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Update on Fatigue Issues at Canadian National Railways

Conclusions récentes des chemins de fer nationaux canadiens dans le domaine de la fatigue

Neuste Erkenntnisse des «Canadian National Railways» zur Ermüdung

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SUMMARY

The paper deals with issues of bridge testing, rivet replacement with high strength bolts, accoustic emission testing and the validity of current fatigue strength curves for riveted connections and corroded members. A brief discussion of Safe Life Techniques, used to predict bridge component lives, is included together with system costs on the effect of fatigue damage.

RÉSUMÉ

Cet article traite des sujets concernant des essais sur des ponts, le remplacement des rivets par des boulons à haute résistance, des méthodes de contrôle accoustiques, et la validité des courbes caractéristiques de la résistance à la fatigue des assemblages rivetés et des éléments corrodés. Il donne également une brève discussion des méthodes de calcul de la durée de vie, utilisées pour évaluer la durée de vie des éléments de ponts, ainsi que de l'effet du dommage en fatigue sur les coûts.

ZUSAMMENFASSUNG

In diesem Artikel wird über Erkenntnisse im Zusammenhang mit Brückenversuchen, Ersatz von Nieten durch hochfeste Bolzen und akkustische Prüfmethoden berichtet. Zudem wird untersucht, inwieweit die üblichen Ermüdungsfestigkeitskurven für Nietverbindungen und korrodierte Bauteile Gültigkeit haben. Ein kurzer Abriss über Techniken zur Voraussage der sicheren Lebensdauer von Brückenelementen ist ebenso enthalten wie einige Anmerkungen zum Einfluss von Ermüdungsschäden auf die Systemkosten.

The railway industry in North America is facing a further 20% increase in Axle loadings. In August of 1989, CN received its first regular Double Stack trains with 35.7 tonnes (78,750 lbs) Axle Weights. The previous limit of 30 tonnes (65,650 lbs) had been in effect from the early 1960's.

In view of the fact that the major bridge building era for CN occurred before 1915 most of our major steel bridges are over 75 years old.

These new loadings put at risk 6 to 7 times the number of connections.

At CN we have been using Safe Life techniques to assure safe railway operation Vis a Vis major potential fatigue distress. The principle is that it is better to replace number of bridge components a few years too soon rather than have one bridge replaced too late.

Our long term objective is to reduce the uncertainty and only replace the critical components as they became critical. This is perhaps a dream but still a worth while objective.

Using the existing AREA rating manual (1) and evaluating the remaining useful lives of our main line bridges based on the 2.3% probability curves used in that document, but with actual historical trains and estimated future traffic, led to an indicated increase of bridge replacements from roughly $3.5m U.S. to $23m U.S. annually over the next 25 years.

The procedure is relatively straight forward (Fig. 1). A root-mean cube stress range and relevant cycles are estimated using the rain flow method. This is plotted against the code detail limit on an S-N diagram for traffic to date and various future traffic projections. The remaining detail life is thus estimated.

If 0.1% of the stress ranges have exceeded the constant amplitude fatigue limit, the limit is assumed not to exist and the S-N line is extended downward at the same slope (2).

Given the remaining detail life it is straight-forward to estimate costs for repairs, retrofits, strengthening or replacement as appropriate.

Since severe fatigue distress has already been observed and calibrated with the methods used this leads to the realization of a major cash flow problem.

The bridge section immediately began searching for ways to reduce the expenditure and obtain more reliable ways to manage the situation. Anything that can attack the 2.3% probability criterion and give more certainty would be of value.

The first action taken was to increase the number of spans tested from an average of 2 to 25 per annum. A mobile testing outfit was purchased and developed containing all the

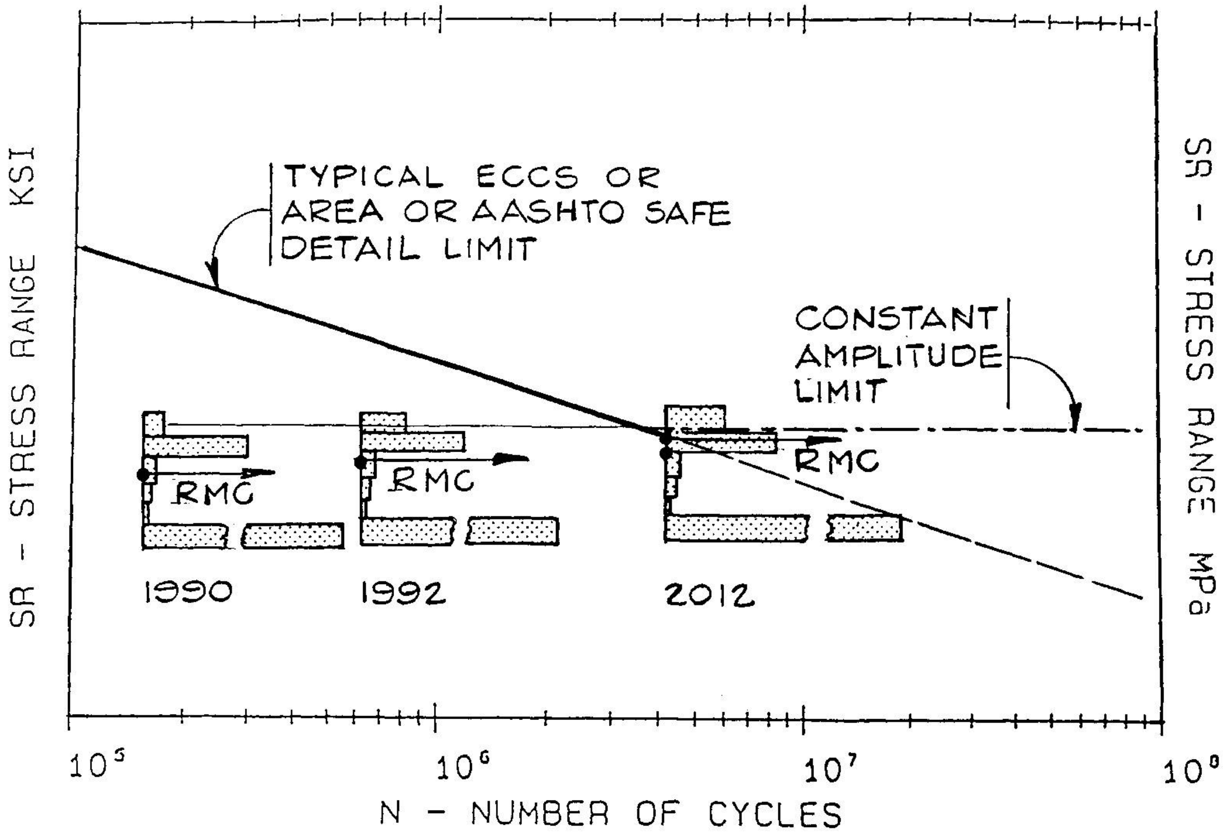


Fig. 1

necessary computers, fibre optic cables, etc. to record up to 24 locations at 1,000 Hz, and to leave a recording device for up to 6 months un-monitored to obtain longer term histograms.

The writer as chairman of the American Railway Association - National Science Foundation Committee on Railway Bridge Testing has seen to a similar program in the United States. To date a Burlington Northern deck plate girder bridge in Illinois has been tested. A bridge on the Norfolk-Southern railroad in Virginia which carries one way fully loaded unit coal trains is under test at the present time (March 1990).

The resultant lower than mathematically modelled stress ranges measured, and subsequently mathematically justified, in all but two CN cases led to a postponement of $7m worth of bridge replacement on the first 25 CN structures measured under real trains.

The next step for CN was to develop in conjunction with Monac, a firm developing a technique put forward by Professor N. Bassim of the University of Winnipeg, an artificial intelligence routine to use accoustic emissions to predict the status of cracking in relation to its position on the "Paris" law curve. The technique was verified at the ATLSS lab at Lehigh University on a series of beams undergoing high cycle fatigue testing. Field testing was done on the Lehigh Canal bridge, and two CNR bridges.

The result is a value for the change in stress intensity factor, K together with the crack growth rate, da/dn. At 22MPa$\sqrt{m}$ (20ksi $\sqrt{in}$) we start to be concerned and would cease operating at 44MPa$\sqrt{m}$ (40ksi$\sqrt{in}$) on our older steels.

This technique was applied to 11 bridges in 1989, and led to the postponement of 7 jobs, the change from replace to retrofit and strengthening on 2 jobs, and the immediate replacement as planned of two bridges.

Presumably working with a 2.3% probability of failure one would expect less than 1 bridge out of 11 in need of replacement. We found two. Some of the critical components will be examined after the bridges are dismantled to gain further confidence in the technique.

Monac testing will have to be repeated to ensure that crack growth rates are not accelerating as traffic patterns change.

Existing North American fatigue criteria on rivets indicates problems above MPa (7 ksi) stress range if 0.1% of all loads exceed the constant amplitude fatigue limit value of 48 MPa (7ksi) for category D (ECCS71) (2).

The slope of the SN curve for welded, riveted and bolted details is - 3 (log scale). Since many girders spans have 100 or more rivets making the cover plate to flange connections, and since the critical crack size is just slightly larger than the rivet head diameter making detection difficult, an economical way of removing rivets, and replacing these with higher fatigue category High Strength bolts is required without damaging the existing steel. Removing 2 or 3 rivets works fine, but removing 100 or so rivets with a 16kg (35 lbs) tool is bound to lead to some nicks or gouges in the flange creating a worse detail.

CN has commissioned a pilot study at Lehigh University's ATLSS Center to investigate the feasibility of a better tool.

Techniques evaluated to date include:

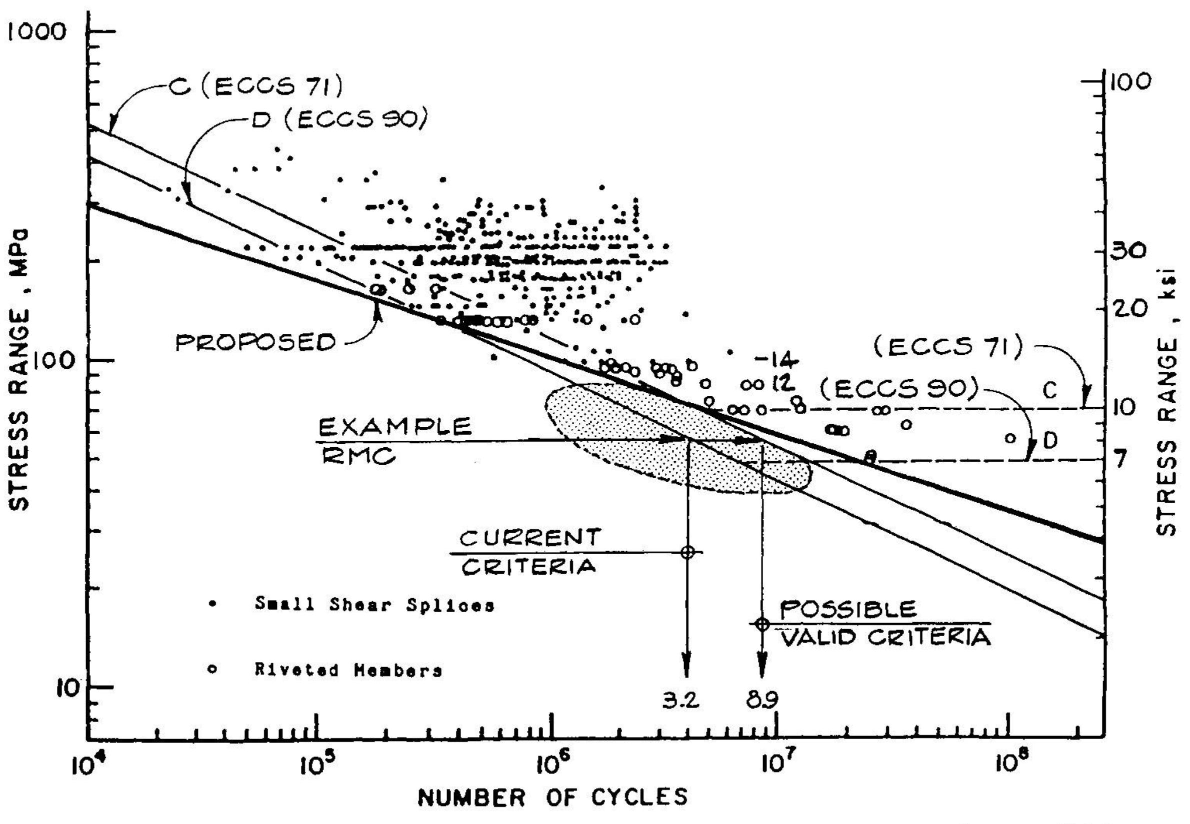
1. Water Jet cutting at pressure rates near 410 PMa (60 ksi)
2. Laser cutting
3. Nitrogen freezing and subsequent impact
4. Grinding and twisting
5. Better pneumatic tools
6. Refined chisels
7. Efforts to reduce tool weight and resultant operator fatigue as well as set-up time
8. Head removal tools
9. Core drilling
10. Hydraulic removal tools

After preliminary study, techniques 3,5,6 and 7 are being pursued further.

I would like to draw your attention to the current recommended North American criteria for rivet fatigue evaluation (Fig. II). There is little relevant test data on real structures in the shaded segment of the diagram (3, Fig. 32) (5). Furthermore it would appear that a different slope somewhere between -4 and -5 also fits the data quite well (heavy line).

If the heavy line were to be valid a considerable number of structures would not be at risk for quite some time. The example in figure II indicates over twice the life for the same probability of failure. The two step ECCS curve addresses this somewhat below 48MPa (7ksi), but does not deal with the problem in the 48MPa (7ksi) to 83MPa (12ksi) stress range. My gut feeling is that a slope appropriate to welded and plain material may not be appropriate for mechanical fasteners.

North American experts suggest that more variable-amplitude testing in the shaded segment is necessary to confirm this. This would be very desirable.



Comparison of fatigue resistance of full-size members with small shear splices. (3, FIG.32)

Fig. 2

Recent tests on badly corroded girders indicate that corrosion cell activity accelerates in poorly corroded beams. From a fatigue point of view current thinking suggests that one must assume a category E or E' detail depending on component thickness at any location where the original section has been reduced by more than 50% (2). Work by Albrecht (4) on sections pitting with up to 21% section loss on weathering steel indicates a reduction from category "A" (ECCS 160) to category "C" (ECCS 90) and he recommends introduction of a pitting factor.

On our railway the first criteria adds $300m to our 25 year bridge replacement bill if it is applied blindly. Clearly this will not be done.

The Albrecht criteria has not been applied since rivets are already the controlling detail in older structures.

Much more research is required to develop more rational criteria in this area, particularly for very badly corroded components.

In summary, it is felt that more testing will lead to:

1. a different slope on the S-N diagram for riveted connections, leading to predictions of longer component lives, and

2. a more rational criteria for badly corroded bridge components.

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