Geotechnical Engineering Journal of the SEAGS & AGSSEA Vol. 45 No.3 September 2014 ISSN 0046-5828

A Novel Mobile Information System for Risk Management of Adjacent Buildings in Urban Underground Construction

Hanh Quang Le[1] and Bin-Chen Benson Hsiung[2]
[1]*University of Transport and Communication, Hanoi, Vietnam*
[2]*National Kaohsiung University of Applied Sciences, Kaohsiung, Taiwan*
E-mail: hanhquangle@gmail.com

ABSTRACT: During the urban underground construction, control of behaviours and assessment of hazards to adjacent structures right at the sites can be extremely difficult owing to processing data from various types of monitored instruments corresponding to multiform of building structures. In this paper, a novel mobile web-based comprehensive information system, named MitiRisk, which is combined from building information model - BIM, mobile web service technology to be presented. In the proposed system, building information model is applied to visualize the current situation of monitoring building structures, whereas, mobile web service technology is used to enable effective necessary data exchange in real-time. Testing examples of the developed system to the O6 station's excavation in Kaohsiung metro system in Taiwan and application scenarios in Metro line 1 (Ben Thanh – Suoi Tien) in Ho Chi Minh metro system in Vietnam, are presented to illustrate the improvements of safety management to adjacent structures in urban underground construction projects.

KEYWORDS: Adjacent structure, Risk Management, BIM, Mobile web service, Urban Underground.

1. INTRODUCTION

Urban underground excavation is attributed to produce significant disturbances to surrounding environments. With the spread of underground constructions in cities, the behaviour of other structures being built close to these excavations has now become an important subject. Studying the rate of settlement of structures built in the vicinity of these excavations could be an importance as well. In urban areas this ground subsidence can affect existing surface and subsurface structures. Predicting excavation-induced deformation of such structures and assessing the risk of damage is an essential part of planning, design and construction of underground projects in an urban environment (Mair et al., 1996).

Practically, the urban underground constructions often cause relaxation in the medium that being excavated (described as ground loss) together with associated ground movements around constructing area (Atkins 2006). Therefore, the excavating-induced ground movements will not only affect to these on-ground existing structures but also other subsurface structures such as piles, deep basements or other utilities.

In order to manage the settlement risk due to the urban underground construction, it must be conducted from design phase to the construction phase. In the design phase, the magnitude and extent of ground movement associated with proposed excavation is handled. Then this predicted magnitude and extent ground movements such as surface settlement, subsurface settlement and horizontal displacement are then applied to assess the potential damage to adjacent buildings and utilities. This assessment can be based on the simplified approaches.

In the construction phase, the proposed assessment is performed during construction using measured settlement data as well as newly obtained information, and correction are made to the initial assessment.

In order to make rapid and exact on-site decisions, the site managers often require enough large amounts of design's information, recorded monitoring data and other knowledge. In the case that it lacks in access to this information right at the work sites, the decision making process is often deferred. Therefore, the internal project management system should be integrated with an efficient and real-time communication mechanism such that any changes that require prior approval can quickly be expedited. Moreover, the communication and the flow of information must be also based on a co-operated mechanism that can combine the real-time monitoring data and the optimal judgments from experts and managers of various disciplines within civil engineering.

The application of a comprehensive information system has long been recognized as a key to increase productivity and improving the quality of underground construction projects. In underground construction projects, the application of advanced IT-based risk management system has recently been recognized as a key to ensure the successful of project.

Maurenbrecher and Herbschleb (1994) discussed the potential uses of geotechnical information systems in the planning of tunnels in Amsterdam, Netherlands. The information system has been shown to produce thematic maps that can be used in tunnel planning and design. Yoo and Kim (2003) introduced a web-based tunneling-induced adjacent building damage assessment system which based on the server-client internet environment using the Microsoft Visual Basic 6.0 and MapGuide ActiveX control software. Yoo et al. (2006) developed a tunneling risk management system (IT-TURISK) in a GIS environment with the capability of performing preliminary assessments of tunneling-induced impacts on the surrounding environment within the framework of artificial intelligent (AI) technique. Mejstrik and Savidis (2010) proposed web-based information and monitoring platform for risk assessment and management of geotechnical engineering projects. Li and Zhu (2013) developed a web-based information system for managing, visualizing and analyzing shield tunnel construction data. This system based on a Web Geographic Information System (Web-GIS) software, ArcGIS server which provide functionalities in data management, 2D and 3D visualizations, geospatial analysis and tunnel analysis.

The mentioned applications however, are still limited in the communication by using of the desktop or laptop. Almost all available risk management systems do not have the modules for the mobile devices such as smartphones. This is still the gap not only in the urban underground construction risk management but also in the general construction management system.

This paper presents a novel advanced IT-based risk management system - MitiRisk, which is combined from BIM-Building Information Model, Mobile web service technology, Desktop and Window mobile phones for tunnels and deep excavations in urban area.

Based on this MitiRisk, the information exchange between site personnel, site office and head office thus become more understandable and visible. Results from before- event prediction can also be included and compared with information obtained from the site in proposed system so measures or decisions regarding risk mitigation may thus be made herein.

More specially, based on this proposed risk management system, the responsible managers can access repository of data in real time through their mobile smartphone to obtain the as-demanded information for their daily business works, and update the new changes or unexpected problems right at the sites which are conforming to real situations.

2. BUILDING INFORMATION MODELING – BIM

2.1 Concept of BIM

Building Information Modeling (BIM) has been being one of the most potential developments in the architecture, engineering, and construction industries. In last decade, BIM was mainly focusing on the architecture and engineering sector, however, BIM technology recently is moving from the world of architecture and engineering to the arenas of construction companies and other parties in charge of construction operations (Kiviniemi et al. 2011).

BIM is an informatics technology that represents the process of development and use of a computer-generated model to simulate the planning, design, construction and operation of a building (Eastman et al. 2006). BIM can be used to establish a comprehensive model of the quantities of a construction project. It is made of intelligent building components which includes data attributes and parametric rules for each object. When completed, a BIM characterizes the geometry, spatial relationships, geographic information, quantities and properties of building elements, cost estimates, material inventories and project schedule. This model can be used to demonstrate the entire building life cycle (Bazjanac 2004). It will provide consistent and coordinated views and representations of the digital model including reliable data that appropriate to various users' needs [Figure 1].

The BIM provides not just 3D virtual models but throughout communication among the participants in project which enables the sharing of the model between the engineer, architect, construction manager and subcontractors. At the BIM meetings during construction phases, the site managers and subcontractors can provide their expert construction knowledge to the design team.

Moreover, the construction engineers can use the building information models to generate construct ability reports, coordinate, plan, schedule and cost estimate. More importantly, BIM can facilitate an effective method for construction site safety related planning activities, connecting the safety viewpoint more closely to construction planning, enabling visualization of safety arrangements in construction projects at different moments of time, and providing more illustrative site plans for communication.

2.2 BIM applications in construction management

Once a BIM is completely established, it can provide the following functions which support for construction management works (Azhar et al. 2008):

- Visualization: the 3D renderings can be easily generated in-house with little additional effort.
- Fabrication/shop drawings: it is easy to generate shop drawings for various building systems and different demands.
- Code reviews: officials and responsible authorities may use generated models for their review of building project.
- Forensic analysis: a building information model can easily be adapted to graphically illustrate potential failures, leaks, evacuation plans, etc.
- Facilities management: facilities management departments can use BIM for renovations, space planning, and maintenance operations.
- Cost estimating: material quantities are automatically extracted and changed when any changes are made in the model.
- Construction sequencing: a building information model can be effectively used to create material ordering, fabrication, and delivery schedules for all building components.

With respect to mentioned functions, according to (Eastman et al. 2006), there are many applications of BIM can be used throughout project's life-cycle [Figure 2]. In the planning phase, BIM can be used by the project team from the beginning of the design to improve their understanding of project requirements and to extract cost estimates as the design is developed. It is easily and visual to determine whether a building of a given size, quality level, and desired program requirements can be built within a given cost and time budget or not.

In the design phase, BIM facilitates simultaneous work by multiple design disciplines. Because the virtual 3D building model is the source for all 2D and 3D drawings, design errors caused by inconsistent 2D drawings are eliminated. In addition, because models from all disciplines can be brought together and compared, multisystem interfaces are easily checked both systematically (for hard and clearance clashes) and visually (for other kinds of errors).

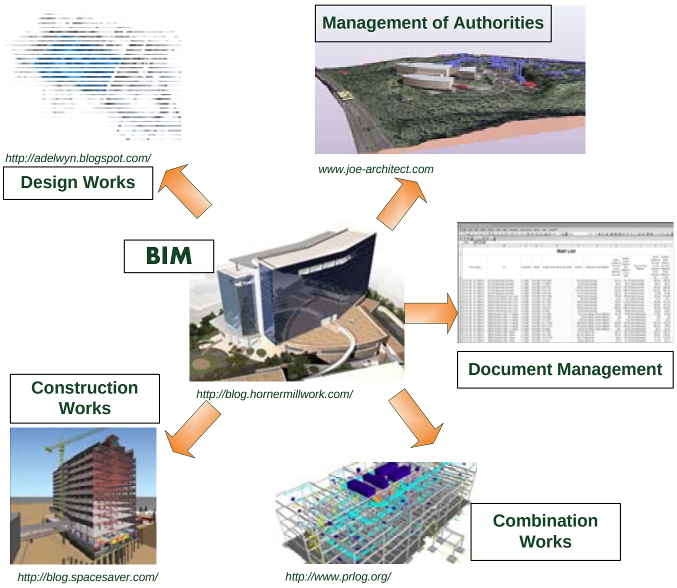


Figure 1 Concept of a Building Information Model - BIM

At any stage of the design, BIM technology can extract an accurate bill of quantities and spaces that can be used for cost estimation. As the design progresses, more detailed quantities are available and can be used for more accurate and detailed cost estimates. It is possible to keep all parties aware of the cost implications associated with a given design before it progresses to the level of detailing required of construction bids. At the final stage of design, an estimate based on the quantities for all the objects contained within the model allows for the preparation of a more accurate final cost estimate.

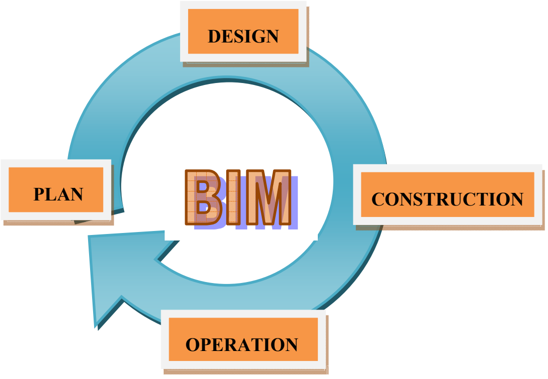


Figure 2 BIM's application during construction project's life cycle

In the construction phase, if the design model is transferred to a BIM fabrication tool and detailed to the level of fabrication objects (shop model), it will contain an accurate representation of the building objects for fabrication and construction. Because components are already defined in 3D, their automated fabrication using numerical control machinery is facilitated.

The impact of a suggested design change can be easily entered into the building model and changes to the other objects in the design will automatically update. Some updates will be made automatically based on the established parametric rules. Additional cross-system updates can be checked and updated visually or through clash detection. The consequences of a change can be accurately reflected in the model and all subsequent views of it. In addition, design changes can be resolved more quickly in a BIM system because modifications can be shared, visualized, estimated, and resolved without the use of time-consuming paper transactions.

In the operation phase, BIM provides a building model that has been updated with all changes made during construction provides an accurate source of information about the as-built spaces and systems and provides a useful starting point for managing and operating the building. This is a source of information (graphics and specifications) for all systems used in a building. This information can be used to check that all systems work properly after the building is completed.

3. MOBILE WEBSERVICE TECHNOLOGY

Along with the growth in mobile networking technologies, access to web data services from mobile devices has been growing in popularity. Web based technologies have been already deployed into the mobile space, as the availability of mobile web browsers can be found in most smartphone devices and as well as normal mobile phones where mobile devices are used to browse and access to web pages. For instance, mobile network operators have expanded their services to third-party applications market such as allow clients to receive a wide range of instant services: share prices, sport scores and ring tones. Mobile web services are designed to be consumed by mobile applications running in hand-held devices such as Pocket PC, tablet PC, Smartphone, etc., which have hardware limitations in display, memory, and processing power.

Accessing web services from mobile devices are continuously getting more attention. The established technologies such as HSCSD and GPRS allow for transfer of data to and from mobile devices on site at remote locations to the head-office. However, this requires data to be stored locally on the device during work, potentially placing collected data at risk if the device is damaged or, in the case of mobile devices, loose battery power and hence state. Consequently, the need for accessing more services and applications that reside on the Web and other mobile devices has led to a mobile web services technology.

The mobile web services technologies are about enabling mobile applications to search accesses and integrate various services and information provided by web applications and / or mobile applications. Wireless Application Protocol (WAP) and Wireless Markup Language (WML) are two important standards that have been introduced to support mobile web service standards. WAP has been introduced as a standard way for enabling access to various types of services from wireless devices. WML is a standard language for representing services and information according to mobile devices constraints such small screen display and processing power (El-Marsi and Suleiman 2005).

The data exchange procedure between the mobile clients and Web services server when the mobile client invokes the service on the server is shown in Figure 3. In this figure, mobile web services

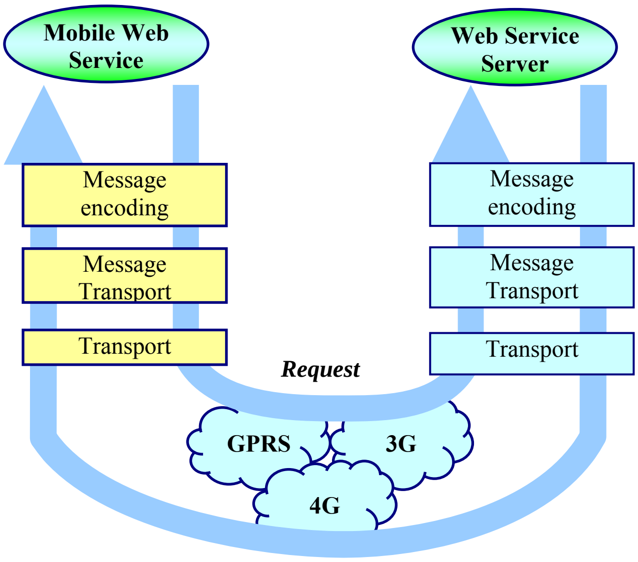


Figure 3 Data exchange between the client and the server based on Mobile Web services technology

client and web services server are connected through the wireless connection such as GPRS or 3G and 4G. Using simple mobile application developed by any framework languages such as Microsoft .NET compact framework or Sun J2ME, the request message is sent to the server via the lower network protocol (i.e. HTTP) after the client encapsulates it with XML using SOAP. On receiving the SOAP request, the server parses the request, executes the corresponding service and returns the result to the client with SOAP. As web service is built under open standard and accepts heterogeneous clients accessing its service, the web service based applications can be loosely coupled and implemented with multi-techniques.

With respect to the continuing advances of mobile computing networks such as 3G and 4G, the improvement of mobile computing devices such as Smartphone, PDA phones and the Mobile Web Services technology, the current challenges of real-time communication and data exchanges among remote construction sites and head offices in construction industry will be promisingly solved.

4. THE COMPREHENSIVE INFORMATION SYSTEM – MitiRisk

4.1 Concept of MitiRisk

Generally, in order to create a good construction risk management system, there are two main things must be resolved: Firstly, the communication must be throughout among all responsible parties. Secondly, the supplied information must be enough and exact with the required commands.

In order to reach these two criteria, MitiRisk is a comprehensive information system that combined of BIM – Building Information Model, Mobile web-service technology, Desktops and Window mobile phones (Figure 4). The BIM will be a combining mechanism to assemble judgments from experts in the offices after receiving actual information from the sites. The mobile web-service technology creates the real-time information exchange between the site managers and experts in offices. Based on the mobile web-service technology, the site managers can directly access to the database in office for receiving and updating actual information by their Window mobile phone that do not need to use the memory of the phone.

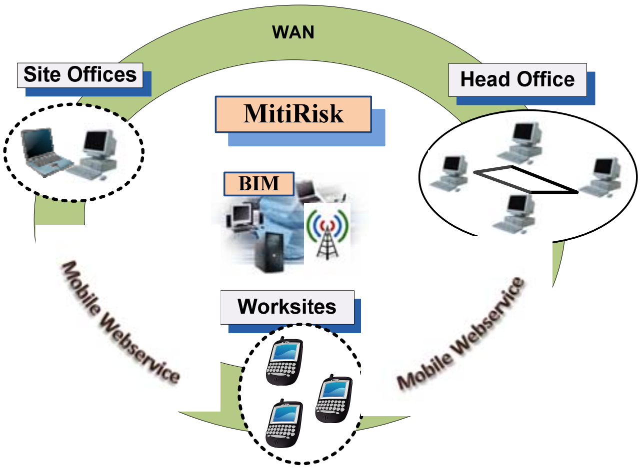


Figure 4 Concept the comprehensive information system - MitiRisk

With MitiRisk, the information exchanges between site personnel, site office and head office become more understandable and visible. Results from before- event prediction can also be included and compared with information obtained from the site so measures or decisions regarding risk mitigation may thus be made timely and effectively.

4.2 Assessment methodology of adjacent structure damage

This section presents the methods that adopted in prediction of excavation and tunnelling induced ground movement and building damage risk-assessment as well as the allowable limitations of potential damages. The results that are estimated by these methods will be the input data for MitiRisk.

First of all, the green-field settlement troughs due to excavation or tunnelling of the considered site are calculated. In this stage the effect of building structures such as foundations or other adjacent utilities are ignored in order to draw the pattern of ground movement. These green-field displacements are then imposed to a simple model of the building.

The settlement-induced deformations and strains of the equivalent building are subsequently calculated and related to a possible damage level. This assessment is to determine the level of damage hazards to adjacent buildings. This result will enable the planning of ground movement monitoring and other risk mitigation measures.

With the case of shield tunnelling, the methods which are introduced in Burland et. al. (1977) and Boscardin & Cording (1989) will be background for ground movement prediction and building damage assessment. Whereas the methods of Peck (1969) and Clough and O'Rourke (1990) will be applied with respect to the cut and cover excavation.

The empirical-analytical method - Limiting Tensile Strain Method (LTSM) (Boscardin and Cording 1989; Burland and Wroth 1974) will be then applied in order to predict the potential damage of buildings due to ground deformations.

Burland & Wroth (1974) noted that a variety of symbols and measures were used to quantify building deformation. They proposed a set of nine parameters to define building distortion, which are shown in [Figure 5]:

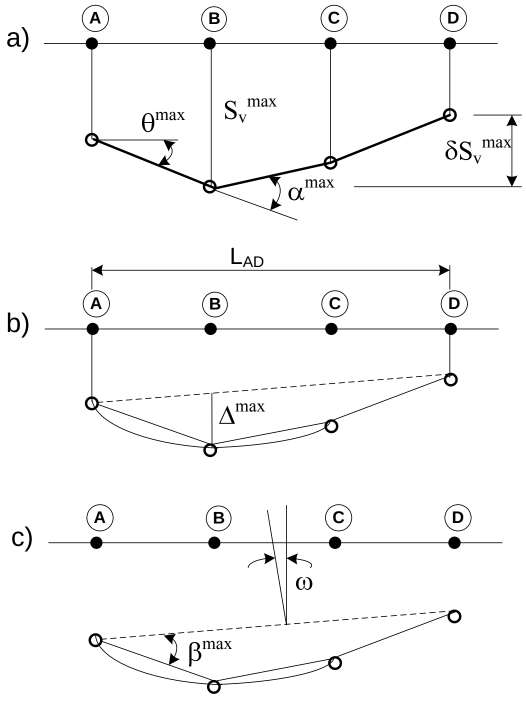


Figure 5 Definition of building deformation parameters

a) **Settlement**: the vertical movement of a point. Positive values indicate down-wards movement (Figure 5a).

b) **Differential** or **relative settlement**: δS_v^{max} the difference between two settlement values (Figure 5a).

c) **Rotation** or **slope**: θ the change in gradient of the straight line defined by two reference points embedded in the structure (Figure 5a).

d) **Angular strain**: α produces sagging or upward concavity when positive while hogging or downward concavity is described by a negative value (Figure 5a).

e) **Relative deflection**: Δ the maximum displacement relative to the straight line connecting two reference points with a distance L. Positive values indicate sagging (Figure 5b).

f) **Deflection ratio**: DR is defined as the quotient of relative deflection and the corresponding length: $DR = \Delta^{max}/L^{AD}$ (Figure 5b).

g) **Tilt**: ω - the rigid body rotation of the whole superstructure or a well-defined part of it. It is difficult to determine as the structure normally flexes itself (Figure 5c).

h) **Relative rotation** or **angular distortion**: β - the rotation of the straight line joining two reference points relative to the tilt (Figure 5c).

k) **Average horizontal strain**: ε_h develops as a change in length δL over the corresponding length L: $\varepsilon_h = \delta L/L$.

With respect to the angular distortion β, the limiting values which are introduced by Bjerrum (1963) for different types of structures will be applied (Table 1).

In order to avoid stability problems, Schultze and Horn (1990) advised to limit the tilt ω for tall structures to the maximum value of: $\omega^{max} = 0.005L/H$; whereas L is the base width of the building and H is the height of the building.

For the structure assessment, although the assessment of Burland (1995) and Mair et. al (1996) is conservative as it assumed a simple brick masonry construction whereas other forms of construction such as framed buildings, may be more robust, this assessment will be applied for the MitiRisk. The relation between the bandwidths of strain level and the different damage categories is illustrated in Table 2.

In Skempton and McDonald (1956), they proposed the limiting values for maximum settlement and maximum differential settlements which applied to construction (Table 3).

Table 1 Angular distortion limits

Angular distortion (Slope)β_{max}	**Damage or allowable criteria**
1/750	Limit where difficulties with machinery sensitive to settlement are to be feared.
1/600	Limit of danger for frames with diagonals
1/500	Safe limit for buildings where cracking is not permissible
1/300	Limit where first cracking in the panel walls is to be expected; limit where difficulties with overheard cranes are to be expected
1/250	Limit where tilting of high, rigid buildings might become visible.
1/150	Considerable cracking in panel walls brickwalls; safe limit for flexible brickwalls.
1/100	Danger limit for statically determinate structures and retaining walls.

Table 2 Building Damage Classification

Risk Category	**Max Tensile Strain %**	**Description of Degree of Damage**	**Description of Typical Damage and Likely Form of Repair for Typical Masonry buildings**	**Approx. Crack Width (mm)**
0	0.05 or less	Negligible	Hairline cracks.	
1	More than 0.05 and not exceeding 075	Very Slight	Fine cracks easily treated during normal redecorations. Perhaps isolated slight fracture in building. Cracks in exterior brickwork visible upon close inspection.	0.1 to 1
2	More than 0.075 and not exceeding 0.15	Slight	Cracks easily filled. Redecoration probably required. Several slight fractures inside building. Exterior cracks visible; some repointing may be required for weather-tightness. Doors and windows may stick slightly.	1 to 5
3	More than 0.15 and not exceeding 0.3	Moderate	Cracks may require cutting out and patching. Recurrent cracks can be masked by suitable linings. Repointing and possibly replacement of a small amount of exterior brickwork may be required. Doors and windows sticking. Utility services may be interrupted. Weather tightness often impaired.	5 to 15 or a number of cracks greater than 3
4	More than 0.3	Severe	Extensive repair involving removal and replacement of sections of walls, especially over doors and windows required. Windows and door frames distorted. Floor slopes noticeably. Walls lean or bulge noticeably, some loss of bearing in beams. Utility services disrupted.	15 to 25 but also depends on number of cracks
5		Very Severe	Major repair required involving partial or complete reconstruction. Beams lose bearing, walls lean badly and require	Usually greater than 25mm but depends on number of cracks

Table 3 Maximum settlement limits

Maximum settlement, S_v^{max}	**Limiting values**
In sand	32mm
In Clay	45mm
Maximum differential settlement, δS_v^{max}	**Limiting values**
Isolated foundations in sand	51mm
Isolated foundation in clay	76mm
Raft in sand	51-76mm
Raft in clay	76-127mm

Other limits have been proposed using the parameter of curvature Δ/L (or deflection ratio). Polshin and Tokar (1957) suggested the allowable deflection ratios for building as presented in Table 4:

Table 4 The allowable deflection ratios

Description of standard value	**Relative deflection of plain brick walls Subsoil**	
	Sand and clay in hard condition	**Clay in plastic condition**
a) For multi-story dwellings and civil buildings:		
at L/H $\leq$ 3	0.0003	0.0004
at L/H $\geq$ 5 (L = length of deflected part of wall; H = height of wall from foundation footings)	0.0005	00007
b) For one-story mills	0.001	0.001

4.3 MitiRisk – Database structure

The MitiRisk's database is a dynamic digital library of all construction information that will exist on the urban underground construction projects. Generally, MitiRisk's database contains one or many single underground projects' information. An underground project information data is further composed of project profile, cost, activity and controlling building information. Each construction activity is introduced by the information as the activity profile, construction technology, required resources and external conditions. The required resources are often represented by material, equipment and labour information. One of the most important parts in MitiRisk is the table of the related building information. This will be composed of structure status and monitoring status. The MitiRisk's database structure is developed and comprised by four major-tables and six sub-tables (Figure 6a) which are described as follows.

4.3.1 Project Profile table

The project profile table contains information that is used to generally depict a construction project such as the crucial identifications of project objectives, expected outcomes or scope, constraints and specifications. Besides, the project profile information also contains the data about contract number, timeframe, contract type and price.

4.3.2 Project cost information table

This part holds all information about the project costs. The project cost information is divided into several categories to reflect the actual project cost status. These include the material costs, labour costs, equipment costs and other costs which are further described by estimated costs, actual costs and the variance. The project costs are calculated based on the finished works and completed quantities from the site daily report system.

4.3.3 Construction Activity's information table

Activity information table contains four main information fields: Activity Profile, Resource Information, Construction Technology and External Information.

Activity Profile table: Activity profile table will store the general information about a construction activity such as activity name, duration, start and finish date and the activity relationships like successor and predecessor activities.

Resource Information table: Resource information table contains the data of manpower, machinery, materials and other data concerning to resources that are used for processing construction activity.

- *Equipment information*: This part has all information about machines and construction tools which are deployed to realize construction activity. For example, type and quantity of machine, the machine's owner and the delivery date.
- *Material information*: The material information is the data that supplies the knowledge about type, origin, quantity and quality of material which used in the activity execution.
- *Labour information*: A part that holds information about the workers who are required to execute the activity (e.g. type skill level and quantity). Besides, this information also includes the source of the required workers such as if the workers are owned by contractor or engaged from local region.

Construction technology table: The information in this part is presented as an abstract of construction technology that is applied to execute the construction activity as well as all of the construction specifications that are to be applied. Besides, the main construction stages will be created via 3D model and stored in this table.

External Information table: The external information table contains the information about the environment conditions which directly affect construction activities such as the weather condition, the geological and geographical conditions.

4.3.4 Controlling Building Information table

This information table is composed by the monitoring data and the predicted design data which are applied for the controlling aims of responsible partners or project participants. This table is created by two main information sub-tables: Structure status and Monitoring status.

Structure status: This table contains the two main information fields. The first is the information that investigated and collected before urban underground construction. The second is the information that shows the potential damages of building due to the underground excavations. The investigated information can be original design plan, history reinforcement and alternation chart, current structure capacity, etc. More important, it holds information about the additional influences with respect to building structures from excavation such as maximum settlement, differential settlement, and horizontal displacement, etc.

Monitoring Status: The information in this table is structured by settlement and deformation controlling statements related to the buildings nearby. This information will be the values of monitoring processes that collected from measuring stations at the ground and buildings. These monitoring results will be automatically analysed with advance data and predicted documentation to evaluate the mechanism of excavating-induced movements and failures at the surface as well as buildings.

Thereafter, the evaluated results will be conveyed to Construction technology table in order to update the current state of 3D construction model which gives the visual pictures for responsible agents of project.

4.4. The architecture of MitiRisk

MitiRisk architecture consists of four logical components: data repository, web server, mobile devices (PDA phones and Smartphones) and desktop computers (Figure 6b). In fact, MitiRisk must additionally contain a hidden component which provides the internet connection for the mobile wireless devices: mobile network provider. Nevertheless, this component is not discussed here, due to the fact that mobile network providers are different among countries in the world.

Web server: Hardware that provides the access to a network. Generating HTTP requests to retrieve different length file according to a particular distribution. The web server contains web services which are remotely called from the mobile users (site managers) to retrieve the required information from the data repository. The server is characterized as a maximum achievable number of connections per second while maintaining the required file mix.

Data repository: It is responsible for storing all the multiple project information of the construction company. This is a central database that is placed in the head office.

Mobile devices: PDA phones or Smartphones which are equipped for every site engineers/managers at construction sites. Each mobile device has a MitiRisk's application installed. This application performs requests and receives project information from project database web services.

Desktop Computers: These computers are located in head office or site offices to implement the BIM as well as to display information in different software. In fact, in the cases that sizes of urban underground projects are small and they do not need to establish site offices, the site engineers/managers will use the mobile devices only.

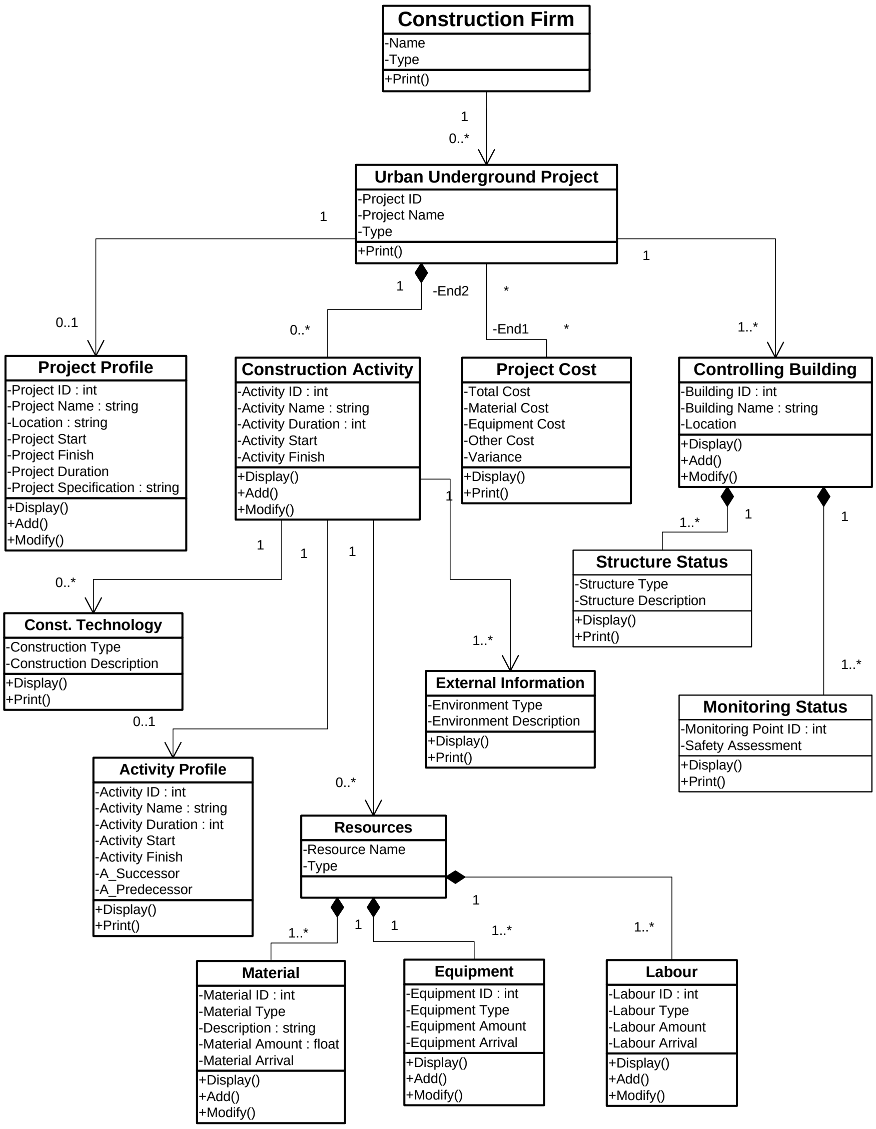


Figure 6a The major core of MitiRisk's Database

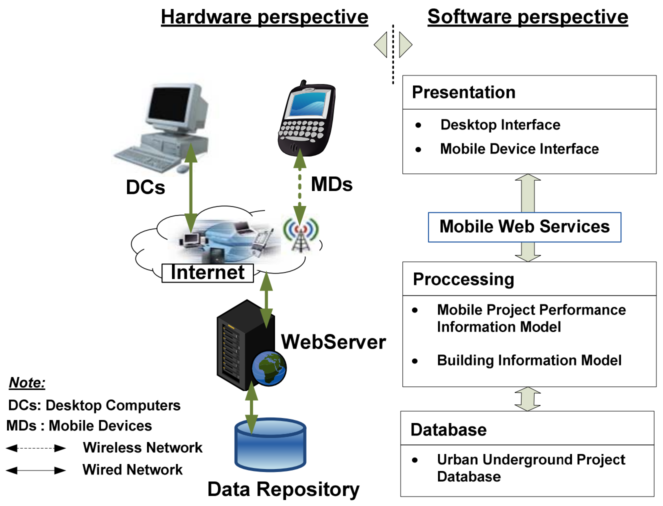


Figure 6b MitiRisk framework overview

5. ILLUSTRATION EXAMPLES OF MitiRisk

Application scenarios of the developed system - MitiRisk to the Metro line 1 (Ben Thanh – Suoi Tien) in Ho Chi Minh City in Vietnam and application examples to the O6 station's excavation in Kaohsiung metro system in Taiwan, are implemented to illustrate the improvements of safety management to adjacent structures in urban underground construction projects.

As previous introduced, the MitiRisk is an information system that combined from desktop and mobile smartphones, therefore there are two testing prototypes were implemented: one for desktop applications and the other one for mobile applications. The methods which are introduced in section 4.2 will be the algorithms of MitiRisk in the estimation for the allowable limitations of potential damages of buildings nearby. Because the practical conditions of bilateral research co-operation, the desktop application was implemented in O6's excavation in Kaohsiung metro system and mobile application scenarios were implemented in Ho Chi Minh City.

5.1 Application scenarios in Metro line 1 in Ho Chi Minh City

Metro Line 1 will start from Ben Thanh Market, whereas the underground section will be 2.6 km pass the Opera House, Ba Son Shipyard, then cross the Saigon River on an elevated track, passing through District 2 on the way to Suoi Tien Park and the terminate in Long Binh in District 9 with about 17.1 km. The Metro Line No. 1 therefore, has the total length of 19.7 kilometres, with three underground stations and 11 elevated stations. The project is scheduled for completion in 2017 and then it will start operation in 2018. In the underground section of Metro Line 1, it will be excavated in the very crowded commercial, historical buildings as well as private houses. Consequently, the control of behaviours and assessment of hazards to adjacent structures is greatly concentrated. To approach this problem, a private building that is adjacent to Metro Line 1 (HML1) – Ho Chi Minh City will be randomly chosen among hundreds of adjacent buildings for a case study, and the results have proved to be convenient with the civil engineers when they have to work at the site based on MitiRisk.

The window mobile smartphone which was applied to test the proposed system – MitiRisk in Ho Chi Minh City is Sony Ericsson Xperia X1. The simple reason that why this device is selected because of it firstly has the operation system is the Microsoft Windows Mobile 6.1 Professional and secondly it has the QWERTY keyboard. With the specific characteristics in construction sites, the QWERTY keyboard is quite more suitable than touch keyboard (touch screen). Although this paper used the Window phone with QWERTY keyboard for testing, however, MitiRisk can also to be implemented in touchscreen Window phones. It is just depend on the demand of users.

The mobile application scenarios in this case study is not a completely organized web service application but an explanatory tool to demonstrate the necessity and applicability of MitiRisk. It is typically tested and explained by six pictures which are presented in Figure 7. As shown in Figure 7, the site engineers can access to the MitiRisk software that installed in their own mobile devices (in here is Sony Ericsson Xperia X1), thereafter, they can handle and update the current situation of the current observed buildings at worksite. The site engineers can check the current situation of a tunnel excavation (Figure 7a); thereafter they can access to the *Structure Status* and *Monitoring Status* folders so that they can immediately check the influences of tunnel projects or control the monitoring parameters due to tunnel excavation such as settlement, torsion or crack parameters (Figure 7b,c,d,e, f).

Compared with other traditional evaluation methods, MitiRisk has been verified to be a more competitive solution with on-demand service feature. The original data can be directly entered or accessed into MitiRisk without a normalization procedure, avoiding the potential information loss. MitiRisk can be offered as a decision support tool for the risk assessment in urban tunnelling construction and worth popularising in other similar projects.

5.2 Excavation of O6 station in Kaohsiung metro system

Excavation of O6 station in Kaohsiung metro system was also selected as background example to demonstrate the function and capability of the proposed system. The O6 Station is located in the junction of Chung-Cheng Road and Ming-Chu Road and the surrounding of O6 Station is populous as shown in Figure 8. It was constructed by cut-&-cover method and the maximum excavation depth is 19.6 m. The pit was retained by a 1m thick, 36 m deep reinforcement concrete diaphragm wall. The major structure of O6 Station is a 2-level basement. The main soil strata of the site consist of the groundwater level was observed at 3.5 m below surface level. Details of the project are stated by (Hsiung 2009).

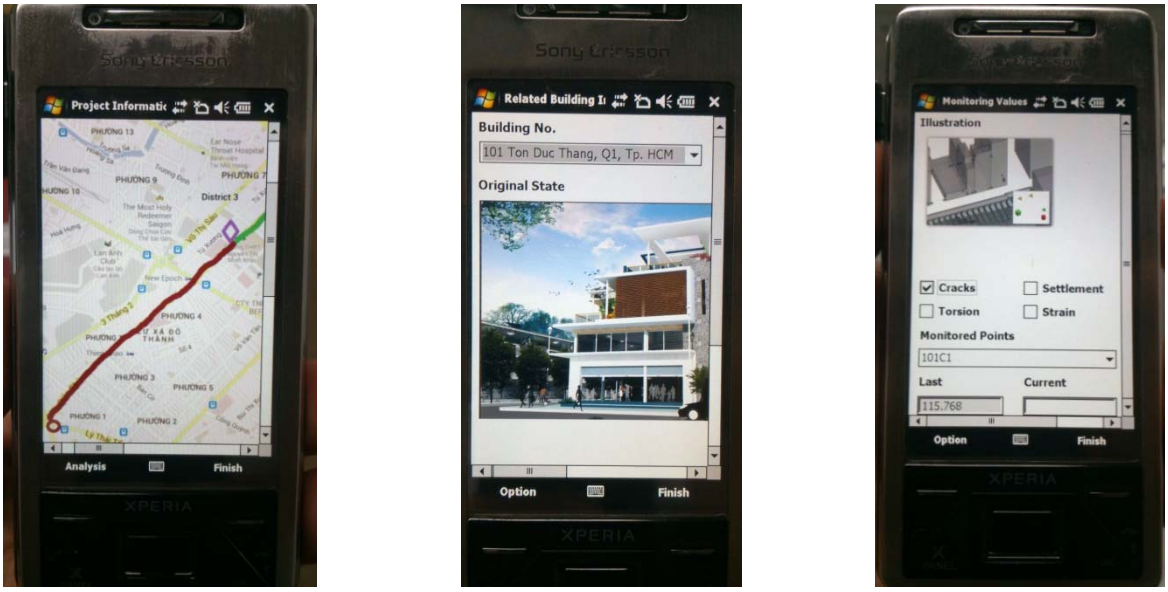
5.2.1 Function Demonstration

First of all, the excavation itself and buildings located nearby are integrated and presented in 3- dimensional model by BIM system, as shown in Figure 9. As indicated in Figure 10, soil stratum data will integrate and visualize in BIM system and said information can become an important references for the selection of retaining structures and supporting system. Together with some details of excavation, influence and potential damage on neighbourhood area can be evaluated first and some alert values can thus be set up together from evaluation results and structure conditions. Possible influence zone given by the user can be defined in said model too so buildings possibly affected can also be shown in BIM model (Figure 11). Works here are eligible to be delivered before start of construction so additional cautions can thus be made to these adjacent structures in advance. Accompanied with alert value defined by the user, data observed at the site can be put into the same BIM model so warning can be given once any measurement is over the alert value. It is thus to provide the real- time warning function of risk mitigation in a 3- dimensional way once said BIM system is used.

5.2.2 Data Management

In order to achieve the real- time warning function indicated above, it is very important that numerous data can be transited on time and organized. Therefore, data management becomes a very important issue to the system.

Data collected from the site can be put into the system bit by bit (Figure 12) but can also be saved into spreadsheet first and then be read by the system directly, as shown in Figure 13. It is anticipated that time of input can be saved and the possibility of key-in error can be reduced as well. In addition, the warning can be shown by an overall view (Figure 14) or by visualization and figure and wording together (Figure 15) and this can help the user to catch up a full picture of condition. A clear warning message is thus eligible to be given by the system herein.



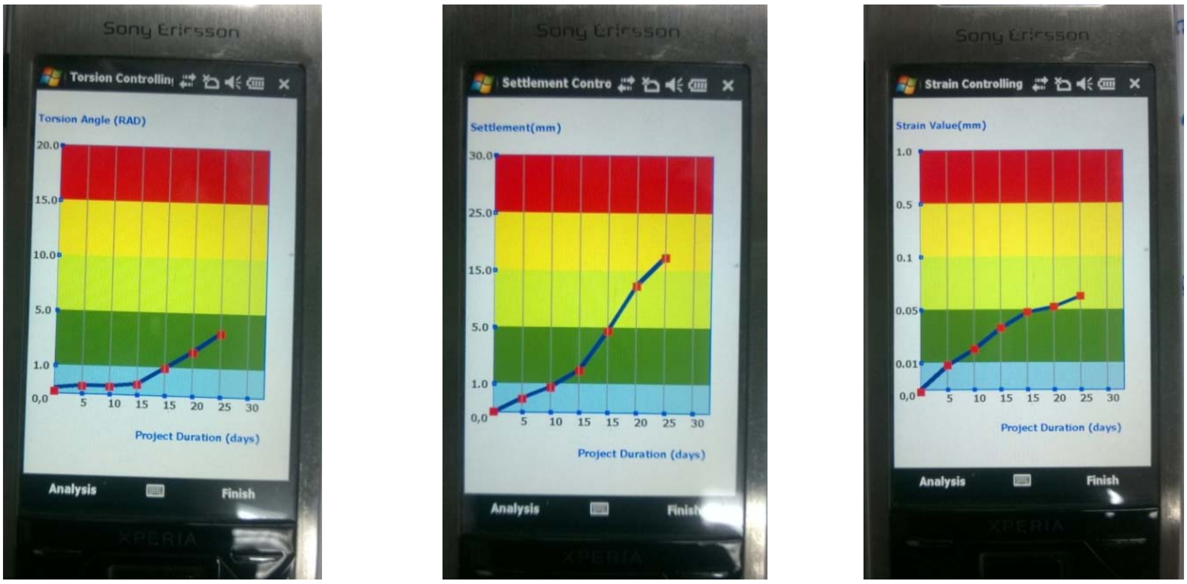
Building No.
101 Ton Duc Thang, Q1, Tp. HCM
Original State

☑ Cracks ☐ Settlement
☐ Torsion ☐ Strain
Monitored Points: 101C1
Last: 115.768
Current:

a) Checking the current situation of urban tunnel excavation

b) Checking the position and influence of tunnel excavation with third party

c) Checking the monitoring parameters of the third party



d) Checking the allowable parameter of Torsion Angle (RAD) of third party

e) Checking the allowable parameter of settlement (mm) of third party

f) Checking the allowable parameter of Strain (mm) of third party

Figure 7 Application scenarios of MitiRisk – Mobile Applications - at worksites

Figure 8 The plan view of main excavation zone of O6 station

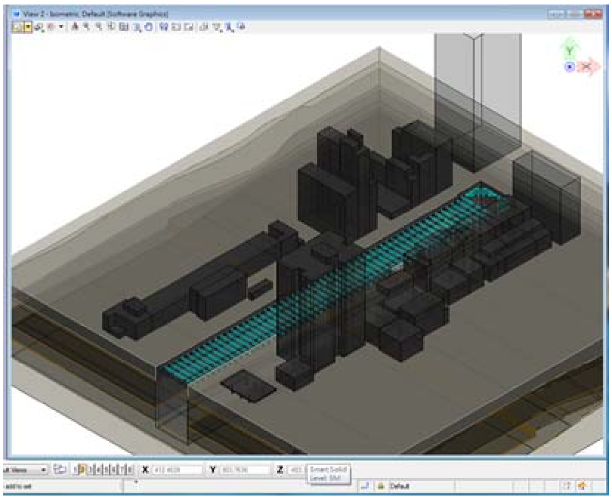


Figure 9 Buildings and Excavation are created in 3D model

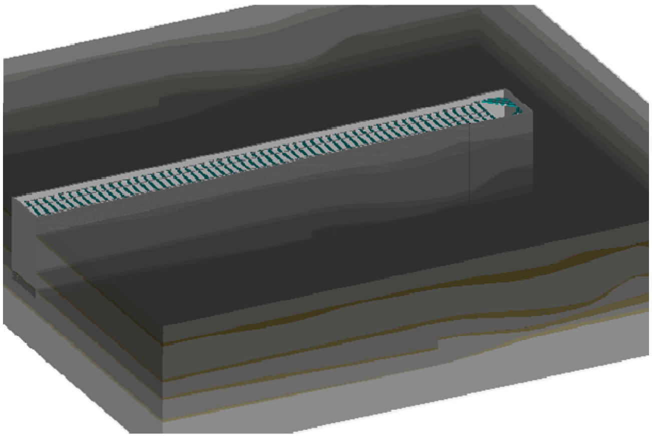


Figure 10 Soil stratum is viewed in 3D model

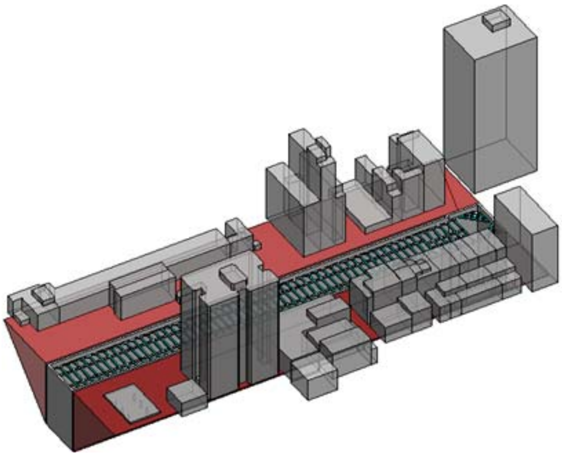
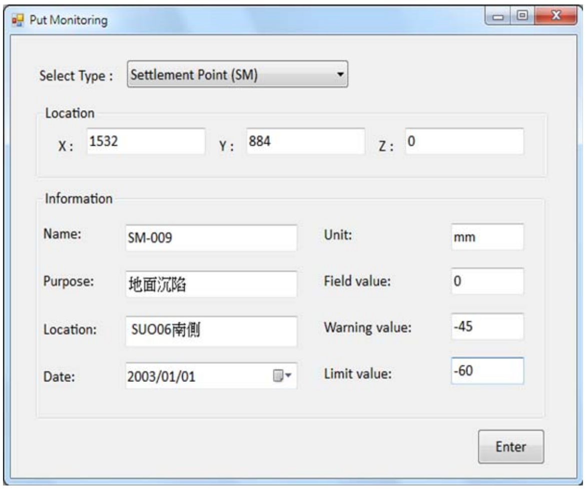


Figure 11 Buildings located inside excavation influence zone



Put Monitoring

Select Type : Settlement Point (SM)

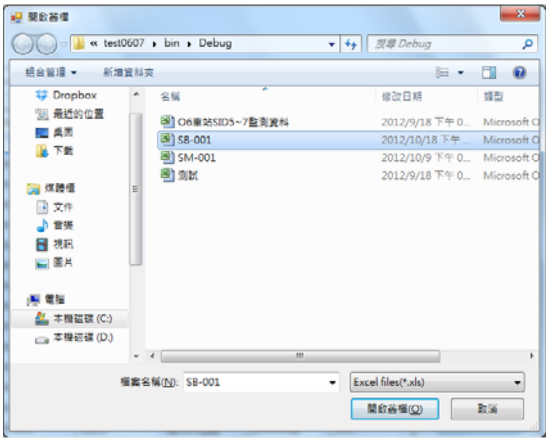
Location

X : 1532
Y : 884
Z : 0

Information

Name: SM-009
Purpose: 地面沉陷
Location: SUO06南側
Date: 2003/01/01
Unit: mm
Field value: 0
Warning value: -45
Limit value: -60

Figure 12 Bit by bit input



開啟舊檔

« test0607 ▸ bin ▸ Debug

名稱	修改日期	類型
O6車站SID5~7監測資料	2012/9/18 下午 0...	Microsoft O
SB-001	2012/10/18 下午 ...	Microsoft O
SM-001	2012/10/9 下午 0...	Microsoft O
測試	2012/9/18 下午 0...	Microsoft O

檔案名稱(N): SB-001
Excel files(*.xls)

Figure 13 Monitoring data management

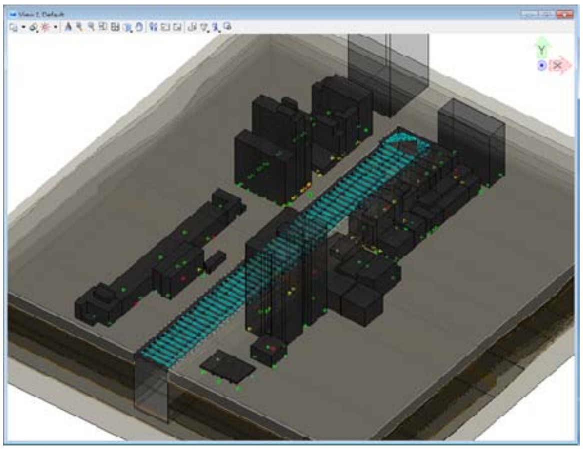
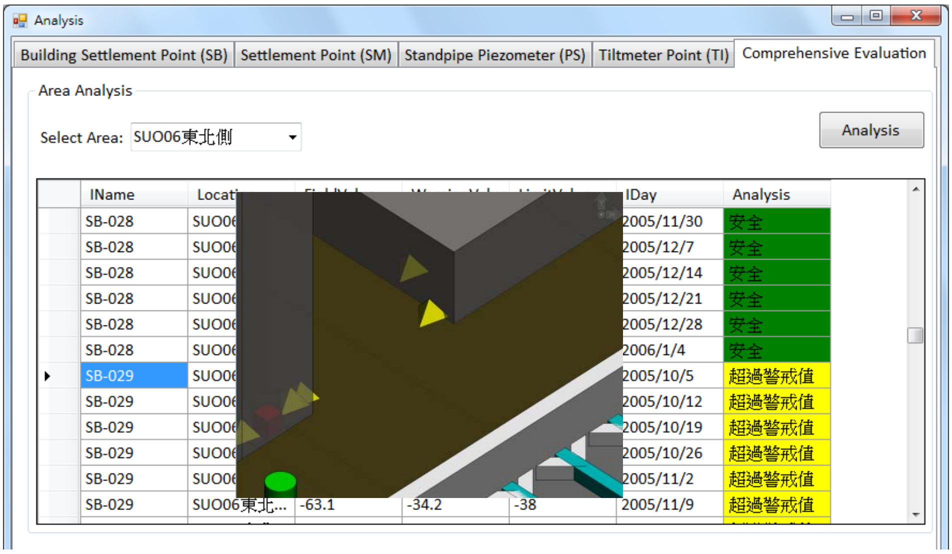


Figure 14 The overview of Monitoring



Select Area: SUO06東北側

	IName	Locati				IDay	Analysis
	SB-028	SUO06				2005/11/30	安全
	SB-028	SUO06				2005/12/7	安全
	SB-028	SUO06				2005/12/14	安全
	SB-028	SUO06				2005/12/21	安全
	SB-028	SUO06				2005/12/28	安全
	SB-028	SUO06				2006/1/4	安全
▸	SB-029	SUO06				2005/10/5	超過警戒值
	SB-029	SUO06				2005/10/12	超過警戒值
	SB-029	SUO06				2005/10/19	超過警戒值
	SB-029	SUO06				2005/10/26	超過警戒值
	SB-029	SUO06				2005/11/2	超過警戒值
	SB-029	SUO06東北...	-63.1	-34.2	-38	2005/11/9	超過警戒值

Figure 15 Warning message by figure and wording together

6. CONCLUSION

MitiRisk enabled new tools, communication chances and procedures addressing site safety aspects can in an effective manner help construction managers to promote top quality site safety planning even in a highly multinational and dynamic environment.

The main scientific contribution of this paper is the development of a new real-time risk management system - MitiRisk. This new system is the integration of Building Information Model – BIM, Mobile webservice technology, Desktop and Window mobile phones so that, it can be used to improve the efficiency of on-site data acquisition and information sharing among responsible participants of urban underground construction project.

One of the main advantages of the proposed system is that the data of urban underground construction project can be visualized in 3D dynamic pictures which can be presented in window mobile phones. This will support to site managers easily analyse and assess the security situation, so that they can quickly solve problems and emergency measures of plan. Another advantage of the system is that the proposed data model facilitates the standardization and sharing construction data between different departments and possibly even between different organizations. The optimal solution exchanges between site managers and responsible partners in site/head office will be understanding and visualization. Every unpredicted problems in the site will immediately be transferred and inputted to database in the site/head office, where contain strong-power analysis tools that very soon generate the optimized solutions.

Additionally, based on the MitiRisk, the internal management system of a construction organization can be supported in following problems:

- Perform robust urban underground construction project management.
- Reduce potential risks by collaborating more effectively among site managers and head office.
- Globally view all projects to find trends and identify problems early.
- Make critical decisions quickly using accurate corporate information.

The further improvements to the proposed system - MitiRisk include the development of advanced analysis functions, the integration with available GIS applications and the expansion of the cooperation such as among construction firms and the owner as well as the third parties.

7. ACKNOWLEDGEMENTS

The project was funded by the Vietnamese Ministry of Science and Technology, Taiwan National Science Council and National Kaohsiung University of Applied Sciences. Their financial support is greatly acknowledged. Furthermore, the authors would like to thank Management Authority for Urban Railways (MAUR) of Ho Chi Minh City for valuable co-operations as well as for their excellent teamwork and feedback.

8. REFERENCES

Atkins W. S., (2006). The risk for third parties from bored tunneling in soft ground". Research Report 453, HSE Books, Health and Safety Executive.

Azhar S., Nadeem A., Mok Y. N. and Leung H. Y. (2008). "Building Information Modeling (BIM): A New Paradigm for Visual Interactive Modeling and Simulation for Construction Projects". First International Conference on Construction in Developing Countries (ICCIDC–I) "Advancing and Integrating Construction Education, Research & Practice" August 4-5, 2008, Karachi, Pakistan

Bazjanac V. (2004). "Virtual Building Environments (VBE) – Applying Information Modeling to Buildings". Research report, Lawrence Berkeley National Laboratory, University of California.

Boscardin M. D., and Cording E. J., (1989). Building response to excavation-induced settlement. Journal of Geotechnical Engineering, 115(1):1–21.

Bjerrum L., (1963). Allowable Settlement of Structures. Proc., European Conf. on Soil Mech. and Found. Engr. E. Wiesbaden, Vol. 2, pp. 135 – 137.

Burland, J.B., (1995). Assessment of risk of damage to buildings due to tunneling and excavation. Invited Special Lecture: In: 1st Int. Conf. On Earthquake Geotech. Engineering, IS Tokyo '95.

Burland J. B., and Wroth C. P., (1974). Settlement of buildings and associated damage. In Proceedings of Conference on Settlement of Structures, pages 611–654, Cambridge. Pentech Press.

Burland, J. B., Broms, B., and DeMello, V (1977). "Behaviors of Foundations and Structures: State of the Art Report". Proceedings, 9th International Conference on Soil Mechanics and Foundation Engineering, Japanese Geotechnical Society. Pp. 495 – 546, Tokyo, 1977.

Clough, G. W. and O'Rourke, T. D. (1990). Construction induced movements of in-situ walls. In Design and Performance of Earth Retaining Structures, Proceedings of a Specialty Conference at Cornell University. American Society of Civil Engineers, New York, pp. 439-470.

Eastman C., Teicholz P., Sacks R. and Liston K. (2006). BIM handbook. "A guide to Bulding Information Modeling for Owner, Managers, Designers, Engineers and Contractor". Second Edition, John Wiley & Sons, Inc.

El-Marsi S. and Suleiman B. (2005). "A framework for providing Mobile Web Services". The second International Conference on Innovations in Information Technology (IIT'05), Dubai, UAE, September, 26-28.

Hsiung B., (2009). "A case study on the behaviour of a deep excavation in sand". Computer and Geotechnics. Volume 36, Issue 4, 665–675.

Li X. and Zhu H. (2013). "Development of a web-based information system for shield tunnel construction projects". Tunneling and Underground Space Technology 37, pp. 146-156.

Kiviniemi M., Sulankivi K., Kähkönen K., Mäkelä T., and Merivirta M. L (2011). "BIM-based Safety Management and Communication for Building Construction". VTT Tiedotteita – Research Notes 2597. ISBN 978-951-38-7783-5(URL: http://www.vtt.fi/publications/index.jsp).

Mair R.J., Taylor R.N., Burland J.B., (1996). Prediction of ground movements and assessment of risk of building damage due to bored tunnelling. In: Proc. Of the Int. Symp. On Geotech. Aspects of Underground Construction in Soft Ground, 713-718, Balkema, Rotterdam.

Maurenbrecher, P.M., Herbschleb, J., (1994). The potential use of geotechnical information systems in the planning of tunnels for Amsterdam. Tunneling and Underground Space Technology 9 (2), pp. 189–199.

Mejstrik M., Savidis S., 2010. A Visual Internet-Based Information Platform for the Improvement of Execution Management in Geotechnical Engineering Projects. Proc. of the 14th World Multi-Conference on Systemics, Cybernetics and Informatics (WMSCI 2010), June 29th - July 2nd, 2010, Orlando (FL), Vol. I: 208-214.

Peck R. B., (1969). Deep excavations and tunneling in soft ground. In Proceedings of the 7th International Conference on Soil Mechanics and Foundation Engineering, pp. 225–290, Mexico City.

Polshin D. E., Tokar R. A., 1957. Maximum Allowable Non-Uniform Settlement of Structures. 4th I.C.M.F.E., London, Vol.1, pp. 402 -505.

Schultze E. and Horn A. (1990). Setzungsberechnung. Grundbautaschenbuch, 1(5). (In Germans).

Skempton A. W., McDonald D. H., 1956. The allowable Settlement of Buildings. Pro. I.C.E., Vol.5, pp. 727 – 768.

Yoo, C., Kim, J.H., (2003). A web-based tunneling-induced building/utility damage assessment system: TURISK. Tunnelling and Underground Space Technology 18, pp. 497–511.

Yoo, C., Jeon, Y.W., Choi, B.S., 2006. IT-based tunnelling risk management system (IT-TURISK) – development and implementation. Tunneling and Underground Space Technology 21 (2), pp. 190–202.