Failures of Fastening Screws and Their Preventive Methods

-Statistical analysis of failures, 1st report-

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1.1. Introduction

Generally speaking, "screw" has been considered one of the most important "5 kinds of simple machines" among "lever", "wheel and axis", "tackle" and "wedge" since ancient times. All mechanical parts could be decomposed into these five kinds of members. A broad definition of fastening screw includes not only the combination of a bolt with a nut but also fastened members. The representative fastener is naturally the combination of a bolt with a nut. In general, fastening screws in a narrow sense has the following advantages:

(1) They can be easily assembled and disassembled.

(2) They can be set, while making necessary adjustments, or can be set with high precision with simple fastening tools.

(3) As the wedge effect of threads can be utilized, even very thick members can be fastened tightly.

Especially, due to recent demands for protecting the global environment, the above advantage (2) will be just emphasized in view point of "recycle" and "reuse". In addition, as the fastened portion is easily broken in comparison with the other parts, the designers have been requested to prepare the safer and higher security fastened members on the basis of theoretical analysis with theory of "strength of materials".

Because of these advantages, about one thousand fastening screws are used, for example, in a car (ref. Fig.1.1[1]). In addition, about 1.5 million screws are settled in a jumbo jet airplane[2]. As far as our belongings, 6 numbers of fastening screws are used in an eyeglass. Moreover, a surprisingly large number of bolts are used in a wide variety of machines and equipment, such as electrical equipment, machine tools, construction machinery, rolling-stock, steel towers, bridges, transportation equipment, etc.

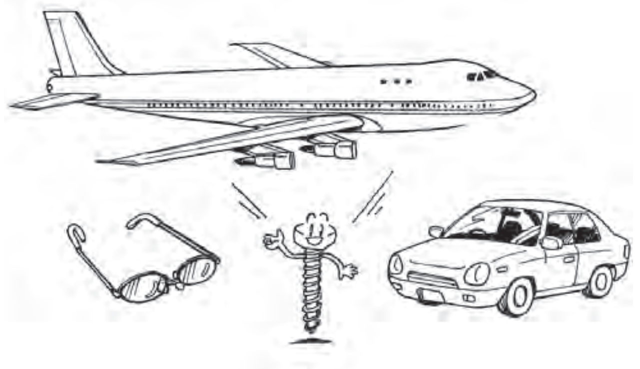

Fig.1.1 Bolts are used in many kinds of productions

1.2. Process from Occurrence of a Problem to Resolution

On the other hand, fastening screws are so widely used in daily life that their usefulness is not fully recognized. We are apt to attach less importance to screws by saying "only one bolt" or "only one screw", in spite of their important functions[3].

Therefore, the author tries to introduce the following process as shown in Fig.1.2, before he refers to the title of "failures of fastening screws and their preventive methods". In other words, the following process will show the most logical method to reach to the goal. At first, to confirm the real circumstances will be the most important before going into investigation for the main problems. Therefore, the author tried to analyze the occurrence of a problem and then, failure of equipment[(4)-(6)]. Then, he can reach to the classification of bolt failure and then, the investigation of cause. The investigation of cause will introduce the countermeasures of bolt failure. Practice of a new idea and verification for bolt failure can be reduced to the end of this problem.

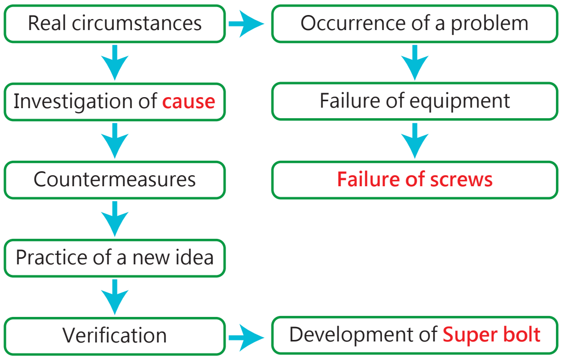

Fig.1.2 Process from occurrence of a problem to resolution

1.3. Losses Through Failures

Losses caused by failures are shown in Fig.1.3[(4)-(6)]. As described later in detail, **more than 85-90% of failures are generally caused directly or indirectly by "fatigue". Losses through failures are classified as direct and in direct.** The former includes the cost of repair work, the cost of work to prevent failures, accident compensation, etc. It is desirable to carry out repair work and work to prevent failures at the same time. In the case of production facilities, however, work to prevent failures is often conducted later during the scheduled shutdown period by giving top priority to restoration, because a line stoppage results in a decrease in production. When a failure results in the injury or death of workers or causes damage to people in the neighborhood, the problem of accident compensation occurs. Furthermore, such failures may bring about an on-the-spot inspection by the authorities concerned and the responsibility problem for the plant safety supervisor. To prevent such an occurrence, efforts to prevent failures and to carry out maintenance work should be made every day. Indirect losses include a decrease in production, and damage to the company's image. We often hear that operators are frightened of increasing the output of a plant for some time immediately after a major accident even if the distance between the control room and the plant is sufficiently great. Although importance has been attached to direct losses in the past, due consideration has recently been given to damage to the image of a company, which prevents the recruitment of first-class workers.

In an extreme case, the fracture of a bolt in a modern computerized system may result in a line stoppage [(4)-(6)]. Therefore, it is necessary to investigate even minor failures as thoroughly as possible instead of making repairs according to some haphazard policy, and there

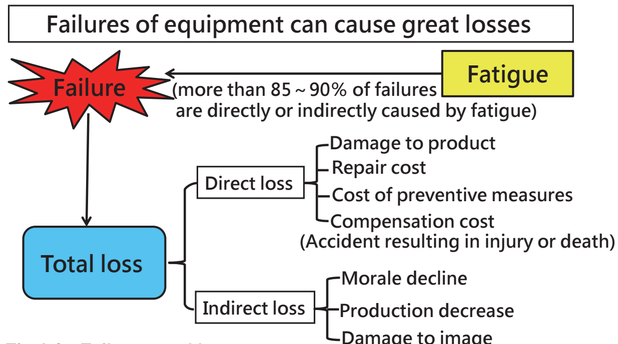

Fig.1.3 Failures and losses

are signs of attempts at a wider contribution to society by not only preventing the recurrence of similar failures, but also by making public the results of such investigations. When the failure investigation is conducted by both the designer and the user, the cause of a failure can be clarified more thoroughly and it is easy to adopt ideal measures.

1.4 Statistical Analysis of Failures

1.4.1 Classification of Failures According to **Failed Members**

The details of the failures of machines and mechanical parts which the author and his cooperating researchers investigated are shown in Fig.1.4[(4)-(6)]. As is apparent from the right figure, **the greatest number of failures is observed in welds,** and failures other than welds decrease in the following order: shafts, bolts, pulleys or rolls, gears, wire ropes, etc. The reason why the greatest number of failures is observed in welds may be because almost all assembly parts are welded parts, the absolute number of welded parts is large, and the strength of welds is generally lower than that of the base metal. The reason why the number of failures in shaft is the second largest after that of welds may be that a shaft is an important member for transmitting power and that replacements cannot be easily or quickly procured.

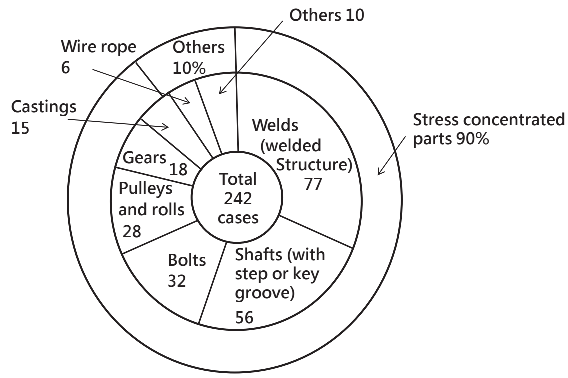

Fig.1.4 Classification of failures according to failed members

Although bolts are ranked third, it might be thought that bolts have, in reality, the largest absolute number of failures among mechanical parts. However, it seems that most broken bolts are appropriately replaced on site because, except in special instances, bolts can be procured soon after breakage or can be fabricated easily. Like shafts, pulleys, rolls, gears and wires are indispensable for transmitting loads, and they are typical mechanical parts.

1.4. 2 Classification of Failures According to **Causes** or **Factors**[(4)-(6)]

According to Fig. 1.4, these failures classified by causes are shown in Fig.1.5. As is apparent from Fig. 1.5, about 80% of failures are caused by fatigue (including simple fatigue, corrosion fatigue, thermal fatigue, etc.), and other causes are static fracture (13%), SCC [stress corrosion cracks] (5%), corrosion, burst, etc. (3%). The ratio of static fracture will be considered to be questionable because the design technique becomes higher and more precise every year under the aid of computer calculation mechanics. Almost all of this ratio should be classified into "indirect fatigue".

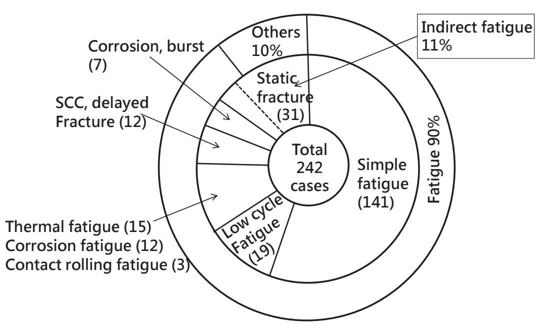

Fig.1.5 Classification of failures according to cause

As far as indirect fatigue is, for example, shown in Fig. 1.6. The flange is fastened with 10 bolts under cyclic load. At first, 3 bolts are fractured by fatigue. Afterward, 4 bolts are fractured by fatigue as second step. The residual 3 bolts are also fractured immediately after the second step. The above first step and second step are caused by "direct fatigue". On the other hand, the residual 3 bolts are caused by "static fracture" by suffering with over load according to macro-scopic inspection. This static fracture does not occur if the former first and second fatigue fracture, do not occur in reality. That is, this static fracture has been induced by the former "direct fatigue". Then, the static fracture could be called to be "indirect fatigue". The direct fatigue plus indirect fatigue becomes 100% in this case. Therefore, direct and indirect fatigue account for 100% in Fig. 1.6. When focusing on Fig. 1.5, almost all of the static fracture should be classified into "indirect fatigue". That is to say, more than 90% of failure cases are directly and indirectly caused by "fatigue".

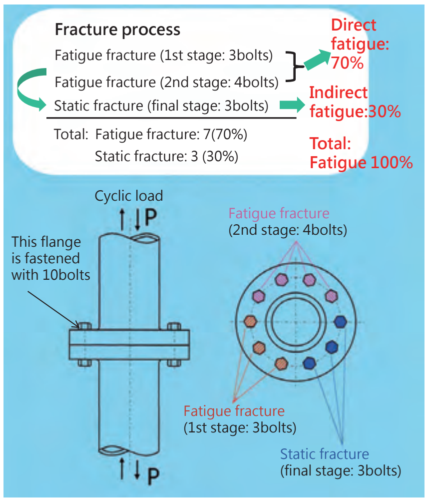

Fig.1.6 Classification of direct and indirect fatigue

Figure 1.7 shows the classification of failures by factors[(4)-(6)], which are an underestimation of external force (35%), poor fabrication (22%), inappropriate standards for use and replacement (16%), inappropriate selection of materials (10%), etc. **Almost all failures are caused by human factors, and the failures can be prevented by conducting prior analyses, acquiring a good knowledge of materials, and paying attention to inspection after fabrication.** Under estimation of external force (33%), inappropriate structure (24%), mis-selection of material, poor machining & fabrication (19%) and assembling & setting (2%): these causes are ascribed to fabricator, i.e. design, manufacturing and installation. On the other hand, inappropriate replacement (16%), inappropriate repairing (6%) : these causes are ascribed to user i.e. operation, maintenance and modification. According to the above, about 80% of failure cases are responsible to fabricator.

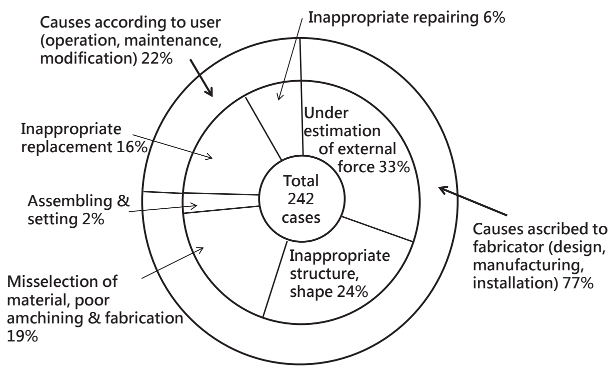

Fig.1.7 Classification of failures according to factor

1.4. 3 Classification of Screw Failures

As above mentioned, a large number of bolts are used in a wide variety of machines and equipment than expected. The classification of bolts failures is shown in Fig. 1.8. As is apparent from Fig. 1.7, **about 90% of failures are caused by "fatigue". About 5% of failure cases are caused by "delayed fracture" with following to "SCC" (3%) and "static fracture" (2%) accompanying with corrosion.** Therefore, the bolts against fatigue will be most important target in view point of the countermeasures to prevent failures in the series of these reports. In addition, delayed fracture and SCC are also referred to the later reports in these series in view point of not only material but also mechanics.

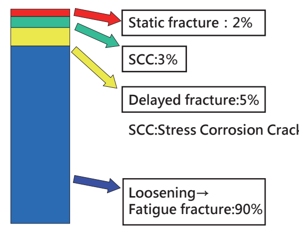

Fig.1.8 Classification of bolt failures

1.4. 4 Condition for the Occurrence of Failures[(4)-(6)]

Figure 1.9 shows the conditions for the occurrence of failures and the countermeasures to prevent failures. Needless to say, a failure occurs when an external force exceeds the resistance of the material. It is necessary to examine whether the cause of the failure is miscalculation of the external force or the wrong selection of a material. Truly rational measures can be taken by examining factors related to both causes.

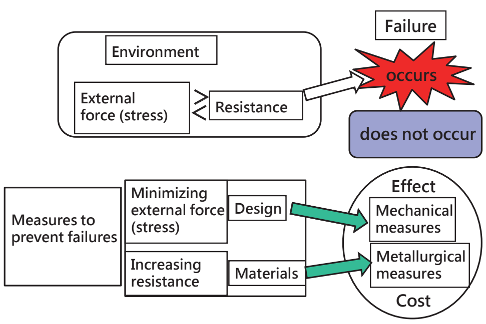

Fig.1.9 Occurrence of failures and measures to prevent them

In other words, it is necessary to take measures to reduce the external forces (including stress) or to increase the resistance or to take measures related to both. In general, those designers who are strong on mechanics may be weak on materials, and vice versa. Therefore, there are many cases in which design is very uneconomical. As the strength of a material is related to its environment, **it is necessary to consider the three factors, i.e, external forces, materials and environments, in determining countermeasures to prevent failures, and to draw a truly rational conclusion on the basis of the effect, cost, etc. of the measures.**

1.5. Conclusions

The main results concerned in this paper are concluded as follows:

(1) Though the greatest number of failures is observed in welds, it might be considered that bolts have, in reality, the largest absolute number of failures among mechanical parts.

(2) More than 90% of failure cases would be directly or indirectly caused by " fatigue".

(3) About 80% of failure cases would be responsible to fabricators.

(4) As far as bolts failures, about 90% of failure cases are caused by fatigue and followed by delayed fracture (5%), SCC (3%), and static fracture (2%) including corrosion.

(5) It is necessary to consider the three factors, i.e. "external forces", "materials" and "environment", in determining countermeasures to prevent failures.

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