A Strategy for Structures Suffering Fatigue Cracking

Procédure d'évaluation des structures sujettes à la fissuration par fatigue

Eine Strategie für ermüdungsgefährdete Tragwerke

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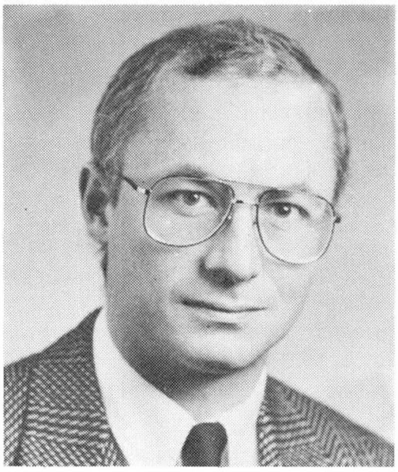

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SUMMARY

The strategy presented in this paper provides a rational tool for evaluating critical details in structures sensitive to fatigue cracking. Approximate and qualitative information, incorporating factors concerning safety, loading, strength, and maintenance history are combined using a simple rating system, thereby creating a framework for decision making.

RÉSUMÉ

La procédure présentée dans cette contribution représente un outil rationnel permettant d'évaluer les éléments critiques d'une structure sujette à la fissuration par fatigue. Les données approximatives et qualitatives concernant, entre autres, la sécurité les charges, la résistance et les travaux de maintenance effectués, sont combinées selon un simple système de répartition en classes. Cette banque de données constitue un outil de décision important pour le choix des mesures à prendre.

ZUSAMMENFASSUNG

Die in diesem Beitrag vorgestellte Strategie ist ein Hilfsmittel zur Einschätzung von kritischen Komponenten in ermüdungsgefährdeten Tragwerken. Annähernde und qualitative Auskünfte, betreffend unter anderem die Sicherheit, die Belastung, die Festigkeit und den bisherigen Unterhalt, werden anhand eines einfachen Einteilungsverfahrens kombiniert, um eine Informationsbasis zur Festlegung von Massnahmen zu schaffen.

1. INTRODUCTION

If fatigue cracks are discovered in a complex structure, development of a rational strategy is essential. It is likely that further inspection will reveal more cracks, and that continued use of the structure will result in crack growth at other locations. Replacement of the structure is rarely desirable due to costs and the inconvenience of interrupting service. On the other hand, if nothing is done, a critical situation may occur; such cracking usually results in reduced safety levels and, at best, increased maintenance costs.

Identification of the causes of fatigue cracking and evaluation of the possibilities of solving the problem at its source are priorities. Clearly, elimination of all causes of fatigue cracking is the best solution. However, all causes are rarely identified and, furthermore, those which are may not be easily eliminated.

The most critical locations may need modifications in order to reduce the risks of cracking. Critical locations should also be inspected more carefully using appropriate inspection technology. Unfortunately, much important information related to factors such as dynamic loading and previous load histories may not be available to the investigator. Consequently, detailed quantitative analyses are often not possible. As a result, indentifying critical locations becomes difficult.

This paper presents a strategy already applied successfully to the evaluation of structures in service. The strategy identifies critical locations in the structure using approximate and qualitative information. Thus, decisions can be made regarding modifications and subsequent inspection tasks.

2. CONCEPT OF RATING CRITERIA

This concept involves rating fatigue-critical details according to six criteria. The first task requires indentification of fatigue-critical details on elements which are subjected to fatigue loading. Typically, these elements are located close to the points of introduction of fatigue loading. In some structures, particularly those subjected to deformation-induced stresses, indentification of such elements requires observation of the structure in service as well as estimates of possible strain directions. Fatigue-critical details on these elements are defined as those details which are vulnerable to fatigue cracking if fatigue stresses were sufficiently high. Since an element may contain several areas of stress concentration, the total number of fatigue-critical details is likely to be several times greater than the number of elements.

A list of the criteria used to rate fatigue-critical details is given in Figure 1. The most important criterion is the rating associated with the CONSEQUENCES OF FAILURE. The events following element failure due to cracking are estimated for each fatigue-critical detail. Situations where cracking at a detail could lead to catastrophic collapse of all or parts of the structure are given a rating of one. A rating of two is given to those details which could cause a local failure if cracking occurred. Local failure is defined as any failure which would compromise the use of the structure in service. Those details which, if failed, would cause cracking in adjacent elements are given a rating of three. Lastly, a rating of four is intended for those details on elements in highly redundant structures where removal of the element would not affect the performance of the structure. These ratings could be lowered to account for details sensitive to rapid fracture.

Evaluation of the LOADING criterion requires careful study. Although all factors which contribute to fatigue loading can rarely be determined exactly, there is usually enough information available in order to classify structural loca-

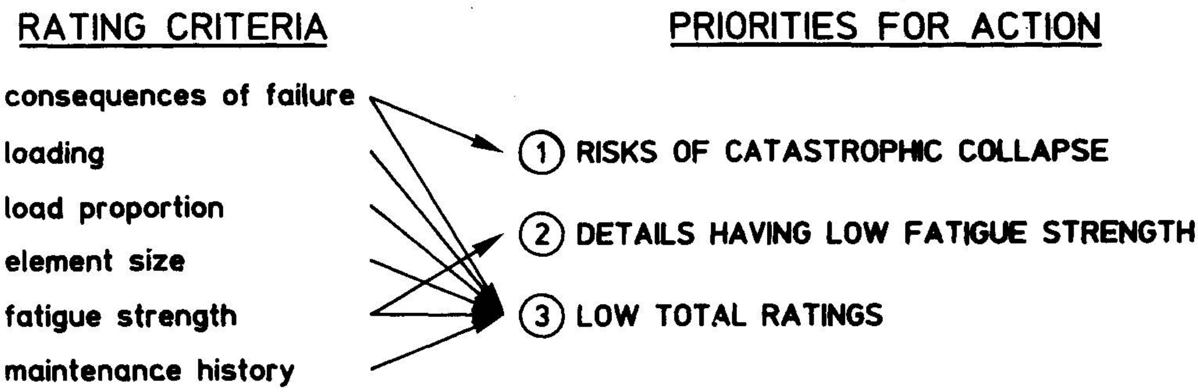

FIGURE 1 : Rating criteria and the use of ratings for setting priorities.

tions in terms of four orders of severity. Load models may provide satisfactory information for quasi-static loading. Correction factors for dynamic effects are often more difficult to estimate, especially if there is noticeable structural movement during fatigue loading. Data from strain gauge or accelerometer measurements, as well as identification of locations where wear or fretting damage is most pronounced, provide important information on dynamic effects. Where total loading effects are estimated to be greatest, details on elements at these locations are given a loading rating of one. Other details are assigned ratings of two, three or four depending upon relative estimates of loading severity.

Estimates of loading severity do not provide sufficient indication of stresses at a given detail. Therefore two additional criteria are employed in order to estimate fatigue stresses. The first criterion is LOAD PROPORTION. If a detail is on an element which carries directly the load, fatigue stresses are likely to be higher than in a detail on an element which is more remote from the point of load application. The second additional criterion for fatigue stresses is ELEMENT SIZE. Other limit states such as deflection requirements, can create situations where elements subjected to similar loading are very different in size. Clearly, larger elements would be subjected to lower fatigue stresses in such situations. As for previous criteria, details are rated from one to four - the most severe cases are given a rating of one and the best a rating of four.

The FATIGUE STRENGTH of a detail determines whether or not fatigue cracks will grow when fatigue loading is applied. Since design recommendations exist for classifying fatigue strength, e.g. [1], a rating using more than four classifications is possible. However, considering the resolution which is possible for other criteria, four classifications are maintained. The best rating of four is reserved for details having good fatigue strengths, for example see Figure 2. The worst rating, one, is reserved for those details which should be avoided in dynamically loaded structures. Intermediate ratings of two and three may be fixed through reference to fatigue-design recommendations.

The final criterion is used to account for the MAINTENANCE HISTORY of the structure. Consultation of maintenance records and interviews with those responsible for structural modifications may reveal valuable information. Again, details on the structure are rated into four groups. Since characteristics of maintenance histories change greatly from one structure to another, it is difficult to provide a general rating framework.

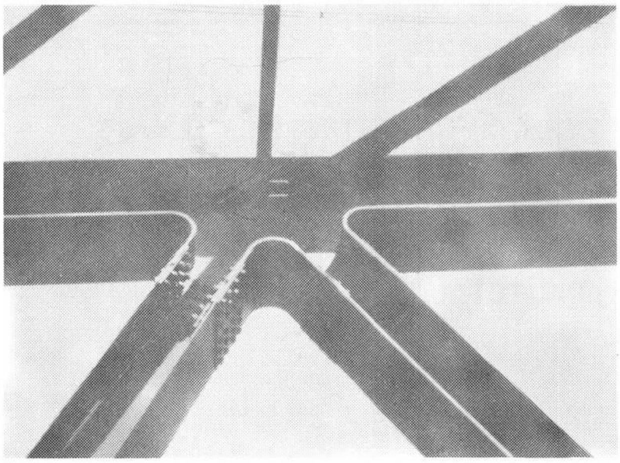

FIGURE 2 : An example of a fatigue-resistant detail.

An example shall be used to illustrate the use of this criterion. A structure, in service for many years and modified several times, was rated according to the following considerations. A rating of one was given to those details where fatigue cracking had been observed and no remedial action had been carried out. A rating of one was also given to locations where remedial action had created a more severe condition, for example, elements containing poorly executed repair welds. A rating of two was assigned to those details where cracking had been observed and remedial action was taken, but it was thought that this action was not going to be successful. A rating of three corresponded to those areas where problems had been rectified satisfactory and no further cracking was expected. Finally a rating of four was given to all those locations where no problems had been observed and none were expected.

The six criteria, consequences of failure, loading, load proportion, element size, fatigue strength and maintenance history, enable six ratings between one and four to be assigned to each fatigue-critical detail. Combination of the ratings requires an estimate of their relative importance. A simple addition of the ratings provides a first estimate of overall severity. If fatigue strength is equally important as fatigue stresses, a combination of the three ratings relating to fatigue stresses into one rating number could be considered. Then, addition is performed to obtain total ratings. Total ratings are used to set priorities, described below, for modification and inspection.

3. PRIORITIES FOR ACTION

Although the total ratings are useful for setting priorities for repair and other modifications, their use, in exclusion of other considerations, is not recommended. An example of priorities is given in Figure 1. Situations where catastrophic collapse is possible are top priorities for action. Secondly, details having very low fatigue strengths should not be present in fatigue loaded structures; modification of all details having a fatigue-strength rating of one is the second priority.

The third priority in Figure 1 employs total ratings. For a given detail, the aim should be to increase its total rating. Ratings for individual criteria provide guidance for each case. For example, the best solution for one detail may involve a reduction of dynamic effects whereas other locations may benefit more by element replacement using more appropriate sections, or by an additional element to share the load. Note, however, that some structural alterations only transfer the problem to other locations. Each case requires individual consideration and not all cases will require modification; a minimum allowable value for total ratings should be fixed whereby details with total ratings above this value do not require action.

If used under appropriate conditions, several improvement methods, such as peening fillet-weld toes and grinding butt-weld reinforcement, are available to increase fatigue strength [2]. Hammer-peening methods, see Figure 3, usually provide the best improvement most economically for details having low fatigue strengths [3]. If the quality of the improvement can be assured, such methods provide useful alternatives to detail modification.

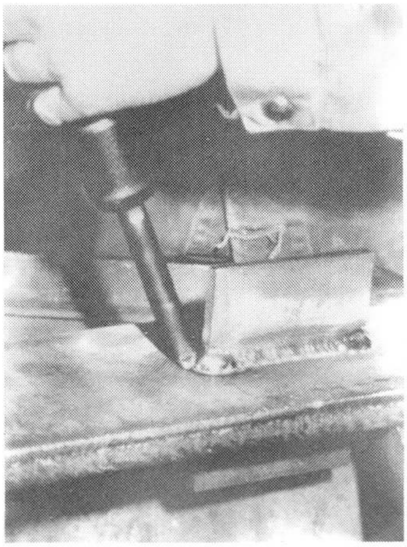

FIGURE 3 : Improvement methods, particularly hammer peening, may increase fatigue strength.

4. USING RATINGS FOR SUBSEQUENT INSPECTION TASKS

The discovery of fatigue cracking in a structure necessitates the development of a rational inspection strategy. Ratings associated with the details should be revised whenever changes are made since they are useful for maintaining appropriate inspection priorities. Repairs should be monitored to ensure that no further cracking will appear. Although ratings are useful guides, they are not likely to identify and place successfully every possible crack location in its correct priority. Therefore, the entire structure should be inspected periodically. A reduction in the inspection effort should be considered only after a decline in the incidence of fatigue cracking has been observed over some time. Finally, an analysis of subsequent crack locations gives an indication of the usefulness of the strategy.

4. FINAL REMARKS

Using this strategy, it is possible to make rational decisions quickly using information which would be incomplete for a detailed structural analysis. Such strategies, if formulated carefully, can increase structural reliability and decrease operating costs. Most structures do not need to be replaced. Unless fatigue cracking is beyond reasonable control, consideration of replacement should be preceded by an attempt to implement a strategy which evaluates the factors discussed in this paper. Finally, this strategy could be extended to cover the evaluation of existing structures, e.g. [4], even when no cracking has been discovered.

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