INSTRUMENTATION AND MONITORING FOR TAIPEI RAPID TRANSIT SYSTEMS

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Abstract: It is vitally important to maintain the safety of construction of rapid transit systems which usually involve deep excavations in densely populated areas with poor ground conditions and Taipei Rapid Transit System (TRTS) is no exception. To achieve this purpose, more than 30,000 pieces of instruments were installed and more than 20 million sets of readings were taken during the construction of the Initial Network of TRTS. These instrument readings were processed at a data center which was managed by the Geotechnical Engineering Specialist Consultants engaged by the project owner automatically and warnings were issued whenever irregularities were detected. A sophisticated software system was developed for the purpose and it has been proved to be efficient and effective. However, with the rapid advancement in computer technology, it is anticipated that a more powerful software system can be developed using the GIS technology so other relevant information such as location map, ground conditions and progress of construction can be displayed at the same time. Furthermore, such information can be shared by various parties, wherever they are, via internet. This will enable preventive actions to be taken in time should adverse situations happen and the potential risk of accidents to be reduced.

Keywords: instrumentation, monitoring, automation, safety.

1. INTRODUCTION

Constructions for mass rapid transit systems inevitably involve deep excavations and tunneling and the safety of structures in the vicinity of the alignment is of primary concern. Instrumentation and monitoring are thus important issues in both design and construction stages. The purposes of instrumentation include:

1. to monitor ground response to constructions,
2. to monitor the performance of temporary works
3. to monitor the performance of permanent works
4. to monitor the response of structures affected by the construction

with the aims of:

1. ensuring that construction can be carried out safely and to provide data for modifying construction procedures, if necessary,
2. ensuring that the adjacent structures will be safe during and after construction,
3. providing data for evaluating the situation should some structures be endangered, preparing contingency measures should actions be needed to safeguard these structures, and evaluating the effectiveness of the contingency measures taken,
4. providing data for preparing remedial measures should some structures suffer from damage and evaluating the effective of these measures,
5. providing data for clarifying responsibility in legal cases,
6. providing data for back analyses for refining design procedures and enhancing construction technology.

In the construction of the Initial Network of the Taipei Rapid Transit Systems (TRTS), which consists of 6 lines with a total length of 68 km (as of 1999) of which two-third is underground, more than 30,000 pieces of instruments were installed and the readings exceeded 20 million sets. Discussed herein are the planning and execution of instrumentation programs and the benefits obtained.

2. PLANNING OF INSTRUMENTATION PROGRAMS

In the construction of the Initial Network of TRTS, instrumentation programs were proposed by the contractors in accordance with the guidelines laid by DORTS and were reviewed by the Geotechnical Engineering Specialist Consultants (GESC) engaged by DORTS. The review is necessary for maintaining the quality of the programs and to ensure that the programs cover the essential aspects of instrumentation. It was also GESC's mission to oversee the execution of the instrumentation and monitoring programs for maintaining the consistency among different contracts and to ensure that the purposes of instrumentation were achieved. The large quantity of data enable system-wide researches to be carried out and this can only be conducted by specialists engaged by the project owner, either in-house or outside. Usually contractors are least interested in researches and, therefore, only these specialists can ensure that the desired purpose is achieved.

Because most of the lines in the Taipei Rapid Transit Systems run through densely populated areas, quite many buildings were inevitably affected by the construction. Building conditions surveys were conducted for documenting the conditions of structures in the vicinity of construction and the results of surveys became the basis for preparing building protection programs. Sufficient instruments were placed to have a full coverage of the zone of influence with emphasis on structures which were vulnerable to the construction. Settlement points were the most useful, but the least expensive, type of instrument to serve the purpose. Inclinometers and piezometers were placed at strategic locations to help interpretation of settlement readings. Tiltmeters were placed on structures which were identified to be sensitive to settlements.

For the safety of temporary works in deep excavations, load cells were installed on struts to ensure that struts would not be overloaded. Inclinometers were routinely used to monitor deflections of walls. Wall deflections are usually the first thing to be reviewed if ground settlements become excessive. Sometimes strain gages were used to monitor the stresses induced in rebars, however, the readings were difficult to interpret. Earthpressure cells were used at a few places to monitor the active and passive pressures acting on diaphragm walls for research purpose but reliable readings were difficult to obtain because, presumably, the cells were likely to be sealed by cement mortar and also because arching effects of soil might have affected the readings. Piezometers were useful in monitoring ground water table as a large portion of ground settlements were induced by groundwater drawdown.

3. EXECUTION OF INSTRUMENTATION PROGRAMS

It is doubtless that the quality of installation of instruments is of vital importance. Malfunctioning instruments will provide misleading information, resulting in either unnecessary panic or omission of signs of danger. Therefore, in the construction of the Taipei Rapid Transit Systems, instruments were installed only by qualified specialist contractors who were subject to the acceptance of DORTS. Initial readings were taken by these specialist contractors and were double checked by GESC. Subsequent readings were taken by specialist contractors and submitted to DORTS in electronic files. Five to ten percents of these readings were verified by GESC either by taking readings together with the specialist contractors or taking readings independently.

As a rule of thumb, instrument readings were taken weekly and this frequency of reading taking was flexibly adjusted in accordance with construction activities. For ground response which varied rapidly with time, close monitoring was carried out. For example, settlements over tunnels were measured daily, or even hourly in some cases, when the heading was within 10m either way from the section of interest. Pore pressure response to tunneling was monitored by using a data log at 5-minute intervals in order to pick up peaks in response.

Readings taken by the contractors were reviewed by GESC with the aid of the computer software specifically developed for the purpose. As depicted in Fig. 1, the readings were first double-checked against the readings taken by GESC to ensure their correctness. Then they were compared with the trigger values, i.e., the alert limit and action limit, preset by detailed design consultants (DDC) to see if they were within the tolerances. There were more than 30,000 pieces of instruments installed and more than 20 million sets of readings obtained, therefore, it was practically impossible to process such a large number of readings manually without the help of computers. A yellow warning notice would be issued if any of the readings exceeded its alert limit and a red warning notice would be issued if any of the readings exceeded its action limit. Contractor was supposed to confirm the correctness of the readings once he received a warning and provide explanation on why the tolerance was exceeded. He was also to prepare contingency program if risk was developing and to implement this program once it was confirmed that danger indeed existed. The alert limits and action limits were subjected to revision by DDC upon reviewing the conditions of the particular structure of concern, the performance of temporary works, and/or ground response.

Once readings indicated that something serious was happening, meetings were called and attended by representatives from DORTS, DDC, contractor and

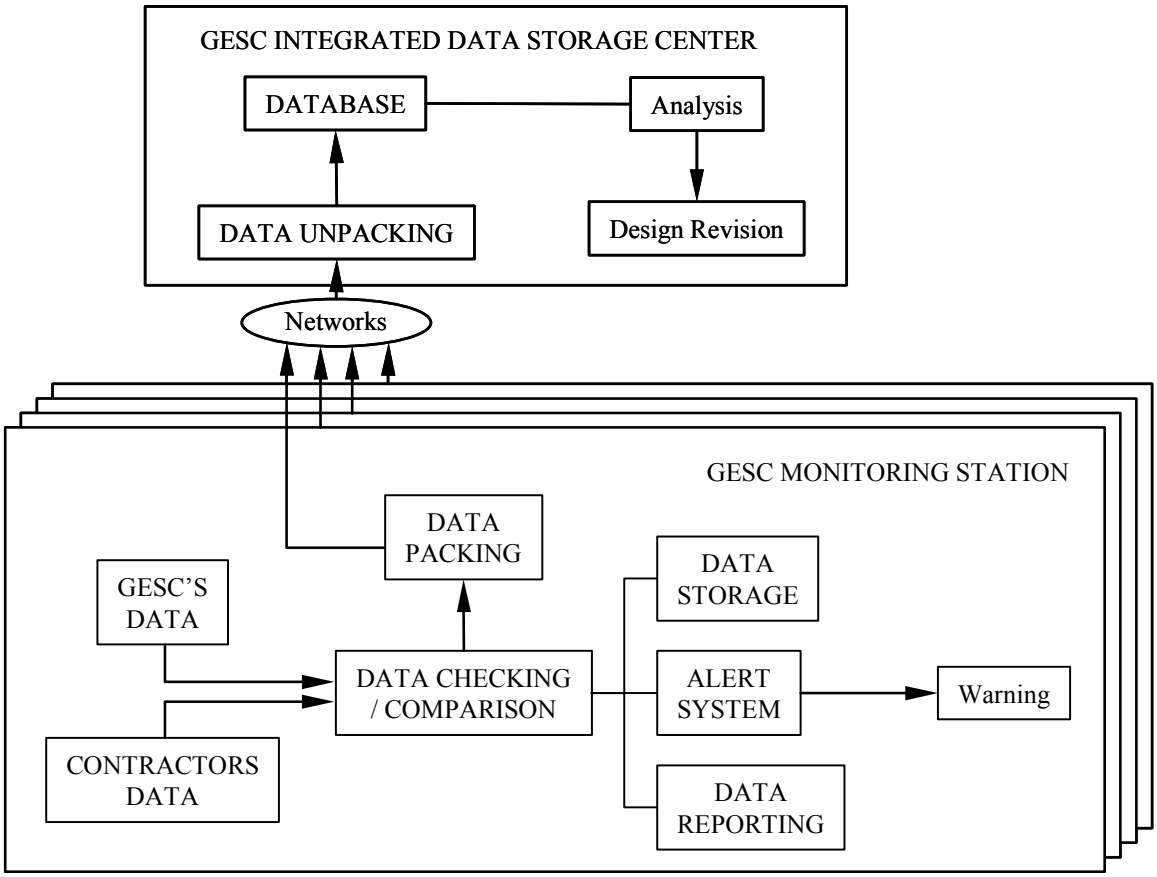

Figure 1. Data collection, Verification and Transmission

GESC to discuss the contingency program proposed by the contractor to determine its feasibility. Meetings usually started with reviewing instrument readings and proper judgments indeed relied on the adequacy and sufficiency of these readings.

4. INSTRUMENTATION FOR REMEDIES

No matter how careful the operation is carried out, accidents still may happen in major underground constructions. This is because of the unpredictable nature of the ground. In the construction of the Initial Network of TRTS, all the major accidents were somehow related to the presence of the Chingmei Gravels and/or drifted woods. Although the extent of the Chingmei Gravels was well defined by explorations and the danger of piping failure was fully realized, the rapid development of piping and the scale of damage made as a result of piping caught everyone by surprise. Frankly speaking, these accidents were not able to be totally prevented no matter how comprehensive the instrumentation program was because the situations became uncontrollable within hours and there were practically no way to stop water from flowing once the water path connected to the Chingmei Gravels. Instrumentation however did provide valuable information for judging how serious the situations were and what remedial actions were to be taken.

Additional instruments were installed whenever a accident happened to provide information for evaluating the situation and confirming the effectiveness of the remedial measures taken. In most of cases, readings were taken hourly till the situation was judged to be stable.

5. INSTRUMENTATION FOR RESEARCH PURPOSES

Construction technology is always undergoing improvement and past experience definitely forms the basis for future development. Many assumptions are inevitably made in designs and some of these assumptions may not be valid to start with and some of them may become invalid as time goes by. It is therefore important to perform back analyses from time to time during construction to see if the design assumptions and design parameters are appropriate and/or if the construction procedures have to be revised. It was one of GESC's duties to provide sufficient data and to offer his judgment to assist DORTS in the decision making process and instrument readings were the most important information needed for fulfilling this duty.

Because this was the first transit system built in Taiwan, about 20% of the instruments were installed for academic purposes. Numerous research papers have been published by the staff of DORTS, DDC, GESC and contractors on the construction of TRTS based on the instrument readings obtained. Most of these papers address to wall deflections, settlements over tunnels, building protection measures and their effectiveness. Other areas covered include pore pressure response to tunneling, jacking up structures, pumping for dewatering, ground freezing, etc. It is firmly believed that TRTS construction has become a milestone for the construction industry in Taiwan and the construction technology, both in design and construction, has been much improved since TRTS construction.

6. LOOKING AHEAD

After Taiwan was admitted to WTO (World Trade Organization), construction industry on the island is now facing international competition. Although, with a solid electronic industry and high quality of manpower, Taiwan certainly has the edge in competing with most of the countries, this edge is diminishing. It is time to seriously think about how the construction industry shall adapt to this fast-changing world. With the rapid advancement in computer technology and the escalated manpower costs, automation is certainly a trend of future. As far as instrumentation and monitoring is of concern, it is envisaged that more and more instruments will be able to take readings automatically and transmit data to data centers via network. The wireless technology will eliminate many of the data-transmission problems which are currently encountered. Furthermore, internet will enable various parties to share data no matter where they are and exchange data in minutes. This is important in dealing with crisis because, as illustrated in Fig. 2, project owner, supervising staff, contractor, designer, etc. can review the same set of data stored in the data center at their own offices and discuss what to do via video conference.

It is also envisaged that, as illustrated in Fig. 3, close-circuit-televisions will be widely used at sites as a tool for construction supervision and the images taken can be transmitted via internet to various parties worldwide. This will enable parties at scattered locations to better understand what is going on at the site and to work out programs to deal with difficult situations. In fact, as illustrated in Fig. 4, all types of digital information, in addition to instrument readings and video images, can be transmitted via internet, including text, audio message, photo images and animation, etc. This will enable various types of safety-related information, including street maps, soil profiles, photos of buildings, etc., to be shared by various parties. It is desirable to incorporate all these data together with other data, as illustrated in Fig. 5, in a comprehensive construction information system to facilitate easy retrieval and display. This is not difficult to achieve because geographic information systems (GIS) have been widely adopted by numerous government agencies for various purposes and the GIS technology is quite mature.

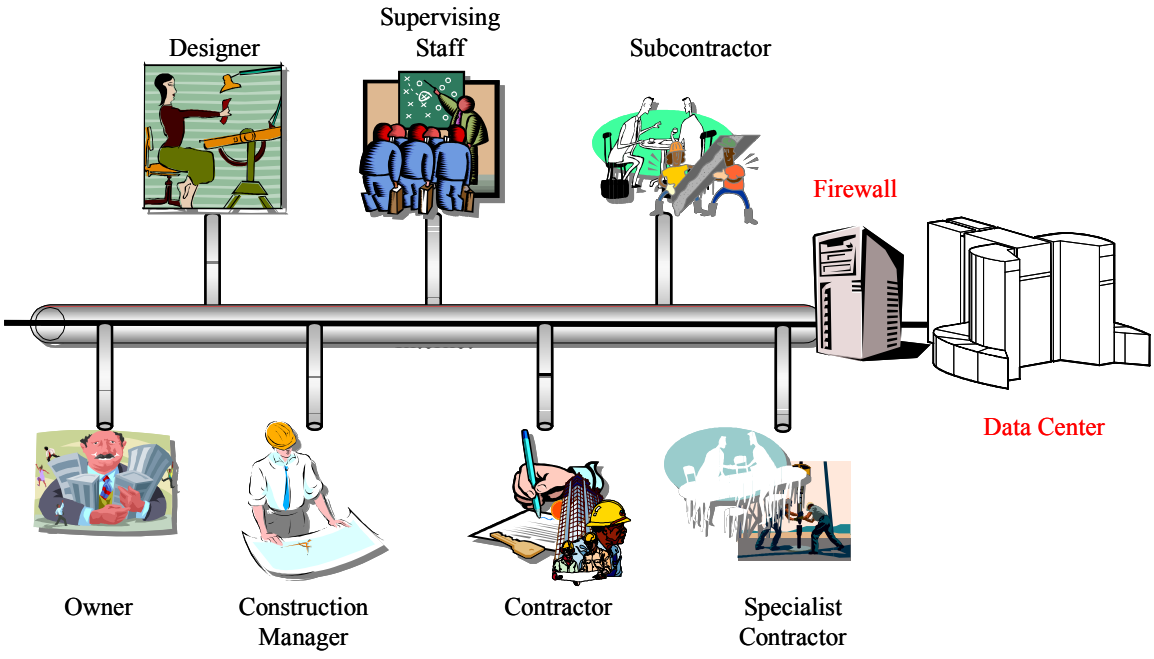

Figure 2. Parties involved in constructions

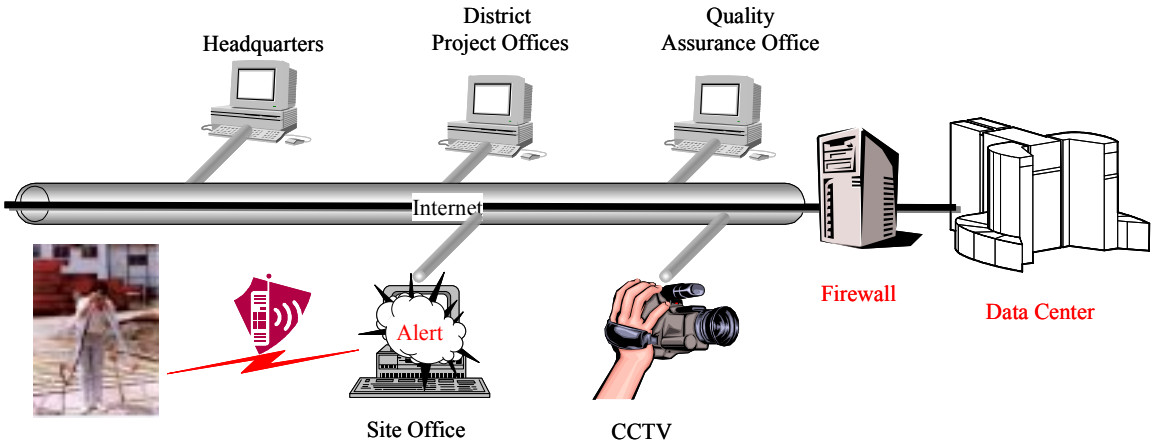

Figure 3. Internet Instrumentation – and – Alert system

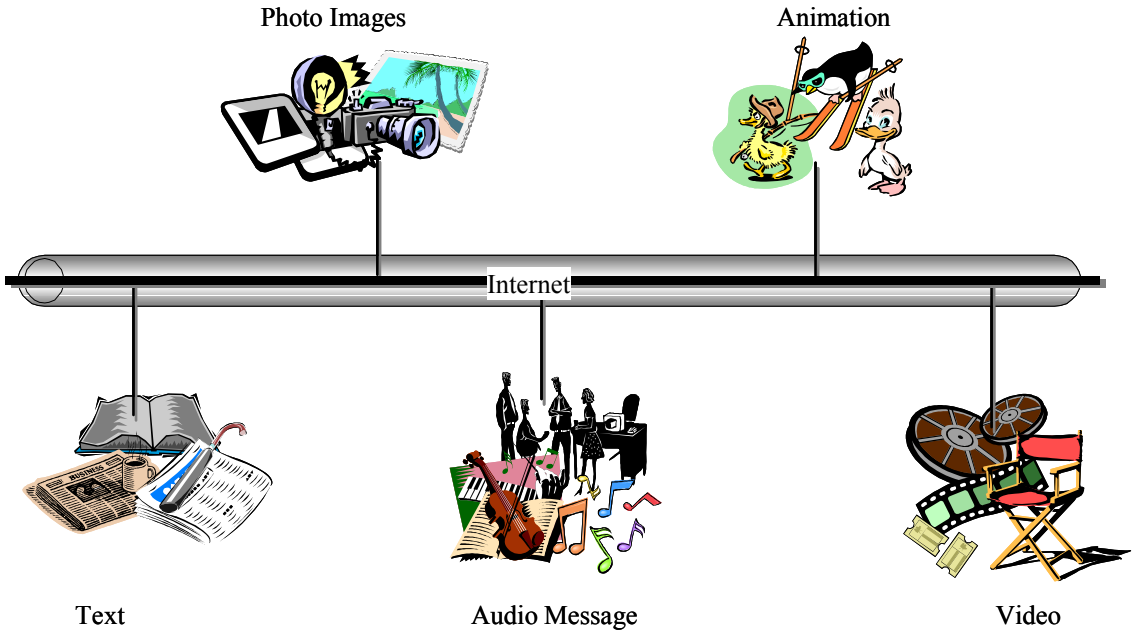

Figure 4. Type of information transmittable on internet

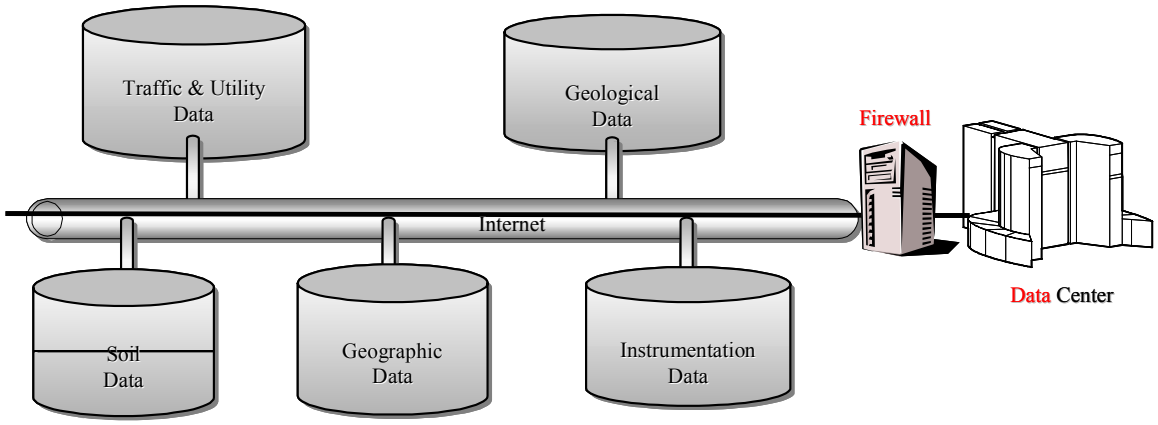

Figure 5. Web geographic – information system for mantaining safety of construction

CONCLUSIONS

The construction of the Initial Network of TRTS was well benefited from the instrumentation and monitoring programs and the researches carried out based on the instrument readings obtained during TRTS construction have greatly enhanced the construction technology in Taiwan. Based on this successful experience, it is recommended that

1. in projects with significant sizes, particularly those involving deep excavations and tunneling in densely populated area, sufficient emphasis be given to instrumentation and monitoring.
2. more importantly, specialists shall be engaged in processing, interpreting and utilizing the data obtained.
3. web geographic information systems (WGIS) shall be developed to incorporate all types of information related to safety of construction to enable various parties to share data via internet.

It is sincerely hope that the construction industry can benefit from the modern technology to improve its quality of work and its competitiveness.