The Development of low cost OSV (On-Site Visualization) devices and its application on Hanoi Metro Line 2

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Abstract

OSV (On-Site Visualization) is a monitoring system in which measured information is shared visually on a real time basis at site. It was introduced by Akutagawa in 2006 and it has been applied at various construction sites in Japan and overseas projects.

Through OSV application on various overseas projects, it has been recognized that a major problem with OSV system is the high cost of electrically driven OSV devices needed to cover many locations for a more effective OSV operation.

Based on the above observation, low cost OSV were developed and trial installation was conducted at the slope of National Highway in Vietnam.

Hanoi Metro Line 2 has been implemented since Mar 2011 under Japanese ODA and the construction works start in 2015. Because the underground station has deep open excavation works located at downtown in Hanoi, the careful construction operation with instrumentation and monitoring are required. In this paper, the plan of various type of OSV installation on Hanoi Metro Line 2 is proposed and the effectiveness of OSV monitoring is examined.

Keywords: OSV monitoring, Hanoi Metro Line 2, Underground, Low cost, Safety.

1. Introduction

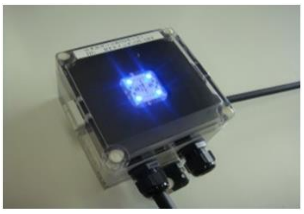
Recently the installation of safety monitoring systems at construction sites has become mandatory and everyone recognizes the importance and requirement of safety. However the ratio of injuries and fatalities have not been reduced so much in Japan[1)] as well as other countries[2)].

A new approach for the safety monitoring of infrastructure and visually sharing the measured information on a real time basis was proposed by Akutagawa in 2006 and has been implemented in more than 50 construction sites including overseas projects in New Delhi and Bangalore[3) - 6)] to improve safety management practices. This new approach is derived by utilizing an On-Site Visualization system, whereby light emitting sensors are used as the key technology for monitoring and giving simultaneous visual presentation of the measured information of structure and ground movement information on site. Fig. 1 shows typical light emitting sensors developed for the implementation of the OSV by which the various phenomena and movements can be monitored and visualized on site in real time. The monitoring items can be listed as follows at normal construction site.

- Settlement monitoring for ground, buildings, utilities, etc.
- Inclination monitoring for ground, retaining wall, building and any other structures
- Axial/bending force for strut, anchor, etc.
- Water pressure for ground, slope, etc.
- Any other pressures such as concrete casting, ground moving, etc.

The difference of procedure for conventional monitoring and OSV monitoring is shown in Fig. 2 and it is obvious that conventional monitoring takes various steps to get the information to site engineers and workers. On the other hand, OSV system shows the safety condition to the engineers and workers directly at site and in real time. This is the salient feature and significant advantage of OSV system especially in overseas projects which have so many unskilled workers.

Light Emitting Deformation Sensor (LEDS). A car battery can supply power for the LEDS. The sensor has a total stroke of 10mm and is capable of showing 5 colors for every interval of 2mm.



Light Emitting Converter (LEC) is a compact data logger and an indicator of the results all in one box. The most attractive feature of this device is that this can be connected to any type of sensor to make your instrumentation strategy more flexible and visible.

Light Emitting Inclination Sensor (LEIS) is suited for monitoring of angle change with precision. Due to an added feature of the constant temperature in the box. The stable reading of inclination is possible.

Laser pointer can be used for simple visual presentation of inclination. For example the laser pointer that experiences rotation 0.1 degree can be identified as the movement of its projection by 174mm on a screen 100m away from the pointer.

Fig. 1. Typical Light emitting sensors developed for the implementation of the OSV

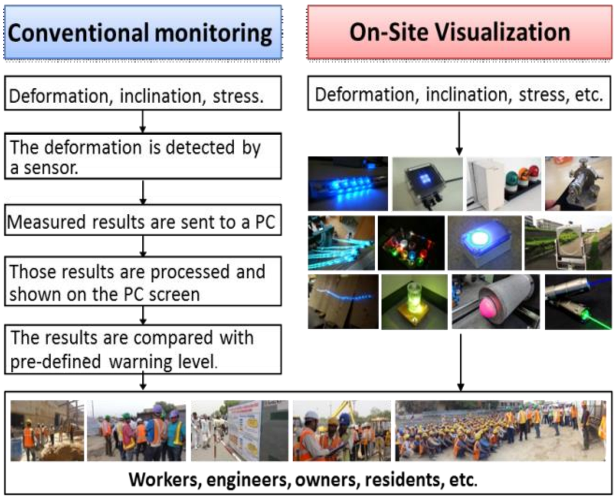


Fig. 2. Comparison of Conventional and OSV monitoring

Fig. 3. Loss of soil behind the wall at Cricket stadium

2. Lessons learnt of OSV Monitoring from past Projects

The OSV monitoring projects have been conducted at the following overseas projects under Japan International Cooperation Agency (JICA) program;

- AIIMS station construction on Delhi metro project
- Okhla bridge (long span bridge) construction on Delhi metro project
- Cricket stadium station construction on Bangalore metro project[7)]

Through the experience of OSV monitoring from the above three projects, the several outcomes such as gaining safety information at site on real time by engineers and workers, uplift of safety consciousness by each worker and solidity of project team through OSV monitoring were confirmed. On the other hand, it also revealed the following problems of OSV monitoring on the project.

- Time required for installation of OSV devices and education of OSV activities
- High cost of OSV devices because of new and special electric devices from Japan
- No full coverage of necessary area by OSV devices because of cost problem

For example, the Cricket stadium station which had a maximum excavation depth of 14m and adjacent high buildings was selected for OSV monitoring, because of the possibility for displacement of the retaining wall posing a danger to workers and potential damage to the buildings nearby. A secant pile wall and a two layer strut system was selected for the stability of 14m depth excavation. In the course of OSV monitoring, an unexpected issue was encountered in an area where the OSV monitoring was not initially planned. A portion of the retaining wall on the south side of Cricket Stadium station was found to be unstable due to a loss of soil behind the wall as shown in Fig. 3. It was decided that one of the tilt sensors with LEC, originally positioned on the roof top of an adjacent building, should be moved to this troubled location to monitor while remedial measures were taken.

From this incident, there was a request from the establishment for simpler mechanical OSV devices with a much lower cost to cover the monitoring area more widely at the construction site.

Now the directions and required measures are discussed for the proliferation of OSV monitoring at construction site in Table 1.

Table 1 The measures for OSV proliferation at construction site

Hard component	Soft component
- Development of low cost OSV devices for monitoring deformation and inclination - No electricity devices for the application at no power site - Ideas to recognize the deformation and inclination not only by the electric LED color but by the other indications	- Idea and tool for the prevention of device broken and stolen - Establishment of the procedure for OSV activities - Education and training for workers and citizen participation on OSV activities

3. Development of Low Cost OSV and Its Trial Application

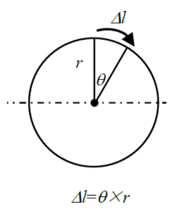
3.1 Conception of low cost OSV

The experience gained from the OSV applications in the above two projects reveals the problems of OSV monitoring, namely high cost of implementation and the limitation of OSV application areas on the project. Now in order to prevent near misses and potential collapses at construction sites and for the proliferation of OSV monitoring, the following low cost OSV devices have been developed for actual site applications.

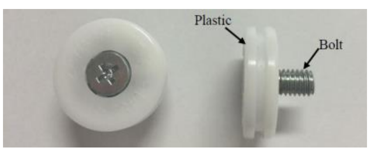
a) Mechanical displacement sensor

A new mechanical displacement sensor (M/d sensor) is proposed for relative displacement measurement without using any electricity. This displacement sensor is a device which can measure the relative displacement between two arbitrary points and show the result by the rotation of the indicator like a needle simultaneously[8) 9)]. As shown in Fig. 4, the sensor consists of two components. The first component is the stiff and flexible thread which can mobilize a pulley, with diameter of 21mm to rotate when a relative displacement between two points connected by the thread occurs. The pulley is to translate the linear displacement to rotations and its diameter determines the sensitivity of the measurement. The second component is the indicator part, here represented as the needle, which is attached on the side of the pulley for visualization of the measured displacement on the plastic board with scales printed on it.

The way the tension of the thread rotating around the pulley is provided is very important factor and the suitable weight to transfer displacement to pully rotation as well as elongation and deterioration of thread shall be examined by laboratory and the field test. The durability of the thread, over a period of time need to be tested, also its longevity under extreme weather conditions (ie sun, rain and wind). The durability of the needle and board made from plastic, if maintained should have a long life cycle. The value of the OSV materials is relatively low, around US$100 including setting fee, and therefore it is easily replaced if damaged or stolen.



(a) Rotation of pulley



(b) Photo of pulley

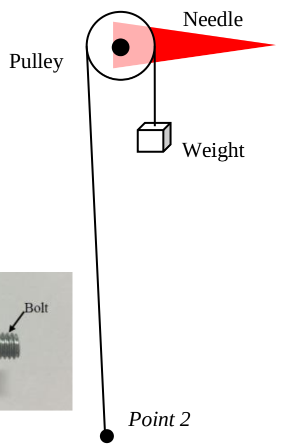
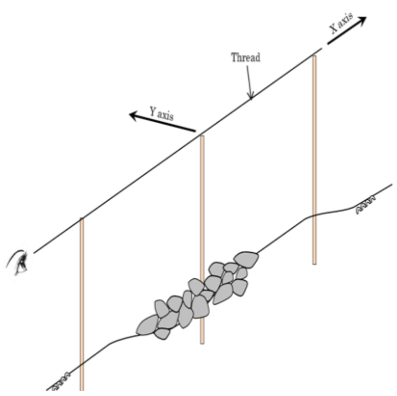
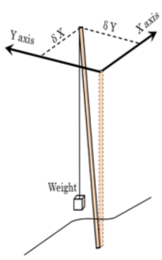


Fig. 4. Layout of the Mechanical displacement sensor



(a) Before ground movement



(b) After ground movement

Fig. 5. Monitoring method for Vertical bars

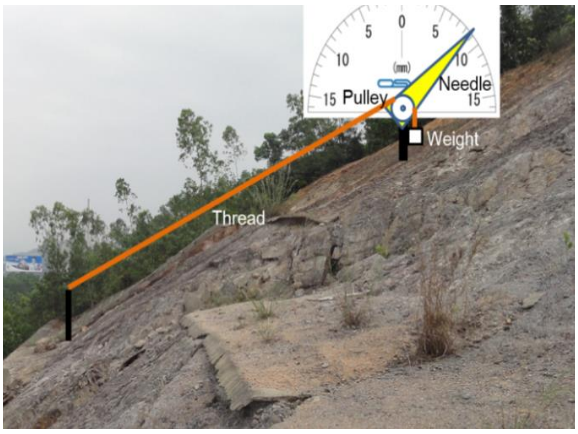


Fig. 6. Monitoring image: Mechanical displacement sensor

Fig. 7. Monitoring image: Vertical bars

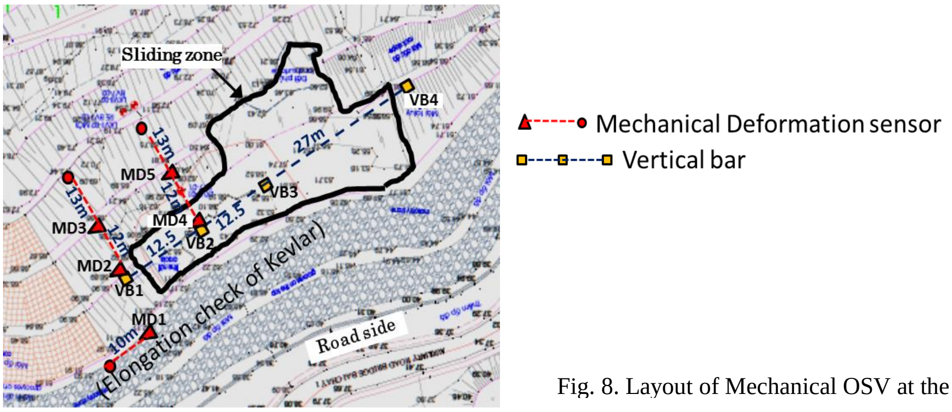


Fig. 8. Layout of Mechanical OSV at the slope

b) Vertical bars with plumb measurement[10)]

A very simple OSV system device to monitor the ground movement is introduced. The multiple vertical bars made of wood or steel bars are installed in to the ground. The initial setting of these bars shall be exactly aligned in a straight line connected with a guide thread and exactly vertical (therefore, all the bars are pointing to the Earth centre point) as shown in Fig. 5.

In cases of any ground movement, it can be seen with the naked eye if any one or more numbers of bars have moved out of their installed straight line and the distance and inclination of the ground movement can be calculated by δx and δy which can be measured manually. The total cost of the OSV system including materials and installation fee will be around US$100 and therefore it is easily replaced if damaged or stolen.

3.2 Application of low cost OSV on National Highway

There was an opportunity to conduct simple and low cost mechanical OSV test on the slope of National highway in Vietnam. The target of this trial is 1) to compare high end OSV and low cost mechanical OSV in terms of its performance, 2) to confirm the effectiveness of the low cost mechanical OSV, 3) to confirm whether the low cost OSV can be applied as the engineering device for detecting movement and deformation of ground / structures of an actual project.

The National highway including cut slope and slope protection was constructed in Vietnam in 2008 under funding by ODA loan. The geological data of this region are composed of Early Triassic sedimentary formations, which mainly consist of alternation of sandstone, conglomerates and siltstone. The formation is overlain by Quaternary formations, which consist of alluvium and diluvium formations. Weathering of the formation is present to a great depth and cut slope area has a high potential of collapse due to rainfall.

Certain slope protection measures such as concrete frame with vegetation, masonry retaining wall were deployed and the projects were handed over to the Government. However, some parts of the slope protection requirement have not been completed due to the Government budgetary problems. As a result some land slide during the rainy season has occurred

3.3 Installation of low cost OSV on the slope

Because there is a possibility of severe incidents / accidents to vehicles and citizens if further slope collapse occurs, allowing soil and stones to fall onto the national highway, an urgent start of the slope protection measures for the project is anticipated. For monitoring during the slope protection works, the low cost OSV monitoring, M/d sensors and vertical bars are proposed as shown in Fig. 6 to Fig. 8, in order to:

- show the evidence of ground movement with the data to the Government
- disclose the OSV monitoring results to the Government for the project to examine how low cost OSV data and results can contribute to further engineering site judgments.

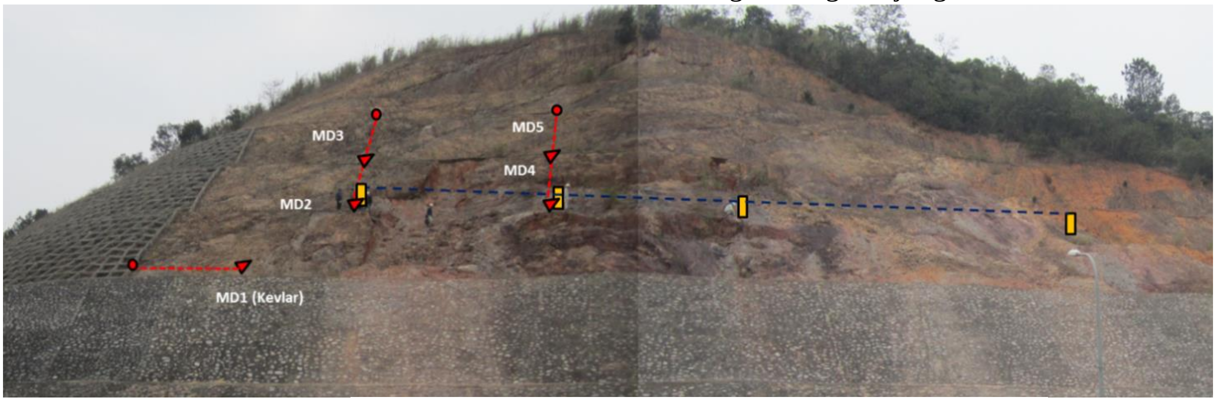


Fig. 9. The condition of slope collapse and OSV application

(a) Setting of Mechanical displacement sensor. (b) Setting of Vertical bars by wood

Fig. 10. Installation condition of Mechanical OSV

The installation work of the low cost OSV devices on the slope have been conducted in mid February 2014 as shown in Fig. 9 and Fig. 10.

M/d sensors were installed along the slope direction covering the sliding zone. Vertical bars were installed at right angles to slope direction. Out of four bars, outside two bars are located outside of the slope sliding zone and the inner side bars are installed inside of the sliding zone.

3.4 Actual monitoring and Lessons learnt

The monitoring works started immediately after the installation of the mechanical OSV devices. Fig. 11 shows the reading of M/d sensors at the Slope. The Kevlar aramid fiber (Poly-paraphenylene terephthalamide) which has high strength and high modulus was selected as the monitoring thread.

Because it is the first time to apply this material under extreme weather condition (ie. wind, rain and sun for long period), the durability of the thread was checked by site elongation tests (see Fig. 13) in comparison with invar cable material which has smallest possible thermal expansion coefficient (less than 3.7×10-6 /degree). As shown in M/d-1 reading in Fig. 11, about 7mm elongation on Kevlar thread at 10m length was observed during the first 3 months and this phenomena coincided with the laboratory test of Kevlar elongation by Akutagwa[11].

Based on the 3 months monitoring and taking into account the elongation of the Kevlar thread, the certain ground movement, of about 5 to 25mm at the Slope was observed and further movement is anticipated when the heavy rainy season starts.

Fig. 12 shows the reading taken of the Vertical bars (VB-1 to Vb-4) for the first 3 months. There are plus and minus reading up to 10 mm range. Because all the readings are by line of sight, this data is still within the tolerances and no radical movement was observed.

It is the first time to monitor the actual slopes by low cost OSV devices so widely in an overseas project and we have observed the following lessons learnt from the above planning, installation and monitoring of the Mechanical OSV.

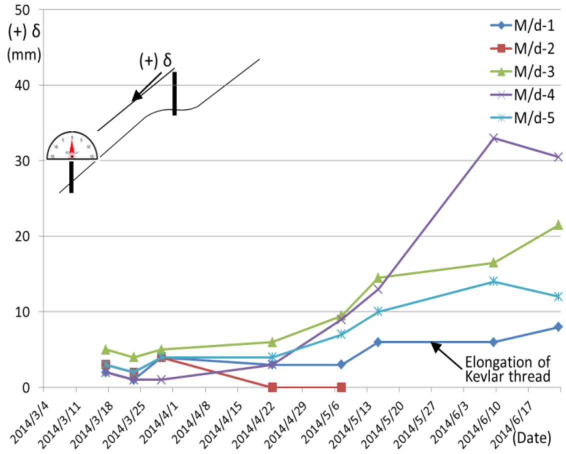


Fig. 11. Monitoring results of M/d sensor for 1st 3 months

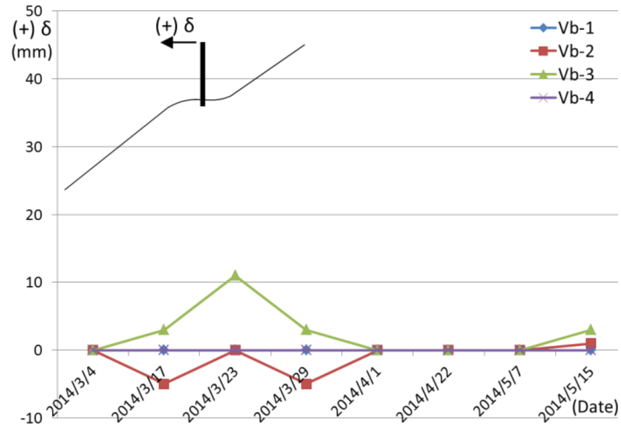


Fig. 12. Monitoring results of Vertical bars for 1st 3 months

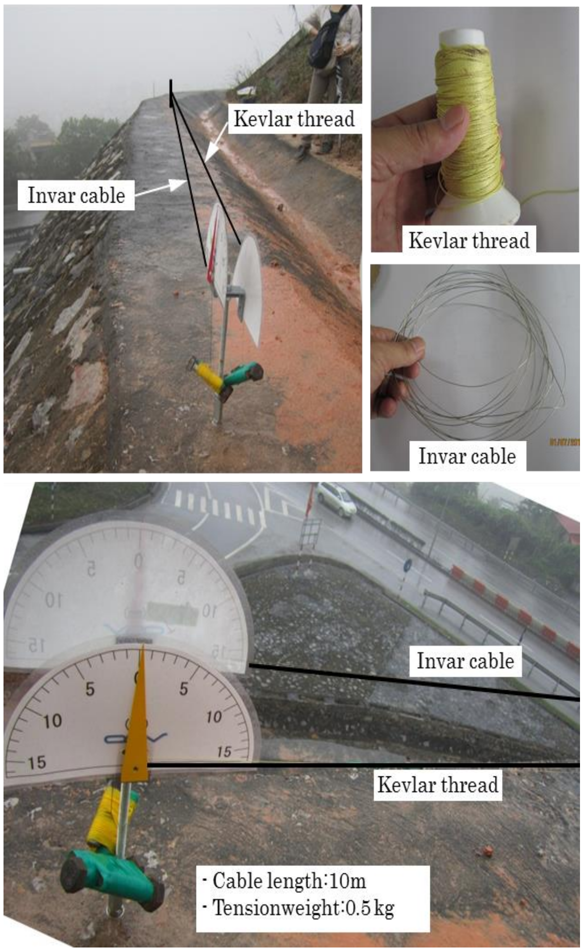


Fig. 13. Elongation and deterioration of Kevlar thread

- Mechanical OSV devices can be set up at site without electricity and without any special techniques.
- It is confirmed that the M/d sensors can measure ground movement and the data can be utilized for engineering judgment for the appropriate actions.
- It is confirmed that Vertical bars can measure the inclination and movement of the ground within certain tolerances.
- The access to the site and access to each monitoring point on the slope is not so easily accessed by the engineers, therefore further improvement of OSV displays will be considered
- The range of display by needle was up to 15 mm for M/d sensor; however this is too small a range to monitor large scale movement of the ground.
- The incident of vertical bars being stolen and/or broken occurred at times. It is therefore not recommended to apply high cost OSV materials at such open / isolated large project areas and it is also important to arrange security systems at site to prevent such incidents.
- So far to date there is no record of any deterioration of materials and devises. Observed and monitoring continuously is still required for the long term effects of deterioration of the devices.
- Consequently, it is concluded that OSV monitoring by low cost mechanical devices is sufficiently successful to judge the site safety requirements and to provide data to assist in determining the safety actions required at site.

4. Application of Low Cost OSV on Hanoi metro Line 2

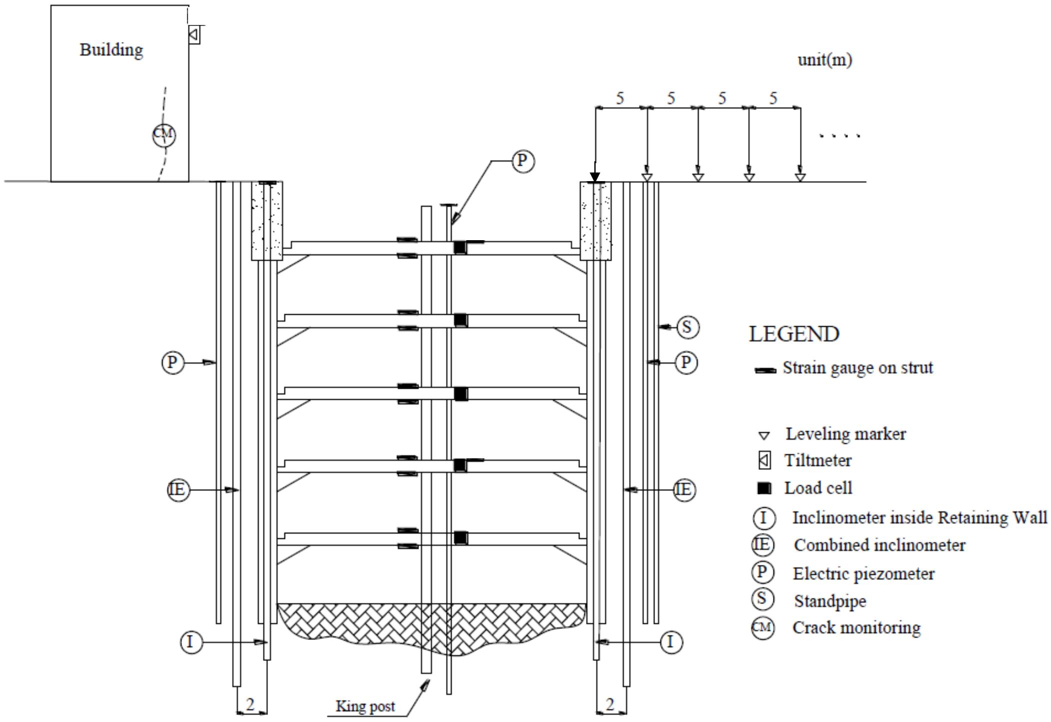
4.1 Introduction

The trial application of low cost OSV at National highway provided the required data for engineers/ workers to grasp the conditions of ground movement effectively and to enable engineering judgment for the necessary action. It means that low cost OSV can be effective monitoring tools to apply at construction site for preventing the near misses and disasters.

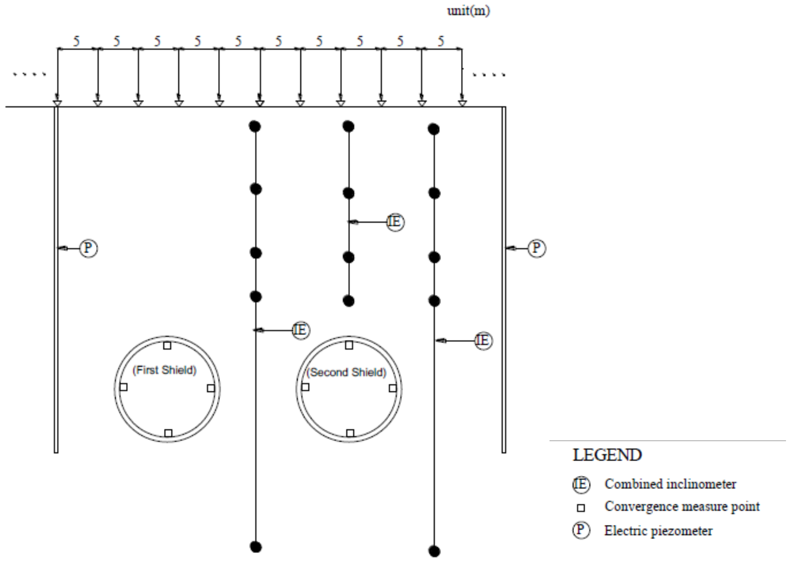
Hanoi metro Line 2 has seven underground stations and they are located in a very congested area at downtown in Hanoi. The well managed safety monitoring system is necessary utilizing OSV system to prevent the construction accidents. In this Chapter, the low cost OSV devices to be applied for Hanoi metro Line 2 are listed and its effectiveness is discussed.

4.2 Safety monitoring based on OSV for underground section on Hanoi metro Line 2

The typical arrangement of monitoring instrumentation at underground section is shown in Fig. 14.



(a) Instrumentation at underground station



(b) Instrumentation in tunnel

Fig. 14. Typical instruments distributions at underground section

The various types of instrumentation are required for safe construction and the possibility of OSV application instead of normal monitoring instrument are summarized in Table 2.

The explained low cost OSV application takes only 5 to 10% of normal electric instrument monitoring because there is no requirement of electricity arrangement and all the materials to manufacture these devices are available in local market as described in Fig. 15 to Fig. 19.

The application of low cost OSV devices on Hanoi metro Line 2 will lead effective safety monitoring

Table 2 List of low cost OSV application on Hanoi Metro Line 2

Monitor item	Instrumentation	Low cost OSV devices	Ref.
1) Station			
Strut force	Strain gauge	Mechanical deformation sensor	Fig.15
Strut force	Load cell	—	
Ground settlement	Leveling marker	—	
Building inclination	Tiltmeter	Plumb measurement	Fig. 16
Inclination of retaining wall	Inclinometer inside retaining wall	Plumb measurement	Fig. 16
Ground inclination & settlement	Combined inclinometer & extensometer	—	
Ground water level	Electric piezometer, stand pipe	Water table bar	Fig. 17
Building crack monitoring	Crack meter	—	
2) Tunnel			
Ground settlement	Leveling marker	—	
Ground inclination & settlement	Combined inclinometer & extensometer	—	
Deformation of tunnel segment	Convergence measure	Tunnel displacement sensor	Fig. 18
Ground water level	Electric piezometer	Water table bar	Fig. 17

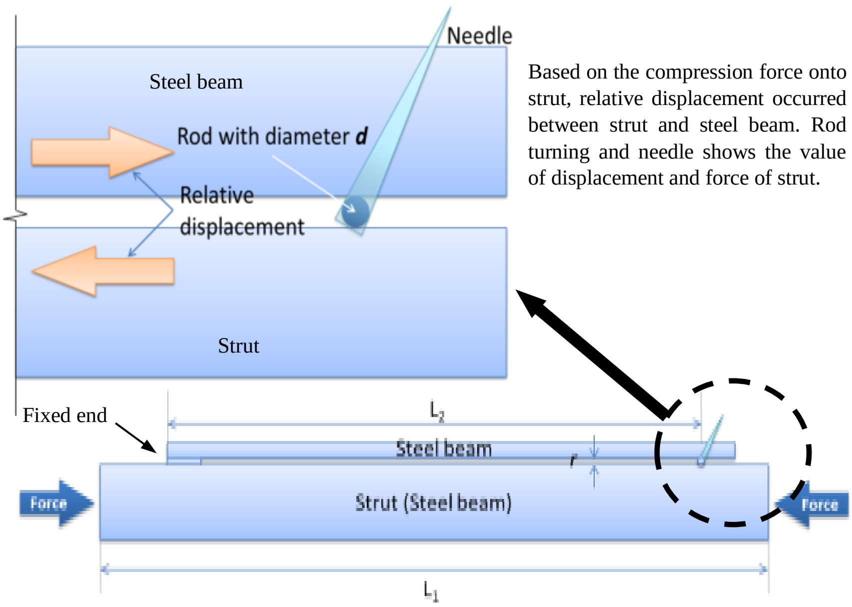


Fig. 15. Function of Strut force and Mechanical deformation sensor

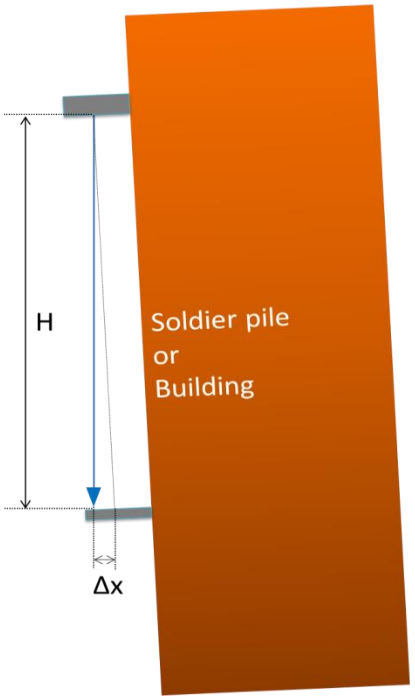


Fig. 16. Function of Plumb measurement for inclination

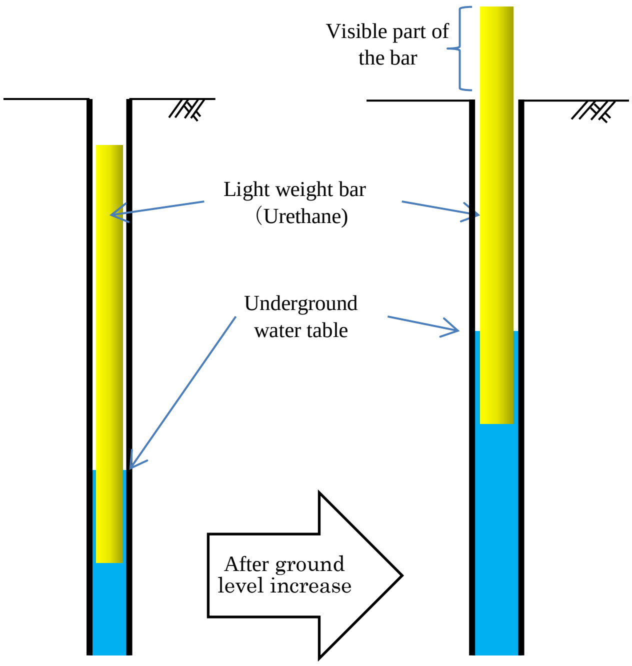


Fig. 17. Water table bar

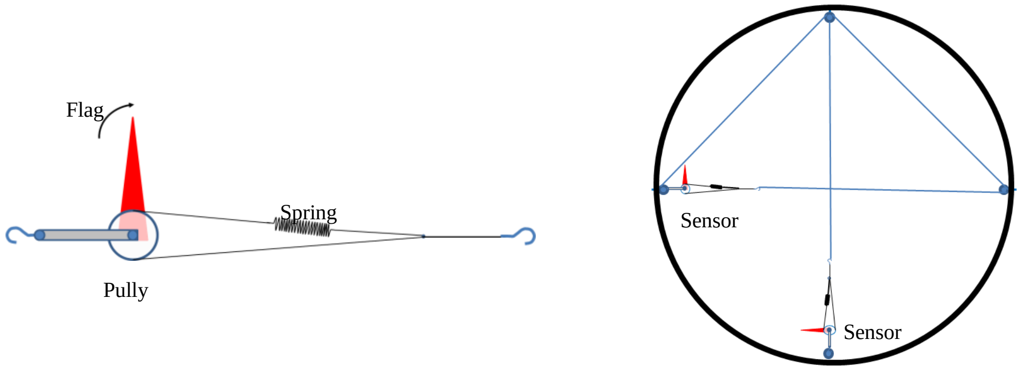


Fig. 18. Tunnel displacement sensor

5. CONCLUSION

The review of the past OSV projects, development of low cost OSV and proposal of low cost OSV application on Hanoi metro Line 2 are examined and the following conclusions are obtained;

- OSV monitoring applying electric high cost devices was conducted on overseas projects, namely AIIMS station (Delhi metro), Okhla bridge (Delhi metro) and Cricket stadium station (Bangalore metro). There were no large collapses through the construction stages, but several near misses and small collapses were observed.
- Although the effectiveness of OSV monitoring as a safety tool was

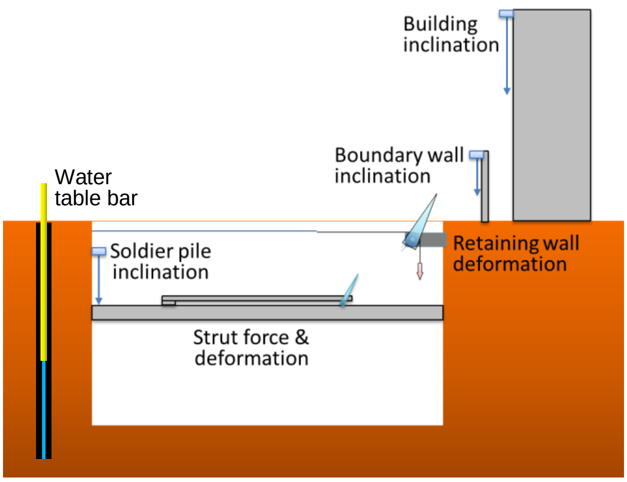


Fig.19. Arrangement of Low cost OSV at underground station

confirmed, the problems of existing OSV, namely high cost of electrical OSV devises and its shortage of number of installation points (less coverage of OSV devices at site due to cost reasons) were revealed. The necessity of improvement of OSV monitoring, namely 1) development of a low cost OSV devices and 2) installation of greater number of OSV devices widely across the sites to grasp any near misses were confirmed.

- The development of simple mechanical OSV namely “Mechanical displacement sensor” and “Vertical bars with plumb measurement” was introduced and there was an opportunity to apply low cost OSV on actual project site in Vietnam. This is the first time to conduct such monitoring scheme at actual project site and the durability of the OSV devices under local climate conditions was monitored for 3 months. Through this trial monitoring, 1) The function and effectiveness of the low cost OSV compared with high end OSV, 2) its sufficiency to conduct engineering judgment based on OSV results were confirmed.
- The application of low cost OSV application on Hanoi metro Line 2 is proposed with detail plan of mechanical systems. It is observed that the total monitoring cost will be reduced dramatically and large volume installation to cover required monitoring area will be anticipated.

The ratio of construction accidents and the fatality of workers are still high compared with other industries especially for overseas construction projects. One of the reasons for these accidents / fatalities is due to a budgetary problem, with insufficient funds being available for arrangement of the instruments and monitoring devices necessary to carry out the construction safely.

The OSV sensors of a new generation, namely those with much simpler mechanisms and structures, should be developed so that a much greater number of sensors can be used per site without causing too much trouble for installation and for funding. It will only be then that the OSV monitoring method can become a truly accepted safety management routine at construction sites around the world.

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