QUALITY ASSESSMENT OF EFFECTIVENESS OF SAFETY MONITORING BASED ON ON-SITE VISUALIZATION USING NEW DEVICES WITH VARIOUS COST RANGES

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OSV (On-Site Visualization) monitoring is a system that measures information which is shared visually in real time at site. It was introduced by Akutagawa in 2006 and has been effectively applied at various construction sites since then. The basic function of the OSV is to show changes in deformation, pressure, inclination, etc. of structures as well as ground movement using colored lights, namely blue, yellow and red through light-emitting converter and LED lights electrically. Through these previous site experiences, the OSV performance has been reassessed; it has been recognized that a major problem with the system is the cost of the number of electrically driven OSV devices needed to cover many locations for a more effective OSV operation. More simple mechanical monitoring devices have now been devised which do not require electricity and are sufficient and reliable enough to monitor structure and ground movement. These low-cost OSV devices have been introduced at the Bai Chay Road project in Vietnam as the first trial of low-cost OSV on an overseas project. Finally we propose a basic strategy for evaluating the performance of the OSV system and improving construction safety, utilizing low-cost OSV.

Key Words : On-Site Visualization (OSV), low-cost, monitoring system, Delhi Metro, Bangalore Metro

1. INTRODUCTION

Recently the installation of safety monitoring systems at construction sites has become mandatory and everyone has recognized the importance and the need for safety. However, the rate of injuries and fatalities has not been reduced very much in Japan1) as well as other countries2).

A new approach for the safety monitoring of infrastructure and visually sharing the measured information in real time was proposed by Akutagawa in 2006 and has been implemented in more than 40 construction sites including overseas projects in New Delhi and Bangalore3)-9) 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 the 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 ordinary monitoring items can be listed as follows at normal construction site:

- Settlement monitoring for ground, buildings, utilities, etc.
Fig. 1 Typical light-emitting sensors developed for the implementation of OSV.

Fig. 2 Comparison of conventional and OSV monitoring.

![Table 1](image)

**Table 1** List of OSV devices used at AIIMS station.

| Monitoring instrument and OSV device | Type of structure being monitored | Number of OSV devices |
|--------------------------------------|-----------------------------------|-----------------------|
| Strain sensor with LEC               | Strut beam                        | 3                     |
| Inclination sensor with LEC          | Soldier pile Boundary wall Nurse’s hostel | 3 2 3             |
| Laser pointer                        | Nurse’s hostel                    | 2                     |
| Light-emitting Deformation Sensor (LEDS) | Between two retaining walls | 5                     |

Note: Detail arrangement is shown in Fig. 14, in Chapter 4

- Inclination monitoring for ground, retaining walls, buildings 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 in procedure for conventional monitoring and OSV is shown in Fig. 2 and it is obvious that conventional monitoring various steps to get the information to site engineers and workers. On the other hand, an OSV system shows safety conditions to engineers and workers directly at site and in real time. This is the salient feature and significant advantage of an OSV system in overseas projects that have many unskilled workers.

2. **LESSONS LEARNED FROM PAST PROJECTS**

1) **OSV Application at AIIMS on Delhi Metro**

The OSV monitoring method has been applied at the southwest entrance construction of AIIMS station (Fig. 3 and Fig. 4) on the Delhi Metro project utilizing Special Assistance for Project Implementation (SAPI) under the Japan International Cooperation Agency (JICA) program.

The installation of retaining walls, namely soldier piles and timber lagging, excavation work to a depth of approximately 10m, installation of one layer of struts to support the excavated walls and other related works were carried out in the area. Additionally, the construction work area was located near an existing nurse’s hostel and a public road.

The monitoring list and site conditions at AIIMS station are summarized in Table 1, Fig. 5 and Fig. 6. During the OSV monitoring period at AIIMS station, there was a small collapse of a retaining wall at a deep excavation spot outside the monitored area. Fortunately a site engineer found this problem and took remedial measures immediately. This incident revealed that if OSV devices covered a larger area, it could have prevented a structure collapse.
Another JICA SAPI project for the application of OSV monitoring was conducted at the Cricket Stadium station in the Bangalore Metro project from June 2011 to February 2012.

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, thus posing a danger to workers and potential damage to the buildings nearby. A secant pile wall and a two-layer strut system were selected for the stability of 14m depth excavation. The application list and site conditions for OSV are summarized in Fig. 7, Fig. 8 and Table 2.

In the course of OSV monitoring, an unexpected issue was encountered in an area where 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 loss of soil behind the wall, as shown in Fig. 9. 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 it while remedial measures were taken. Owing to this incident, there was a request for the establishment of simpler mechanical OSV devices with a much lower cost to cover the monitoring area more widely at the construction site.
Note: Detail arrangement is shown in Fig. 16 in Chapter 4.

Fig. 7 Layout and OSV location at Cricket stadium station.

(3) Lessons learned from these two projects

For the abovementioned projects, all the OSV devices had the function of outputting measured information using LED lights except for the laser pointers. This electrically-based approach is one of the attractive ways for disclosing critical information at construction sites. However, there could be many more alternatives to issuing warning messages using much simpler OSV sensors. They would use extremely little or no electricity; have an extremely simple structure, yet still be able to work as OSV sensors to give advanced warning of potential problems for the site workers. As a consequence, the experience of OSV applications mentioned in the above two projects, reveals that a budgetary problem exists due to the high cost of OSV monitoring in relation to the requirement for an electric power supply to drive the system and, light-emitting convertors with monitoring instruments. Finally, the

Table 2 List of OSV devices used at Bangalore Metro.

| Monitoring instrument and OSV device | Type of structure being monitored | Number of OSV devices used |
|-------------------------------------|----------------------------------|----------------------------|
| Strain sensor with LEC             | Strut beam                       | 3                          |
| Load cell for anchor with LEC      | Ground anchor                    | 2                          |
| Inclination sensor with LEC        | Secant pile Buildings: 6         | 2                          |
| Multiple ground inclination sensors with LEC | Ground behind retaining wall | 2                          |

Fig. 9 Loss of soil behind the wall at Cricket Stadium.
covered monitoring area by electric OSV devices becomes limited because of this budgetary problem.

The following is a summary of remarks and lessons learned through the experience of the above two projects:

(a) Installation procedure

Most OSV devices have data logging systems for connecting to the computer in a monitoring cabin. Hence IT expatriates from Japan were required to install and set up the system to connect the instrument sensor, OSV devices and the computer. Now it is desirable to simplify the system, by showing only the OSV color on-site to save time and costs.

(b) Visibility

Visualization of measured data should be done on the spot at the work site. However, management should be able to view the same data from the computers on their desks. Therefore, a total arrangement for visibility should be designed primarily for people on site and secondly for people in the office. Additionally, the range of visualization should be as wide-ranging as possible. For example, the LED color on strut sensors at AIIMS station showed only on one side and the workers on the other side could not see the LED color. It is recognized that any unsafe condition must be immediately relayed to the engineers and workers on site.

(c) Sound output

As pointed out by many who participated in the questionnaire survey, a sound output function (warning siren or buzzer) should be added to OSV sensors. Details as to what triggers these sound warnings should remain as future topics.

(d) Portability

For some cases, portability of OSV sensors is required. The ones used in this practice were installed semi-permanently at respective positions and were never removed afterwards. However in different cases, the area of interest may vary day by day, demanding that OSV sensors be moved from position to position as requested. For such cases, a stand-alone power supply system, wireless data transmission and easy removal and re-installation procedures are required.

(e) Cost to manufacture electric OSV devices

The cost for manufacturing electricity-driven OSV devices should be lower than that for the current level. As demand increases, costs will naturally go down accordingly provided that they are manufactured in Japan. The international strategy for manufacturing OSV sensors remains as an important topic to be worked out soon.

(f) Simpler OSV sensors at a much lower cost

In these projects, all the OSV sensors function by outputting measured information as light such as LEDs, rotation lamps, or laser beams using electricity. This electricity-based approach is indeed an attractive way for disclosing critical information at construction sites. However, there could be many more alternatives to issuing warning message using much simpler OSV sensors. They would probably use no electricity; have extremely simple structure, yet still can work as OSV sensors to protect workers. Organized efforts should be made to develop these new sensors to be used along with electricity-based sensors in the future.

(g) Strategic safety management practices

A strategic guideline for executing a monitoring project based on the OSV concept needs to be prepared. The guideline should be compiled in such a way that a monitoring planner could decide the number of OSV devices, locations to install them with reference to a given budget, required accuracy and visibility for processing data, in a rational way.

3. EXECUTION OF SAFETY MANAGEMENT ACTIVITIES WITH OSV

Through OSV monitoring at construction site, it was recognized that the utilization of OSV in site safety management was very important. The Delhi Metro and Bangalore Metro conducted the following safety management activities (Fig. 10 to Fig. 12) utilizing the monitoring colored lights at site;

- Safety OSV induction talk to contractor’s site engineers, workers and citizens
- Daily site walkthrough and inspection with OSV
- Emergency evacuation drill with OSV for site workers

Through the OSV safety management experience, many advantages of OSV application were confirmed, including safety improvement with real-time safety information at site, increase in safety consciousness among workers, and unifying the construction team through unique observation systems.

4. RATIONAL ASSESSMENT AND PLAN OF OSV MONITORING

(1) Rational assessment of OSV performance

On the above two projects, the details of OSV arrangement, namely the category and item of monitoring, applied OSV device, the location of installation and the number of devices were determined based on the site condition and the monitoring budget of the project without in-depth assessment of monitoring requirements. Specifically the type of OSV devices at the time of the past two projects was all electrical devices to show structure and ground movement through LED lights utilizing state-of-the-art technology. Therefore it was always
necessary to set up an electrical battery together with a backup system not only for OSV devices but also for logging data-producing output graphs and so on. In this Chapter, in order to improve the safety monitoring system effectively at site and evaluate the cost effectiveness of the monitoring arrangement, the rational assessment method for OSV performance and OSV cost is proposed in a quantitative manner. In detail, the capability and appropriateness of the following key items of OSV monitoring system are evaluated in this rational assessment method:

a) Unit division: Is the site area which has the potential for any accidents fully covered by the required number of monitoring devices?

b) Functionality: Is the appropriate OSV function installed in the device or not?

c) Threshold value: Are threshold values based on site movement properly defined or not?

d) Visibility: Is visibility such as brightness in day time and the range of colors sufficient or not?

e) Monitoring costs: What is the impact of monitoring costs (devices and related equipment) compared with structure construction cost?

f) Action plans: Have appropriate action plans (reports to safety managers, emergency evacuations, etc.) been established or not?

Out of the above items, quantitative assessment is preceded by items a, b, d, and e. For unit division, it is important to grasp the possibility of incidents occurring and define the monitoring items and number of locations for the proper assessment as shown in Fig. 13. For functionality, the OSV device’s suitability to adapt, quality and accuracy are examined quantitatively. For visibility, brightness of OSV color, ease of recognition and range of visualization are examined quantitatively. For item c and f, it is assumed that there is proper arrangement by site management; there is no evaluation for this assessment. Table 3 shows indices for defining the performance of OSV monitoring. Provided that all the indices are defined for all monitoring units, the sum of the product $\sum ((F) \times (V))$ with maximum score at 1.0 is calculated which may be plotted against the cost index for visual presentation of the overall performance of the OSV monitoring as shown in Fig. 13.
(2) OSV performance evaluation for AIIMS station project

Based on the rational method of OSV performance assessment, OSV arrangement and assessment results at AIIMS station are shown in Fig. 14, Fig. 15 and Table 4. A total of 37 devices covered the area of potential incidents, namely strut buckling, soldier pile deformation, boundary wall collapse and nurse hostel inclination. The OSV cost consists of monitoring instruments, OSV devices, batteries, cables and site fixing materials without engineering and labor fees.

The structure construction costs indicate the direct construction cost of the AIIMS entrance structure including permanent and temporary works. Regarding the OSV performance at AIIMS station, the number of covered OSV units reached 18 out of the required units which means 50% coverage of the area and it is a higher value compared to the Cricket Stadium station in Bangalure project. However the visualization, namely brightness and visual zoning had some problems because this was the first OSV application in India.
OSV performance evaluation for Cricket Stadium station project

Based on the concept of OSV performance assessment, the OSV arrangement and assessment results at Cricket Stadium station are shown in Fig. 16, Fig. 17 and Table 5.

Regarding OSV performance, the monitoring area at the Cricket Stadium was huge (length 180m x width 30m) compared with that of the AIIMS station project where OSV coverage was very limited. Therefore, the number of monitored units reached only 13 out of a total of 102 (only 13% of the required area was monitored). On the other hand, the OSV Visualization index (V), namely brightness, ease of recognition and range of visualization got full scores because they were improved entirely after the experience at AIIMS station in the Delhi Metro project.

(4) Summary of OSV performance and OSV cost issue

Fig. 18 summarizes OSV performance versus OSV cost index for the two projects. The cost for OSV devices shows 0.26% and 1.0% of the construction cost and these values are relatively high in overseas projects because the emphasis on safety and monitoring is less in overseas projects. However the overall OSV performance achieved at present is far less than the acceptable level of performance, say 0.7 to 0.9 and some basic improvements on the OSV application are still needed to prevent any site near misses and potential collapse.

### Table 3 Indices for defining performance of OSV monitoring.

| Functionality Index (F) | Definition: OSV device’s suitability (whether it meets the purposes of monitoring), quality (whether it has no errors or down time) and accuracy (whether it has no wrong or ambiguous outputs) |
|-------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0 to 0.33               | No installation or very poor condition                                                                                                                                                    |
| 0.33 to 0.67            | Middle to good condition                                                                                                                                                                   |
| 0.67 to 1.0             | Good to very good condition                                                                                                                                                               |

| Visibility Index (V) | Definition: Brightness of OSV color (whether it can be seen under sunlight), ease of recognition (whether it has 5 colors to recognize safety levels or it shows clear safety levels on the screen board in the case of laser pointers) and range of visualization (whether the light or display faces have a limited range or not) |
|---------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0 to 0.33           | No visualization or very poor visualization                                                                                                                                                    |
| 0.33 to 0.67        | Middle to good visualization                                                                                                                                                                  |
| 0.67 to 1.0         | Good to very good visualization                                                                                                                                                              |

| Cost Index (C) | Definition: OSV device cost (equipment, cable, software) divided by structure construction cost shown by percentage.                                                                                           |
|----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

### Table 4 OSV performance assessment on AIIMS station.

| Possible near misses, collapse | Name of monitoring unit | OSV device | OSV Function (F) | OSV Visualization (V) | Remarks |
|--------------------------------|-------------------------|------------|------------------|-----------------------|---------|
| Strut buckling                 | Strut unit-1 to 9       | Strain sensor with LEC | 1.0              | 0.33                  | F: OSV suitability, quality, accuracy are OK: 1.0, V: Easy recognition is OK, Brightness and one side display to be improved: 1/3=0.33. |
| Soldier pile deformation       | Pile unit-1 to 10       | Inclination sensor with LEC | 1.0              | 0.67                  | F: OSV suitability, quality, accuracy are OK: 1.0, V: Easy recognition and display is OK, Brightness to be improved: 2/3=0.66 |
| Retaining wall deformation     | Wall unit-1 to 10       | Light-emitting Deformation Sensor | 1.0              | 0.67                  | Score is the same as soldier pile deformation |
| Boundary wall collapse         | B wall unit-1 to 3      | Inclination sensor with LEC | 1.0              | 0.67                  | Score is the same as soldier pile deformation |
| Nurse hostel inclination       | Building unit-1 to 5    | Inclination sensor with LEC and Laser pointer | 1.0              | 0.67                  | F: OSV suitability, quality, accuracy are OK: 1.0, V: Easy recognition is OK, Brightness to be improved: 2/3=0.66 |

Total unit number $n=37$ \[\sum(F) \times (V) = 11.1\] OSV performance score $= 11.1/37 = 0.30$

OSV device cost = US$ 49,900, Structure construction cost = US$ 5 million, OSV cost index= 1.0%
Table 5 OSV performance assessment on Cricket Stadium station.

| Possible near misses, collapse unit | Name of monitoring unit | OSV device | OSV Function (F) | OSV Visualization (V) | Remarks |
|------------------------------------|-------------------------|------------|-----------------|----------------------|---------|
| Strut buckling                     | Strut unit-1 to 30      | Strain sensor with LEC | 1.0 | 1.0 | F: OSV suitability, quality, accuracy are OK: 1.0, V: Easy recognition, brightness and display zone are sufficient: 1.0. |
| Anchor collapse                    | Anchor unit-1 to 8      | Anchor head load cell with LEC | 1.0 | 1.0 | Score is the same as strut buckling. |
| Soldier pile deformation           | Pile unit-1 to 30       | Inclination sensor with LEC | 1.0 | 1.0 | Score is the same as strut buckling. |
| Retaining wall deformation         | Wall unit-1 to 30       | Wall inclination sensor with LEC | 1.0 | 1.0 | Score is the same as strut buckling. |
| Building inclination               | Building unit-1 to 4    | Inclination sensor with LEC | 1.0 | 1.0 | Score is the same as strut buckling. |

Total unit number n = 102

\[ \sum (F) \times (V) = 13 \]

OSV performance score = 13/102 = 0.13

OSV device cost = US$ 76,500, structure construction cost = US$ 30 million, OSV cost index = 0.26%
5. APPLICATION OF LOW-COST OSV

(1) Conception of low-cost OSV

The experience gained from the OSV applications in the above two projects reveals problems in OSV monitoring, namely the high cost of implementation and the limitation of OSV application areas in the project. 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 that can measure the relative displacement between two arbitrary points and simultaneously show the result by the rotation of the indicator such as a needle\(^{14}, 15\). As shown in Fig. 19, the sensor consists of two components. The first component is the stiff and flexible thread that can mobilize a pulley, with diameter of 21 mm 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, 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 tension on the thread rotating around the pulley is a very important factor and the suitable weight to transfer displacement to pulley rotation as well as elongation and deterioration of the thread shall be examined in a laboratory and in the field test. The durability of the thread, as well as its longevity under extreme weather conditions (i.e., sun, rain, and wind), need to be tested over a period of time. The needle and board made from plastic, if they are well maintained, should have a long life. The value of the OSV materials is relatively low, around US$100 including a setting fee, and therefore it is easily replaced if damaged or stolen.

b) Vertical bars with plumb measurement\(^{16}\)

A very simple OSV device for monitoring ground movement is introduced. The multiple vertical bars made of wood or steel bars are installed in 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’s center point) as shown in Fig. 20.

In case of any ground movement, it can be seen with the naked eye if any one or more bars have moved out of their installed straight line and the distance and inclination of the ground movement can be calculated by \(\delta x\) and \(\delta y\) 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 at any time.

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Fig. 18 OSV performance versus OSV cost.

Fig. 19 Layout of the mechanical displacement sensor.

Fig. 20 Monitoring method for vertical bars.
(2) Application of low-cost OSV on Bai Chay Road

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

The Bai Chay Road including a cut slope and slope protection was constructed in Vietnam in 2008 are funded through an ODA loan. The geological data of this region is characterized by Early Triassic sedimentary formations, which mainly consist of alternating sandstone, conglomerates and siltstone. The formation is overlain by Quaternary formations, which consist of alluvium and diluvium formations. Weathering of the formation has a great depth and the cut slope area has a high potential for collapse due to rainfall.

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

(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. 21 to Fig. 23, 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.

The installation work of the low-cost OSV devices on the slope have been conducted in mid-February 2014 as shown in Fig. 24 and Fig. 25.

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 the slope sliding zone and the inner side bars are installed inside the sliding zone.
(4) Actual monitoring and lessons learned

The monitoring works started immediately after the installation of the mechanical OSV devices. Fig. 26 shows the reading of m/d sensors at the slope. The Kevlar aramid fiber (Poly-paraphenylene terephthalamide) that has a high strength and high modulus was selected as the monitoring thread.

Because it was the first time to apply this material under extreme weather conditions (i.e., wind, rain and sun for a long period), the durability of the thread was checked by site elongation tests (see Fig. 27) in comparison with invar cable material that has the smallest possible thermal expansion coefficient (less than 3.7×10⁻⁶/degree). As shown in M/d-1 reading in Fig. 26, about 7mm elongation on the 10m-long Kevlar thread was observed during the first 3 months and this phenomenon coincided with the laboratory test of Kevlar elongation by Akutagwa(17).

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

Fig. 28 shows the reading taken of the vertical bars (VB-1 to VB-4) for the first 3 months. There are plus and minus readings up to 10 mm range. Because all the readings are by line of sight, these data are still within the tolerances and no radical movement was observed.

This is the first time to monitor the actual slopes by low-cost OSV devices so widely in an overseas project. The following were observed from the above planning, installation, and monitoring of the mechanical OSV:

- Mechanical OSV devices can be set up at site without electricity and 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.
Table 6 OSV devices and monitoring unit on Bai Chay Road.

| Possible near misses, collapses | Name of monitoring unit | OSV device | OSV Function (F) | OSV Visualization (V) | Remarks |
|--------------------------------|-------------------------|------------|----------------|----------------------|---------|
| Slope movement                 | Slope unit-1 to 10      | M/d sensor | 1.0            | 1.0                  | F: OSV suitability, quality, accuracy are OK; 1.0, V: Easy recognition and display zone are sufficient: 1.0. |
| Vertical bar                   |                         | 0.67       | 1.0            |                      | F: OSV suitability, quality: OK. Accuracy has some problems: 0.67, V: Easy recognition and display zone are sufficient: 1.0. |
| Total unit number              | n= 10                   | ∑(F) x (V)= 5.3 |               | OSV performance score= 5.3/10=53% |

OSV device cost= US$ 900, Structure construction cost = US$ 0.85 million, OSV cost index= 0.1%

![Image](image1)

Fig. 27 The elongation and deterioration of Kevlar thread.

![Image](image2)

Fig. 28 The monitoring results of vertical bars at first 3 months.

![Image](image3)

Fig. 29 OSV arrangement and monitoring unit on Bai Chay.

- It is confirmed that vertical bars can measure the inclination and movement of the ground within certain tolerances.
- Access to the site and access to each monitoring point on the slope are not easily achieved by the engineers, therefore further improvement of OSV displays will be considered.
- The range of display by needle was up to 15 mm for the m/d sensor; however this is too small a range to monitor large-scale movement of the ground.
- The vertical bars were stolen and/or broken at times. It is therefore not recommended to apply high-cost OSV materials to 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 has been no record of any deterioration of materials and devices. Observation and continuous monitoring 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 each site.
### Table 7: Simulation: OSV performance for low-cost OSV application at AIIMS station.

| Possible near misses, collapses | OSV devices | Safety monitoring unit | OSV Function (F) | OSV Visualization (V) | Remarks |
|---------------------------------|-------------|------------------------|-----------------|-----------------------|---------|
| Strut buckling                  | Strut deformation sensor | Strut unit-1 to 10 | 1.0 | 1.0 | F: OSV function, quality, accuracy are OK; 1.0, V: Visualization is sufficient: 1.0 |
| Soldier pile inclination        | Plumb measurement | Pile unit-1 to 10 | 0.67 | 1.0 | F: OSV function, quality, accuracy are OK, accuracy to be improved: 0.67, V: Visualization is sufficient: 1.0 |
| Retaining wall deformation      | Mechanical displacement (M/d) sensor | Wall unit-1 to 10 | 1.0 | 1.0 | F: OSV function, quality, accuracy are OK, 1.0, V: Visualization is sufficient: 1.0 |
| Boundary collapse               | Plumb measurement | B wall unit-1 to 3 | 0.67 | 1.0 | Score is the same as soldier pile deformation. |
| Nurse hospi inclination         | Plumb measurement | Building unit-1 to 5 | 0.67 | 1.0 | Score is the same as soldier pile deformation. |
| Total Unit number n= 38        |              | Σ(F) x (V) / n = 31.9 | OSV performance score =31.9/38= 0.84 |

OSV device cost = US$ 7,200, Construction cost of AIIMS = US$ 500 million, OSV cost ratio= 0.14%  

| Unit ID | Name of monitoring unit | OSV device | OSV Function (F) | OSV Visualization (V) | Score (F x V) |
|---------|-------------------------|------------|-----------------|-----------------------|---------------|
| 1       | Slope movement-1        | M/d sensor | 1               | 1                      | 1             |
| 2       | Slope movement-2        | M/d sensor | 1               | 1                      | 1             |
| 3       | Slope movement-3        | (No OSV)   |                 |                        |               |
| 4       | Slope movement-4        | (No OSV)   |                 |                        |               |
| 5       | Slope movement-5        | (No OSV)   |                 |                        |               |
| 6       | Slope movement-6        | M/d sensor | 1               | 1                      | 1             |
| 7       | Slope movement-7        | M/d sensor | 1               | 1                      | 1             |
| 8       | Slope movement-8        | Vertical bar | 1               | 0.67                   | 0.67          |
| 9       | Slope movement-9        | (No OSV)   |                 |                        |               |
| 10      | Slope movement-10       | Vertical bar | 1               | 0.67                   | 0.67          |
| Total unit: 10 |              | Total Score = |               |                        | 5.34          |

**Fig. 30** OSV performance analysis on Bai Chay.  

**Fig. 31** Function of plumb measurement for inclination.  

**Fig. 32** Function of m/d sensor for retaining wall deformation.  

**Fig. 33** Function of strut force and deformation sensor.
(5) OSV performance on Bai Chay Road

Based on the above low-cost OSV installation and monitoring results, OSV performance assessment is conducted as shown in Fig. 29, Fig. 30 and Table 6. The score of OSV performance at Bai Chay Road has reached 0.53 under a very small cost index at 0.1%. Because it is a trial installation of low-cost OSV, the unit coverage is only 60% of total quantity of 10. In the case of actual monitoring, it is easy to cover the full unit area with low-cost OSV so a higher score can be reached.

6. COMPARATIVE SIMULATION OF OSV PERFORMANCE

The trial application of low-cost OSV at Bai Chay Road provided the required data for engineers and workers to grasp the conditions of ground movement effectively and to enable engineering judgments for taking necessary action. Now two cases of simulation assessment have been performed utilizing the data from the AIIMS station project and Bai Chay Road project.

(1) Simulation of low-cost OSV on AIIMS station

The simulation assessment of the low-cost OSV applications on AIIMS station project is examined assuming application of low-cost OSV devices instead of expensive electric OSV devices.

Figs. 31 to 34 show the function and mechanism of low-cost OSV devices and how they can effectively show the deformation and inclination of structures at the site by the rotation of needle and plumb movement. As shown in Fig. 33, the steel beam (L2 length) with the same material of strut has a fixed end on one side of the strut and a free end at the other side so it can measure relative displacement (compression force of the strut) between the strut and the steel beam through rod turning and needle display.

The simulation of the application of low-cost OSV at AIIMS station shows a drastic reduction of the cost index (from 1.0% to 0.14%) and an increase in OSV performance from 0.30 to 0.84 as shown in Fig. 35 and Table 7. We can judge that this score value is quite sufficient to minimize the construction near misses and potential collapses at each site.

(2) Simulation assessment of electric OSV on Bai Chay Road

The simulation assessment of the electric OSV application on Bai Chay Road is examined assuming the application of electric OSV devices instead of low-cost OSV devices for the comparison of each performance as shown in Fig. 36 and Table 8.

The summary of simulation assessment on AIIMS station and Bai Chay Road is shown in Fig. 37. The simulation of the application of the electric OSV at
**Table 8** Simulation: OSV performance in the case of electric OSV application at Bai Chay Road.

| Possible near misses, collapses | Name of monitoring unit | OSV device | OSV Function (F) | OSV Visualization (V) | Remarks |
|-------------------------------|-------------------------|------------|-----------------|-----------------------|---------|
| Slope movement                | Slope unit-1            | Light-emitting Deformation sensor (LEDS) | 1.0               | 1.0                   | F: OSV suitability, quality, accuracy are OK: 1.0, V: Easy recognition and display zone are sufficient: 1.0. |
| Total unit number             | n= 10                   | Σ(F) x (V)= 6.0 | OSV performance score= 6.0/10=60% |

OSV device cost= US$ 9000, structure construction cost = US$ 0.85 million, OSV cost index= 1.1%

![Image](326)

**Fig. 36 OSV performance analysis on Bai Chay Road.**

Bai Chay Road shows a drastic increase of cost index (from 0.2% to 1.1%) under similar OSV performance values (from 0.53 to 0.60). The low-cost OSV application on Bai Chay Road is a trial case and we can judge that if the number of low-cost OSV devices are increased, sufficient coverage and high score can be achieved.

7. CONCLUSION

In this paper, the review of past OSV projects, assessment of OSV performance and the development of low-cost OSV are examined and the following conclusions are obtained:
- OSV monitoring using high-cost electric devices was conducted on overseas projects, namely AIIMS station (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 confirmed, the problems of existing OSV, namely the high cost of electrical OSV devices and their shortage in quantity of installation points (less coverage of OSV devices at the site due to cost reasons) were revealed. The OSV performance assessment together with the OSV cost analysis has been conducted based on past overseas projects and the necessity of improving OSV monitoring, namely 1) the development of a low-cost OSV device and 2) installation of a greater number of OSV devices widely across a site to grasp any confirmed near misses.
- The development of a simple mechanical OSV namely the “mechanical displacement sensor” and “vertical bars with plumb measurement” was introduced and there was an opportunity to apply a low-cost OSV on the actual project site in Vietnam. This was the first time a monitoring scheme such as this was conducted at an actual 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 and 2) its sufficiency to conduct engineering judgment based on OSV results were confirmed.
- Simulation of low-cost OSV applications on AIIMS station was examined and its result shows a
dramatic improvement of OSV performance and cost reduction was achieved. Another simulation of the application of the electric OSV at Bai Chay Road shows a drastic increase in the cost index under similar OSV performance values when compared with low-cost OSV case.

- The assessment of OSV performance together with cost analysis enables us to quantify the level of safety arrangement versus installation cost. Although it is necessary to assume the precondition and to investigate the parameters for accurate evaluation of OSV performance, it indicates that the method is quite an effective tool for the establishment of site safety plans and monitoring plans at actual construction sites.

The rates 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 budgetary problems, with insufficient funds for arrangement of the instruments and monitoring devices necessary to carry out construction safely.

The OSV approach for safety management should be part of daily routines at construction sites. For this to happen, the simplicity and affordability of the OSV devices and related systems have to be maintained. Whereas high performance aspects, such as wireless data transmission or automatic data logging, are favored by the managing side, simplicity and reliability are key concepts that need to be considered for those who actually operate the systems on site within limited budgets. New generation OSV sensors, 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 funding. Only then can the OSV monitoring method become a truly accepted safety management routine at construction sites around the world.

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