Special feature article

Risk-based Maintenance

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Profile

1953 Born in Tokyo
1975 Graduated from Department of Mechanical Engineering, Faculty of Engineering, The University of Tokyo
1977 Master's degree in Marine Engineering from the Faculty of Engineering, The University of Tokyo
1980 Doctorate in Marine Engineering from the School of Engineering, The University of Tokyo
1981 Associate professor, Department of Marine Engineering, The University of Tokyo
1995 Associate professor, Department of Mechanical Engineering, School of Engineering, The University of Tokyo
1997 Professor, Department of Mechanical Engineering, School of Engineering, The University of Tokyo

Major positions
Japan Society of Mechanical Engineers fellow, High Pressure Institute of Japan chairperson, Japanese Society for Strength and Fracture Materials chairperson

1 Recent Trends in Maintenance

I would like to start by covering some recent trends in maintenance in the industrial field I am relatively involved with. The concept of maintaining safety of mechanical structures was dramatically changed after the introduction of the "maintenance standard" to the concept of maintenance for mechanical equipment for nuclear devices about ten years ago. The maintenance standard is a standard for the maintenance stage after service. Accordingly, design standard that regulates the design phase for mechanical structures and the maintenance standard that regulates the service phase are clearly separated.

There are many uncertainties regarding load and damage mode in the design stage, and we often have to rely on predictions. On the other hand, we can confirm the accuracy of design stage predictions by compiling inspection data and defect information in actual use of mechanical structures in the service stage. As a result, we can reduce the degree of uncertainty, so the safety factor does not necessarily have the same value in design and service stages. Above all, we can say that integrity assessment of flaws and damage detected at inspections being conducted in the service stage and acceptance of flaws in some cases is a major change.

Deterioration is unavoidable for mechanical structures, just as humans age. Flaws are thus more or less detected at inspections. But we developed a system of structural integrity assessment and are applying suitable countermeasures.

The maintenance standard is being introduced to maintenance of various industries other than nuclear field, too. Irrationality of maintenance in the service stage is greatly reduced as a result, but issues regarding flexibility of maintenance still remain. Introduction of risk measures for maintenance has thus been gaining attention in recent years.

Fiscal 2010 was, in some ways, a very meaningful year for Japan in the field of maintenance. The reason is that a standard for risk-based maintenance (RBM) will be issued by the High Pressure Institute of Japan for application to maintenance of pressure equipment. I have been participating in the establishment of this standard as a project manager from the initial stage of the project, which has taken approx. nine years till today. By introducing RBM, prioritization becomes possible in planning of maintenance inspection programs, allowing concentrated inspection of parts that truly need maintenance. That is advantageous in terms of cost, in addition to safety. Many issues need to be overcome, however, in introducing RBM. First of all, establishment of standards is important, and we can expect that application to industry will be accelerated by issuing private-sector standards.

RBM was introduced first in the chemical engineering and petroleum refining fields, and is expanding to a broad range of industrial fields with application proceeding to shipbuilding, gas, electric power, steelmaking and rocket ground facilities. I believe that such industrial trends related to maintenance will also be of reference for the railway field as well.

2 Concept of Risk-based Maintenance

Items such as scope of inspection, degree of inspection, frequency of inspecting areas and the non-destructive inspection method to use need to be determined in maintenance planning. Risk is adopted as an index for clarifying priority in risk maintenance technologies. That risk can be given as the product of the probability of failure occurring to the inspected area and the consequence of failure to the surroundings. In other words, risk is the expected value of the degree of impact. Fig. 1 shows the concept of distribution of risk held by devices in a system.

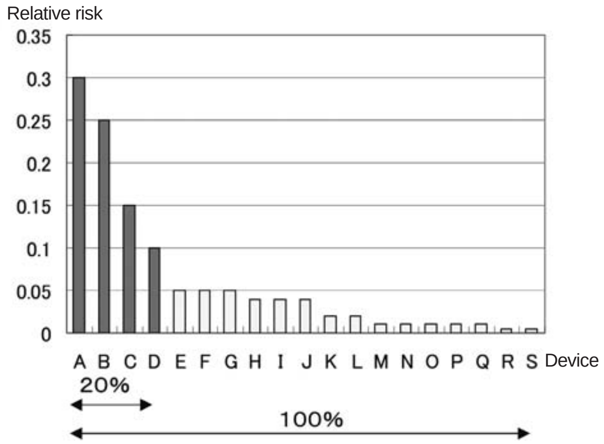

Fig. 1 Conceptual Image of Distribution of Risk in a System

A to S on the horizontal axis are the devices in a system and the vertical axis is the relative risk each device holds. The graph shows that 80% of the total risk of the system is concentrated in just 20% of the devices. In that case, it would be irrational to inspect all devices with the same level of priority. It is thus important to identify the 20% of devices and raise their priority level in the inspection program. That is the basic concept of risk maintenance technology. This concept is called the 80-20 rule (Pareto principle). When putting emphasis particularly on the viewpoint of inspection, the concept is called risk-based inspection (RBI).

In final decision-making, decisions to mitigate risk are made upon adding factors such as cost, and the concept is called risk-based maintenance (RBM) when the process up to this stage is included. Fig. 2 shows the general procedures for RBM. First of all, data and other information needed for evaluation are collected. Based on the data, risk evaluation is made for each part. Risk is evaluated as the product of consequence of failure and probability of failure. Based on the results of risk evaluation, a decision is made on priority for inspections. The inspection plan is then created based on that decision. As a result, how to mitigate risk is indicated and proposed. Reassessment is done for the proposal by comparing to factors such as current laws and regulations, and the operation is repeated from the beginning if problems are detected.

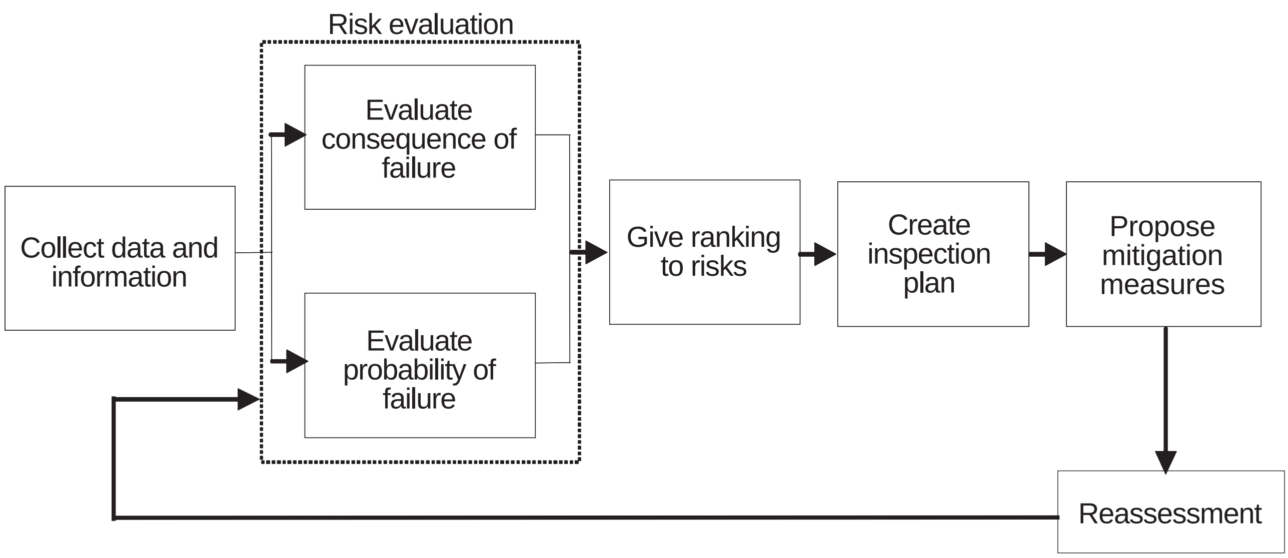

Fig. 2 General Procedures of RBM

3 Why RBM is Needed Now

The inspection method where inspections are made by predetermined procedures using predetermined devices on predetermined locations at predetermined intervals is called uniform inspection in this paper. Uniform inspection where predetermined things are rigorously practiced fits well with the diligent national character of Japanese people, and it is a concept that can be widely accepted by them. Mechanical inspection in Japan can be said to have been for the most part uniform inspection. However, it was recognized in the West at an early stage that practicing maintenance only by this method leads to various problems.

Little damage is detected at inspections in the time right after mechanical structures come into actual use after they are manufactured as those structures are not very old. The frequency at which defects come up is also probably low. Not very many problems will become apparent in this stage using the uniform inspection method. But deterioration of structures progresses after long-term use, and the frequency at which damage and defects are reported in inspections rises. Parts at which damage is predicted to occur are usually identified in establishment of inspection programs, and the inspection method is determined based on that. Parts where damage is predicted are naturally considered in design, and inspection can be rigorously conducted. Thus, the frequency at which unpredicted damage is discovered does not actually become high even after long-term operation. Not all deterioration and damage to mechanical structures can be predicted, however. Unpredicted damage modes may thus occur, and deterioration may progress faster than expected. Those parts are often not stipulated as measurement locations in inspection programs, and much of the damage detected in inspections inevitably will occur in such places.

While almost no damage is detected at parts stipulated in the inspection program, it is often detected at unstipulated parts. In Japan, those unstipulated parts are normally added to the inspection program as inspection parts if damage is detected there. The frequency of that could increase with the deterioration of mechanical structures, but what do you think would happen if such a method continues to be used? We would end up with the unrealistic situation where frequent inspection is done for the entire range of parts. Costs would skyrocket in that case, and concentration of inspections on parts that truly need them could not be done, creating a situation that is insufficient from a safety standpoint also.

In other words, it is clear that concentrating inspections on parts truly in need of inspection would be rational from the standpoint that resources which can be allocated to maintenance such as human resources and machinery are limited. It would be difficult to predict all damage and defects in advance, so the concept of optimizing the inspection program based on signs of damage observed in inspection could be extremely effective. RBM is thus a system for flexibly reconsidering the inspection program upon evaluating inspection priority based on signs of damage.

A flexible inspection method through RBM can lead to shortened inspection time, so it can be expected to have an effect of leading to increased capacity rate for mechanical structures. If a company's competitiveness lies in long-term operation of mechanical structures at a high capacity rate, introduction of RBM is quite meaningful. In maintenance for mechanical structures, independent safety activities are also being required more in the context of greater deregulation. RBM manages maintenance by the visible indicator of risk, so it can be said to be an effective tool in promoting independent safety activities.

4 Skill Transfer and RBM

Decision-making is required in establishing an optimum maintenance plan, and RBM can play a significant contribution in this stage. But even before RBM was introduced, veteran personnel had probably made decisions in their heads on items such as what is optimum, what inspections are smoother and what needs to be prioritized to secure safety. At one time, there were many such highly skilled veteran craftsmen, and their presence probably led to the high level of reliability for devices in Japan. All would be well if a company had lots of such human resources. But if veteran craftsmen retire without transferring their skills, that could lead to the creation of a dangerous situation the moment they leave. To prevent such a situation, we need to draw out the know-how that they have in their heads, transform it into explicit knowledge and steadily transfer those skills to the next generation. The process of transforming know-how into explicit knowledge, however, usually runs into major obstacles. That is because veterans practice their skills unconsciously, making it difficult for them to express on their own what principles those actions are based on.

It was actually the financial sector, not maintenance, for which a focus on risk was made at a very early stage. Active studies were made in the financial sector from the viewpoint of what decision-making process successful investors base their decisions on. As a result, that decision-making process could be reasonably explained as decisions being made upon combining both the probability of events and the danger of investment. In other words, that decision-making is the concept of risk itself. Replacing investors' decision-making process with the decisions of veterans in maintenance, a reasonable explanation of the decision-making process can be made if we think of risk as evidence that they unconsciously decide priority. Even if not explicitly thinking of risk evaluation, they are doing the same thing as that evaluation unconsciously. In other words, if we can bring out the risk evaluation procedure in the minds of veterans and establish guidelines, that procedure will become materials for skill transfer to the next generation. In fact, it is this aspect that is sometimes emphasized as a benefit of RBM.

5 Feelings on Railway Maintenance

The concepts on maintenance covered in this article have been trends in the range of areas that I have been mostly involved with—mechanical equipment for plants and the like. While they may seem unrelated to railway equipment, that is not necessarily the case. Some aspects have common basic concepts, and there are many things one should learn from maintenance methods of other fields. The general idea of the maintenance standard is fitness for service (FFS), right wording, indeed. While I do not have a grasp of the details of railway maintenance, I expect that maintenance methods can be greatly optimized by introduction of FFS in fields where it is performed uniformly across the board. When doing so, it is important to systematically link inspection data and defect information with establishment of an inspection program. A tremendous amount of information of this kind is probably accumulated on a daily basis for railway equipment, and that information is a true treasure house that must not be set aside. The information should be utilized, and you should go forward with FSS and even more flexible RBM. In doing so, you should also partner with universities that are proficient in academic aspects such as statistical engineering and reliability engineering.

6 Expectations for Railway Maintenance

I feel that railways are characterized by their including wide-ranging elements related to safety. Those innumerable elements include tracks, rolling stock and other mechanical equipment as well as electrical circuits such as scheduling systems along with natural disasters, in-station structures, and more. I think there is a limit to handle all those uniformly as safety measures. And I hear that JR East has already started efforts similar to RBM in some fields, so there must be many areas in the railway industry where the basic concepts of RBM that I introduced could be applied. A few that I can think of when applying RBM to safety measures in stations other than mechanical equipment are the following.

(1) Evaluating station structural layout
(2) Establishing priority of cost allocation for countermeasures to dangerous events
(3) Establishing priority of development for danger detecting technologies
(4) Deciding utilization of inspection data and priority of inspections

How to optimize safety with limited resources is an issue that will be unavoidable in the future. I think that the concept of RBM will be highly effective in optimizing safety for the railway industry too. I would thus encourage you to further implement concepts such as RBM and go forward to the next stage.