A Conceptual Methodology and Practical Guidelines for Managing Data and Documents on Hydroelectric Projects

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Summary

Hydroelectric Projects produce a lot of data. In response, more and more projects are using document management systems (DMS). Dedicated data collection systems are often used for materials testing and for inspection records. Most of these systems are being developed or adapted on an ad hoc basis during the course of the project and QS procedures are often not strictly enforced. Procedures for recording, storing and presenting engineering data are often informal and developed only late in the project course. This trend, in the authors' opinion, represents an overall loss of project control, which can lead to increased project risk and overruns, particularly given the data's contractual and monetary implications.

This paper presents a conceptual methodology for implementing a data management system for hydroelectric projects, primarily intended for use by Owners. It addresses the necessary procedures and terms of reference for consultancy contracts and tender documents for construction. These contractual provisions help ensure that procedures for engineering data will be put in place early and that they will be used throughout the project. The workflow procedures define formal steps for data checking, review and approval. Engineering classification of data (by time, location, work type, etc.) is introduced as a mechanism of organizing and finding data. An outline for functional requirements for a computer database system to manage project engineering data will be presented.

A major problem is that data management is started late (often only after construction has begun), and information is therefore compiled late (e.g. as-builts) and is not sufficiently available during the work phase to be useful for inspections and for the definition of final design measures (such as for tunnel finishing). Data is often not uniquely identifiable by date and location (e.g. tunnel chainage) making it difficult to find. Rigorous QS procedures such as those used during materials testing and for document control are not followed for data handling. Multiple instances and gaps in data may even exist, making it impossible to later demonstrate the completeness and correctness of collected data.

A better approach is to define the authoritative set of engineering data considered vital to the project. The definition begins in the initial project planning stages and evolves as the project moves into tendering and construction. Formal procedures for data handling, including recording, storage and presentation need to be developed following well-known QS procedures similar to those required for materials testing and document control. The procedures need to address the checking, review and approval of recorded engineering data. After compilation and presentation of data sets (such as longitudinal tunnel profiles), best done shortly after data collection, additional checking can be made during inspections. Procedures must ensure that all resulting data corrections are logged and traceable.

The authoritative set of engineering data should be agreed by all involved parties and used throughout the project by the designers, contractors and experts. It is recognized that during the planning and construction, data in many forms will be produced and maintained for various purposes. The aim of having an authoritative set of engineering data should be to facilitate findings of fact by establishing a baseline for evaluating the quality of the work and for evaluating changed conditions.

1. Overview

More and more project managers are using centralized document management systems (DMS) for the electronic tracking of documents, which typically integrate a workflow for document approval and transmittal. Some electronic document systems use an engineering classification system (document metadata) for filing and retrieval. If properly configured and implemented for a project, DMS saves substantial engineering time, especially for document transmittal and for document retrieval. DMS can also provide a user friendly means of complying with project quality management (QM) procedures. For more information on using DMS for construction projects, refer to a previous paper *Collaborative Best Practices for Construction Projects* by the authors (2008, ITA in Agra, India).

Unfortunately rigorous procedures for the electronic tracking of data are less developed. A great deal of project data resides in spreadsheets or in the data repositories of different software products, where QM procedures are often not strictly enforced. Procedures for data handling are typically developed or adapted on an ad hoc basis during the course of the project. Procedures for recording, storing and presenting engineering data are often informal and developed only late in the project course. Data are often stored in proprietary and/or undocumented formats that need special knowledge (or software) to be processed. The data can become worthless if the person who knows how to handle it leaves the project, or even if the software version changes. Multiple instances and gaps in data may even exist, making it impossible to later demonstrate the completeness and correctness of collected data. This trend, in the authors' opinion, represents an overall loss of project control, which can lead to increased project risk and overruns, particularly given the data's contractual and monetary implications.

For specialized activities such as materials testing and for geological mapping of tunnels, dedicated data collection systems are being used more frequently during projects. Such systems can provide more rigorous procedures for data handling, but are often implemented as standalone systems, and are not well integrated with other project management procedures. In order to analyze the information available in the data collected by various systems or persons, the integration of data is important to allow informed and timely decisions making.

In the author's experience, more robust systems for the electronic tracking of engineering data are needed to improve the efficiency of data handling, to ensure the integrity of data, to make the data more useful for analysis and for project management, and to ensure that QM procedures are followed.

This paper presents a conceptual methodology for implementing a data management system for hydroelectric projects, primarily intended for use by Owners. It addresses the necessary procedures and terms of reference for consultancy contracts and tender documents for construction.

The term *engineering data* includes all project planning data (such as topography, geological site investigations) and construction data (such as for production, encountered geological conditions, materials testing, inspections and sensor data), as distinct from project documents, which may make reference to the data.

In this paper we will primarily draw on our experience with pressure tunnels to provide examples of handling the associated engineering data. The emphasis will be on data from geological mapping, applied rock support and tunnel production. These demonstrate the importance of good data tracking for decision-making at the tunnel face, for measurement and payment purposes, for monitoring of construction schedules, for claims handling, for deciding final lining measures and for as-built documentation.

2. Data Collection

Without the collection of good data, a discussion of the storage and presentation of engineering data isn't very meaningful. What is good data? Using the unlined pressure tunnel example, good geological data results from competent people having adequate access to the tunnel to perform mapping and inspections. But will this alone ensure good data collection? A clear record of where the data are obtained (e.g. tunnel chainage) and the time of the observation are also essential. For example, will it later be clear whether the chainage refers to the tunnel drive or to the tunnel itself, of what the "right hand side" and "left hand side" of the tunnel refers to? Wherever data is produced through human observations – like in geological mapping – it is also important that different people stick to the same terminology to describe the observations. It is also important to know who recorded the data, to ensure traceability in case any questions arise.

More generally, procedures are required that document:

- Who recorded the data
- Who checked the recorded data
- Who approved the recorded data for entry into the permanent project record
- Metadata ("data about the data") describing the data, including location and time

- which methods were used to gather the data.

The procedures must ensure that both consistent formats (e.g. date and location) and a consistent terminology (e.g. geological descriptions) are used throughout the data collection process. The procedures must also ensure that all required data is recorded (by using for example checklists).

Engineering data can include individual data points (e.g. testing results) as well as compiled data (e.g. shift reports, geological mapping). Hence different forms of data may be available. Data collection procedures must consider all data forms, which will be encountered in the project, such as:

- "Raw data" – a geotechnical parameters, geological mapping, production data
- "Instructed data" – rock support or grouting instructions
- "Published data" – scans of original shift reports, surveyed tunnel profiles, drilling logs
- Proprietary ("closed") – data formats, which can only be used in conjunction with the corresponding computer software to produce reports
- "Data reports" – data presentations produced using raw or published data

Recommendations:

1. Put someone in overall charge of managing engineering data, with a clear definition of his role in QM and in the project management team. Even the best possible data handling system won't work without the right people using and overseeing the system. Depending on the project size and organization, the duties of the "data manager" could be additional to their other engineering and construction responsibilities.

2. Develop procedures for handling engineering data for the project early, so that these can be incorporated early in work procedures and in contract documents and so that the computer software can be configured accordingly.

3. Define a project geometry that will be used for all location information (e.g. tunnel alignments with chainage range). This could in turn be part of a project work breakdown schedule (WBS) and consideration should be given for using the project WBS as an additional data classification parameter. Define strict workflows to ensure that changes to basic information like project geometry, etc. are populated to all systems and all persons at the same point in time.

4. Develop a common terminology for project data reporting. Also define measurement units and formats (e.g. date), which will be used for data reporting. Define drawings scales to be used for published data.

5. Separate the data collection, data storage and data presentation tasks. The format required for presenting data is probably not appropriate for recording the data. Multiple presentations (reuse) of the same data, in different formats, will probably also be required.

6. Develop "clipboard" forms for recording data in the field in a format which encourage consistent usage and which are structured as checklists to ensure completeness. Data entry should be carried out using "friendly" screens that match the printed inspection forms. Make sure that forms allow the location to be given (e.g. chainage) for individual data points (e.g. different types of rock support such as rock bolts and shotcrete ending and starting at different chainages).

7. After recorded field data is entered into the data storage system, a data report should be produced and printed in exactly the same format as that used for data collection. This "check print" facilitates checking.

8. Formal checking of collected data should be required, following similar QM procedures as for reports and other documents.

9. Formal approvals of collected data should be required, following similar QM procedures as for reports and other documents. Multiple approvals may be required, for example by the site supervision and by the contractor. Data handling procedures must consider corrections, which might be required to data during the approval process. Any changes to the data later agreed should be recorded and traceable.

10. At the start of the project, establish a project culture for managing data, by training all personnel to understand and use the procedures and software efficiently. Even the best systems will fail if users are unable or unwilling to use them.

11. Data from automated sensors may need appropriate data reduction algorithms for collecting data over a long period of time.

12. All recorded data, its corresponding metadata and the approval trail, should all be stored together to ensure integrity.

Example data collection forms:

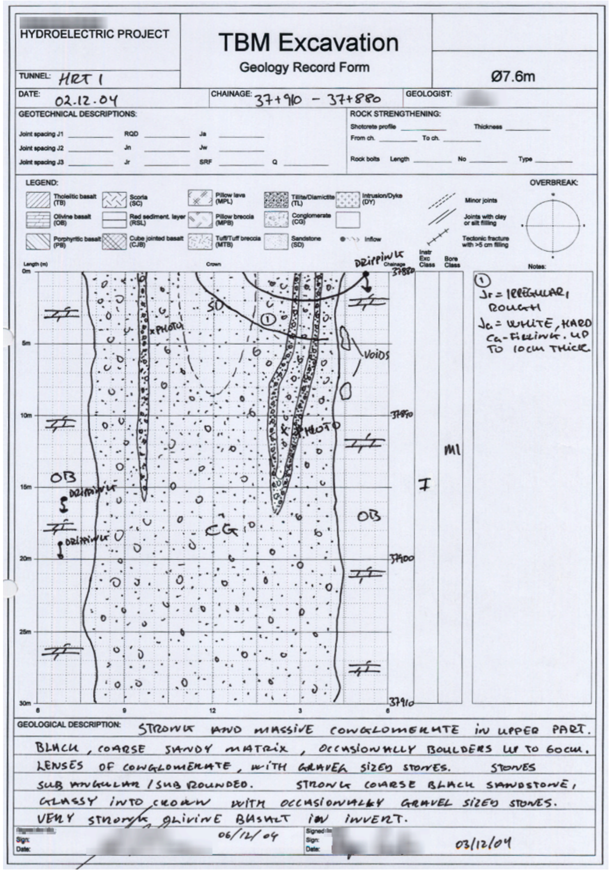

Figure 1. Example of geological mapping for pressure tunnel

Figure 1. Shows an example of a geological mapping form used during the excavation of a tunnel-by-tunnel boring machine (TBM). The form includes an area for sketching the mapping by hand and for a text description (using terminology agreed for the project). Back in the office, the sketch could be scanned (perhaps after being redrawn in the office), input into a tunnel database and used for as-built drawings. The text data could be entered into the tunnel database using a combination of parameter fields and descriptive text. Better use might be made of checkboxes on the form for some geological and geotechnical properties.

HRT Rock Support &Final Lining Inspection Form

Tunnel Drive	HRT 1		Reinspection 2006-11-21		
Engin.		Signature		Date	23.08.2005
Engineer		Signature		Date	16/9/2005

Chainage (m) From	Chainage (m) To	Excv. Class	Rock Type cwn/wall/inv	Water Inflow in HZ (l/s)	Erodability cwn/wall/inv	Leakage pot.	Rockbolts Nr/m²	Rockbolts Loc.	Rockbolts L (m)	Mesh Type	Mesh Loc.	Ribs Type	Ribs Loc.	Shotcrete s (m²)	Shotcrete t (mm)	Shotcrete Loc.	Shotcrete Fib.	Inv. Conc.	Drain holes (pattern m x m)	Comm. Nr.
Instructed Rock Support and Final Lining Becoming PB+CG at 38+610							(Ch. 38+585 - 38+595)													
38+660	38+385	I	PB/SC+RSL/CG+SD				Total 7	SPOT	2											
Installed Rock Support																				
38+660	38+385	I					ROCKBOLTS NOT INSTALLED													
Additional Rock Support and Final Lining Measures Requested by Engineer																				
38+660	38+385				N-L/N-L/N-L	N														
Instructed Rock Support and Final Lining (DYKE 38+365)							(BOLTS NOT INSTRUCTED 38+370 to 38+360)													
38+385	38+320	II	RSL/SD/PB				1	10-2	2						50	9-3	Y			
Installed Rock Support																				
38+385	38+320	I					NO ROCK SUPPORT INSTALLED													
Additional Rock Support and Final Lining Measures Requested by Engineer																				23.08.05
38+385	38+320				H/L/N	N				~~5~~	~~8-4~~ ~~5m~~				~~200~~ 150	8-4	Y		2-2	

Comments:	→ to be checked in tunnel by			
Scaling	Rem. unacc. shotcrete	Drain. behind shotcrete	Contact grouting	Consolid. grouting
Concrete backfill voids	Smoothing of shotcrete	Shotcrete cover over bolts		

Figure 2. Example of tunnel inspection data for pressure tunnel

Figure 2. shows an example of a tunnel rock support data form used for walkthrough tunnel inspections, for the final checking of rock support applied during excavation and for the definition of final requirements. The corrections noted were entered in the database record together with checking and approval. The forms were only used for collecting tunnel data. Instructions to the contractor were issued in the required contractual format.

After compilation and presentation of data sets (such as with longitudinal tunnel profiles), best done shortly after data collection, additional checking can be made during later inspections and the data handling procedures should take advantage of this additional checking.

Documents: 1 - 11 of 11						
#	Document	Rev.	Approval			Title
			Complete	Who	Status	
1	14-C-3.93.0051	C1	2006-08-07	KAJ/EW	A	Headrace; Rock Support and Final Lining; HRT, Ch 38+955 - 39+285; Inspection Form
2	14-C-3.93.0052	C1	2006-08-07	KAJ/EW	A	Headrace; Rock Support and Final Lining; HRT, Ch 38+660 - 38+955; Inspection Form
3	14-C-3.93.0053	C1	2006-08-07	KAJ/EW	A	Headrace; Rock Support and Final Lining; HRT, Ch 37+820 - 38+660; Inspection Form
4	14-C-3.93.0053	C2	2006-11-21	KAJ/EW	A	Headrace; Rock Support and Final Lining; HRT, Ch 37+820 - 38+660; Inspection Form
5	14-C-3.93.0054	C1	2006-08-07	KAJ/EW	A	Headrace; Rock Support and Final Lining; HRT, Ch 36+200 - 37+820; Inspection Form
6	14-C-3.93.0054	C2	2006-11-21	KAJ/EW	A	Headrace; Rock Support and Final Lining; HRT, Ch 36+200 - 37+820; Inspection Form
7	14-C-3.93.0055	C1	2006-08-07	KAJ/EW	A	Headrace; Rock Support and Final Lining; HRT, Ch 34+940 - 36+200; Inspection Form
8	14-C-3.93.0055	C2	2006-11-09	KAJ/EW	A	Headrace; Rock Support and Final Lining; HRT, Ch 34+940 - 36+200; Inspection Form
9	14-C-3.93.0056	C1	2006-08-07	KAJ/EW	A	Headrace; Rock Support and Final Lining; HRT, Ch 32+744 - 34+940; Inspection Form
10	14-C-3.93.0057	C1	2006-08-07	KAJ/EW	A	Headrace; Rock Support and Final Lining; HRT, Ch 31+400 - 32+744; Inspection Form
11	14-C-3.93.0058	C1	2006-08-07	KAJ/EW	A	Headrace; Rock Support and Final Lining; HRT, Ch 30+383 - 31+400; Inspection Form

Figure 3. Example of tunnel data tracking

In Figure 3. an example of the electronic tracking of final tunnel inspections, including the approvals, is shown.

3. Data Storage

In the experience of the authors, an integrated and shared, centralized database is the preferred way of organizing and enforcing procedures for data collection. This must be started early so that it is readily available during the work phase for inspections, for claims management and for the definition of final design measures.

Some of the advantages of a centralized database are:
- Project engineering data is maintained in a secure location, by computer professionals, who are responsible for data integrity and backups.
- Engineering data is accessible by all project participants (with appropriate data privileges).
- Data access rights are managed in a central place. Users have only one login for access to all information.
- By using good data collection procedures and appropriate QM procedures for data checking and approval, it can be ensured that the engineering data maintained in the database is accurate and complete (no data gaps).
- Multiple instances of the same data, which leads to confusion, can be identified and eliminated.
- Data is uniquely identifiable through the consistent use of metadata for the engineering classification of the data, including location and date stamps. Specific search requests for data can be carried out.
- Because all data is stored together and is classified ("keyed"), analysis of the engineering data across disciplines and organizational entities is possible (e.g. analysis of the effect of geological conditions on tunnel production).
- Archiving of data is much easier.

Recommendations:

1. Develop requirements for computer infrastructure and database software for the project early, so that these can be incorporated in work procedures for handling engineering data and in contractual provisions. Allow time for the sourcing, procurement and configuration of appropriate computer infrastructure and database software. If existing software will continue to be used for data handling, allow time and budget for the necessary customization and configuration work.

2. Involve competent computer specialists with the selection of computer infrastructure and database software, who understand both database technology and construction project procedures.

3. Make sure that the database software selected for the project is appropriate for the procedures developed for collecting and handling engineering data. Make sure that the project engineering requirements determine the selection of software and not vice versa.

4. If more than one software system is in use, ensure that the systems are able to exchange data. Strive for solutions where these data transfers can be done automatically (without human interaction) to minimize possible sources of error.

5. Include appropriate provisions in the contractual documents for the handling of engineering data, for example in the submittals section of the Technical Specification.

6. An authoritative set of engineering data should be agreed by all involved parties and used throughout the project by the designers, contractors and experts.

4. Data Presentation and Reporting

Ideally all routine needs for data presentation should be accommodated by the implemented software solution for data handling. During the construction phase of pressure tunnels this normally includes:

- Daily geological reports and production reports of tunnel excavation,
- Site Instructions for rock support, grouting, etc.
- Geological mapping and installed rock support data for tunnel record
- Weekly reports of tunnel progress
- Monthly reports of tunnel progress
- Quantities reports for payment certification
- Tunnel inspections reports
- As-built tunnel profiles showing geology, rock support, etc.

A good selection of standard report styles, making use of appropriate graphs and charts, should be available at the start of each work phase. The required reports should be carefully scoped out during project development and required submittals and approvals identified in contract documents. The presentations can be improved and adjusted as the work progress independent of the data collection procedures. The stored project data always remains intact. When adjusting data presentation strive for consistency in visual style (e.g. the same rock type should be presented with the same color in all presentations).

In hydropower projects a large amount of data coming from different sources should be expected. To be able to assess project risks, it is essential that the available data can be evaluated in a short time. Analysis and graphing tools are needed that allow the automated generation of data reports.

Claim management requires dealing with situations where specific data are required to either support or avert a claim. This means being prepared to answer questions that cannot be foreseen. Data that is only stored as published data (e.g. scanned PDFs) often cannot be further processed or analyzed using a database system. This is important to consider when selecting specialized software such as for drill hole logging, materials testing and tunnel profiling.

Recommendations:

1. Scope out requirements for reporting which involves data analysis and presentation early in the project to make sure that these requirements can be accommodated by the selected database software system.

2. Make sure that the database software supplier can provide adequate standard chart styles and report styles to provide basic automated reporting capability. Make sure that the report styles can be adjusted and improved, preferably by the software user.

3. Make sure that specialized software procured for the project includes adequate provisions for data export to the database system (avoid locked data).

4. Be aware that no database software system can foresee all analysis and reporting needs. It is important that selected data can conveniently be exported from the database and downloaded to other software (e.g. spreadsheets) for further processing.

In Figures 4, 5 and 6 some typical examples of data presentation for tunnel construction are shown, corresponding to common practice in the industry.

<u>Examples of data presentation:</u>

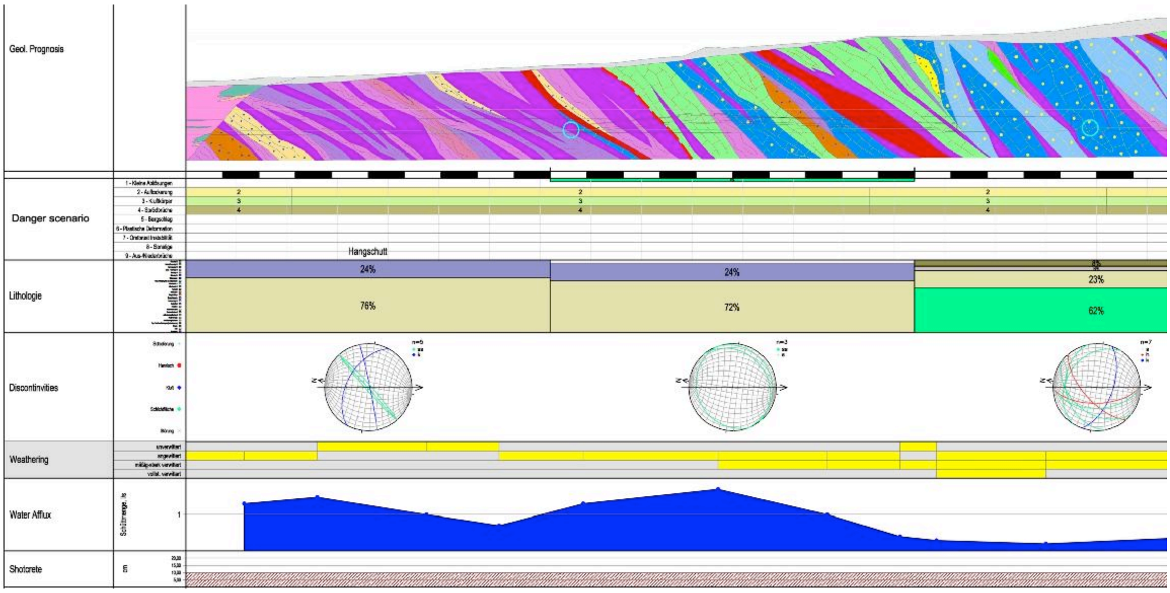

Figure 4. Example of a tunnel data presentation using a longitudinal profile

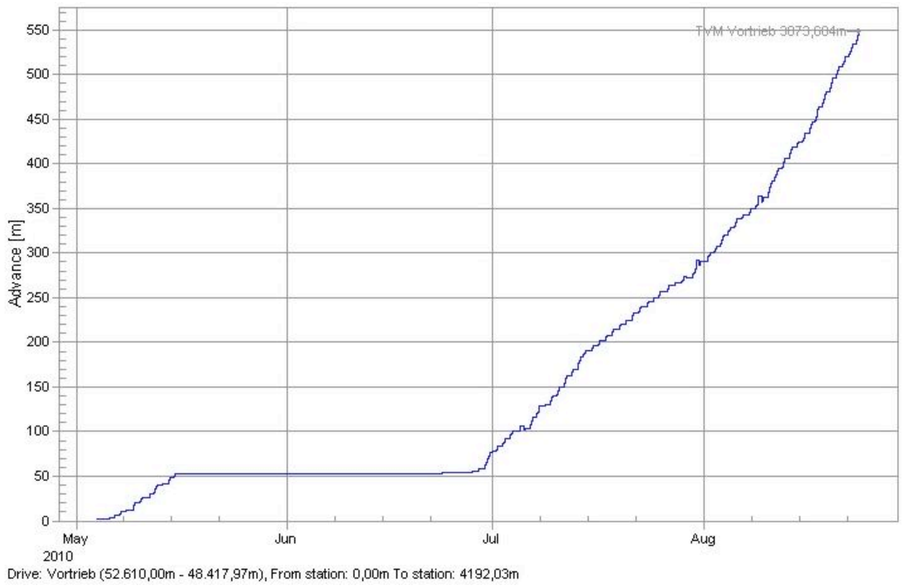

Figure 5. Example of data presentation showing using a time-distance diagram to show tunnel advance.

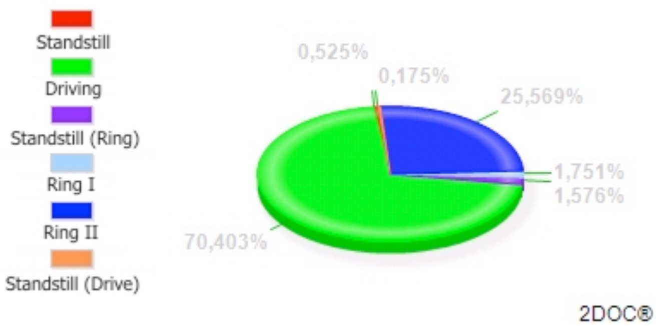

Figure 6. Example of data presentation showing breakdown of TBM production

5. Contractual Aspects

Appropriate contractual provisions help ensure that procedures for managing engineering data will be put in place early, accepted by all parties, and will be used throughout the project.

It is important to realize that during the planning and construction of a hydropower project, data in many forms will be produced and maintained. The recommended approach is to define an authoritative set of engineering data considered vital to the project. The definition begins in the initial project planning stages and evolves as the project moves into tendering and construction. The authoritative set of engineering data should be agreed by all involved parties and used throughout the project by the designers, site supervision, contractors and experts.

The contractual aim of having an authoritative set of engineering data should be to facilitate findings of fact, by establishing a baseline for evaluating the quality of the work and for evaluating changed conditions. Formal procedures of data handling, including data collection, storage and reporting should to be developed, as described above, following well-known QM procedures.

Some recommendations for contractual provisions relating to the Terms of Reference and Technical Specifications for the handling of engineering data are described below.

Recommendations:

1. Requirements for the handling of engineering data should be established by the project Owner early in the project. These requirements should be included in the Terms of Reference in Tenders for engineering services (together with requirements for a Document Management System). This ensures competitive bids for the required computer hardware and software. The requirements must ensure that adequate technical support will be available from the software vendors.

2. Quality Management Requirements (such as those in the Conditions of Contract for construction contracts) should explicitly require quality management procedures for the handling of engineering data and documents.

3. Individual sections of the Technical Specifications should specifically address the requirements for the submittal and approval of engineering data, including data collection, data storage and reporting. Time allowances for submitting and approving engineering data should also be given. The time allowed for data transmittal is especially important for data collected from monitoring devices (e.g. tunnel convergence, TBM machine parameters).

4. Assign data ownership for all recorded data, and ensure that project participants have access to the data they need. Ensure that the data ownership is assigned to the Owner after the project ends and that an appropriate license to access the data is provided.

Figure 7. Photo showing tunnel inspections in TBM rear zone

In Figure 7 typical inspection conditions in a tunnel are shown. Note the access restrictions to the tunnel wall, which affect data collection, and need to be addressed in contract provisions.

6. Conclusions

Implementing data management systems for hydroelectric projects is important and can lead to significant efficiencies and help reduce project risk. The requirements for the data collection and management process should be defined by the project Owner at the start of the project and included in the project's terms of references. This should include defining the authoritative set of engineering data considered vital to the project.

Responsibility for the data management effort should be explicitly assigned to an engineering data manager, who is a member of the project team. The data manager should further define the methodology and the quality procedures to be used, and actively promote and manage them to ensure that they become part of the project culture.

Formal procedures for data handling, including recording, storage and reporting must be developed, ideally modeled after well-known QS procedures, such as those used for materials testing and document control. All data should have engineering classification applied to it to enable it to be easily located and correlated with related data. All project members should have access to the data required for performing their assigned tasks.

The data management procedures should:

- Be agreed upon and used by all involved parties
- Be applied to all data that has bearing on quality of work, changed conditions and other contractual issues
- Require that all data is identified and classified using a standardized project terminology (classification system)
- Include formal mechanisms for checking, correcting and approving all data, and ensuring that all data corrections are logged and traceable
- Separate data collection and checking from data use (e.g. reporting)
- Be agreed as an authoritative source for findings of fact

Benefits are:

- Better quality control
- Better recognition of risk
- Less time lost searching for data
- Faster problem solving due to the ease of cross checking
- Better data sharing leads to better resolution of problems

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