and ARCADIS-Geotechnika Inc. have designed and all the time successfully operated measurement systems. They were gradually applied to special-interest objects providing permanent alarm information systems informing entrusted persons by means of SMS in case of the presence of dangerous levels of methane.

II. Drilling of the Tunnel and Geological Profile of Special-Interest Area

Drilling of tunnel pipes took place in extremely difficult geological conditions with a very low overburden and a densely built-up area above the tunnels. The area of each tunnel tube is approx. 125 m^2. The overburden varies from merely 6m for provisional portals to a maximum value of 21m. For the whole length of drilling, it was performed within highly plastic Neogenous clay. To secure safety in the underground drilling (construction site) and to minimize the impacts on surface buildings, emergency measures have been introduced. The forefield (working face) is divided into 6 small particular stopes (segments), so called kernel method of stope. The ceiling of the tunnels is made up of tough steel prebuilt support and shot/injected concrete. This is the first time in the Czech Republic using steel reinforcing elements specially designed for this construction. Together with the drilling of the tunnels, there was also a construction of protective walls made of pillars of jet injections along the significant parts of the tunnels.

Near-surface bed of the area is covered by embankments whose presence declares construction activities in the past. Natural cover consists of loess loam with solid or rigid consistence being put in layers by Aeolian activity during the Pleistocene period with a rare presence of deep-brown residues representing fossil soli horizons. Loam clay and clay within subsoil of the loess have deluviofluvial genesis. It is material flooded by rainfall water and it comes from older generation of loessal covers and geests of Neogenous clays containing weather-worn rounded fragments of kankar. There is an occurrence of Quarternary aluminous or clayey gravelly sediments whose presence is incoherent. According to performed engineer-geological research the biggest thickness gravelly strata was documented under

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Vodova street and also under the neighbouring complex of municipal water pool Dobrak. This is the place where calotte of designed projects corresponds to gravelly character as much as possible.

Pre-Quarternary subsoil in the whole area of interest consists of rock coming from Neogenous (Miocene) period of Lower Badenian age and it is made up of calcic greatly silty loam/clay. From the point of view of deformation risks, the most important aspect is high plasticity and presence of expanding clayey minerals caused by their ability to expand and contract. Expansion or contraction of the clays do not reach dangerous levels. The rock (respectively soil) has a greeny grey color, with yellow-brown or rusty areas in higher parts of the massive. Investigational works prove the clays have been significantly damaged by tectonic activities, sporadically in the zones of several tens of meters thick. They have shape of rough blocky character as far away as irregularly small-sized fragmentary decomposition character, often with radial structures at diffraction which is scabrous shaped in saddle.

Underground water is linked to the gravel-sand complex of strata that create very good conditions for transport and accumulation of underground water.

Therefore, underground water has a character of static supplies. There is no continuous level but discontinuous aquifers with local character. Level of underground water responds to atmospheric rainfall slowly, with oscillations in range of centimetres during the year.

Chosen objects were fixed by so called compensatory injection/grout, thus controlled uplift of the objects parallelly (in phase with/synchronized with) declines caused by drilling. Before starting, more than 100 surfaced objects had to be fixed up. During the drilling process there was permanent supervision over the state of objects and of utilities networks on the surface including the emergency services of sanitation companies and large measurements on both surface and underground that monitors the impacts of the construction with instant forwarding the alarm states to entrusted persons.

Future safety equipment for the tunnels is designed at the top-class European level. It will be above standard autonomous and automatic ventilation system with aspiration of polluted air. In case of fire, it will be possible to drain up to 250 cubic meters of air per second, with 100% backup (installed power is 500 cubic meters). Fluxionary ventilation fans at both portals will be able to control air velocity within the tunnels and thus eliminate the leakage of polluted air out of the portals. Lightning of the tunnels will be fully automatic, too, including emergency modes with the possibility to adapt particular conditions in the tunnels and its closest surroundings. According current conditions will be corresponding to variable road signs, both at big Brno circle and whole Brno itself. An emergency mode will enable one-directional operation in each tunnel pipe, mainly in case of repair works or shut-down.

Fig. 1. A view of drilling in the tunnel

III. Monitoring of Methane Presence

During and right after the drilling process under surface built-up area, there occurs declines of terrain and objects. These declines can reach up to tens of millimeters for certain objects. In order to ensure the resistance of these objects to the possible uneven decline of foundations, they have been statically fixed. Besides these measures, some parts of the utilities networks have been repaired or replaced, particularly the installation of flexible connectors for gas pipelines. During the drilling process there arose a potential danger of declines of the objects located directly above the working face of above the already impacted tunnel tube. Some of the sanitation work had been done before the construction as it was mentioned above. However, these measures don’t entirely eliminate all the risks regarding the possible damages of the utilities networks (water, electricity, gas) close to the decline points. The most dangerous risk is just a gas which mostly serves for cookery and heating the water. Gas pipeline (distributing natural gas, methane) mostly goes through the peripheral wall into the basements. An unexpected decline of the object might cause a deformation or other damage to the gas distribution in cellarage areas which would lead to a massive leak of gas within the object and consequent impact on health and life, mainly in case of an explosion.

There used to be manual measurements of methane concentration in the objects and also on the ground surface above the current tunnel drilling point. These measurements are not continuous, therefore it was decided to apply a monitoring system in chosen objects which will continuously and permanently observer concentration of a gas and in case of its exceeding it immediately sends SMS to predefined cell phones.

IV. Monitoring Warning System

Monitoring system guarantees continuous monitoring of methane concentration in particular objects, including power failures. In case of exceeding methane level, or in case of switching on/off the power 230 V, it automatically sends SMS alarm, containing detailed information about object id, time and leakage location. Based on this alarm, there comes an intervention of experts to find out reasons of leakage and

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to take security measures to fix the situation.

Monitoring system is based on sending SMS in case of predefined events. If one or more events occur, it activates particular input of GSM unit and it takes care of sending SMS to given phone numbers. System also detects possible thefts of the equipment and its damages.

System uses detector of flammable gas GS-133 by Jablotron. Detailed hardware specification can be found in [2]. The sensor detects all main flammable gases (natural gas, coal gas, propane, butane, acetylene, hydrogen) and its alarm limits can be set in two levels of concentration.

The main subsystem is GSM communication unit GD-06 (possibly GD-04) by the same producer. The unit serves as multichannel universal GSM alarm and driver. It groups signals from particular sensors and binary signal to determine a status of power line 230 V. Information about changes of the states can be sent in form of SMS up to 8 phone numbers. It also allows calling these numbers and communicating by hands-free set in case of answering the phone. The device also supports GPRS technology and thus it can be used for industrial applications, automation data measurements and other similar purposes. Detailed description of the communicator can be found in [3].

The monitoring system includes backup power source for both GSM communicator and sensor(s). This source is permanently connected to power source of 230 V, detailed specification can be found in [4].

From conception point of view, the system is divided in two parts. The first one contains detectors of gas leakage, the second one serves as evaluation unit made of a distribution box with GSM communicator, backup power source and necessary wiring electro components. The block scheme of entire system is illustrated in Fig. 3 and evaluation unit in Fig. 2.

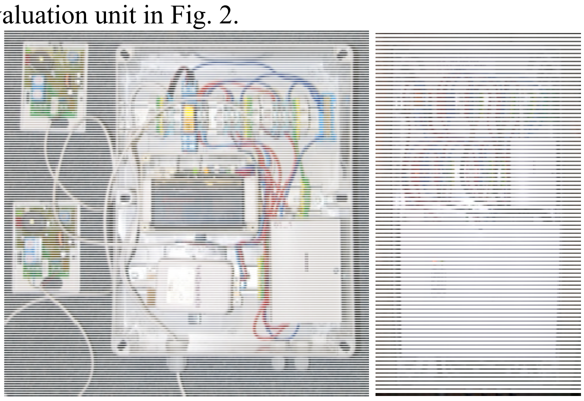

Fig. 2. Illustrating photo of evaluation unit with connected sensors

V. Function of the System

Monitoring system works based on activation or deactivation of particular input of GSM communicator, up to 6 channels that contain signals from particular gas sensors and state of power line 230 V. GSM communicator evaluates these states and according predefined values it reacts to their change by sending alarm SMS to given cell numbers (up to 8).

The appropriate function of gas detector is indicated by green LED that permanently shines after sensor stabilization, while red LED is activated in case of gas presence.

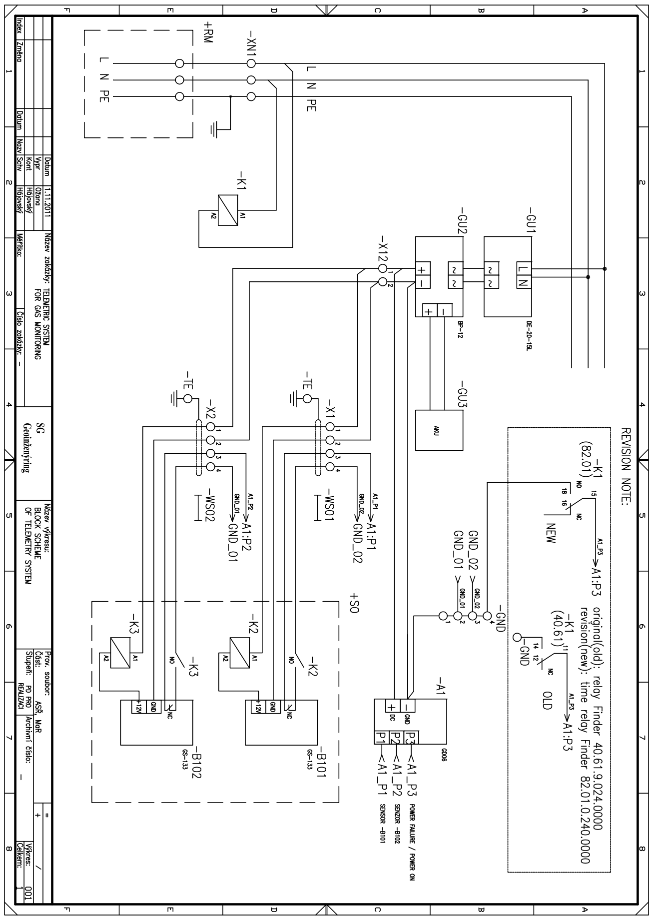

Fig. 3. Block scheme of the system

System is configured in the following way: Gas sensors are activated at predefined sensitivity of 17±3% LFL (lower flammable limit), corresponding to 0,75% of methane:

"CIDLO METANUx ""KDE"" POZOR NASTAL UNIK PLYNU"

KDE – indicates location of alarm situation
x – index of sensor

As a protection against theft or damage, signals contain so called associated alarm serving for detection of these events.

Receiving an alarm SMS does not necessarily indicates presence of methane, but it can also mean that the power of the sensor is down and thus the sensor is not operating, which is unacceptable state. Therefore, immediately after receiving SMS it is necessary to do a personal checkout and indicate what happened.

Monitoring system also sends an alarm SMS in case of power failure, it in the following form:

"Komunikator GD-06 hlasi: NAPAJENI 230V ""KDE"" POZOR VYPADEK NAPETI 230V"

KDE – location of event, it can also be indicated by the cell number that sent this SMS (monitoring points can be stored within the phone).

If the power is renewed, the system sends the following message:

"Komunikator GD-06 hlasi: NAPAJENI 230V ""KDE"" NAPAJENI 230V OBNOVENO"

Received messages help to find out duration of a failure.

It is necessary to outline that a possible power failure (230 V) does not cause any interruption of functionality of monitoring system, it is supplied by a backup source that guarantees approximately 24 hours functionality since a failure. In case of receiving an alarm text message it is advised to carry out a personal visual checkout of particular location within 24 hours, to find out the reasons of failure and to release the power line. If the power line is renewed within this interval (confirmation SMS is received), this checkout is not necessary.

Energetic consumption of the entire system is very low. Results of load tests confirmed the consumption power of 0.5 kW per day. However, it is a peak value, normal operation reaches around 0.3 kW/day. It leads to the conclusion that the whole costs needed for electrical energy per year is approximately 700 CZK for a single installation

VI. Experience and Adjustment of the System

During the development and operation of the described system there were no serious complications or unexpected situations. The only one small problem that occurred several times was a huge amount of messages sent during short but frequent repeating failures (several tens within 2 minutes). Because the system responses immediately, it lead to a significant increase of the costs. Therefore the system was adjusted and added by a time relay with time constant of 10 minutes that restricts alarm states. This adjustment has three benefits: a failure less than 10 minutes is thus ignored, it reduces the costs of operation, and it saves the lifetime of the other relay that is not endangered by frequent on/off switching any more. If the power is not released in 10 minutes, then an alarm SMS is sent.

Fig. 4. Overview of installed evaluation unit

Another planned adjustment of the system is extension of sensor electronics by indication of its own failure. During the operation of current system there is no on-line information if the sensor itself is all right, it can only be indicated by visual checkout of LED diodes located within the sensor. The suggested adjustment will lie in development of the electronic circuit taking care of states of LED diodes and consequently handing over to supervised system.

VII. Conclusion

Within the scope of cooperation between Department of Cybernetics and Biomedical Engineering and experts from GEOtest Brno Inc. and ARCADIS-Geotechnika Inc. there has been developed a large monitoring system that autonomously ensured and will again ensure on-line information and warning system regarding methane presence in the object of interest. During the drilling of the tunnel there were up to 6 units under continuous operation adapted to received information from 1 to 4 sensors of flammable gas. It is plan to modify the current system to ba able to connect other types of sensors for measurement of temperatures and deformations.

During tunneling, and after its completion there were step-by-step deployed 8 monitoring units that were moving along with the ongoing excavation. Each unit provided monitoring of 2-4 potentially dangerous places with a possible occur of land decline and gas leakage due to pipeline damage. Since the beginning of monitoring system service there was either no indication of methane leakage nor any false alarms. Sometimes there are alarm messages indicating failure of a power source 230 V. This is primarily due to overload of the grid at the installation site, or unexpected failure of other, previously unanticipated causes. These failures were fixed up within a few hours while the monitoring system used alternative DC power supply to overcome this power failure.

References

[1] Královopolské tunely v Brně [online]. 2008. Dostupné z WWW: <http://www.casopisstavebnictvi.cz/clanek.php?detail=643>

[2] Detektor hořlavých plynů GS-133 [online]. 2008. Dostupné z WWW: <http://www.jablotron.cz/upload/download/GS-133_CZ_MEX51008.pdf>

[3] GSM komunikátor GD-06 Allegro. 2008. Dostupné z WWW: <http://www.jablotron.cz/upload/download/mhg51004.pdf>

[4] Zálohovaný zdroj BP-12 [online]. 2008. Dostupné z WWW: http://www.jablotron.cz/upload/download/mbc51104.pdf

[5] R. Hajovsky et al, "*Monitorování úniků plynu při stavbě Královopolských tunelů v Brně*". Automa. 2009, č. 4, pp. 20-21., ISSN 1210-9592.

[6] R. Hajovsky, j. Lossmann, "Safety Monitoring of Building Sites During Construction of Traffic Tunnels", The Conference Proceeding of The 13 th International Conference Geotechnics 2012, High Tatras, Slovakia 2012, pp. 195-200, ISBN 978-80-248-2785-8

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