An Evaluation System for Steel Structures of Hydroelectric Power Stations Based on Fault Tree Analysis and Performance Maps

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Summary

This paper presents an evaluation system for steel structures of hydroelectric power stations, including hydraulic gates and penstocks, based on Fault Tree Analaysis (FTA) and performance maps. This system consists of fault tree diagrams of FTA, performance maps, design and analysis systems, and engineerin databases. These four modules are integrated by appropriate hyperlinks so that the user of this system can use it easily and seamlessly. A well developed system was applied to some illustrative example cases, and they showed that the developed methodology and system worked well and the users found the system useful and effective for their maintenance tasks at powerstations.

1 Introduction

In the 20th century, many hydroelectric power stations were built in the world. Most of the prospective sites have already been developed in advanced nations, and most future developments in developing countries are facing difficulty due to environmental issues. So far, technologies related to design and construction of hydraulic gates, valves, and penstocks, which are main steel structures of hydroelectric power stations, have usually been transferred from experienced senior engineers to junior engineers in the On-the-Job Training (OJT) manner. However, due to the recent decrease of the number of hydropower projects, the technology transfer is becoming difficult.

On the other hand, many of the existing hydroelectric power stations exhibit some degree of degradation, and may experience catastrophic disasters unless engineers inspect the facilities and make engineering judgments appropriately. Although extensive knowledge in design, construction, and maintenance is necessary to make sound judgments, such knowledge is distributed in various organizations, groups, or companies and is not integrated. Therefore, it is necessary to systematize the existing technologies, various data and knowledge and to develop a computer system so that every engineer can make sound judgments and junior engineers can inherit the advanced technologies from the system.

In this research, we have developed a system, which can support especially the owner side engineering tasks throughout the design, construction, and maintenance of hydraulic gates and penstocks, and which can be used for training and education for engineers as well. The system consists of the following four modules; 1) fault tree diagrams based on the Fault Tree Analysis (FTA) method, 2) a performance map for evaluating the soundness of structures, 3) design and analysis systems, and 4) engineering databases. These four modules are integrated into one system. This system intends to aim at managing the distributed functions and knowledge in a seamless manner.

This paper presents the architecture of the system, describes its prototype system, and shows an illustrative example of application of the system.

2 System Development Concept

Hydraulic gates are installed for controlling water of rivers, waterways, spillways, water tunnles, etc. Although there are many types of hydraulic gates, most typical ones include roller gates and radial (tainter) gates (Fig. 1). A penstock is a pressure pipe, which is usually made of steel, and which supplies water from an intake, water tank, or water tunnel to a water turbine (Fig. 2).

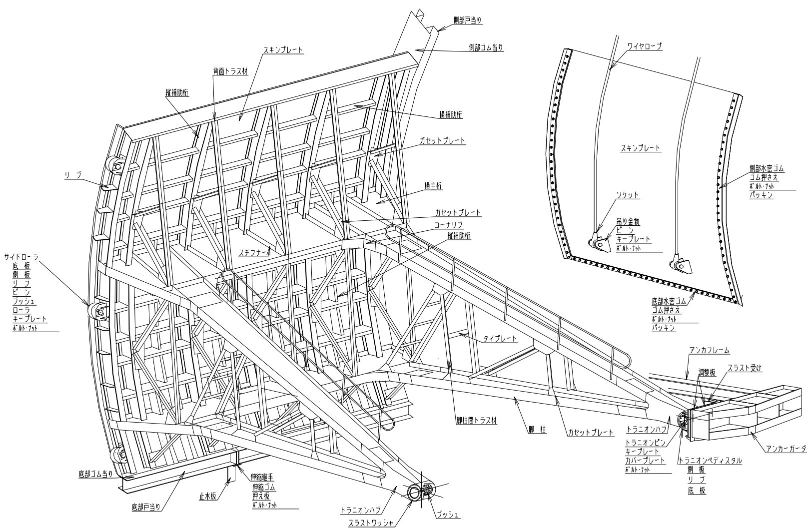

Fig. 1 Radial gate

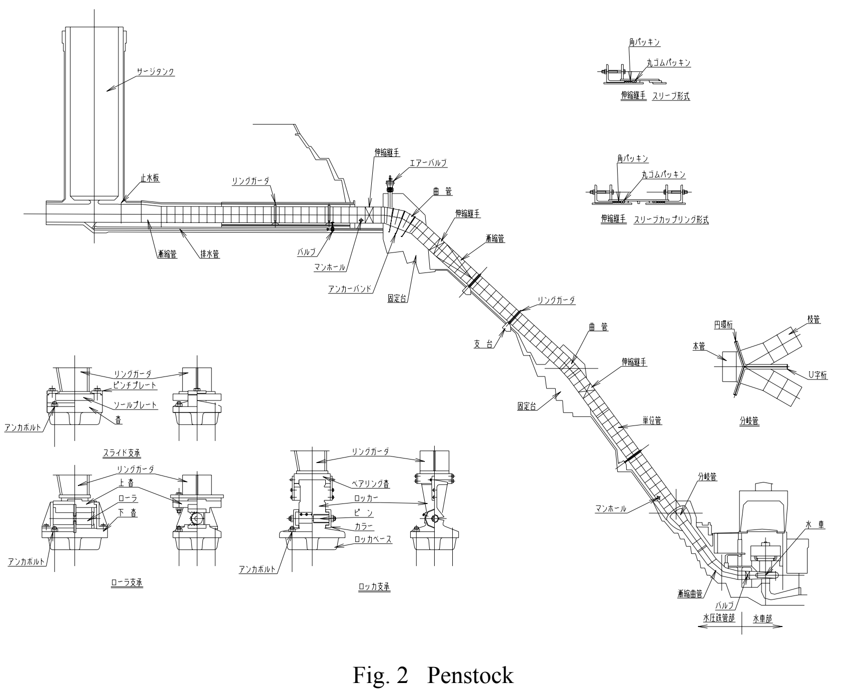

Fig. 2 Penstock

Required performances must be clearly identified and defined. They are classified as safety, serviceability (functionality), durability, earthquake resistance, and adjustability to socio-environments in this research. Failure to maintain the required performances is critical and must be prevented. To prevent such failurs or to repair a failed structure, causes of failures must be identified. A fault tree of Fault Tree Analysis (FTA) is a suitable technique for representing a failure and its causes systematically. Each cause is related to a performance of the relating component of the structure. Required performance for each member and component must be identified and systematized. Such system may be represented as a performance map. To evaluate the performance, design calculation systems and structural analysis programs are necessary. These systems should be linked to related performances and should be invoked by clicking the performance icons. Engineering databases including documents such as specifications, standards, regulations, and knowledge such as previous failure cases and engineering know-hows are useful. They should be linked to performance maps and fault trees.

In this research, fault trees, permance maps, design and analysis systems, and engineering databases are integrated, as shown in Fig. 3, so that the user can operate the system in a seamless manner.

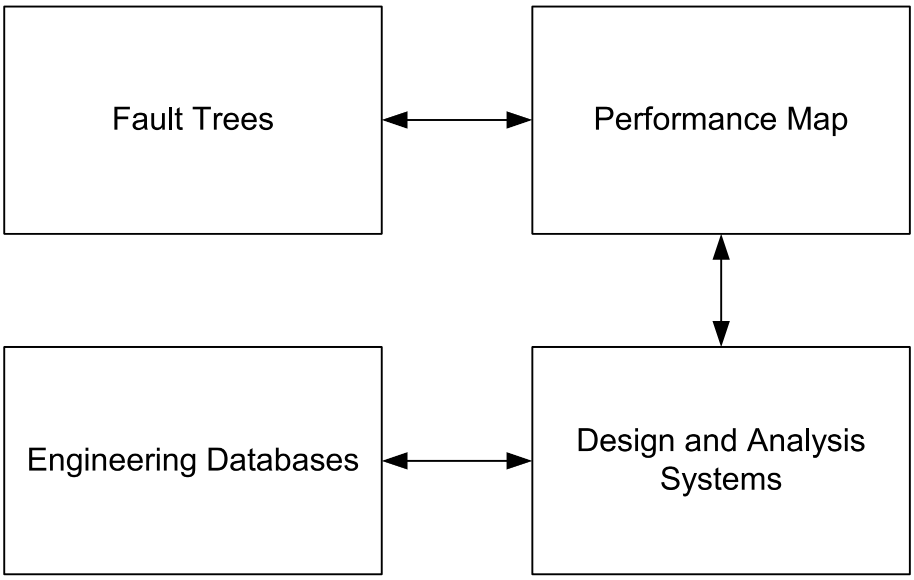

Fig. 3 Integrated System Architecture

3 Fault Trees

A Fault Tree Analysis (FTA) (Sutton 2003) is one of the methods for evaluating the reliability of a system, machine, structure, or a facility. In FTA, undesirable events, i.e., faults or failures, are identified adn enlisted as “top events.” Then, the causes of each top event are determined and further the causes of of the cause are determined. This process is repeated until no more detailed causes can be found. Top events and causes are laid out hierarchically so that the diagram is called Fault Trees. For each event or cause, its causes are linked with the logical gates such as AND, OR, etc. A part of the Fault Trees for radial gates is shown in Fig. 4.

4 Performance Maps

A performance map presents required performance for the facility in a hierarchical manner, where each of the basic required performances: safety, serviceability (functionality), durability, earthquake resistance, and adjustability to socio-environments, has its detailed required performances. And more detailed performances are attached to the intermediated performances. The leaf, i.e., most detailed required performance has its checking criterion, which is usually expressed as inequality and which is attached to the leaf node. Each checking criterion has its checking or confirmation method, which is expressed as a provision of a standard, specification, or regulation, or analysis method, or site investigation. Those items including required performance classes, checking criteria, and checking methods are represented concisely as a form of table.

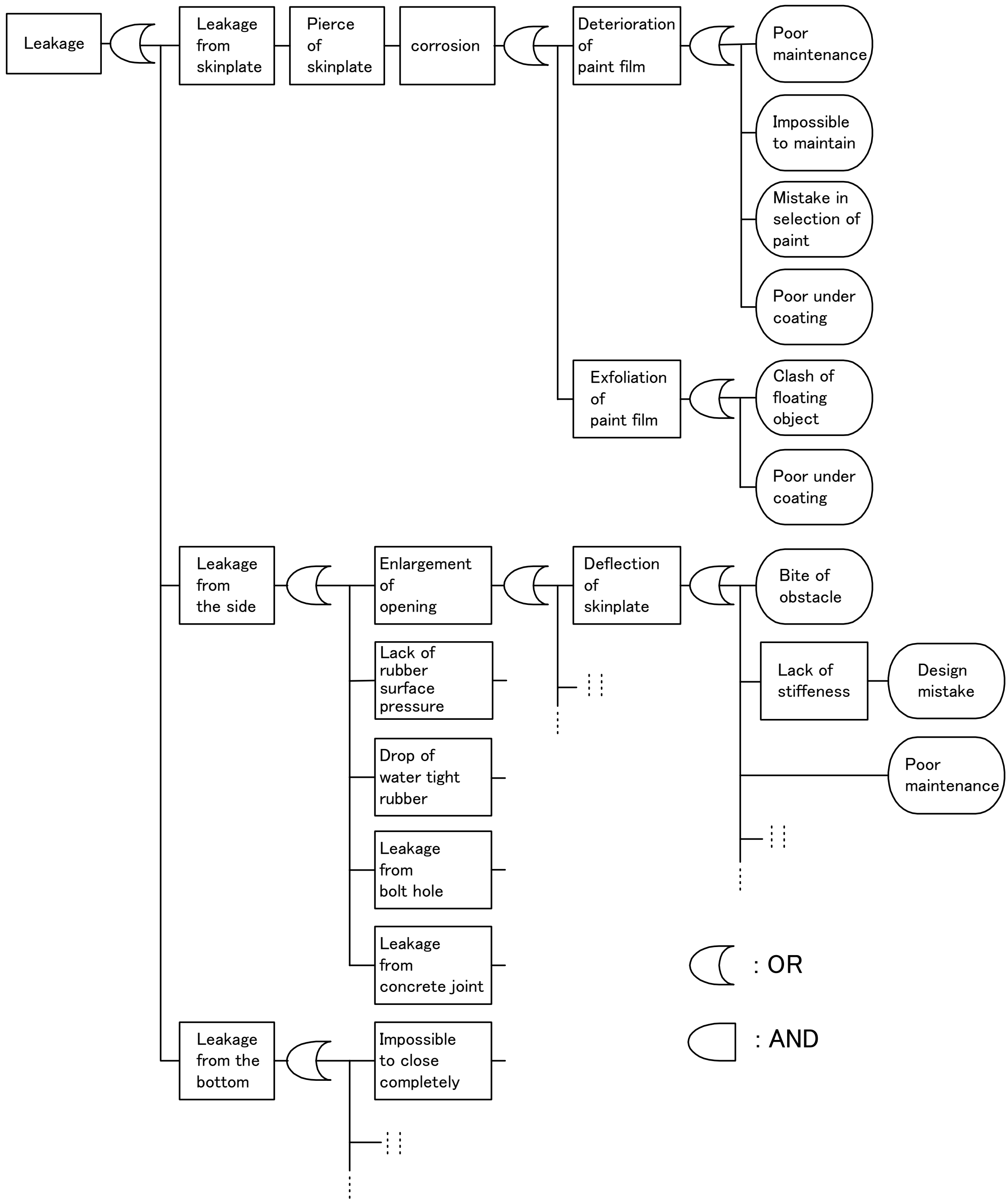

Fig. 4 A part of the fault trees for radial gates

5 Design and Analysis Systems

In this research, each checking method in the table of a performance map has a link to the corresponding design and analysis system. We implemented design calculation programs, using Microsoft Excel and Visual Basic for Application (VBA). Analysis systesm such as finite element system has appropriate links to the corresponding slots in the performance map or the design calculation system. Thus, users of the this system can easily perform necessary calculation for checking the criteria.

6 Engineering Databases

Users often need various data of many types of materials and components. Such data are often stored in databases. Hence, the system can have direct or indirect access to relational databases. Further, engineers often reference many types of documents including manuals, previous design cases, regulations, standards, specifications, etc. In this sytem, such information is photo-scanned if it is a form of paper and stored in the database electronically. Users can have easy access to necessary information, using keyword query and linkages.

7 Application

In this section, an illustrative example of the application of this system to a penstock failure is briefly described. Suppose a user notified leaking water from a join of the penstock. The user can easily identify some of the plausible causes of the leakage of water by first identifying the top event, and then traversing the Fault Tree downward. The user can assume that the causes are either of ductile, brittle, or fatigue fractures. Then, the user can identify the required performances corresponding to the causes in the performance map, and then can check the criteria of the performances, executing design calculation and structural analysis systems. Based on the output of the analysis, which shows harmful deflection, the user can inference that the main cause should be ductile fracture. As the result, the user now can develop a countermeasure, i.e., recovery of strength, by replacing the matrial or increasing the thickness of the penstock joint.

8 Conclusion

In this research, a system was developed to support the owner side engineers throughout the lifecycle of steel structures of hydroelectric power stations, including hydraulic gates, penstocks, etc. This system consists of Fault Trees based on FTA, performance maps, design and analysis systems, and engineering databases. These four components are integrated by appropriate hyperlinks so that the user of this system can use it easily and seamlessly. A well developed system was applied to some illustrative example cases, and they showed that the developed methodology and system worked well and the users found the system useful and effective for their maintenance tasks at powerstations.

9 References

Sutton, I.S. (2003). eBook Fault Tree Analysis. Sutton Technical Books.