# Inspection planning and maintenance of structures subject to fatique

# Inspection Planning and Maintenance of Structures Subject to Fatique

Organisation de l'inspection et de l'entretien de structures sensibles à la fatique

Plannung von Inspektion und Unterhaltung ermüdungsgefährderter Tragwerken

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An increasing number of fatigue sensitive structures, including bridges, aircraft and offshore platforms are being used beyond their design lifetimes. There is growing concern about the safety of such structures, especially because the fatigue life can vary a lot from the design life. However, it is important to note that structures are usually redundant and failure of a single section does not constitute structure collapse; collapse usually occurs after a sequence of section failures. Furthermore, in the case of fatigue there is some time elapsed between the individual section failures, i.e. fatigue is a progressive phenomenon. Therefore it is possible to use inspection schemes to monitor fatigue damage. If the damage is excessive (i.e. the safety of the structure drops below an acceptable level), then appropriate repair can be carried out. In other words, effective inspection strategy can allow us to use existing structures beyond their design life and yet maintain an adequate level of safety.

In this paper, two important aspects of such inspection strategy are discussed; selection of sections to be inspected and use of inspection results in assessing the safety of a structure.

A section should only be inspected if there is a relatively large likelihood of detecting damage (if there is a relatively low chance of detecting damage, it is not worth inspecting the section). The likelihood of detecting damage will be large only if 1) there is a relatively high probability of damage occurring in the section and 2) the damage can be detected (this is a function of the location of damage and of the detection method used). These two factors can be combined to give a net probability of detecting damage at a section (as described in Dalane, et.al., 1991).

Furthermore, a section is only worth inspecting if it is important to the integrity of the structure (i.e. it is not worth inspecting a section whose failure does not significantly reduce the safety of the structure). This effect can be measured by the increase in system failure probability due to the failure of the section.

Based on the above concepts, we propose a measure of importance for inspection :

Importance of section i = P [Detect damage at section i]
* {P[system failure with section i failed] - P [system failure with intact structure]}

where P[ ] is the probability of occurrence of event [ ]. Note, the system failure probabilities are calculated for the time period after inspection.

In terms of using inspection results to assess the safety of a structure, we suggest using Bayes theorem, e.g.,

P[Collapse in sequence i,j,k given an inspection outcome]
= P [Collapse in sequence i,j,k and inspection outcome]/P[Inspection outcome]

## Application to an offshore structure

This tripod steel jacket platform is located in the North Sea in a water depth of 70 m with an airgap of 22 m (Fig.1). The two main sources of risk are extreme waves and fatigue. Therefore systems reliability analyses were carried out to identify important sequences of failures, both in fatigue and under an extreme wave, that lead to collapse. (Note, important sequences are those that are most likely to occur). These sequences and their probabilities of occurrence are shown in the failure tree of Fig. 2. (Karamchandani, et.al., 1991). In this failure tree, each branch corresponds to failure of a section in fatigue or an element under an extreme wave. Each node corresponds to a damaged state of the structure and the number in the node is the probability of reaching the corresponding damage state i.e., it is the probability of occurrence of the sequence of section failures represented by the branches leading to the node. Note, all the initial failures are in fatigue.

Using the important measure defined above, section 680B was found to be the most important member for inspection. Note, this is easy to understand. It is most likely to be damaged and it is also important for the integrity of the structure - in fact it occurs in almost all the important sequences - (Fig. 2). Therefore, inspection of this section in the 10th year of service is considered. Four hypothetical outcomes of the inspection are studied; no damage is found, a 14 mm crack is found, a through-thickness crack is found, and the section is found to be failed. These observations are used to update the probability of occurrence of two critical sequences (the most important sequence of two fatigue failures, i.e., 680B in fatigue followed by 611B in fatigue and the most important sequence of combined failures, i.e., 680B in fatigue followed by 620 under an extreme wave). The results are presented in Fig. 3 in terms of the hazard rate. (The hazard rate is an annual measure of risk. The hazard rate of the sequence at time t years is the probability that the sequence will occur in time [t,t+1] given that it has not occurred in time [0,t].

Consider the sequence of two failures in fatigue (680B followed by 611B) in Fig. 3a. The dashed line A is the original hazard rate (i.e, without inspection). If no crack is found, the hazard rate is lower than the original rate. This is to be expected because the inspection tells us that the structure is "safe" at the 10th year. If a through-thickness crack or a failed section is found, then the hazard rate is larger than the original rate. This is also to be expected because the inspection tells us that the structure is weaker than expected at the 10th year. The most interesting result is when a crack of 14 mm depth is found (note, wall thickness is 28 mm). Initially, the hazard rate is lower than the original rate, but soon it becomes much higher. The reason for this is the following. This information tells us that there is still some time to failure and therefore the hazard rate for the immediate future is very low. However, this information also tells that the fatigue damage is occurring faster than expected and therefore if we look at a more distant instant of time, there is a greater chance that the sequence will occur, i.e., the hazard rate is greater.

The results for the sequence of combined failures, i.e., 680B in fatigue followed by 620 under an extreme wave, are similar. The main difference is in the case where a failed section is found - the updated hazard rate is constant. This is because the remaining event in the sequence is failure of 620 under an extreme wave and this has a constant annual probability of occurrence.

## References


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Karamchandani, A.K., Dalane, J.I., and Bjerager, P., "Systems Reliability of Offshore Structures including Fatigue and Extreme Wave Loading"; Journal of Marine Structures, 1991.

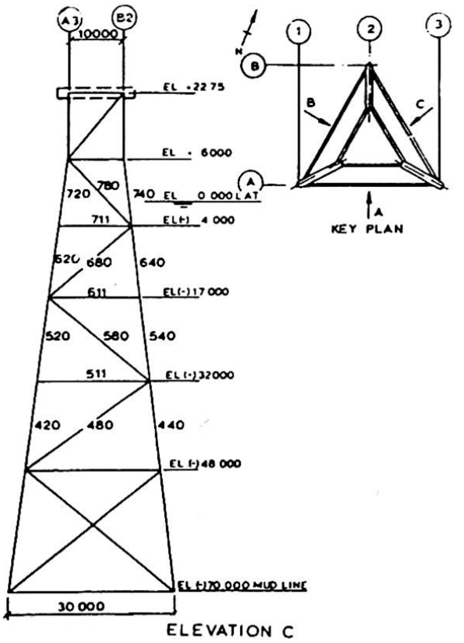
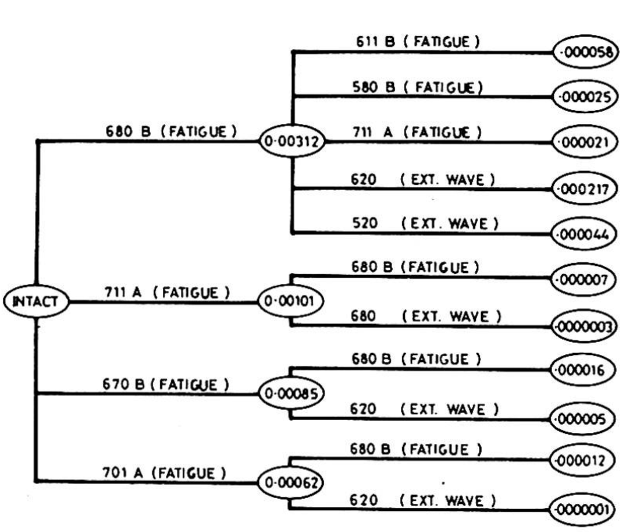




Fig. 1 Tripod Platform




Note: The symbols A and B indicate the two ends of a member (e.g.570B is the section at end "B" of member 570)

Fig. 2 Important sequences of failures


a) Sequence : 680 B in fatigue followed by 611 B in fatigue b) Sequence : 680 B in fatigue followed by 620 under an extreme wave. Notation : A-no inspection (design stage) B-no crack is found C-14mm crack is found D-Throug thickness crack is found E-Section is found to have failed.

Fig. 3. Updated hazard rate of most important sequences with inspection after 10 years in service (Dalane, 1991)