Manuscript number: wes-2021-125 (revision 1)

Title: Damage Equivalent Load Synthesis and Stochastic Extrapolation for Fatigue Life Validation

Thank you very much for the thorough revision of the paper. Many of my comments have been answered comprehensively and the quality of the paper has been significantly improved. Nonetheless, there is still one major topic which has to be discussed and some small minor points.

Major points:

1) For me, the relevance of 1-year extreme DELs (or even longer return periods) is still not completely clear. Perhaps, I just misunderstand your definition of 1-year DELs. If this is the case, the definition of it should be stated more clearly in the paper. And additional explanations are required.
   However, I think the problem is something different. Hence, I try to explain my previous comment in more details in the following.
   Let me give an example, so that it becomes clearer:

   The 10-min short-term DEL is

$$L_{ST} = \left(\sum\nolimits_{i=1}^{n}\left(\frac{n_i L_i^m}{N_{eq}}\right)\right)^{\frac{1}{m}}.$$

   If it is assumed that this the load history that corresponds to this 10-min intervals occurs for an entire year, we get:

$$L_{eq} = \left(6N_v\sum\nolimits_{i=1}^{n}\left(\frac{n_i L_i^m}{N_{eq}}\right)\right)^{\frac{1}{m}}.$$

   Since the factor $6N_v$ is not relevant for the following considerations, I will just use L_{ST}.

   In the long-term, if we would have measurement for the entire lifetime (e.g. 25 years), the long-term DEL would be:

   $L_{25-years} = \left(\sum_{j=1}^{n_{25}}(L_{ST,j}^m)\right)^{1/m}$,

   where $n_{25} = 54787$ is the number of 10-min short-term DELs. This value is the real lifetime DEL and no extrapolation is required.

   However, we normally do not have 54787 short-term DELs. Hence, you propose – if I am correct – to take all short-term DELs you have, to fit a distribution to them and then use the short-term DEL value that occurs with a certain probability as the long-term DEL. For example, for 25 years, you use the DEL occurring with a probability of 1/54787.

   What does this mean? If we would have 54787 short-term DELs, this value is just the highest short-term DEL. Hence, the value that you approximate using your extrapolation is: $L_{max,25-years} = \max_{j=n_{25}} L_{ST,j}$. Hence, you assume that the fatigue life is dominate by a single high short-term DEL value. For high values of m, the two expressions are quite similar. Hence, for blades, your assumption and therefore your extrapolation approach is reasonable. However, for smaller values of m, your approximation is no longer correct. Moreover, it is not a good measure for the correct value. Let me demonstrate this by a simple example:

The real exceedance probabilities for some short-term DELs [1, 2, 3, 4] are [1 0.3 0.1 0.01]. The exceedance probabilities by a fitted distribution are [1 0.2 0.05 0.01]. Hence, the tail of the distribution is well approximated, whereas for higher probabilities the DELs are underestimated. This is what we see in Fig. 5 for example. Since, the tail of the distribution is well approximated, $L_{max,25-years}$ will also be correct. However, the calculation the long-term DEL for $m = 10$ and $m = 4$ gives us (for simplify the example, it is assumed that the DELs are integer values, e.g., the value 1 occurs in 70% of the cases):

$$L_{LT,m=10,real} \approx (0.7 \times 1^{10} + 0.2 \times 2^{10} + 0.09 \times 3^{10} + 0.01 \times 4^{10})^{\frac{1}{10}} = 2.63$$
$$L_{LT,m=10,fit} \approx (0.8 \times 1^{10} + 0.15 \times 2^{10} + 0.04 \times 3^{10} + 0.01 \times 4^{10})^{\frac{1}{10}} = 2.58$$
$$L_{LT,m=4,real} \approx (0.7 \times 1^{4} + 0.2 \times 2^{4} + 0.09 \times 3^{4} + 0.01 \times 4^{4})^{\frac{1}{4}} = 1.92$$
$$L_{LT,m=4,fit} \approx (0.8 \times 1^{4} + 0.15 \times 2^{4} + 0.04 \times 3^{4} + 0.01 \times 4^{4})^{\frac{1}{4}} = 1.73$$

Hence, the real long-term is only well approximated for high values for m. In this case, $(0.01 \times 4^{10})^{\frac{1}{10}} = 2.52$, which corresponds to $L_{max,25-years}$, dominates the entire fatigue behavior, cf. $(0.7 \times 1^{10} + 0.2 \times 2^{10} + 0.09 \times 3^{10})^{\frac{1}{10}} = 0.11$. However, for $m = 4$, the influence of $L_{max,25-years}$ is less pronounced: $(0.01 \times 4^{4})^{\frac{1}{4}} = 1.26$ compared to $(0.7 \times 1^{4} + 0.2 \times 2^{4} + 0.09 \times 3^{4})^{\frac{1}{4}} = 0.66$.

This is why in my opinion, the relevance of 1-year extrapolated DELs has to be critically discussed in the paper. I do not say that it is not relevant. Especially for composite materials, the proposed approach can definitely be applied. However, for steel components, the described limitation has to be discussed or – if my understanding is incorrect – additional explanations have to be added to clarify your approach.

Minor points:

1) Perhaps it would help if you clearly differentiate between short-term DELs (e.g. based on 10 min intervals; $L_{ST} = \left(6N_v \frac{\sum_{i=1}^{n}(n_i L_i^m)}{N_{eq}}\right)^{1/m}$) and long-term DELs being the "sum" of many (n_{ST}) short-term DELs ($L_{LT} = \left(\sum_{j=1}^{n_{ST}}(L_{ST,j}^m)\right)^{1/m}$) over a longer time period. In my understanding an "aggregated DEL" is a long-term DEL, but it seems as if you use this expression differently.
2) L. 190 (of the revision): Perhaps refer to Fig. 9b
3) L. 248-250 (of the revision): I am sorry, but you cannot see "that the extrapolation […] provides a good representation". It is true that in Fig. 5, it can be seen that the 1-year DEL is fitted well. However, in Fig. 5, you do not know which measurement corresponds to which line etc. Hence, please reformulate or remove this statement or make the figure clearer.
4) Fig. 6 and 7: Different scales of the vertical axis make comparisons complicated.

5) In Fig. 9b, it would help if the first eigenfrequencies of the blade (flapwise) and the tower (FA) are marked, since the first peak for the tower moment is not clearly visible.
6) L. 291 (of the revision): You state that is it “possible to directly simulate multi-year damage equivalent moments”. However, if I am correct, this is only possible if std. deviation, minimum and maximum load levels are available. This should be stated here again.

<u>Editorial changes, syntax, typos, etc.:</u>

1) L. 212 (of the revision): “wind directions” and not “wind direction”
2) L. 278 (of the revision): “Fig. 9b” and not “Fig. 9B”