

European traffic on road bridges and recalibration of damage equivalence factor for fatigue verification

The evolution of European traffic, combined with the current revision works of the Eurocodes, represents an opportunity to improve the simplified method for fatigue checks (also known as the lambda method) for road bridges. The works reported herein focus on the development of the λ_1 factor curves for the damage effect of highway traffic on road bridges, using the existing Eurocode FLM3 model. The aim of the research is to model the traffic and resulting stress ranges at details on bridges with different static systems. The simulation results shall be as similar as possible to reality by introducing different parameters that were not taken into account in the previous simulations, including the passage of multiple vehicles at the same time in the flowing and congested traffic conditions. Within this study, the validity of the formulas for λ_2 and λ_3 were also checked. The new curves have less dispersion and may be taken into consideration to update the current curves from EN 1993-2.

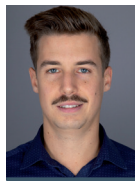
1 Overview

The current European standard is based on 30-year-old models of real traffic and the resulting λ_1 curves have limitations. In particular, the current curves were generated based on a limited number of influence lines (only 4) which lead to curves that may be unsafe or very conservative in some cases.

It should also be pointed out that modelling heavy vehicles using individual axles increases the accuracy of the model, in comparison to modelling each vehicle as a single load as it was often done previously.

The research work is primarily motivated by the goal to update the actual lambda method by proposing a set of new λ_1 curves, which includes all the relevant parameters, that is:

- Comparison between two different traffic models;
- Bending moment and shear forces;
- Different types of influence lines;
- Different slopes for the fatigue curves of the details;
- Modelling of traffic divided into individual axles and modelling of heavy vehicles as single loads;
- Different traffic volumes;
- Multiple heavy vehicles and congested traffic on the influence line effects;
- Spans longer than 80 m.



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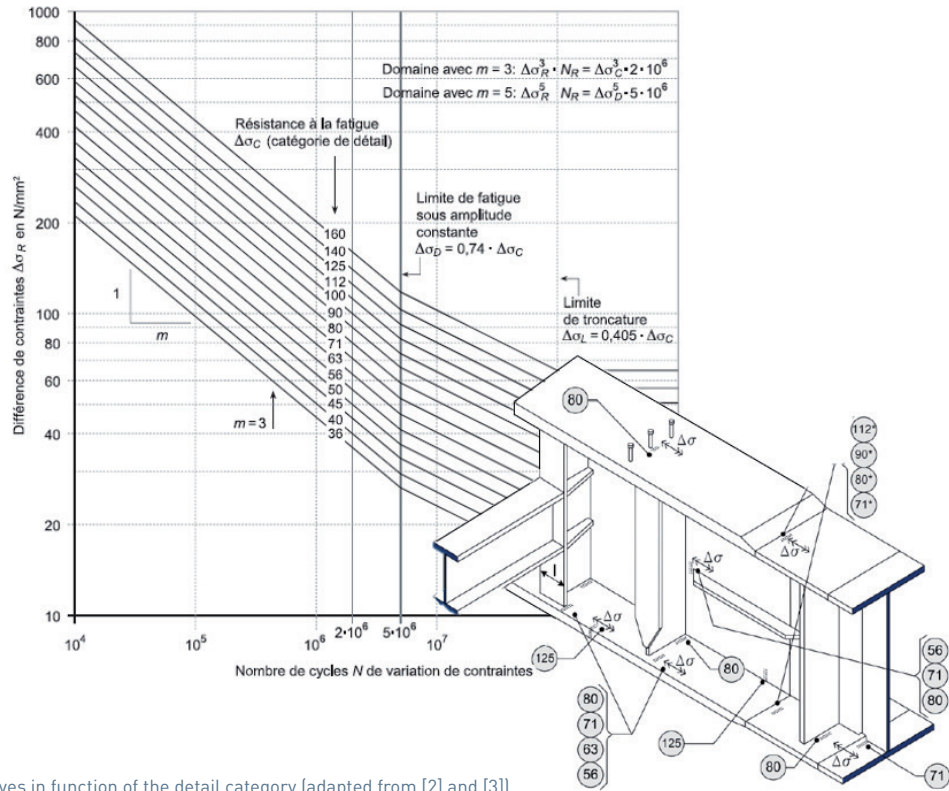
Gianluca Bianchi erhielt den VSS-Preis 2020 für seine Masterarbeit, verfasst am Resilient Steel Structures Laboratory (RESSLab) der EPFL.

Gianluca Bianchi a obtenu le prix VSS 2020 pour le mémoire de master rédigé au Resilient Steel Structures Laboratory (RESSLab) de l'EPFL.

In order to propose a more complete update, the validity of the factors λ_2 and λ_3 is also studied in detail as those are directly related to the factor λ_1 determination. Finally, convergence studies and variance analysis of the results are presented, as well as a special case analysis. The scope of the study is limited to using the existing EN 1991-2 Fatigue Load Model 3 (FLM3) model^[1], with its advantages and disadvantages, and not developing a new one. The only exception is the discussion on the usefulness of the second vehicle.

2 Basic concepts of fatigue checks

Fatigue resistance of construction details is standardized to obtain a diagram in which the number of cycles (N) is plotted on the x-axis and the stress range $\Delta\sigma$ on the y-axis. The value $\Delta\sigma_C$ represents the resistance of the detail for $2 \cdot 10^6$ cycles. The value $\Delta\sigma_D$ represents the knee point where the slope changes from m to k for amplitude loadings, usually 3 and 5 and is fixed at $5 \cdot 10^6$ cycles. Finally and linked to the previous, $\Delta\sigma_L$ represents the cut-off limit below which it is possible to neglect the stress ranges in the cumulative damage computation and corresponds usually to 10^8 cycles. The family of curves under normal stress ranges in the EN 1993-1-9 are shown in Fig. 1.



1 | Fatigue resistance curves in function of the detail category [adapted from [2] and [3]].

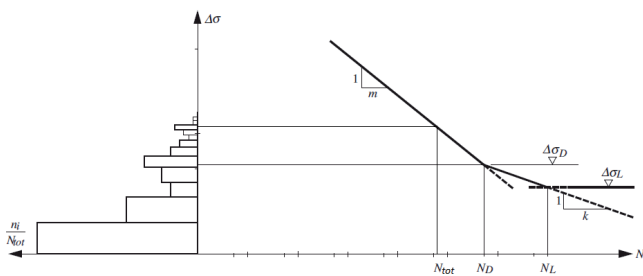
2.1 Verification with linear (Palmgren-Miner) damage accumulation rule

The Palmgren-Miner damage accumulation rule is given by

$$D_{tot} = \sum_{i=1}^k n_i d_i \quad (1)$$

where D_{tot} = total damage; n_i = number of cycles at stress range level i ; and d_i = individual damage due to a single cycle of stress range i , equal to $1/N_i$.

The cumulative damage method consists in collecting the histogram of the stress differences $\Delta\sigma_i$ during the life of the structure, the damage at each stress level being function of its level as can be seen in Fig. 2. This method is clearly the most accurate but complex form to evaluate the fatigue damage due to the fact that it requires the evaluation of the whole histogram of the cycles. At the end of the procedure it is possible to compute the value of the equivalent stress range for $2 \cdot 10^6$ cycles, $\Delta\sigma_{E,2}$:



2 | Effect of $\Delta\sigma_i$ under the limits of fatigue $\Delta\sigma_D$ and the cut-off limit $\Delta\sigma_L$ [extracted from [4]].

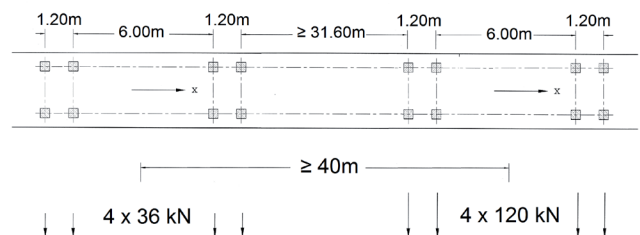
2.2 Verification with lambda factor

According with the EN 1993-2, verification of fatigue should be performed using:

$$\gamma_{Ff} \Delta\sigma_{E,2} = \lambda \gamma_{Ff} \Delta\sigma(Q_{fat}) \leq \frac{\Delta\sigma_C}{\gamma_{Mf}} \quad (2)$$

where λ = damage equivalence factor; and $\Delta\sigma(Q_{fat})$ = stress range calculated with a defined EN 1991-2^[1] fatigue load model, the FLM3. The fatigue check is by convention carried out at 2 million cycles.

This method has been developed to simplify the cumulative damage method, introducing lambda correction factor that correlates real damage to that of the passage of the FLM3, a single vehicle model vehicle is used to obtain a “reference stress range” at each detail location within the structure, see section 3.1 for more explanation. Even if called single vehicle model, where relevant, two vehicles in the same lane should be taken into account. This was introduced to generate a larger reference stress range for fatigue checks, in particular of intermediate support sections.



3 | Fatigue Load Model 3 (modified from [5]).

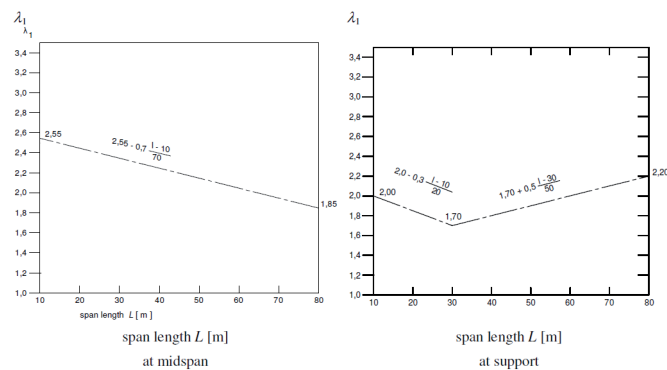
2.3 The lambda factor

EN 1993-2 defines the damage equivalence factor for road bridges with up to 80 m span as follows:

$$\lambda = \lambda_1 \lambda_2 \lambda_3 \lambda_4 \quad \text{but} \quad \lambda \leq \lambda_{\max} \quad (3)$$

2.3.1 Factor for damage effect of traffic λ_1

EN 1993-2 contains two graphs to extract the factor for damage effect of traffic λ_1 in function of the span length, as shown in Fig. 4.



4 | λ_1 for bending moments on road bridges according to EN 1993-2 (extracted from [6])

2.3.2 Factor for traffic volume λ_2

$$\lambda_2 = \frac{Q_{m1}}{Q_0} \left(\frac{N_{\text{obs}}}{N_0} \right)^{\frac{1}{m}} \quad (4)$$

where Q_{m1} = average gross weight of the heavy vehicles in the slow lane; Q_0 = average gross weight of the model; N_0 = reference number of heavy vehicles per year (= 500 000); N_{obs} = total number of heavy vehicles per year in the slow lane; and m = fatigue resistance curve slope to be replaced by the 2nd slope k where it applies.

2.3.3 Factor for design life λ_3

$$\lambda_3 = \left(\frac{T_{\text{Ld}}}{T_{\text{ref}}} \right)^{\frac{1}{m}} \quad (5)$$

where T_{Ld} = design service life of the bridge; T_{ref} = reference service life (= 100 years); and $m = m$ or k .

2.3.4 Factor for traffic on other lanes λ_4

$$\lambda_4 = \left[\sum_{j=1}^n \left(\frac{\lambda_{2,j} \Delta \sigma_j}{\lambda_{2,1} \Delta \sigma_1} \right)^m \right]^{\frac{1}{m}} \quad (6)$$

where j = number of lanes with heavy traffic; and $m = m$ or k .

2.3.5 Factor λ_{\max}

The factor λ_{\max} is defined as the maximum value taking into account the fatigue limit (all stress range cycles remaining below $\Delta \sigma_D$). Similarly to λ_1 , it is given in the form of two graphs in EN 1993-2.

3 Theoretical development and algorithms implementation

3.1 The lambda method procedure

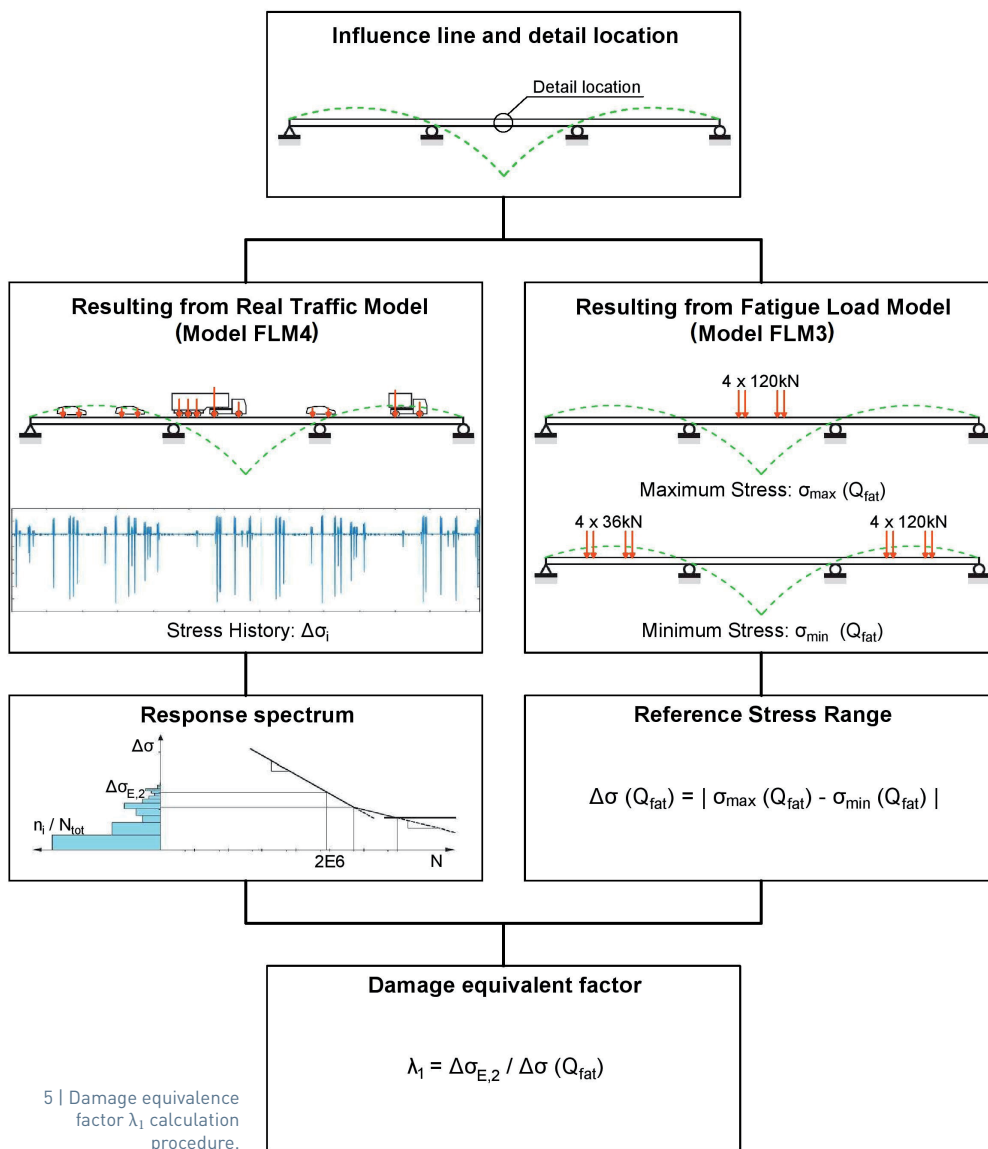
The procedure in Fig. 5 explains how to compute the damage equivalence factor λ_1 for the influence line of a defined static system and detail location.

The real traffic model gives a stress histogram which is obtained from the simulation process. The two slope S-N curve is shifted vertically until the curve level at which damage = 1 is pinpointed, assuming failure occurs when linear damage accumulation reaches one. Once the position of the S-N curve is fixed, the equivalent stress range $\Delta \sigma_{E2}$ obtained corresponds to that stress level at which the S-N curve equals $N = 2$ million cycles.

DE Der europäische Verkehr auf Strassenbrücken und die Rekalibrierung des Schadensäquivalenzfaktors für den Ermüdungsnachweis

Die Entwicklung des Verkehrs in Europa sowie die derzeitige Überarbeitung der Eurocodes sind eine Gelegenheit, die vereinfachte Methode für Ermüdungsnachweise (auch als Lambda-Methode bekannt) für Strassenbrücken zu verbessern. Die im folgenden Beitrag erwähnten Arbeiten legen den Fokus auf die Entwicklung der λ_1 -Faktorenkurve hinsichtlich Schadenswirkung des Autobahnverkehrs auf Strassenbrücken unter Verwendung des aktuellen ELM-3-Modells der Eurocodes. Ziel der Untersuchung ist es, den Verkehr und die daraus entstehenden Spannungsschwingbreiten an Brückendetails

mit verschiedenen statischen Systemen zu modellieren. Es sollen möglichst realitätsnahe Simulationsergebnisse erzielt werden, indem verschiedene, in den vorherigen Simulationen nicht berücksichtigte Parameter integriert werden, wie etwa die Durchfahrt mehrerer Fahrzeuge zur selben Zeit – sowohl bei fließendem Verkehr als auch bei Stau. Im Rahmen der Studie wurde auch die Gültigkeit der Formeln für λ_2 und λ_3 geprüft. Die neuen Kurven weisen weniger Dispersion auf und könnten für eine Aktualisierung der aktuellen Kurven von EN 1993-2 in Betracht gezogen werden.



In parallel, the stress ranges are obtained for the FLM3 model placed at the positions corresponding to the minimum and maximum stress values. The absolute difference between the two is the reference stress range $\Delta\sigma(Q_{fat})$.

Once the equivalent stress range $\Delta\sigma_{E,2}$ and reference stress range $\Delta\sigma(Q_{fat})$ are obtained, the damage equivalence factor λ_1 is defined in coherence with Eq. (2) as the ratio between the two values.

FR Trafic européen sur les ponts-routes et recalibrage du facteur d'équivalence de dommage pour la vérification en fatigue

L'évolution du trafic européen, combinée à la révision actuelle des Eurocodes, est une opportunité pour améliorer la méthode simplifiée de vérification de la fatigue (également connue sous le nom de méthode lambda) des ponts-routes. Les travaux rapportés dans le présent article montrent le développement des courbes du facteur partiel de correction λ_1 , à travers la sollicitation des ponts-routes par le trafic autoroutier et en utilisant le modèle FLM3. Ces recherches ont pour but de modéliser, avec différents systèmes statiques, le trafic et les étendues de contraintes qui en résultent au niveau des détails

de construction des ponts. La simulation doit être la plus proche possible de la réalité. Pour cela, il convient d'introduire différents paramètres qui n'ont pas été pris en compte lors des précédentes simulations, et d'inclure le passage simultané de plusieurs véhicules dans des conditions de fluidité et de congestion du trafic. La validité des formules pour les facteurs partiels de correction λ_2 et λ_3 a également été vérifiée dans le cadre de cette étude. Les nouvelles courbes présentent une moins grande dispersion et peuvent être prises en compte pour mettre à jour les courbes actuelles de la norme EN 1993-2.

3.2 Implemented influence lines

A set of 19 influence lines have been chosen in this study, covering different bridge configurations and detail locations that represent the typical cases. They are deemed to cover all the other cases as they include the upper and lower bound of all the possible shapes.

Table 1 Set of influence lines

Influence line				
Midspan M	1S-MM*	2S-MM	3S-MM	3SH-MM
Midspan V	1S-MV	2S-MV	3S-MV	3SH-MV
Support M	-	2S-SM*	3S-SM	3SH-SM
Support V	1S-SV	2S-SV	3S-SV	3SH-SV
Lateral Midspan M	-	-	3S-LM	3SH-LM
Lateral Midspan V	-	-	3S-LV	3SH-LV

*Used for comparison

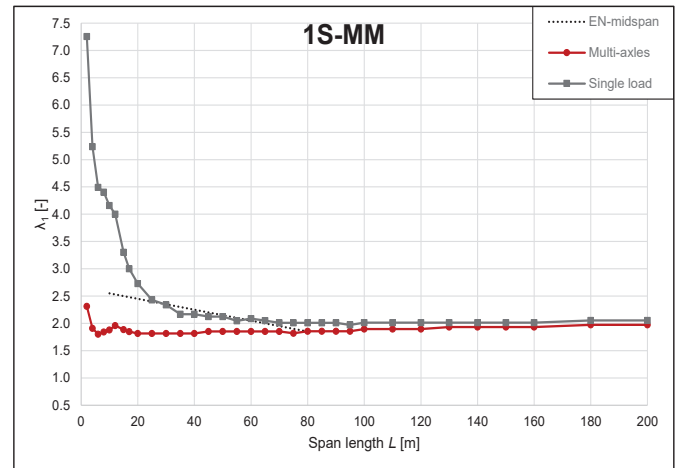
The last static system has lateral spans with half-length of the main span; this static system does not represent necessarily the reality of a normal bridge configuration, but it is useful to understand the behaviour of the configurations amplifying the effect of having smaller lateral spans.

3.3 Set of heavy vehicles

Two different sets of heavy vehicles have been used for modelling the real truck traffic and compute the new λ_1 curves: The first one is based on the A16 Highway in the Netherlands, a set of heavy vehicles taken from WIM measurements; The second one, used for all the simulations, is the FLM4 “equivalent lorries” defined in the EN 1991-2 (based mostly on the Auxerre traffic model, dating from 1986). This latter set of lorries stems from the need to have a standardized set of lorries that are already included in the EN 1991-2. The first set was used to recheck the validity (upper bound) of the second set of lorries, which indeed was shown to overestimate fatigue damage^[5]; even if dating the aggressive Auxerre traffic model is still proven valid. The light vehicles are introduced into the model essentially to consider properly the larger distances between lorries and they are modelled with only a type of vehicle.

3.4 Real traffic with multi-axes model

Some of the simulations done from other authors were reproduced using a single load model that is assigning a single force for each heavy vehicle from the real traffic model. In this study and developed code, the behaviour of a more accurate model taking into account the division of each heavy vehicle into its individual axles is made.



6 | Comparison considering multi-axes model and single load model, free-flowing conditions 1S-MM.

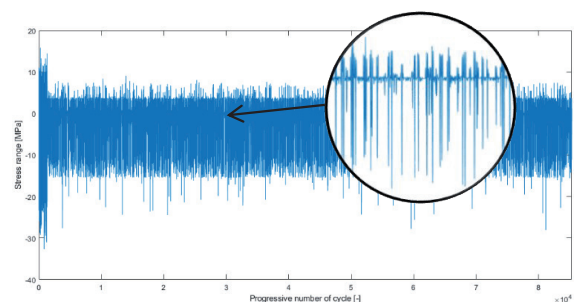
As can be seen in Fig. 6, as the span gets shorter, the single load modelling becomes completely false because the λ_1 value tends to the ratio between the total load of the vehicle and the FLM3 axle load. On the opposite, for spans longer than approx. 80m, the results are equivalent as the distances between axles within each vehicle is not relevant anymore to get the extremes. The actual λ_1 curve (as given in Fig. 4) is represented as a dotted line, and one can see that the multi-axes simulations results significantly differ from it. One reason can be the use of the FLM3 with one single lorry only, but other reasons as explained previously play a major role.

3.5 Traffic modelling

The simulations introduce two important features for modelling as close as possible worse real traffic conditions for fatigue. First they take into account the random probability of multiple trucks on a bridge, i.e. on an influence line. Previous simulations have sometimes considered passing trucks one-by-one and this simplification influences the results significantly (for spans longer than a truck length).

The other feature is the possibility to consider both free-flowing traffic and congested traffic. This is possible with the help of two different statistical laws:

- For free-flowing traffic, the density function for the inter-vehicle distance is randomly sampled from a Gamma distribution, based on the density function of Davenport. It is calculated with a speed of 80 km/h;
- For congested traffic, the flow conditions are randomly sampled from a Beta distribution and it is calculated with a speed of 20 km/h.

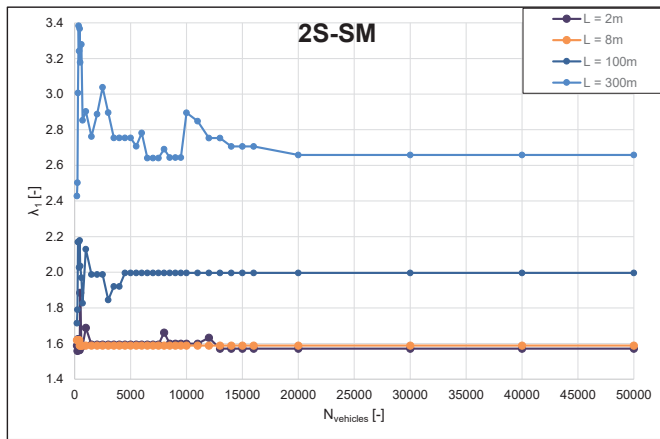


7 | Stress history of the “real” traffic simulation, 20% congested.

3.6 Convergence to exact solution

As the number of heavy vehicles per year is 500 000 (one lane), the total number of vehicles including light vehicles to simulate the design service life of a bridge may range from 200 million to 1 billion (typically 5% to 25% of trucks in the traffic). The results of convergence analysis show that from a certain number of vehicles, the results tend to be constant and it is not necessary to simulate such large numbers, the cumulative damage can be extrapolated to 100 years linearly. Indeed, the maximum traffic volume is assumed from day one (design value) and thus no increase during the service life as to be considered.

As one can see from Fig. 8, the convergence to constant values occurs quickly and is reached already for approx. 20 000 vehicles (note that one week of traffic can range from 40 000 to 200 000).



8 | Convergence in function of the number of vehicles, 2S-SM.

3.7 Comparison with previous simulations

Finally, it is possible to compare the new simulation model results with the simulations made in the past, especially with the ones from Merzenich and Sedlacek^[7] at the origin of the present EN 1993-2 λ_1 curves.

The simulations by Nussbaumer and Walbridge were made to validate the Swiss code SIA261, in relation with the National Annex of EN1993-2 for Switzerland.

Table 2 Comparison with previous simulations

Parameters	Merzenich and Sedlacek, 1995 (EN 1993-2)	Nussbaumer and Walbridge, 2009 (SIA 261)	Maddah, 2013	Bianchi, 2019
Enough influence lines	X	✓	✓	✓✓
Different m slope	X	X	X	✓
Varied set of lorries	✓	X	✓	✓✓
Different types of traffic	X	X	X	✓
Division by axles	X	X	X	✓
Lorries one-by-one	✓	✓	✓	✓
Free flowing traffic	X	X	✓	✓
Congested traffic	X	X	X	✓
Stop-and-go traffic	X	X	X	X
Detailed numerical analysis	?	?	?	✓
Spans longer than 100 m	X	X	X	✓

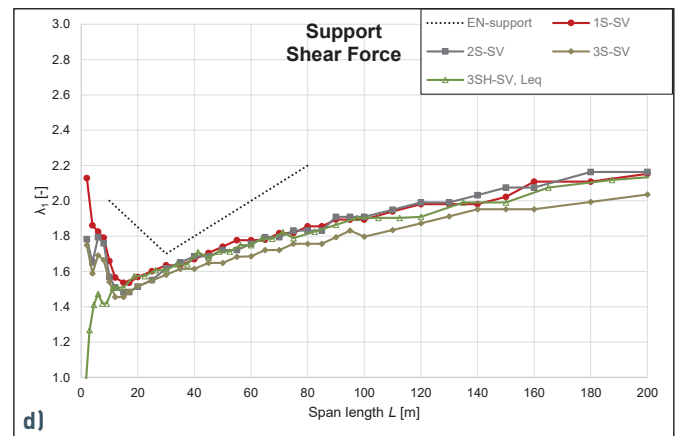
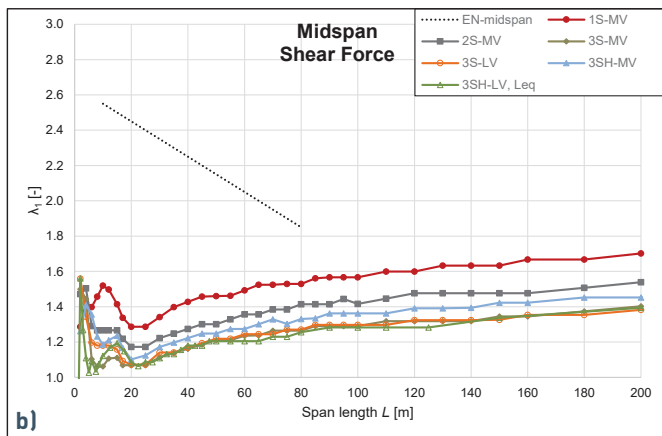
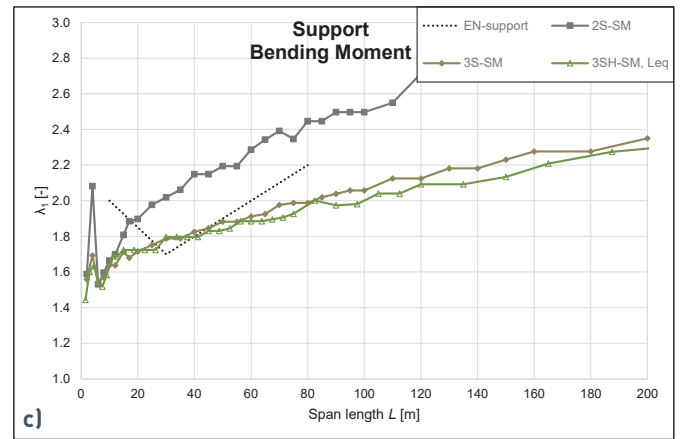
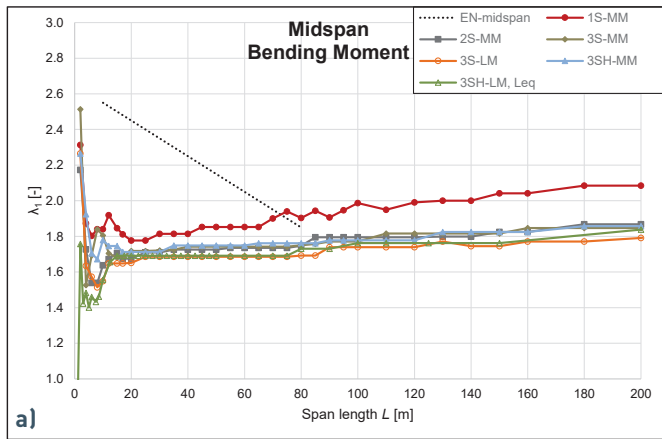
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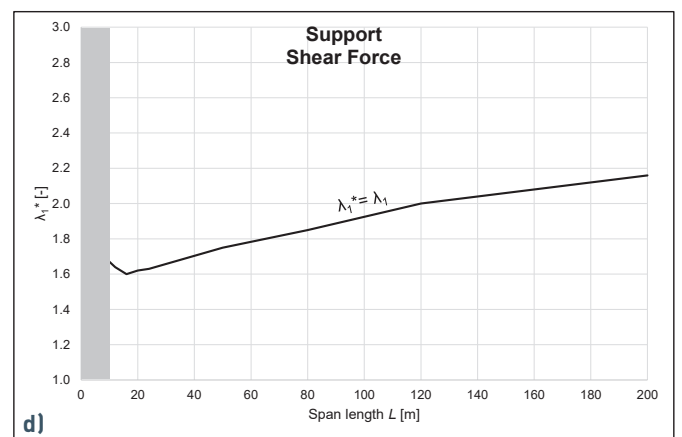
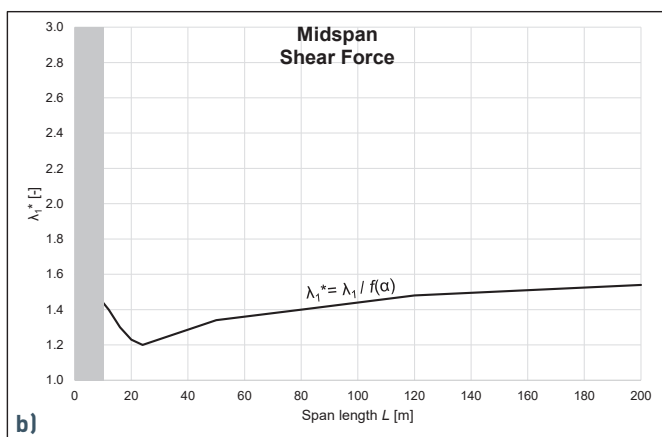
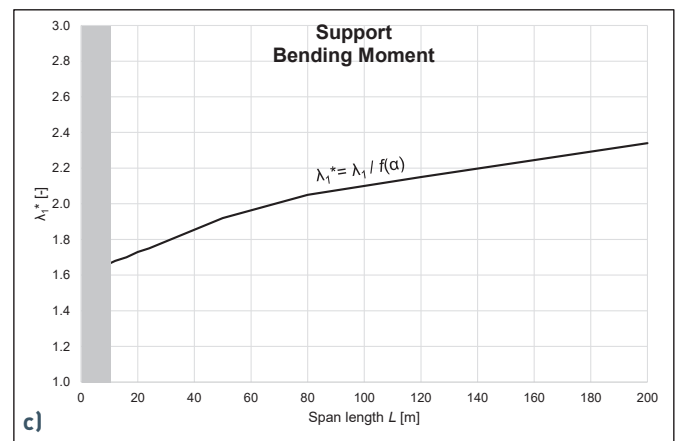
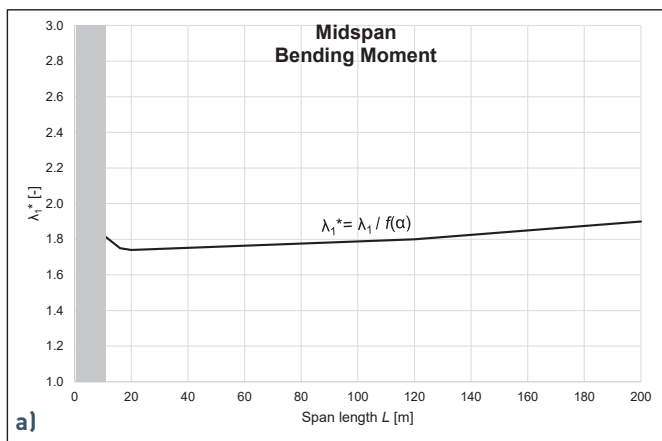
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9 | Set of λ_1 curves for midspan bending moment (a), midspan shear force (b) support bending moment (c) and for support shear force (d).



10 | New factor λ_1^* curves for midspan bending moment (a), midspan shear force (b), support bending moment (c) and support shear force (d).

4 Analysis of the final simulations

4.1 Classification of the λ_1 curves results

Once the λ_1 curves for each of the 19 influence lines are obtained, we chose to observe their similarities in order to regroup them in a logic manner. A minimum n_b of curves should be selected to covers the major number of cases and being easy to use. The classification has been made and we propose four different graphs in Fig. 9 because the curves obtained are very different and should not be regrouped in only two graphs as done previously. The results are presented with a maximum span length of 200 m as this value covers the vast majority road bridge spans.

All the curves show significant dispersion for spans shorter than 10 m. The reason is the placement of individual axles within a real heavy vehicle, which the FLM3 model does not represent well. Thus, as in the present version of EN 1993-2, the propositions that follow are valid for spans longer than 10 m. For very short spans, one should directly use the FLM4 model from EN 1991-2 and the damage accumulation rule (Eq. (1)).

As all the influence lines regrouped in the same graph have λ_1 curves with the same shape but that do not necessarily fall on the top of each other, i.e. there can be a scaling, a correction formula is introduced where needed.

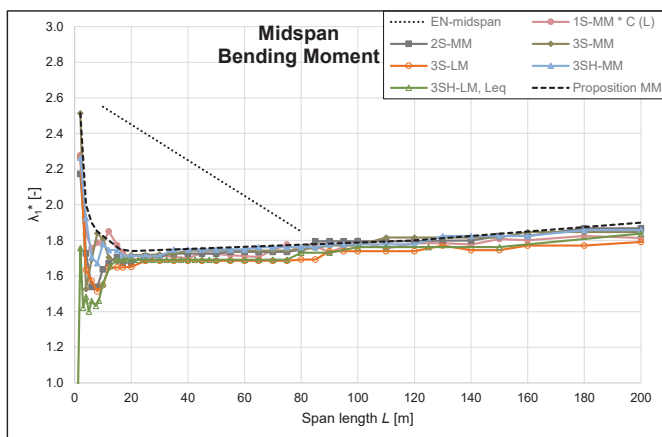
4.2 Proposition for EN 1993-2 λ_1 curves

Finally, the results of the simulations have been used to propose the new version of λ_1 curves for EN 1993-2 for highway bridges. A set of graphs with a unique curve per graph has been developed, together with the introduction of a correction formula as follows:

$$\lambda_1 = \lambda_1^* \cdot \left[\sqrt{\left(\frac{L}{200}\right) \cdot \alpha + 1} \right] \quad (7)$$

where λ_1 = final value including correction; λ_1^* = value obtained from the graphs; L = span length; and α = influence line factor. The values of α from Table 3 were calibrated to fit with the numerical results. The new curves of λ_1^* are presented in Fig. 10.

As an example, Fig. 11 shows the application of the new formula to the set of λ_1 curves for midspan bending moment (Fig. 9a). The resulting curve (proposition MM) is the upper bound of the now very narrow set of curves.



11 | λ_1 results for midspan bending moment, and curve obtained by Eq. (7).

4.3 Traffic volume factor λ_2 proposition

As the new damage equivalence factor λ_1 has been generated with an average gross weight of the lorries in the slow lane Q_m of 411.1 kN, i.e. computed from FLM4 lorries and frequencies corresponding to long distance, the Q_0 of the traffic volume factor λ_2 must be updated to this value. For simplification, it is possible to assume a Q_0 value of 410 kN.

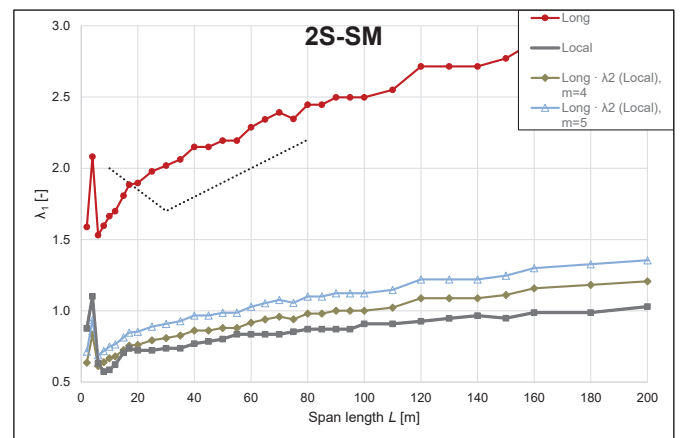
Table 3 Influence line factor α

Influence line	α
1S-MM	0.15
1S-MV	0.20
2S-SM	0.30
Others*	0

The general case does not need any correction, therefore α is set equal to zero and thus λ_1 is equal to λ_1^

As already mentioned, the reference number of heavy vehicles N_0 per year used is 500 000. Simulations for other reference number of heavy vehicles have been carried out, and compared to the $\lambda_1:\lambda_2$ curve obtained using Eq. (4). In terms of shape, the factor λ_2 fits well for all the cases. However, the matching is not optimal. Thus, the value of the exponent m (usually taken as $k=5$ in the case of a fatigue resistance curve with double slope $m=3|5$) has been varied to find the exponent m that fits better with the simulations.

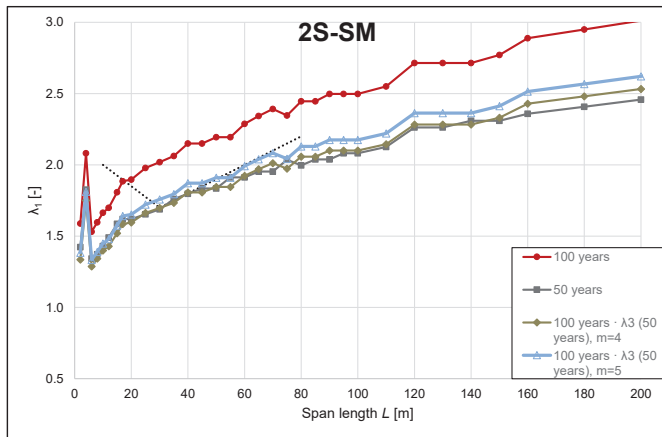
Fig. 12 summarizes the results for the case of local roads. Using $m=5$, there was a maximum discrepancy between the simulation and the application of the factor of 34 %, using $m=4$ this maximum discrepancy dropped to 18 % (2S-SM influence line).



12 | Comparison between direct simulation and application of λ_2 with different m for local roads (50 000 heavy vehicle/year), 2S-SM.

4.4 Design life factor λ_3 proposition

The same procedure as explained in the previous section was used to compare direct simulation results and application of λ_3 for a design service life of 50 years instead of 100 years. As previously, it was found that updating the value of the exponent to $m=4$ leads to a better match between the results, as shown in Fig. 13.



13 | Comparison between direct simulation and application of λ_3 with different m for 50 years design life bridge, 2S-SM.

4.5 Equivalent span length L proposition

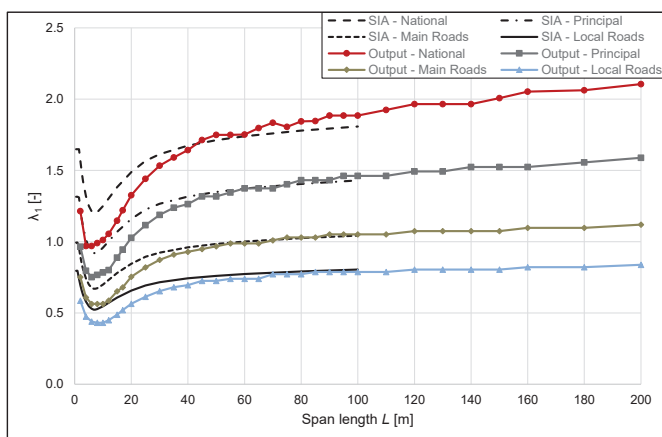
In EN 1993-2, detailed guidance on the appropriate ‘span length’ to use in any λ curve graph is given. To simplify, our proposition is to use in general the real span length L as “equivalent span length”, with one exception – for the support section, the average between the two adjacent spans should be considered.

5 Swiss Code application

The SIA fatigue load model was not fully implemented as it was not the main objective of the work. Still some comparisons were done to verify the ability of our new simulation algorithm to reproduce the SIA 261 λ_1 curves shape and identify potential sources of improvement applicable for the Swiss traffic.

The FLM3 of EN 1991-2, used in the previous simulations, has been replaced with the Load Model 1 in accordance to SIA 261 to obtain the SIA curves of λ_1 .

As can be seen in Fig. 14, the correspondence between the SIA curves^[9] and the simulation is very good, especially the shape, even though the “real” traffic model used in the actual version of SIA was not implemented in the simulation algorithm.



14 | Results of the simulations with SIA traffic model and SIA 261 λ_1 curves.

6 Conclusion

This work aimed at studying the fatigue check using the damage equivalence factor λ_1 and proposes improvements. Different comparisons were performed by changing some parameters of traffic models, set of lorries, slope of the fatigue resistance curve, different model of vehicles, fatigue load models (FLM).

An accurate approach to the definition of the factor λ_1 curves for highway bridges has been performed. Different parameters have been introduced to describe the real traffic and a major number of influence lines have been simulated. The large number of results was possible due to the great effort put in the development of the simulation algorithm to obtain a full λ_1 curves.

The set of results shows how each of the parameters influences the shape and value of λ_1 . It was concluded it is preferable not to regroup all resulting λ_1 curves into only two curves, as in the presently done in EN 1993-2. Instead, four different graphs for midspan/support and bending moment/shear force were proposed.

These graphs are able to cover a large number of practical cases, as in EN 1993-2, but reduce significantly the uncertainties associated with the practical assessment of the damage equivalence factor λ_1 . The results also fill the gap in the code for spans longer than 80 m. Furthermore, for factors λ_2 and λ_3 , it is recommended to use $m = 4$.

References

- [1] European committee for standardization (2003) Eurocode 1 – Actions on structures – Part 2: Traffic loads on bridges.
- [2] Merzenich G.; Sedlacek, G. (1995) Hintergrundbericht zum Eurocode 1 – Teil 3.2: «Verkehrslasten auf Strassenbrücken». Forschung Heft Strassenbau und Strassenverkehrstechnik.
- [3] SIA (2013) Swiss standard SIA 263 – Construction en acier.
- [4] Hirt, M.;Bez, R.; Nussbaumer, A. (2006) Construction métallique (TGC volume 10). PPUR.
- [5] Maljaars, J.; Steenbergen, R.; Abspoel, L.; Kolstein, H. (2012) Safety Assessment of Existing Highway Bridges and Viaducts. Structural Engineering International 1/2012.
- [6] European committee for standardization (2006) Eurocode 3 – Design of steel structures – Part 2: Steel Bridges.
- [7] Sedlacek, G.; Merzenich, G.; Paschen, M.; Bruls, A.; Sanpaolesi, L.; Croce, P.; Calgaro, J.A.; Pratt, M.; Jacob, Leendertz, M.; De Boer, V.; Vrouwenfelder, A.; Hanswille, G. (2008) Background document to EN 1991 – Part 2 – Traffic loads for road bridges – and consequences for the design. JRC Scientific and Technical Reports.
- [8] Pedro, J.O.; Reis, A. (2010) Nonlinear analysis of composite steel-concrete cable-stayed bridges. Engineering Structures 32 (9).
- [9] SIA (2014) Swiss standard SIA 261 – Actions sur les structures porteuses.