Chapter 95

TUNNELING DATA: TURNING INFORMATION INTO INTELLIGENCE ON THE NEIS PROJECT

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ABSTRACT

This paper will discuss how the construction management team and the contractor working together on the City of Los Angeles, North East Interceptor Sewer project, managed information on a daily basis. Data was synthesized from various sources including: inspection, survey, instrumentation, laboratory and the tunnel boring machine data logger systems to produce state-of-the-art reports and graphics which will become industry standard. Special emphasis is placed on how the data is managed and interpreted in a clear and objective manner, permitting the tunnelling processes to be carefully monitored and suggesting appropriate action to be taken by the construction management team and contractor.

INTRODUCTION

The North East Interceptor Sewer (NEIS) is part of the City of Los Angeles (City) Board of Public Works program to construct a series of new interceptor sewers linking the San Fernando Valley in the north of the City with the Hyperion Sewage Treatment Plant in St. Monica Bay to the south. The purpose of the system is to provide additional sewage capacity to the north of the recently completed East Central Interceptor Sewer (ECIS).

The NEIS project involved the construction of approximately 8500 m of 2.40 m finished diameter (ID) pipeline in a tunnel. The tunnelling portion of the works is now complete and was carried out using 2 No. Lovat Earth Pressure Balance (EPB) Tunnel Boring Machines (TBM) for the Lower and Middle Reaches and 1 No. fully shielded rock TBM for the Upper Reach. All TBMs had identical bore dimensions of 3.864 m. The two EPB TBMs were launched from a dual-cell slurry-wall shaft with cell diameters of 7 and 5.5 m diameters and joined via a center wall. Further detail of the NEIS shaft construction has been presented by McKenna et al. (2003).

The first EPB TBM was launched in a southerly direction from the Richmond shaft in May 2003 and completed the 2836 m Lower Reach with a breakthrough into the existing ECIS/NEIS shaft at the Mission and Jesse site in July, 2004. The second EPB

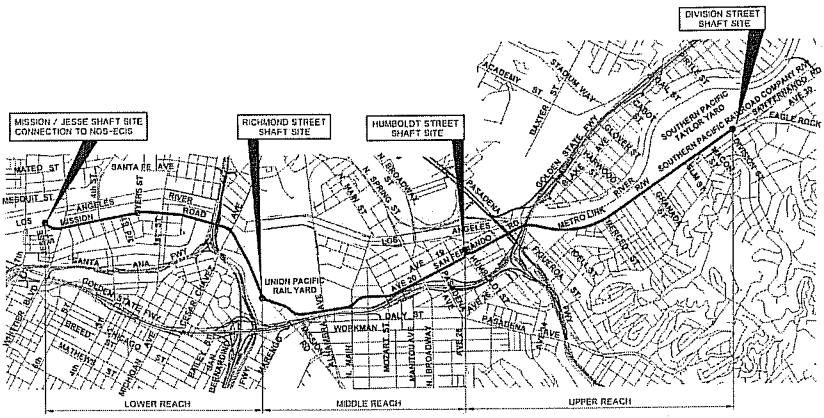

Figure 1. Plan of NEIS sewer tunnel alignment

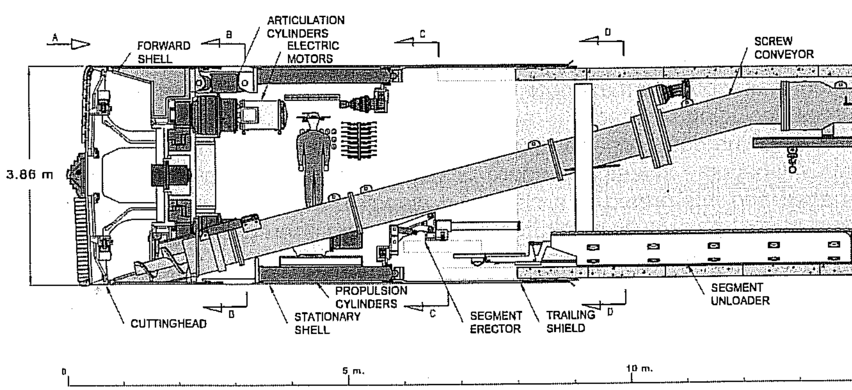

Figure 2. The Lovat ME152SE Series 20800 EPB-TBM shield

TBM was launched in October 2003 and completed the 2323 m Middle Reach with a breakthrough into the Humboldt shaft at the end of November 2004. The Upper Reach tunnel was constructed using the Humboldt shaft as a base and was launched in June 2003 and completed its drive of 3269 m with a breakthrough into the Division St. Shaft in July 2004.

GETTING THE DATA

It has often been noted that too much information is as dangerous as too little. On the NEIS project the large amount of data generated by the three TBMs was handled very smoothly through a network of computer stations linking the TBMs, the work sites and the main offices of the contractor and City construction management team.

Figure 3 shows how the Taylor Bros.-Shea-Frontier Kemper-Kenny Joint Venture (TSFK) set up their computer network using it to distribute real time data and to display

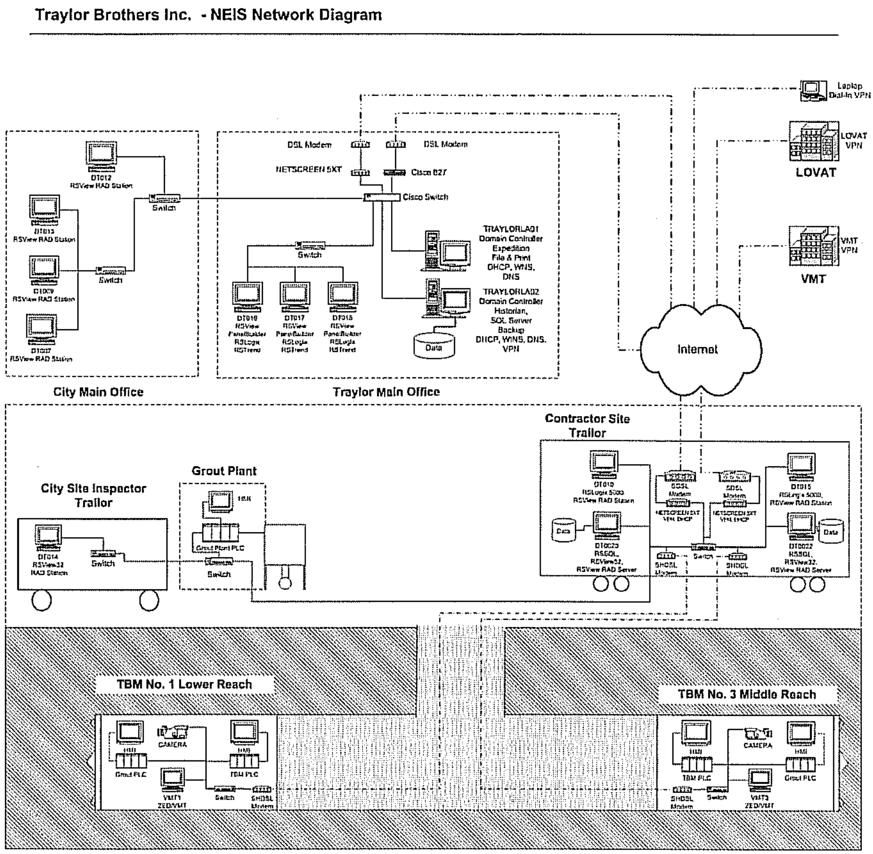

Figure 3. The NEIS network diagram for the EPB-TBMs at the Richmond shaft site

and record to a database file, so that the primary project stakeholders could both share and review the data.

The contractor needed the availability of continuous real-time data in graphical format in order to effectively control his works. The City inspectors used the data to assist in the supervision and verification of the progress of the works. The City construction management team carefully followed the TBM advance in order to be aware of any issues arising from tunneling that would require their action.

CONTRACTOR DATA MANAGEMENT

The NEIS specification clearly defined that the TBM had to be equipped with a guidance, alignment control and (TBM) monitoring system. In addition, the specification required a visualization and data-logging function to be incorporated and installed in the City offices. TSFK put together a comprehensive computer network which knit together the TBMs and the work sites such that at a click of a mouse it was possible to know the current status of any TBM on the job.

Figure 4 illustrates how the data was presented to the TSFK management team in the main office during the operation of the TBMs. A program called RSTrend was used

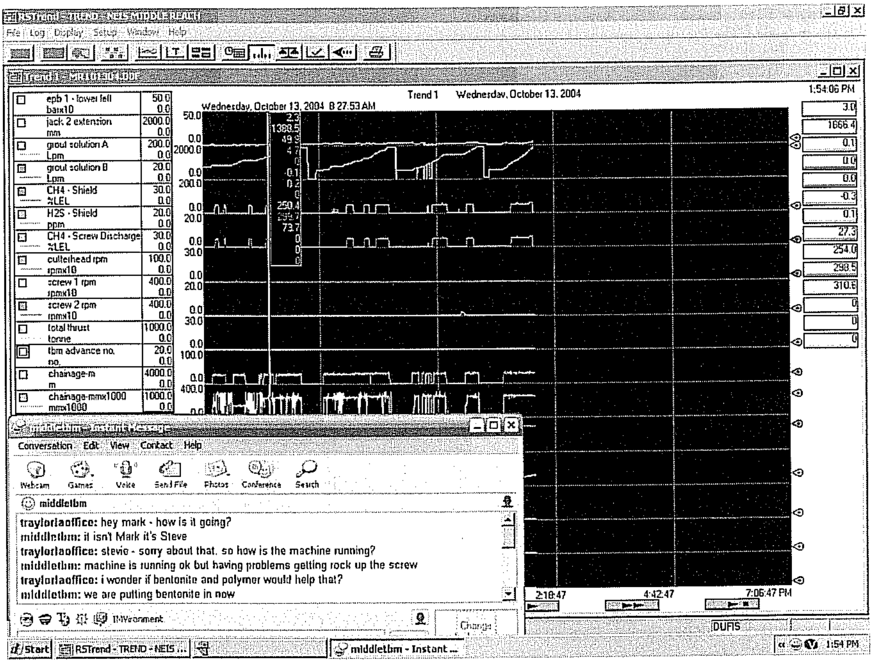

Figure 4. RSTrend being used in conjunction with instant messenger software to communicate between the main office and the TBM

to track the progress of the TBMs. This program had the capability to plot, log and display any of the more than 120 variables sent from each of the TBMs and grout plants with respect to time. In addition TSFK used an instant messaging program to communicate with the TBM operator in parallel with the RSTrend software. This set-up facilitated ease of communication between TBM operators, site supervision, and the main office. The main advantage of the instant messaging program over the conventional telephone system was the fact that very precise instructions could be communicated at any time, even during TBM advance when ambient noise levels would make verbal communication practically impossible. Visitors to the TBM were often surprised to see the level of computer sophistication in the tunnel one incredulous visitor remarked that the operators in the NEIS tunnels had better high-speed internet access than he had at home.

As obliged by the specifications TSFK provided several computer stations for the City Inspectors and Engineers. These systems used RSView alone to monitor the functions of the TBM and view progress of the TBM advance. Figure 5 shows a sample of the Center of Thrust window of the TBM Human-Machine Interface (HMI) screens. These screens were identical to those in the tunnel and could be viewed from any of the remote stations by selecting the desired window. Given the appropriate software these screens could be used to actively alter certain TBM parameters, however for obvious reasons the City stations were limited to passive viewing without editing capabilities.

TSFK used the RSTrend and RSView to monitor the TBMs and provide assistance to the TBM operators. This function was particularly useful during the early phases of the works where the learning curve could have a dramatic effect on tunnel production

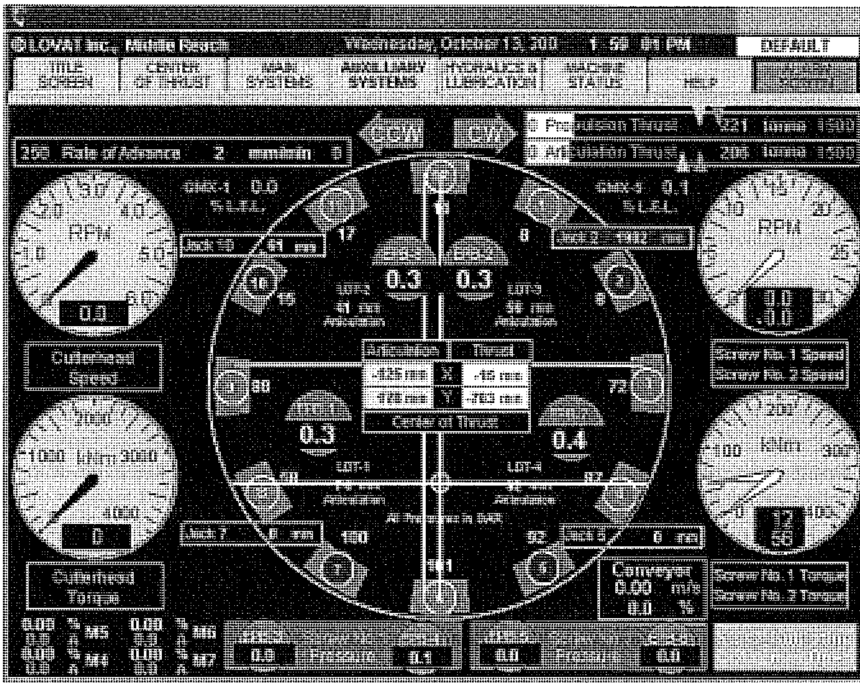

Figure 5. RSView screen showing activity on the TBM

and many errors in TBM operation could be avoided. For example a TBM operator who was experiencing problems with the TBM advance and was uncertain about the ground conditioning settings while excavating through a mixed face could send a request for assistance to the main office. An experienced engineer could respond directly by making setting changes to the system by actively taking part in a dialogue with the operator. One of the greatest obstacles to the efficient distribution of skilled tunnel contractor personnel is the difficulty and time required to access the TBM. By employing state-of-the-art methods the TSFK team was able to overcome these traditional challenges and successfully complete the tunneling works.

CITY DATA MANAGEMENT

During the early stages of the ECIS project it was recommended that a specialist sub-consultant be retained by the principal consultant working as an integral part of the City construction management team, who would be dedicated to the technical issues arising from TBM and tunnelling related issues on that project. The NEIS project continued with this strategy due in part to the important contributions made by the specialist to the successful completion of ECIS and with a view to the bolstering of the wider talents of the city-consultant team.

The role of this experienced TBM specialist was multi-faceted and addressed a need for the City construction management team to have on board a person who could review TBM and tunnelling related proposals and procedures and provide sound recommendations and advice. The TBM specialist would then follow on to concentrate on monitoring and reviewing the daily tunnelling activities of the NEIS TBMs and assist in the management of the tunnelling program together with the tunnel unit leaders. On the NEIS project the tunnel unit leaders were key members of the construction management team who were assigned to each of the tunnel reaches and responsible for all aspects of the works including temporary works construction, pre-excavation grouting, tunnelling and pipe-laying and the subsequent permanent works construction. The TBM specialist role was to review and coordinate all tunneling data from the various sources or data streams on a daily basis by creating easily understandable graphics for the unit leaders and providing a permanent record of the tunneling activities.

THE DATA STREAMS

During the earlier work on ECIS the TBM specialist had developed a graphical method to represent all the important data which could be known regarding the tunnel excavation. It was requested that a similar approach be used on the NEIS project as the construction management team had become used to a consistent format. The following data was gathered on a daily basis in order to be synthesized into one complete graphical report.

- Baseline geological section drawings and boring data
- Selected TBM data from TBM data logger files
- TBM stationing data
- Survey data from surface settlement points
- Instrumentation data from extensometers and piezometers
- Selected data from the City Standards Department soil data reports
- Selected data from the City Inspector reports

The Geotechnical Baseline Report GBR was prepared for the NEIS project as a joint effort of the City Geotechnical Engineering Division (GED) and their consultants CDM-Jessberger. The GBR included interpreted long sections generated from the borehole logs for each tunnel reach. These long sections were further divided into 100 m intervals for inclusion in the graphic report produced by the TBM specialist.

Most modern TBMs are equipped with at least one PLC in order to facilitate control of the many operational variables used in the automation of a multitude of TBM functions. With the advent of PLC control on TBMs an opportunity to gather data from many sensors and equipment presented itself. In one form or another, data-logging capabilities have been included as standard equipment on many TBMs over the past 15 years. However the use of data gathered from the TBM by any party aside from the contractor was rare except where a claim arose requiring a careful analysis on the part of both contractor and owner. Obviously this type of approach to the use of TBM data for the aims of claim resolution alone was reactive and occurred well after the actual tunneling activity had been concluded. The NEIS team, on the other hand, was in favour of a much more proactive approach. They insisted that the data be made available on a daily basis, gathered and processed efficiently, such that timely reports could be produced. In this manner it would be possible to deal with tunneling issues as they arose and look for early resolution which could positively impact the ongoing works.

The rapid availability of fully integrated reports did have a pronounced effect on the prosecution of the works. When a disagreement arose, for example, a differing site condition where a length of harder than expected material caused a slower than expected TBM advance, immediate recourse to the data created an objective basis from which conclusions could be drawn and fair resolutions obtained without recourse to dispute review or costly arbitration.

On the NEIS project City tunnel inspectors were provided with a simple data base program permitting each inspector to input data on TBM position, soil type and consistency, muck volumes, grout volumes and comments. In the Inspector database the input was preformatted such that a consistent manner of describing conditions was maintained in a reliable format readily transferable to graphical reporting.

SYNTHESIZING THE DATA STREAMS

In order to produce a single coherent report that would take into account all of the important parameters outlined above it became necessary to make a decision as to how the data should be presented. In its simplest form the data variables can simply be graphed with respect to time. Such graphics reveal the TBM activities in great detail from important data relating to the TBM advance and ring build to such minute details as the main drive pinion oil temperature or tail seal grease pressure. However the use of this level of detail is of far greater value to the contractor and was employed by TSFK on the project to permit observation and intervention in the TBM operations from the remote office locations.

For the purposes of the Engineer it was determined that a fixed interval for the graphics would be most appropriate for their needs and in order that the above information could be related in an easy to read, at-a-glance format. Therefore a fixed stationing interval of 100 m was chosen to permit easily identifiable sections of a given tunnel drive.

The geological baseline long section drawings were broken down into the fixed interval of 100 m and incorporated on the first page of the report. These sections were seen as fundamental to an understanding by all parties of the soil characteristics at that station and any expected changes in the characteristics within that section to be excavated.

The TBM position was plotted with respect to time such that a sloping line diagram was generated for each 100 m interval.

Observations made by the tunnel inspector regarding muck and grout volumes, TBM position, ring building and mining times permitted easy cross reference to the data logger information and filled in the missing data which the data logger was not equipped to capture.

Surveyors and instrumentation technicians provided key data with respect to the TBM interaction with the soil. If movements in instrumentation or monitoring points were noted the position of these could be easily correlated to the activity of the TBM. Such correlations in turn, could lead to conclusions as to how the activity may have contributed to the movement observed and appropriate corrective actions could be initiated.

The TBM data logger file saved some 120 data points every 10 seconds (more than 1 million per day per TBM) into a database file format (*.dbf). These dbf files were saved on a daily basis providing a complete 24 hour period with a file size of approximately 20 MB before conversion to the spreadsheet format. Generally two methods were employed for the analysis of the TBM data logger file. On a daily basis the TBM data alone could be graphed over 24 hours or added to create an update to the existing 100 m interval reporting graphics.

Through the City Standards Division it was possible for samples of the soil to be taken from site and tested on a daily basis such that bulking factors, material classification and other data were obtained. Using the soil bulking factors and the excavated volume observations made by the tunnel inspectors it was possible to

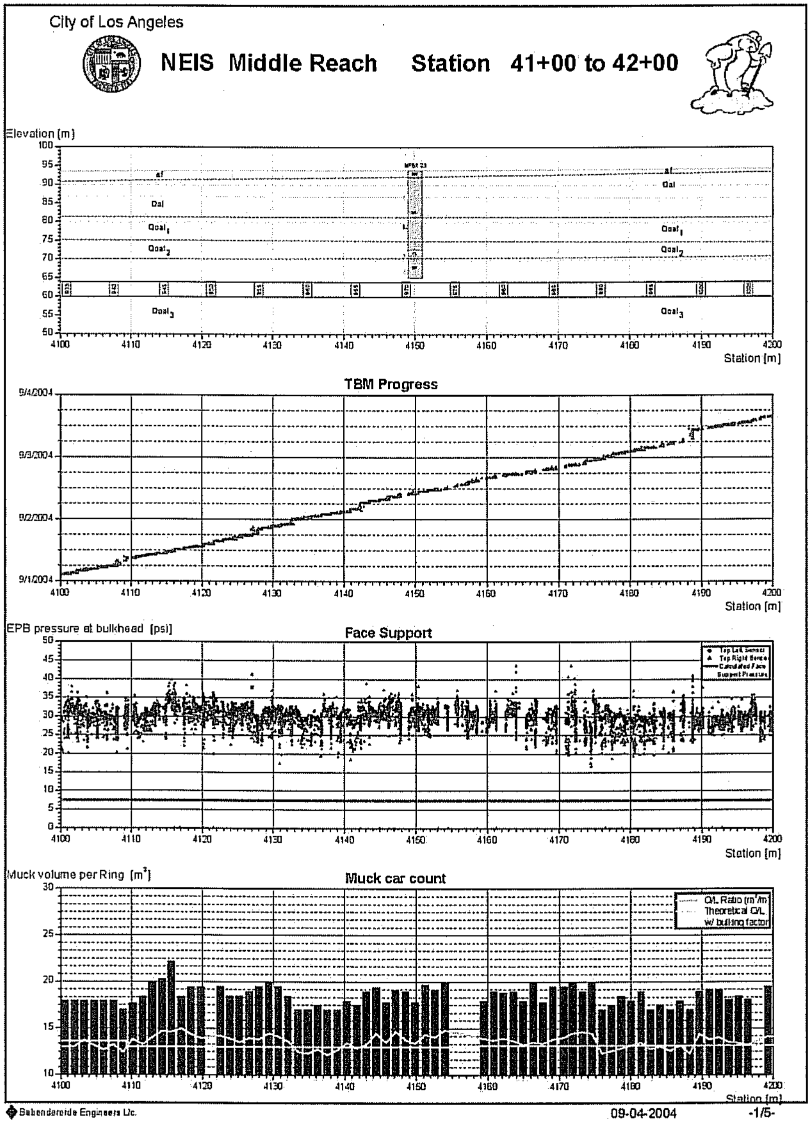

Figure 6. Page 1 of the NEIS graphic report showing geology with tunnel ring numbers, TBM progress, face support pressure and muck volume counts with theoretical and actual Q/L ratio

calculate both theoretical and real bulked volumes in terms of m^3/m excavated and compare them directly on the report graphic.

In this manner the integration of many disparate pieces of information were brought together within 24 hours or less of the events taking place permitting the construction management team to follow the events of the tunnel drive and draw some conclusion as to the control of the TBM advance.

THE GRAPHIC REPORT

The basic reports for the EPB TBMs employed on the NEIS project were developed to incorporate all of the important parameters outlined above. Each 100 m interval was divided into 5 pages of 3 to 4 graphics per page. The software used to produce the final output was *Origin Graph* 7.0. This software was chosen due to its ability to handle very large data files like those generated by the TBM data logging system. All variables were plotted with respect to tunnel station so that at any given station the geology, time and date, volume of material excavated, bulking factor, grouting volumes and pressures, ground conditioning settings, cutterhead power consumption, screw speed, cutterhead speed, penetration rates, and others could be presented.

Figure 6 below shows page 1 of the graphical report. All important details of the tunnel drive have been included in this report. The graphics synthesize everything known about the TBM advance for this period in a concise format. These concise reports proved to be of particular value to the City construction management team tying together the available data and making sure everyone involved was on the same page.

CONCLUSION

Thanks to the cooperative and open approach TSFK took toward the sharing and dissemination of the TBM data and the excellent teamwork shown by the various City departments, a timely and successful completion of the tunneling works was achieved. Moreover, the data collected and produced by the various collaborators provided the opportunity to create graphical reports which reflect state of the art construction management techniques, helping to summarize not only the TBM activity but to achieve a high degree of project integration as a result.