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Manual of Geological Boring and Engineering Investigation of Dam Geology for Next-Generation Dam Engineers

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ABSTRACT:
The Geology and Foundation Research Group of the Japanese Society of Dam Engineers (JSDE) has been editing the "Manual of geological boring and engineering investigation of dam geology for next-generation dam engineers." This paper gives an outline of the manual and introduces the editing policy used for the manual's creation. Recently, the following technological concerns have been highlighted in engineering investigations of dam geology. (1) Technology for boring and investigating dam geology has advanced and diversified. (2) On-the-job training opportunities for young engineers have become less abundant. (3) Young engineers have come to depend on the Internet for information and their knowledge has become fragmented. Therefore, the next generation of engineers must have comprehensive and systematic technological knowledge, from the fundamental tools to the latest innovations. The publication of the JSDE manual is intended to address these concerns.

Keywords: engineering geology, dam geology, core logging, borehole test, geotechnical manual

1. GEOLOGICAL TECHNOLOGY IN THE CONSTRUCTION OF DAMS IN JAPAN

Dam construction is a comprehensive project in which various operations are systematically completed in stages, from initial planning and investigation of the dam to its design, construction, and maintenance. For this series of technical processes, scientific and engineering knowledge of geology are needed. Therefore, coordination between geological and civil engineering technologies systematically contributes to all steps of dam construction.

Specifically, the technologies have been brought together to generate systematic techniques for the surveying of geological structures; measurement, evaluation and classification of rock mass; creation of geologic maps; modeling of foundations; and designing of dams. Moreover, these techniques have been used to solve complex problems about the hydraulic and mechanical aspects of the base rock and reservoir slope of dams.

Cooperation between geological engineering and civil engineering is a consequence of the development of rock mechanics not only in Japan but also around the world, and is used when building the foundations of rock mass structures such as bridges, nuclear installations, tunnels, and underground caves. In the future, that young geological and civil engineering engineers can utilize and develop the techniques in both subject areas will be vital.

2. CURRENT GEOLOGICAL SURVEYING OF DAMS IN JAPAN: AN OVERVIEW

2.1. Necessity of Detailed and Advanced Geological Survey Techniques

A dam must be integrated with the foundation rock to provide a support function such that it bears mechanical loads from the immerse pressure generated by water storage, to provide a seepage control function to prevent water leakage, and to smoothly pass stored water downstream. Furthermore, the natural slope that constitutes the reservoir must also provide a seepage function and stability.

Dam construction is broad in scope and includes various other construction tasks such as excavation and the building of reservoir management facilities, roads, banks, tunnels, and bridges. The Japanese archipelago has problematic geological features, for example, being located on the active tectonic belt of a plate boundary, and having steep topographic features and weak rocks. Moreover, there are social restrictions, such as dense populated land use in mountainous areas. Consequently, the geological conditions for dams in Japan are not necessarily good.

Thus, reliable dams are rationally constructed in Japan by evaluating, from a theoretical viewpoint, the geological conditions clarified by geological surveying. As a result, advanced geological surveying of the dam site, reservoir, and surrounding area is necessary.

2.2. Necessity of Advanced and Rationalized Geological Survey Technology

The necessity of rational dams construction is now more commonly recognized in Japan than was previously the case. Moreover, environmental considerations and cost containment have become major subjects of interest in dam construction, reflecting public opinion in Japan and the severe budget problems faced by the government.

In light of these considerations, the progression of new dam technology is needed in Japan. The research and development of this technology is actively being performed, and many promising results are being obtained. In connection with geology, for example, construction methods are being developed for cemented sand and gravel dam (C.S.G.D) and concrete-faced rockfill dam (C.F.R.D). Furthermore, design and construction methods have been created for the effective utilization of low-quality materials.

Thus, in Japan, various technological developments and cost-cutting measures are being actively advanced in dam design and construction in connection with geology. To realize these methods, technological development must also be accomplished in the geological surveying of dams.

2.3. Advanced Geological Survey Technology in Dam Construction Projects

Suitable techniques must be selected in order to plan a dam by using such advanced geological survey technologies. Thus, flexibility in the corresponding technical thought processes is required to manage varying conditions, such as the geographical features affecting the form and scale of the dams. Moreover, any new technology adopted must be the most suitable for each individual dam, since more rational design and greater cost containment can be achieved by doing so, while securing the quality, safety, and reliability of the dam.

2.4. Advancement of Boring Survey Technology and Necessity of Rational Application

2.4.1. Comprehensive explanation of boring survey technology
Boring surveys are typically used for dam constructions in Japan as a highly general and effective method for geological investigation. A boring survey collects a core directly from hidden underground geological layers, which can then be observed and used to perform various investigations, such as permeability and mechanical tests, and an investigation of the physical properties of the borehole.

In Japan, among the explanations of boring survey technology, “Boring Pocketbook”, “Boring Log Creation Explanation” and “Method of Geotechnical Survey” are popular reference manuals and considered very useful.
However, an indication of the importance of combining investigation techniques, estimating results, and the sense of a geological survey and evaluation by such technical documents is not enough for a construction project.

For this reason, boring surveys in Japan are conducted by the sponsoring organization, consultants, and the engineers, all of which have various viewpoints. As a result, when Japanese geological survey results are used for evaluation, often many problems occur.

2.4.2. Standardization of boring survey information
In Japan, data storage systems are being developed, such as databases containing geological information and geological maps, as well as the “public works support integrated information system (CALS/EC).” For that purpose, the standardization of geological information and preservation of data quality are indispensable.

2.4.3. Precise application of advanced boring survey technology
In recent years, highly precise data have become acquirable through the rapid progress of boring survey and examination technology, for example, boring and core extraction technology; and borehole investigation and measurement technology, such as wall photography, permeability tests, geophysical prospecting and borehole loading tests. These developed technologies must be used to evaluate the various features of dam geology.

2.5. Progression of Geological Technology and Necessity of Engineer Training

The engineer's roles and responsibilities in responding to the present condition of geological survey and evaluation technology are as follows.

i) Young engineers and all on-site engineers must understand geological survey techniques, as well as acquire systematic knowledge and information in order to evaluate dam technology.

ii) They must gain strong scientific insight and imaginative skill to capture the essence of geological structures and phenomena.

iii) They must achieve high-level technical capabilities based on the essence of science and engineering; that is, not to be caught up in existing notions.

To realize these roles and responsibilities, young engineers must experience multifaceted engineering work, understand the different viewpoints in various operations as well as receive on-the-job training. Moreover, engineering conventions based on the technical concepts and fundamentals studied in the book are important for acquiring systematic knowledge. Of course, it is also necessary for young engineers to add new viewpoints, to reconstruct geological technology, and to develop by using existing knowledge and the experiences of veteran engineers.
The young engineers will be brought up to the excellent engineer and lead the Japanese geological technology in the future. Finally, to support developing countries, Japanese geological technology of dams might be disseminated by the young engineers.

3. OUTLINE OF TECHNICAL MANUAL

As the background described in Sections 1 and 2, for the past 5 years, the Geology and Foundation Research Group of the Japanese Society of Dam Engineers has been editing the "Manual of geological boring and engineering investigation of dam geology for next-generation dam engineers."
This technical manual theoretically explains to young engineers not only of the dam engineering but also civil engineering, geological survey and boring survey technology in detail. The book consists of 5 parts and 15 chapters. Hereinafter, an outline of each part and each chapter is given.

Table of Content

3.1. Part 1: geological survey and boring survey technology of dams

3.1.1. Chapter 1: outline of geological survey of dams
Chapter 1 explains the purpose of the geological survey and explains the survey roles in all stages of dam construction from the planning and investigation stages of a dam to its design, construction, and maintenance. In this discussion, the manual describes the plan–do–check–study (PDCS) cycle, which is a fundamental aspect of how geological surveys progress as shown in Fig.1:

- Plan (design a site investigation)
- Do (implement the investigation)
- Check (assess the investigation)
- Study (evaluate the results of the investigation)

As the name suggests, the PDCS cycle is analogous to the plan–do–check–act cycle, which is a technique used

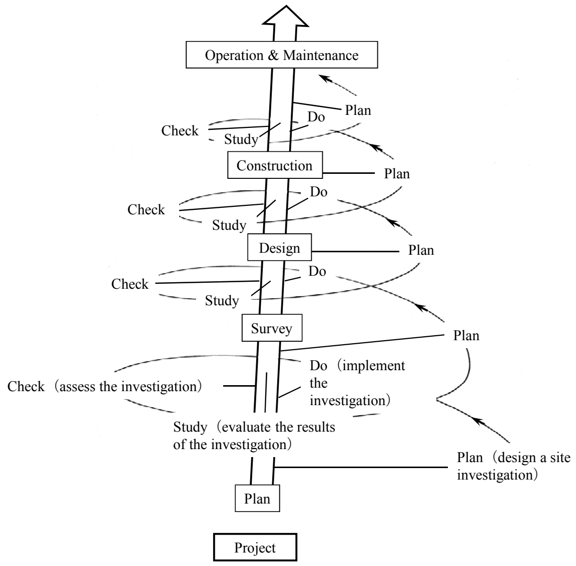


Figure 1. Outline of PDCS cycle for dam construction

in quality control.

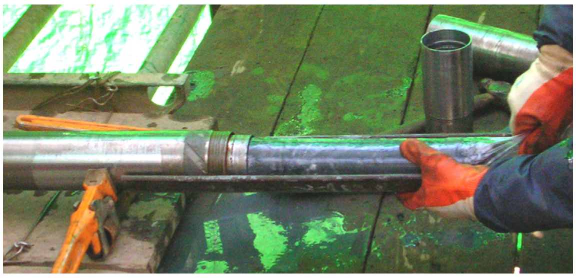
3.1.2. Chapter 2: on-site boring survey technology
Chapter 2 explains on-site boring survey technologies, such as boring machines and core extractors. Here, high-quality core extraction and the storage of extraction cores are discussed.

(a)Technology for high-quality core extraction
The extraction of low-quality cores has been the cause of mistaken judgments in the past. Moreover, the extraction quality can affect examination and measurement of the borehole or the core. For this reason, techniques for using core extraction technology have been developed in Japan. As a result, nowadays, core extraction is generally performed in all areas, even those with weathered rock or that is part of a fault zone.

Many techniques are used to ensure extraction quality is maintained, for example, (1) adapting a double core barrel and core pack tube as shown in Fig. 2 or (2) using large-scale coring as shown in Fig. 3. Boring survey engineers are skilled in these highly technical developments. In particular, when we excavate jointed rock or weak rock and require high-quality sampling cores, we use foaming fluid in combination with large-scale coring as shown in Fig. 4.

(b) Storage of extraction cores
The extracted cores are protected by a core box during conveyance, storage, and observation (Figs. 3 and 4).
The most suitable core box must be selected and is set by the borehole caliber. Written down on the box are the investigation name, borehole number, drill name, depth, altitude, period, investigation contractor name, and other details. Core observation and photography are performed promptly after core extraction

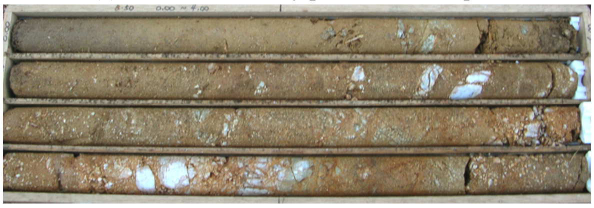
(a) Core pack tube as equipped



(b) Core wrapped in a core pack tube

Figure 2. Core extraction by core pack tube

(a) Core extraction by previous techniques



(b) High-quality core extraction by large-scale boring

Figure 3. Comparison of cores extracted from the topsoil

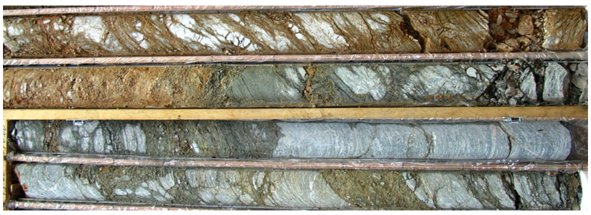


Figure 4. High-quality core extracted during landslide investigation by large-scale boring using foaming fluid

3.1.3. Chapter 3: observation of extracted cores

Chapter 3 explains core observation methods, namely, the creation of borehole logs for a boring survey. A summary is recorded in this log of the observation time, the drilling condition, the results of core observation and any general information. Core observations and evaluations based on geographical features and the geological formation process are also described in the survey report. The representative of Japanese borehole log is shown in Fig. 5.

3.1.4. Chapter 4: investigation of borehole wall

Chapter 4 explains borehole wall photography and caliper logging methods. By analyzing photographs of the borehole wall, the dip and strike, the opening widthof a discontinuity can be measured. Moreover, when performing the various borehole examinations and measurements, wall photography and caliper logging methods are used to estimate the conditions at the testing position.

3.1.5. Chapter 5: investigation and examination of hydraulic characteristics

Chapter 5 explains the methods applied to investigate hydraulic characteristics of the dam foundation, reservoir, and slope. Lugeon tests, permeability tests based on Darcy's law, groundwater level and flow investigations, seepage failure tests and other examinations are described.

3.1.6. Chapter 6: examination of the physical and mechanical properties of boreholes

To design the dam foundations and evaluate the stability of the slope, an examination of the physical and mechanical properties of the borehole is needed.

Chapter 6 explains the purpose, application, and research examples of the following tests, which are commonly used in Japan for the geological survey of dams: (1) borehole loading test, (2) standard penetration test, (3) seismic/electrical prospecting and tomography technology.

3.1.7. Chapter 7: tests on extracted cores

Chapter 7 explains the purpose of various tests that are conducted on the extracted cores, for example, density tests, water content tests, compression tests, and permeability tests. Moreover, indices used for quantitative evaluation are measured through simple examinations, such as point load tests and needle penetration tests. A slaking test can also be performed on soft rocks to study degradation characteristics due to dryness and wetness. Finally, mineral analysis aimed at classifying rock types is achieved by using microscope observations and X-ray diffraction analysis.

3.2 Part 2: geological survey of dam sites

3.2.1. Chapter 8: overview of geological surveying of dam sites

To estimate any problems that may arise during dam construction, highly precise geological information is needed, such as geological structure, foundation rock quality, mechanical characteristics, and water permeability. Such information must be obtained and evaluated, and one of the most effective and reliable investigation techniques is to utilize boring survey technology.

Chapter 8 describes the purpose of the geological survey of the dam site, the methods involved, planning of a boring survey, and the important task of core observation.

3.2.2. Chapter 9: grouting test

In Chapter 9, after outlining the basic principles of grouting, the content of the grouting test is explained. For grouting design, the construction track record of completed dams is referred to. However, the geological conditions of each dam are different, and especially for rock that has been, for instance, fractured or weathered, the design and construction of suitable injections is highly complex. Thus, a grouting test is carried out in order to determine the best injection method at each dam site.

3.2.3. Chapter 10: application of the geological survey to a dam site and results utilization in design and construction methods

Geological survey data are obtained by various examination methods, such as ground surface exploration, the boring survey and geophysical exploration, and we must select and estimate the data which information is significant.

Furthermore, we must process the data in order to create geological map, modeling and evaluation of dam site by a geological interpretation and numerical analyze.

In Chapter 10, a description is first given of how to manage the fundamental considerations in an investigation and the test results of a dam site. Next, principal methods used for estimating the dam foundation are explained, for example, rock mass classification and the creation of geological maps. Furthermore, evaluation of the investigation and results, design, and construction are described based on the workflow of the geological survey of the dam, which is characterized by the technical stages and PDCS cycle of a dam's construction.

3.3. Part 3, chapter 11: geological survey of dam material

The dam material must be secured, and the required quality and quantity of the material must be estimated based on achieving its maximum effectiveness. For that purpose, an accurate and detailed advanced geological survey is necessary to determine the optimal site. In addition, we must formulate an exact and efficient extraction and execution scheme for the materials.

Chapter 11 explains the investigation and evaluation of dam materials—such as aggregates for a concrete dam and materials for the core zone, filter zone, and rock zone of a rockfill dam—from the viewpoint of the boring survey technology associated with the rock mass.

3.4. Part 4: geological survey of the slope

3.4.1. Chapter 12: Geological survey of the excavate slope

During dam construction, excavations for the dam foundation, road, and quarry for the dam materials cause changes in the mechanical properties and permeability of the site, and problems with slope stability have often occurred in the past. Therefore, a geological survey of the dam project area must be performed with great care, and a precise design is required to avoid these issues.

In Chapter 12, investigation of the excavate slope and the basic problems connected with formulating its planning and design are first outlined. Next, factors of the excavate slope related to its instability, investigation, measurement and evaluation are explained from the viewpoint of the boring survey technology associated

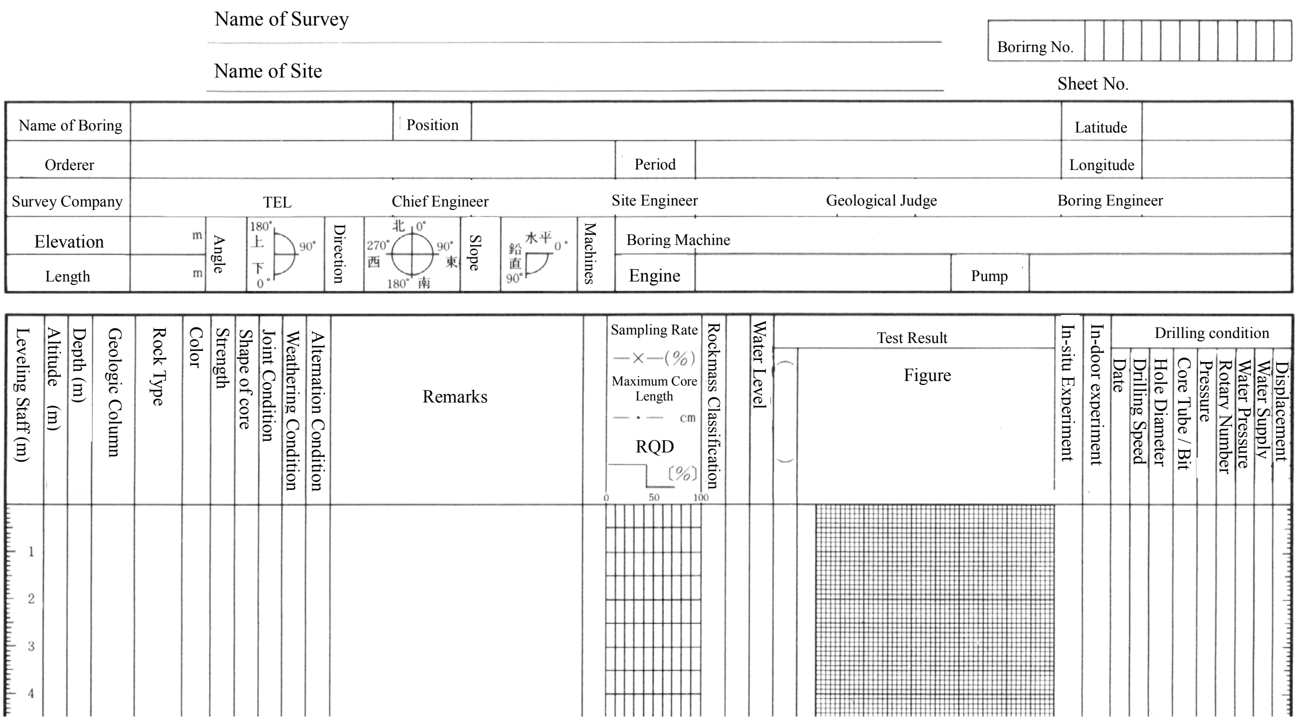


Figure 5. Japanese borehole log

with the rock mass. Finally, the planning and design of the excavation method are noted.

3.4.2 Chapter 13: Geological survey of landslides
Landslides can often occur in Japan at dam reservoir slope due to the complicated geological conditions and the change of hydraulic conditions by water storage. Many landslides may also occur in connection with the excavations for the dam foundation, road, and so on. Hence, a detailed geological survey is necessary to estimate the stability of the slope around the dam.

Chapter 13 describes, from the viewpoint of the boring survey, the evaluation method of reservoir landslides, fundamental analysis of measurements, and factors related to, and mechanism of, the instability.

3.5. Part 5: management of boring survey technology

3.5.1. Chapter 14: safety measurements and management using the borehole
After completing dam construction, the safety of dam's functions must be managed and maintained by continuously measuring the characteristics of the dam structure, rock mass foundation, and excavation slope.

In Chapter 14, an outline is given of the safety measurements that can be conducted on the borehole for both concrete and rockfill dams.

3.5.2. Chapter 15: preservation of boreholes, storage of extracted cores and data retention.
In Chapter 15, methods for the preservation of boreholes and the storage of cores are summarized, and the retention of boring survey data is described based on currently developed information processing technology.

(a)Preservation of boreholes.
Measurements of the groundwater level in boreholes are typically needed after a boring survey, and an existing hole can be utilized for these in many cases. For this reason, data such as the location, latitude and longitude, altitude, and boring direction must be retained. Moreover, after boring has been completed, the area about the ground surface opening of the borehole must be protected to prevent collapse. In particular, when a borehole is used for long-term measurements of, for example, groundwater level, the borehole needs to be suitably protected.

(b)Storage of extracted cores.
Appropriate protection of the core box is also necessary, during its storage and transportation. Especially after completion of the core observation and evaluations, the core boxes must be stored in the warehouse.

(c) Retention of survey data
Factors such as the pressure from water storage, the weather (e.g., heavy rain and snow), and earthquakes can cause instabilities in dams in the long term, and so we must estimate the mechanical loads due to these factors during the construction and maintenance of a dam.
Therefore, geological survey and technical data must be organized and stored appropriately such that they can be utilized for the necessary analysis of stability.

4. CONCLUSION

In Japan, geological and civil engineers have been playing an active part in the field of geological surveys in connection with dam design and construction. In the future, many young engineers are expected to enter into this field. To become a valuable guide for young engineers and on-site engineers, the "Manual of geological boring and engineering investigation of dam geology for next-generation dam engineers" should aid next-generation engineers in advancing geological survey techniques and dam technology.

We hope that engineers will develop with passion and a rich imagination based on specialist knowledge, in not only dam engineering but also various other fields connected with engineering geology.

REFERENCES

Japan Geotechnical Consultants Association (2003): Boring Pocketbook, Ohmsha, JAPAN.
Japan Construction Information Center (1986): Boring Log Creation Explanation, Japan Construction Information Center, JAPAN
Japanese Geotechnical Society (2004): Method of Geotechnical Survey, Japanese Geotechnical Society, JAPAN.