Lenkungskreis Fahrzeuge
Arbeitskreis Brückendynamik – AP 2

User Manual

ZBBD
for investigations on dynamic compatibility between rolling stock and bridges

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Inhaltsverzeichnis

1 Issues

Version	Datum	Kapitel	Änderung
1.0	2020-02-14		Initial Issue

1 General, contacts

The software is provided to the sector by the working group "AK Brückendynamik" of the National German "LK Fahrzeuge".

If properly used as explained in this manual, the results can be accepted as proof of the investigation stages 1 and 2 required by SNB RW 810.0200A81 of DB Netz.

For any questions concerning the software, please contact the working group directly via this e-mail address:
mailto:lk-fahrzeuge.ak-brueckendynamik@deutschebahn.com

Concerning the approval process, please contact DB Netz directly:
mailto:technischer-netzzugang@deutschebahn.com.

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2 Introduction / Background

Within the description of the interface between rolling stock and bridges, some open issues related to the dynamic compatibility were noticed in Germany as well as on European level.

Thus, German infrastructure operator DB Netz AG published the guideline 810.0200A81 in 2016 (currently part of TNB of DB Netz), which requests that all rolling stock coming into service on the infrastructure of DB Netz for the first time on 2016-11-01 or later, has to be checked concerning bridge dynamics compatibility.

The necessity to perform these compatibility checks was discussed within the German Railway Sector Group (Lenkungskreis Fahrzeuge) between DB Netz AG and representatives of railway undertakings, rail vehicle industry and related authorities, resulting in a mandate to develop this software tool (SW-tool). The requirements for the development of this SW-tool were

- to provide an effective and simple tool for the assessment of train configurations and vehicles in the dynamic system rolling stock/bridge,
- to provide a free accessible calculation tool for all relevant stakeholders of the German (and European) railway sector and to extent the calculation capacities inside the sector,
- to improve the knowledge about dynamic rolling stock/bridge interaction within the whole railway sector including the rolling stock side,
- to provide a common tool for the comparison between the relevant characteristics of new and proven rolling stock design,

- to enable bridge dynamic experts to use the calculation results of the existing rolling stock as basis for the further development of dynamic load models.

Currently the SW-tool covers the stages 1 and 2 of the evaluation processes described in the rule SNB RW 810.0200A81 and can be used by all interested parties, including vehicle manufacturers and railway undertakings. In the next development step, the SW-tool will be extended to proof the dynamic compatibility of new rolling stock by comparison with all existing German rolling stock. Furthermore, the SW-tool will enable to check a train against the trains specified in RIL 804 and the High-Speed Load Model defined in EN 1991-2 (HSLM).

The SW-tool contains an algorithm to create all possible train configurations (in the SW-tool called “combinations”) from a single vehicle up to multiple units within certain boundary conditions to be defined by the user, such as the length or the maximum numbers of vehicles or wheelsets of the train.

Necessary input data for the rolling stock evaluation are the wheelset loads in different defined load conditions combined with the geometric data of the longitudinal positions of all wheelsets of a train configuration.

3 Basics

3.1 Bending moments and shear forces

3.1.1 Algorithm

The static bending moments and shear forces are calculated with a model of moving loads on a simply supported bridge with a constant value of bending stiffness *EI* along the span (see Fig. 1).

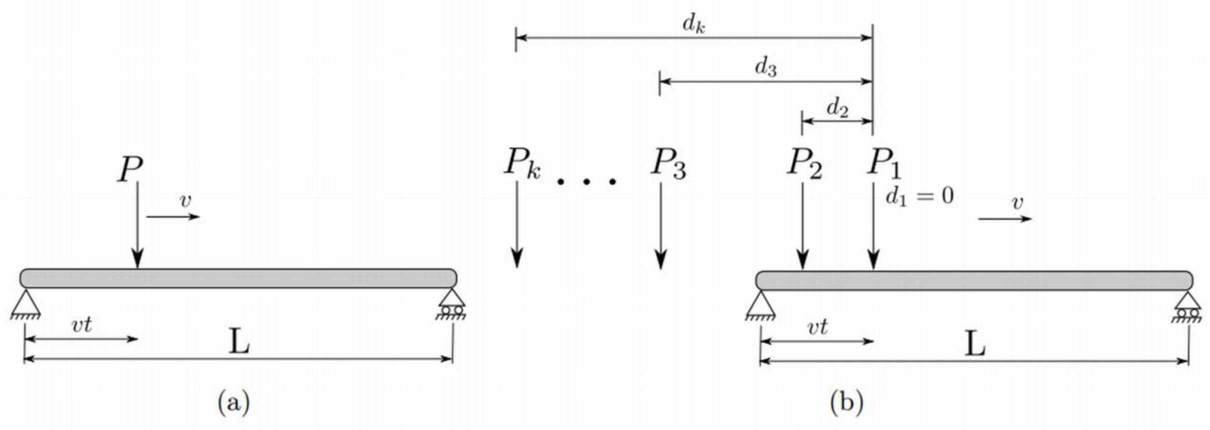


Figure 1: Moving loads on a simply supported bridge /8/

In this model a train is represented by its static vertical wheelset forces (axle loads) P_i and the distances d_i between the wheelset and the first wheelset.

3.1.2 Static moment

For classification of vehicles into line categories according to EN 15528 the maximum bending moments and maximum shear forces along the span are compared with the values achieved with the reference train.

In this SW-tool only bending moments M_{stat} at mid-span are investigated for the investigated train and for the reference trains, because the maximum dynamic oscillation is assumed at mid span.

3.2 Dynamic Train/Bridge Interaction

Investigations on dynamic interaction between a train and a bridge are based on the same model of moving loads on a simply supported bridge (see Fig. 1):

A train is represented by its static vertical wheelset forces (axle loads) P_i and the distances d_i between the wheelsets and the first wheelset. and a bridge is represented by a simply supported beam of the length *L* with constant values of bending stiffness *EI*, mass per length *m* and Damping ζ along the span. Only vertical bending deformation (Euler-Bernoulli beam model) is considered - without torsion nor dynamic interaction with the vehicle's suspension. For time step calculations the wheelset forces are distributed over three rail support points as suggested in EN 1991-2, 6.3.6.1, figure 6.4 for the point forces of LM71. The SW-tool allows to modify the distance between the rail support points (sleeper distance) a = 0,65 m. In the case a=0 the wheelset forces are not distributed.

In this model, the natural frequency of the system is defined by the bending stiffness, the mass per length of the unloaded bridge and the length, while the excitation frequencies depend on the speed *v* and the distances d_i.

The dynamic response of the bridge in this SW-tool is described by the max. values of deflection, acceleration and bending moment.

3.2.1 Response determined by time step calculation (TSC)

3.2.1.1 General

This software uses the algorithm CALDINTAV (see /8/, /9/. /10/) to determine the response of the model. It was provided and developed by the Computational Mechanics Group of the Technical University of Madrid, Spain.

It determines the displacement and acceleration in time domain at the mid-span of the simply-supported bridges as well as the bending moments in mid-span (L/2) and at L/4.

To assess the excitation potential of a train, it is necessary to perform a parametric calculation for a wide (but practical) range of bridge parameters and train velocity.

3.2.1.2 Calculation method (CALDINTAV)

3.2.1.2.1 Deflection and acceleration

The governing equation of motion for the vertical vibration of the railway bridge under the moving load can be expressed as:

$$m\ddot{u} + c\dot{u} + EI\frac{\partial^4 u}{\partial x^4} = p(x,t) \tag{1}$$

where *u*(*x,t*) is the vertical deflection, *p*(*x,t*) is the vertical loads at distance *x* and at instant *t*, *EI* is the bending stiffness, *m* is the mass per length.

The external damping mechanism is introduced by the familiar term $c\dot{u}$. In order to solve the equation of motion (1), the modal superposition technique is used in the CALDINTAV algorithm. The solution of the equation (1) can be decoupled into an infinite set of modal generalised coordinates $q_n(t)$ and mode shapes $\Phi_n(x)$ as:

$$u(x,t) = \sum_{n=1}^{\infty} q_n(t)\Phi_n(x) \tag{2}$$

For the simply-supported bridges, the *n* mode shape can be expressed in function of sin as:

$$\Phi_n(x) = sin\left(\frac{n\pi x}{L}\right) \tag{3}$$

being *L* the span length of the bridge, *x* the bridge local coordinate. Applying the orthogonality relationship of the mode shapes, the governing equation of motion (1) is uncoupled for each generalized coordinate $q_n(t)$ as following:

- for a moving load:

$$\ddot{q}_n(t) + 2\zeta\omega_n\dot{q}_n(t) + \omega_n^2 q_n(t) = \frac{P\Phi_n(vt)}{\int_0^L m\Phi_n(x)^2 dx} \tag{4}$$

- or for a convoy of moving loads:

$$\ddot{q}_n(t) + 2\zeta\omega_n\dot{q}_n(t) + \omega_n^2 q_n(t) = \sum_{k=1}^{N_P} \frac{P_k\Phi_n(vt-d_k)}{\int_0^L m\Phi_n(x)^2dx} \tag{5}$$

In order to solve the differential equations (4) or (5), the integration based on the interpolation of the excitation /11/ is applied in the CALDINTAV program. The solution of the differential equation at time *i* + 1 can be determined as:

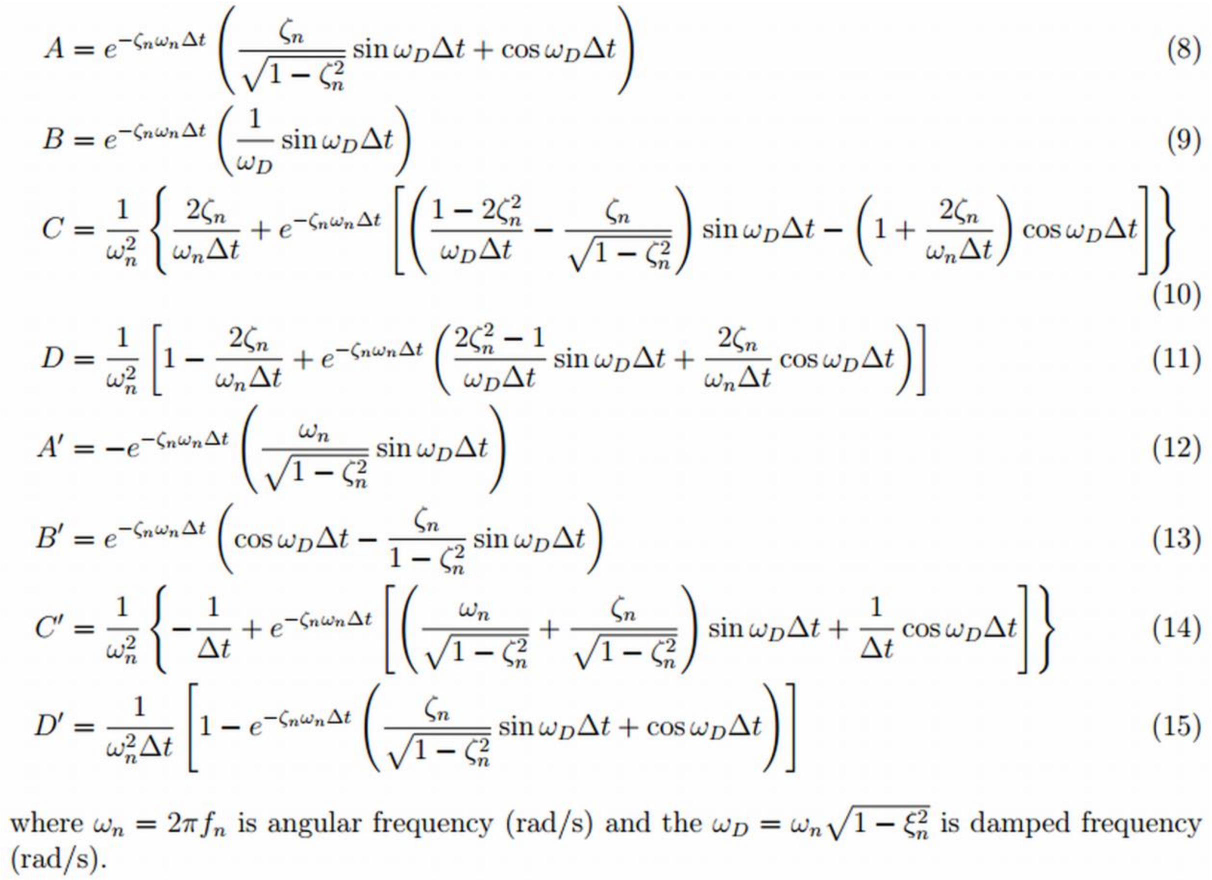
$$\boldsymbol{w}_{i+1} = A\boldsymbol{w}_i + B\dot{\boldsymbol{w}}_i + C\boldsymbol{Q}_i + D\boldsymbol{Q}_{i+1} \tag{6}$$

and its velocity is given by

$$\dot{\boldsymbol{w}}_{i+1} = A'\boldsymbol{w}_i + B'\dot{\boldsymbol{w}}_i + C'\boldsymbol{Q}_i + D'\boldsymbol{Q}_{i+1} \tag{7}$$

where

- $\boldsymbol{w} = [q_1, q_2, \dots, q_n]^T$ is a vector of uncoupled generalised coordinates,
- $\boldsymbol{Q} = \left[\frac{P\Phi_1(vt)}{\int_0^L m\Phi_1(x)^2}, \frac{P\Phi_2(vt)}{\int_0^L m\Phi_2(x)^2}, \dots, \frac{P\Phi_n(vt)}{\int_0^L m\Phi_n(x)^2}\right]^T$ is a vector of modal forces,
- *A*, *B*, *C*, *D*, *A*’, *B*’, *C*’, *D*’ are the eight coefficients that depend on the structure parameters ω_n, ζ_n and on the time step Δt (detailed expressions can be found in Fig. 2). For the case of the convoy of moving loads, for the loads that do not enter the bridge ($vt - d_k < 0$) or leave the bridge ($vt - d_k > L$) the modal loads are zero.



$$A = e^{-\zeta_n\omega_n\Delta t}\left(\frac{\zeta_n}{\sqrt{1-\zeta_n^2}}\sin\omega_D\Delta t + \cos\omega_D\Delta t\right) \tag{8}$$

$$B = e^{-\zeta_n\omega_n\Delta t}\left(\frac{1}{\omega_D}\sin\omega_D\Delta t\right) \tag{9}$$

$$C = \frac{1}{\omega_n^2}\left\{\frac{2\zeta_n}{\omega_n\Delta t} + e^{-\zeta_n\omega_n\Delta t}\left[\left(\frac{1-2\zeta_n^2}{\omega_D\Delta t} - \frac{\zeta_n}{\sqrt{1-\zeta_n^2}}\right)\sin\omega_D\Delta t - \left(1 + \frac{2\zeta_n}{\omega_n\Delta t}\right)\cos\omega_D\Delta t\right]\right\} \tag{10}$$

$$D = \frac{1}{\omega_n^2}\left[1 - \frac{2\zeta_n}{\omega_n\Delta t} + e^{-\zeta_n\omega_n\Delta t}\left(\frac{2\zeta_n^2-1}{\omega_D\Delta t}\sin\omega_D\Delta t + \frac{2\zeta_n}{\omega_n\Delta t}\cos\omega_D\Delta t\right)\right] \tag{11}$$

$$A' = -e^{-\zeta_n\omega_n\Delta t}\left(\frac{\omega_n}{\sqrt{1-\zeta_n^2}}\sin\omega_D\Delta t\right) \tag{12}$$

$$B' = e^{-\zeta_n\omega_n\Delta t}\left(\cos\omega_D\Delta t - \frac{\zeta_n}{1-\zeta_n^2}\sin\omega_D\Delta t\right) \tag{13}$$

$$C' = \frac{1}{\omega_n^2}\left\{-\frac{1}{\Delta t} + e^{-\zeta_n\omega_n\Delta t}\left[\left(\frac{\omega_n}{\sqrt{1-\zeta_n^2}} + \frac{\zeta_n}{\sqrt{1-\zeta_n^2}}\right)\sin\omega_D\Delta t + \frac{1}{\Delta t}\cos\omega_D\Delta t\right]\right\} \tag{14}$$

$$D' = \frac{1}{\omega_n^2\Delta t}\left[1 - e^{-\zeta_n\omega_n\Delta t}\left(\frac{\zeta_n}{\sqrt{1-\zeta_n^2}}\sin\omega_D\Delta t + \cos\omega_D\Delta t\right)\right] \tag{15}$$

where $\omega_n = 2\pi f_n$ is angular frequency (rad/s) and the $\omega_D = \omega_n\sqrt{1-\xi_n^2}$ is damped frequency (rad/s).

Figure 2: Parameters for exact integration /7/

3.2.1.2.2 Bending Moments

The bridge of span *L* is defined with coordinate *x* ∈ [0,*L*]. The displacement response (vertical deflection) at a given point *x* and time *t* is defined by *u*(*x,t*), with positive values taken downwards. The derivatives will be denoted by $\dot{u} = \partial u/\partial t$, $\ddot{u} = \partial^2 u/\partial t^2$, $u' = \partial u/\partial x$, $u'' = \partial^2 u/\partial x^2$.

The bending moments at a given points are defined as proportional to the curvature which may be approximated by the second derivative of the deflections $\kappa \approx -u''$,

$$M(x,t) = -EIu'' \tag{16}$$

where a positive sign for *M* is defined for downward bending of the midspan.

The solution is obtained by modal expansion using a given number of mode shapes *φn*(*x*) and modal generalized coordinates $q_n(t)$:

$$u(x,t) = \sum_{n-1}^{N_\Phi} q_n(t)\Phi_n''(x) = \sum_{n-1}^{N_\Phi} q_n(t) sin\left(\frac{n\pi x}{L}\right) \tag{17}$$

In this expression modes are normalised with the criterion $\max_{x\in[0;L]}\Phi_n(x) = 1$. Substituting the modal expansion (17) in equation (16) the expression for moments is obtained:

$$\begin{aligned} M(x,t) &= -\sum_{n-1}^{N_\Phi} q_n(t) EI\Phi_n''(x) \\ &= EI\left(\frac{\pi}{L}\right)^2 \sum_{n=1}^{N_\Phi} n^2\, q_n(t) sin\left(\frac{n\pi x}{L}\right) \end{aligned} \tag{18}$$

As examples the following cases are given:

- Moments at $x = L/2$ with $N_\Phi = 3$´

$$M\left(\frac{L}{2}, t\right) = EI\left(\frac{\pi}{L}\right)^2 [q_1(t) - 9q_3(t)] \tag{19}$$

- Moments at $x = L/4$ with $N_\Phi = 3$

$$M\left(\frac{L}{4}, t\right) = EI\left(\frac{\pi}{L}\right)^2 \left[\frac{1}{\sqrt{2}} q_1(t) + 4q_2(t) + 9\frac{1}{\sqrt{2}} q_3(t)\right] \tag{20}$$

For this SW it is assumed that the dominant effect is caused by the first bending mode – meaning that it is sufficient to assess the results only at mid span $x = L/2$ (see Figure 3).

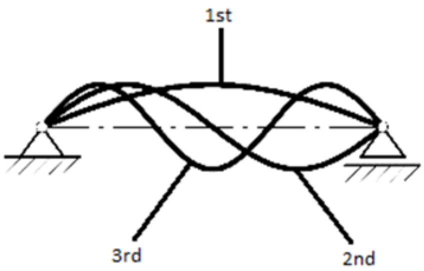
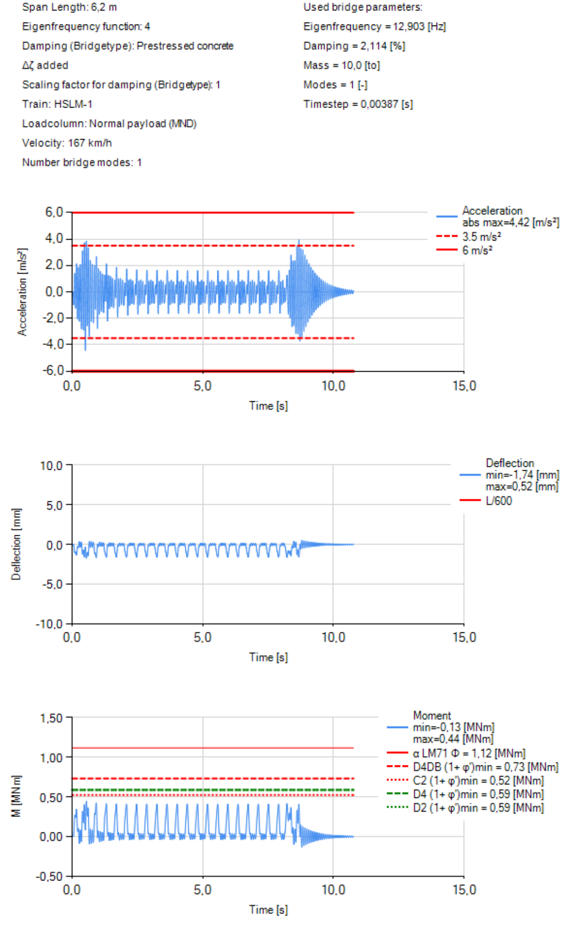


Figure 3: 1st, 2nd and 3rd bending mode of a simply supported beam

3.2.1.3 Results of single train passages calculated by TSC

Figure 4 shows results of single time step calculations (one passage of one train – here HSLM 1 according to EN 1991-2 - over one bridge) at different speeds. The speeds were chosen to show the behaviour at different resonance speeds (Harmonics of the excitation frequency given by the coach length at 167 km/h, 209 km/h, 279 km/h and 418 km/h) and at two speeds in between (237 km/h and 300 km/h).

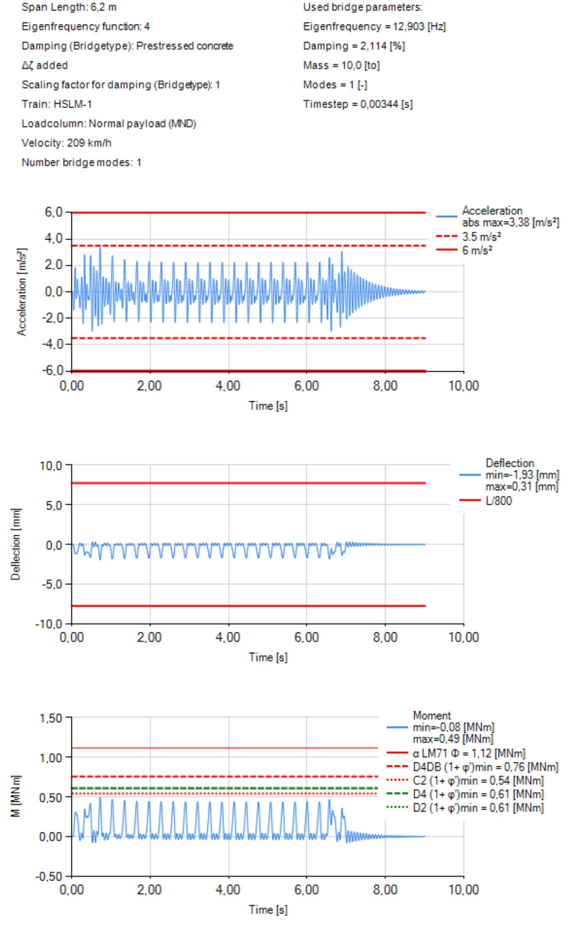
Resonance speed 18 m 12,9 Hz / 5 = 167 km/h



Span Length: 6,2 m
Eigenfrequency function: 4
Damping (Bridgetype): Prestressed concrete
Δζ added
Scaling factor for damping (Bridgetype): 1
Train: HSLM-1
Loadcolumn: Normal payload (MND)
Velocity: 167 km/h
Number bridge modes: 1

Used bridge parameters:
Eigenfrequency = 12,903 [Hz]
Damping = 2,114 [%]
Mass = 10,0 [to]
Modes = 1 [-]
Timestep = 0,00387 [s]

Resonance speed 18 m 12,9 Hz / 4 = 209 km/h



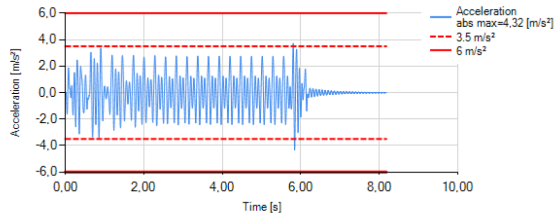
Span Length: 6,2 m
Eigenfrequency function: 4
Damping (Bridgetype): Prestressed concrete
Δζ added
Scaling factor for damping (Bridgetype): 1
Train: HSLM-1
Loadcolumn: Normal payload (MND)
Velocity: 209 km/h
Number bridge modes: 1

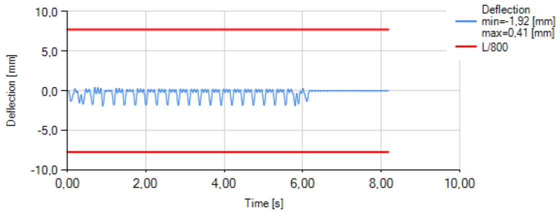
Used bridge parameters:
Eigenfrequency = 12,903 [Hz]
Damping = 2,114 [%]
Mass = 10,0 [to]
Modes = 1 [-]
Timestep = 0,00344 [s]

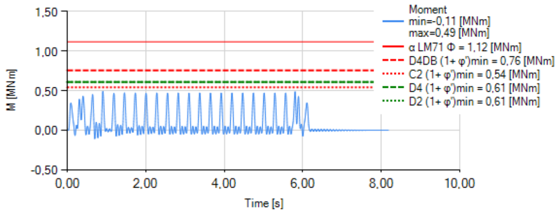
Speed between resonances = 237 km/h

Span Length: 6,2 m
Eigenfrequency function: 4
Damping (Bridgetype): Prestressed concrete
Δζ added
Scaling factor for damping (Bridgetype): 1
Train: HSLM-1
Loadcolumn: Normal payload (MND)
Velocity: 237 km/h
Number bridge modes: 1

Used bridge parameters:
Eigenfrequency = 12,903 [Hz]
Damping = 2,114 [%]
Mass = 10,0 [to]
Modes = 1 [-]
Timestep = 0,00304 [s]



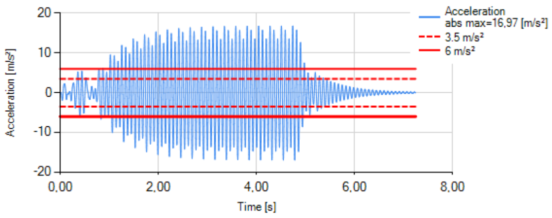


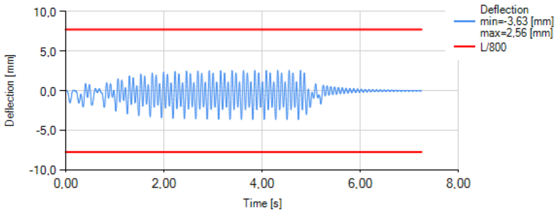


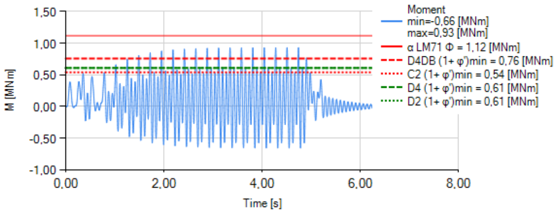
Resonance speed 18 m 12,9 Hz / 3 = 279 km/h

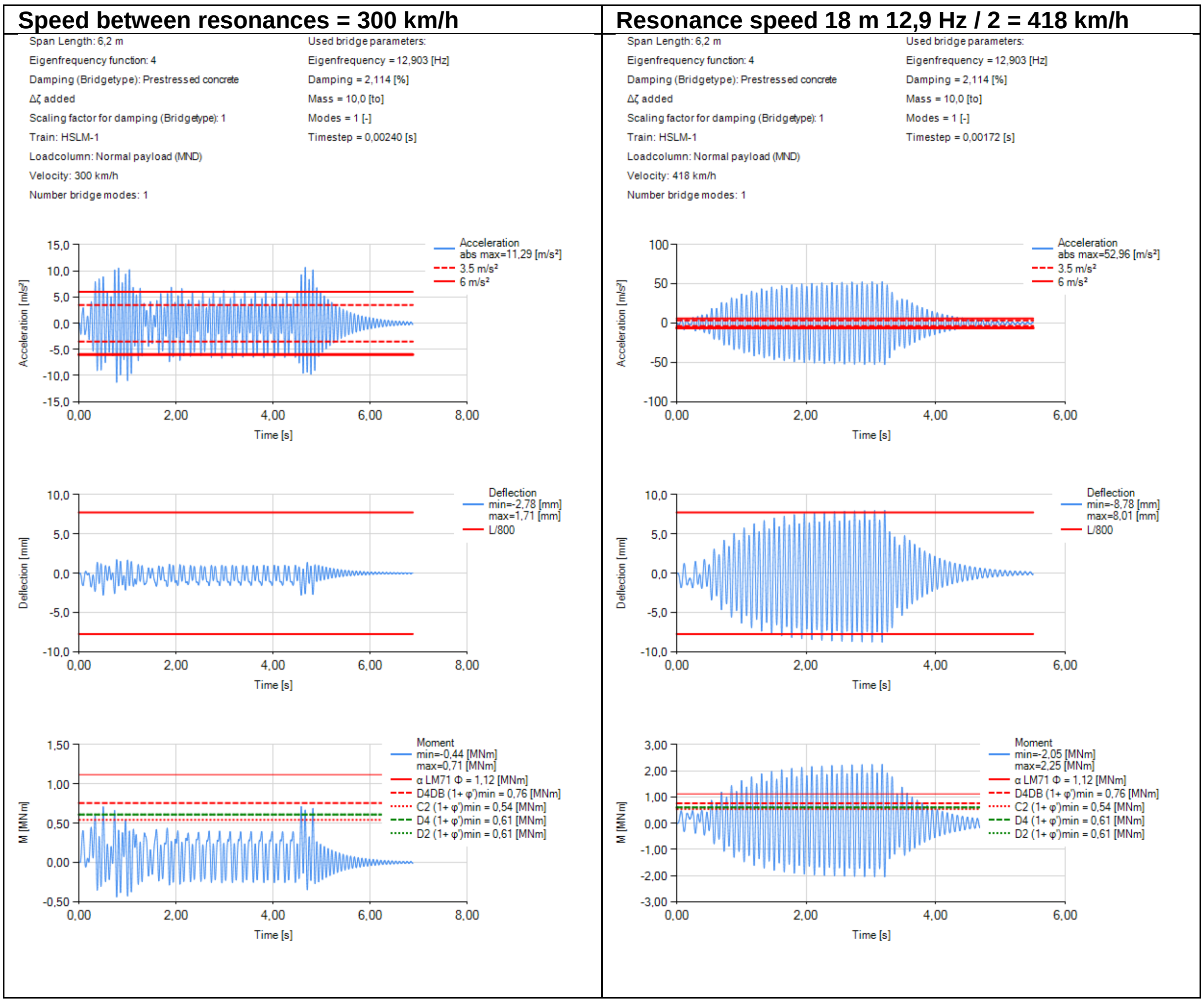
Span Length: 6,2 m
Eigenfrequency function: 4
Damping (Bridgetype): Prestressed concrete
Δζ added
Scaling factor for damping (Bridgetype): 1
Train: HSLM-1
Loadcolumn: Normal payload (MND)
Velocity: 279 km/h
Number bridge modes: 1

Used bridge parameters:
Eigenfrequency = 12,903 [Hz]
Damping = 2,114 [%]
Mass = 10,0 [to]
Modes = 1 [-]
Timestep = 0,00258 [s]









Speed between resonances = 300 km/h

Span Length: 6,2 m
Eigenfrequency function: 4
Damping (Bridgetype): Prestressed concrete
Δζ added
Scaling factor for damping (Bridgetype): 1
Train: HSLM-1
Loadcolumn: Normal payload (MND)
Velocity: 300 km/h
Number bridge modes: 1

Used bridge parameters:
Eigenfrequency = 12,903 [Hz]
Damping = 2,114 [%]
Mass = 10,0 [to]
Modes = 1 [-]
Timestep = 0,00240 [s]

Resonance speed 18 m 12,9 Hz / 2 = 418 km/h

Span Length: 6,2 m
Eigenfrequency function: 4
Damping (Bridgetype): Prestressed concrete
Δζ added
Scaling factor for damping (Bridgetype): 1
Train: HSLM-1
Loadcolumn: Normal payload (MND)
Velocity: 418 km/h
Number bridge modes: 1

Used bridge parameters:
Eigenfrequency = 12,903 [Hz]
Damping = 2,114 [%]
Mass = 10,0 [to]
Modes = 1 [-]
Timestep = 0,00172 [s]

Figure 4: Results of the passage of HSLM 10 (coach length 18 m) over a 6,2 m long bridge with a natural frequency of 12,9 Hz at different speeds

3.2.2 The DER Method from ERRI D 214

3.2.2.1 Signature, Spectrum

Based on a Fourier approach, ERRI D214 /1/ provides a formula for the acceleration at the mid of the bridge span consisting of a mass-dependent constant factor Γ, an amplification factor $A(L/\lambda)$ that depends on the span length L and the wavelength λ and a spectrum that depends only on the vehicle parameters “positions of the wheelsets *i*” x_i and “axle loads of the wheelsets i” P_i and the damping of the bridge. In case of no damping, it is possible to describe the pure vehicle depending part of the acceleration by the signature $S_0(\lambda)$. This approach allows comparing different train designs generally with respect to their dynamic behaviour during the passage over a bridge. On the other hand, some assumptions for simplification limit the validity of the model. For example, it is assumed, that the passage time of a train depends only on the train length and not on the span length – meaning that short trains on long bridges cannot be handled correctly.

Note: The results of the DER- method contain only the dynamic of the response, the static part is neglected. Furthermore, only the first order of bending is included as for the acceleration only the midspan is relevant.

Acceleration $$\Gamma = Ct\ A\left({}^{L}/_{\lambda}\right)\ G(\lambda,\zeta) \text{ with} \tag{21}$$

- the factor depending on mass $$Ct = \frac{8\pi L n_0^2}{K^*} = \frac{4}{m\pi} \tag{22}$$
- the influence line $$A\left({}^{L}/_{\lambda}\right) = \left|\frac{cos\left(\frac{\pi L}{\lambda}\right)}{\left(\frac{2L}{\lambda}\right)^2 - 1}\right| \tag{23}$$
- the spectrum $$G(\lambda,\zeta) = \frac{Max}{i=0;N-1}\left\{\frac{1}{\zeta x_i}\sqrt{\left[\sum_{k=0}^{i} P_k cos\left(\frac{2\pi x_k}{\lambda}\right)\right]^2 + \left[\sum_{k=0}^{i} P_k sin\left(\frac{2\pi x_k}{\lambda}\right)\right]^2}\ \left[1 - e^{-2\pi\zeta\frac{x_i}{\lambda}}\right]\right\} \tag{24}$$
- the signature $$S_0(\lambda) = \frac{Max}{i=0;N-1}\left\{\sqrt{\left[\sum_{k=0}^{i} P_k cos\left(\frac{2\pi x_k}{\lambda}\right)\right]^2 + \left[\sum_{k=0}^{i} P_k sin\left(\frac{2\pi x_k}{\lambda}\right)\right]^2}\right\} \tag{25}$$
- and

x_i (x_k)	Longitudinal coordinate of wheelset i [m]
P_i (P_k)	Vertical wheelset force of wheelset i [kN]
i	Wheelset index
N-1	Index of last wheelset (Index of first wheelset = 1)
k	Internal variable for summation over wheelsets
ζ	Damping [-]
λ	Wavelength [m]
L	Span Length of Bridge [m]
K^*	Stiffness of one-mass oscillation model [kN/m]
n_0	Natural frequency of bridge [Hz]
m	Mass per length of the bridge [kg/m]
Γ	Acceleration at mid span [m/s²]
Ct	Mass constant [m/kg]
A	“Amplification” [-]
$G(\lambda,\zeta)$	Spectrum [kN/m]
$G_{aggr}\ (\lambda,L,\zeta)$	Spectrum [kN/m] not simplified
S_0	Signature [kN]

The Spectrum $G(\lambda,\zeta)$ is a simplified version of the assuming that the span length L is short compared to the total length $\lambda+L$.

As the aggressiveness (defined as the product $A\left(L/_{\lambda}\right)\,G$) contains anyway the span length L as parameter, for the calculation of aggressiveness (and acceleration) in this SW-tool the spectrum $G_{aggr}(\lambda, L, \zeta)$ is used instead of $G(\lambda,\zeta)$:

$$G_{aggr}(\lambda, L, \zeta) = \underset{i=0;N-1}{Max}\left\{\frac{1}{\zeta(x_i+L)}\sqrt{\left[\sum_{k=0}^{i} P_k cos\left(\frac{2\pi x_k}{\lambda}\right)\right]^2+\left[\sum_{k=0}^{i} P_k sin\left(\frac{2\pi x_k}{\lambda}\right)\right]^2}\;\left[1-e^{-2\pi\zeta\frac{x_i+L}{\lambda}}\right]\right\} \qquad (26)$$

In this formula the duration of the passage of the train is correctly represented by the train length plus the span length instead of the train length only.

Note: The spectrum $G(\lambda, L, \zeta)$ as given in equation 5.7 of ERRI D214, RP6, part A, needed a division by the span length *L* in order to remain consistent with set of formulae used above (simplified approach in equation 5.8 of ERRI D214, RP6, part A):

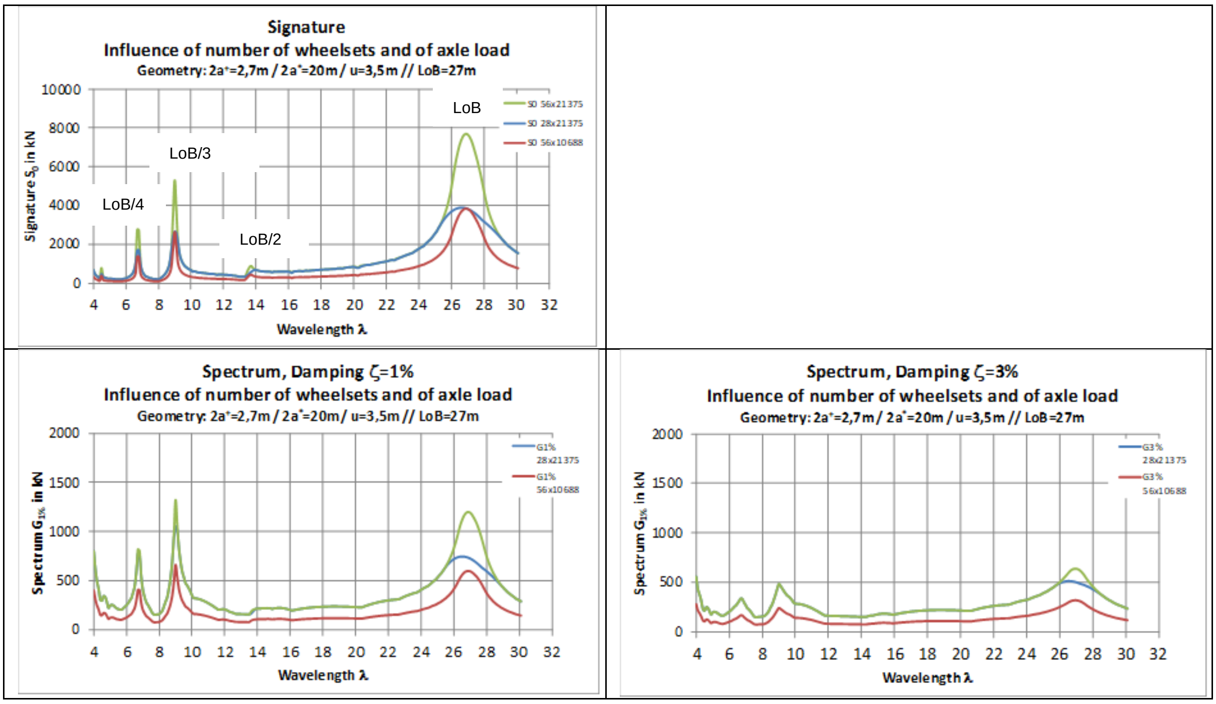


Figure 5: Signatures and Spectra of trains with 27-m-coaches

In Figure 5 the signature and the spectra with typical damping values (see also Figure 10) of 1 % (left diagram) and 3 % (right diagram) of a train consisting of coaches with total 56 wheelsets (green curve) are presented. For comparison also results are shown for the same train with 50 % wheelset load (red curve) and a shorter train with 50 % of the wheelsets (blue curve) and an unchanged wheelset load.

The excitation wavelengths are determined by the coach length *LoB* and the oscillations of higher order. For the (undamped) signature peaks, a reduction of number of axles has a similar effect as a reduction of the axle load, while in the spectrum with increased damping the effect of the number of wheelsets becomes less important than the wheelset load (For damping values of different bridge types see 4.1.3).

To decide which wavelength range of the signature is relevant for the resonance excitation of a bridge the natural frequency and the speed need to be considered:

3.2.2.2 Determination of relevant train configurations from a set of vehicles with similar wheelset loads and -distances

The parameter study described in 3.2.1 using the detailed time step calculations to study the effect of both, the static and the dynamic response is very time consuming. For a huge number of combinations with a similar static axle load distribution, it is therefore recommended to use the spectra to detect few combinations covering the dynamic behaviour of all possible combinations. The envelope of the TSC results of these few detected combinations will then be representative for all possible combinations.

3.2.2.3 Aggressiveness

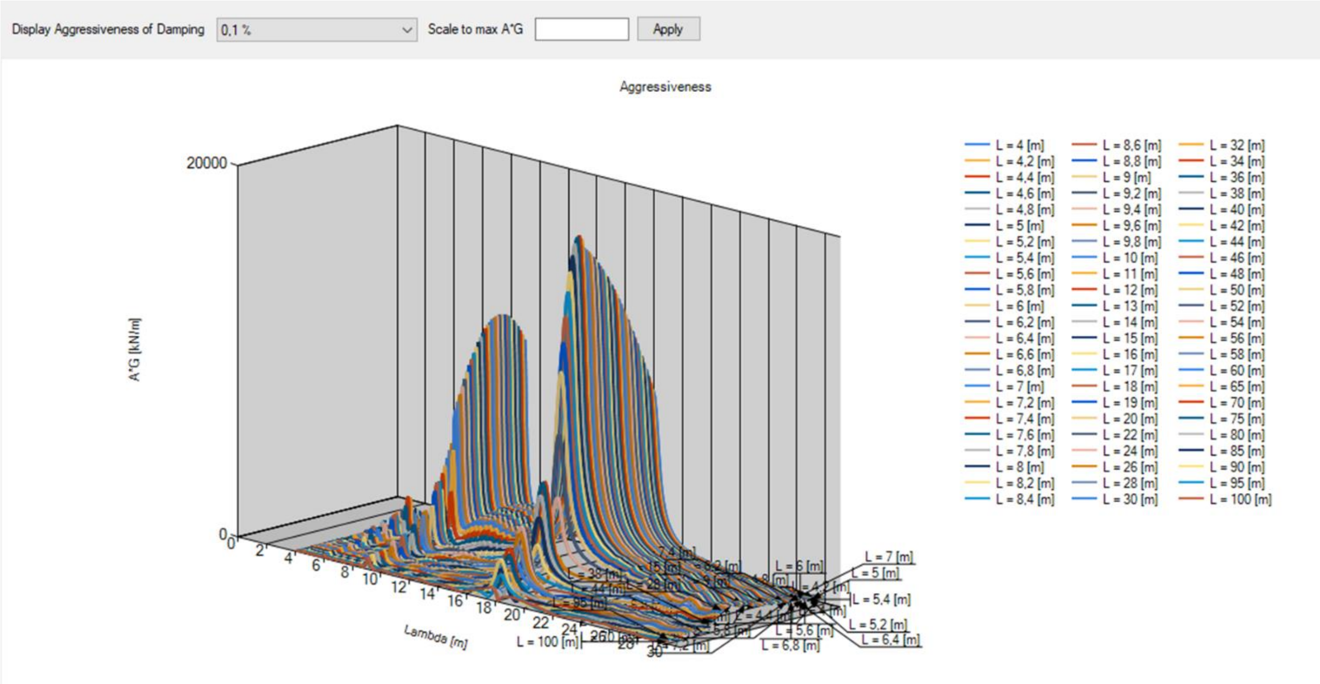

Display Aggressiveness of Damping: 0,1 %

Figure 6: Representation of the aggressiveness of the model HSLM-A1 as 3-D presentation over the wavelength λ and the span length L.

The aggressiveness $A(^{L}/_{\lambda})\ G)$ can be calculated for different functions of natural frequencies ν=ν (L). The envelope of the calculated combinations and the chosen functions of natural frequencies can be presented as 3-D-diagram (see Figure 6).

It is possible to replace the wavelength λ as parameter by the speed V for a certain Eigenfrequency function ν=ν (L) leading to diagrams of aggressivity over speed for a certain Eigenfrequency function. The SW-tool enables to perform this transformation in the 2-diagrams (intersections of the 3-D-presentation shown in Figure 9)

4 Bridge parameter study - Time Step Calculation

To assess the combination of static and dynamic response of a train when passing a bridge, it was found useful to assess the behaviour of a train on a large set of bridges representing a majority of new and existing railway bridges. To perform the necessary calculations in a limited time, the Code CALDINTAV that uses the simplified bridge model shown in Fig. 1 (see 3.2.1) was integrated in this SW-tool.

Note: The deflections and the bending moments calculated by this method contain the dynamic and the static parts of the response, while the results of the DER-method contain only the dynamic part of the response.

To cover a large field of new and existing bridge designs it is necessary to vary the following bridge parameters:

- Length L
- Natural frequency n_0
- Damping ζ
- Mass per length m

Further the speed is varied between 60 km/h and the maximum train speed plus 20%.

Note: The investigations at increased vehicle speed according to EN 1991-2 are required for the dynamic check of real bridges to cover the uncertainty of the natural frequency of a bridge. The intention here is to assess a train design on a large range of bridges. If the range of bridge parameters is large enough, the speed increase should not be necessary.

4.1 Bridge parameters included in the study

4.1.1 Length *L*

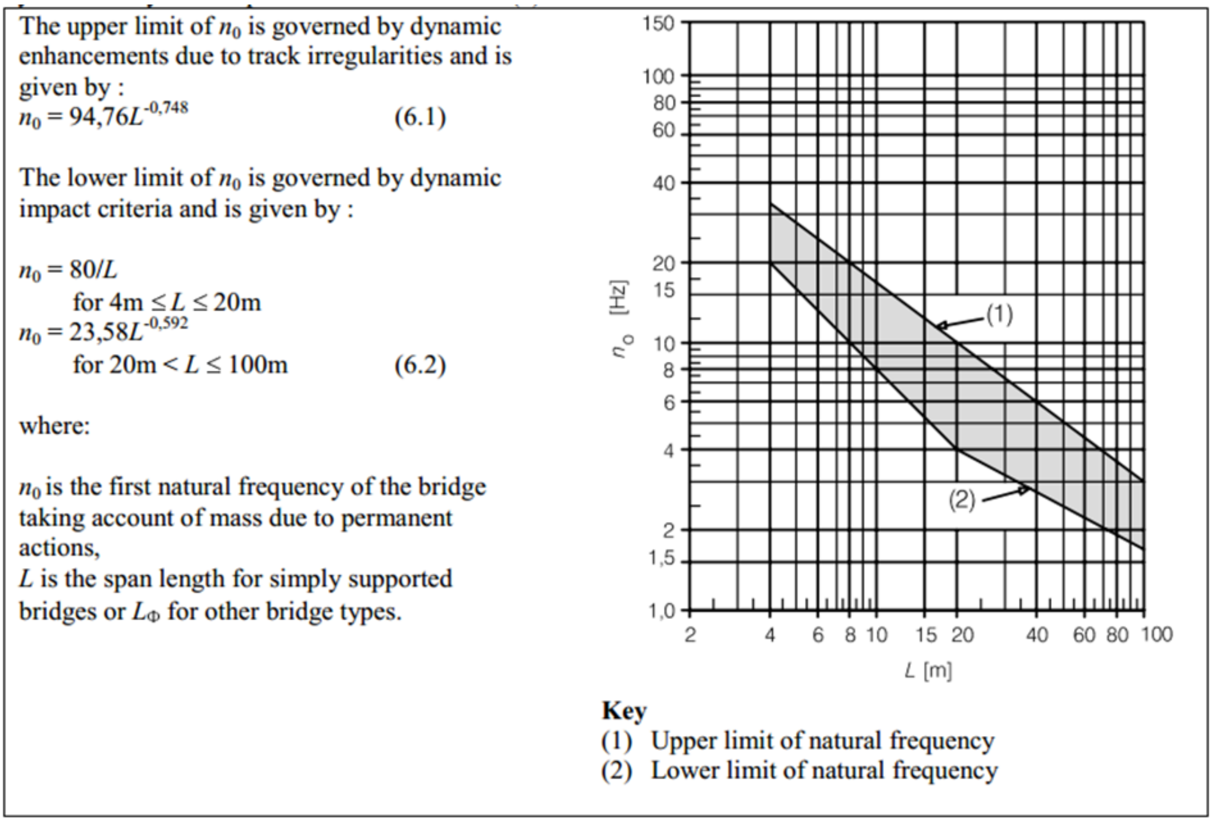
The length L is varied between 2 m and 100 m. To cover the responses with a sufficient resolution, the whole range is divided in four zones. In each of these zones a constant step size DL is used.

Zone	Range of span lengths *L*	Step size ΔL
1	2 m- 10 m	0,2 m
2	10 m – 20 m	1 m
3	20 m - 60 m	2 m
4	60 m – 100 m	5 m

Figure 7: Span-lengths used for calculations

4.1.2 Natural frequency n_0

EN 1991-2 describes an acceptable field on the natural frequencies (denominated n_0) for new bridges. It is described by an upper and a lower frequency function (see Figure 8). To cover also existing bridges, it is possible to choose up to five functions for the natural frequency in the SW as linear combination.



The upper limit of n_0 is governed by dynamic enhancements due to track irregularities and is given by :

$$n_0 = 94{,}76L^{-0{,}748} \qquad (6.1)$$

The lower limit of n_0 is governed by dynamic impact criteria and is given by :

$$n_0 = 80/L \quad \text{for } 4\text{m} \le L \le 20\text{m}$$

$$n_0 = 23{,}58L^{-0{,}592} \quad \text{for } 20\text{m} < L \le 100\text{m} \qquad (6.2)$$

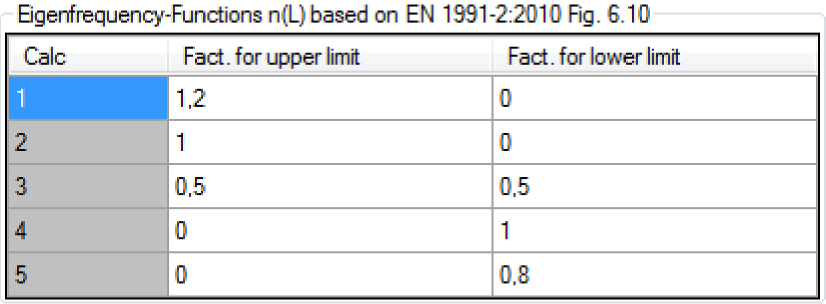
where:

n_0 is the first natural frequency of the bridge taking account of mass due to permanent actions,

L is the span length for simply supported bridges or L_Φ for other bridge types.

Key
(1) Upper limit of natural frequency
(2) Lower limit of natural frequency

Figure 8: Range of natural frequencies specified in /4/, Fig. 6.10 for new bridges



Eigenfrequency-Functions n(L) based on EN 1991-2:2010 Fig. 6.10

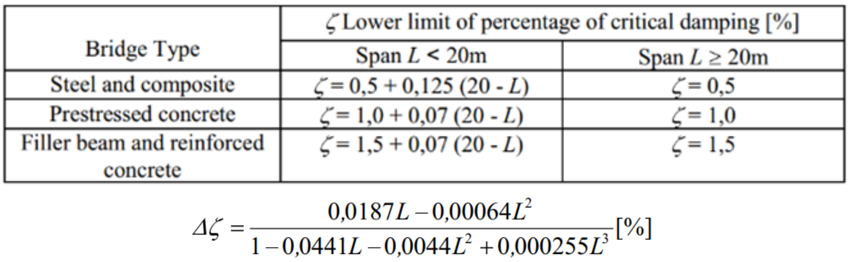
Calc	Fact. for upper limit	Fact. for lower limit
1	1,2	0
2	1	0
3	0,5	0,5
4	0	1
5	0	0,8

Figure 9: Menu for functions of natural frequency with default settings

4.1.3 Damping ζ

In table 6.6 of EN 1991-2 typical damping functions are defined, which can also be used in the SW (see functions A1, B1 and C1 in Figure 10). To include the behaviour of real trains in the investigations EN 1991-2 specifies also an additional damping $\Delta\zeta$. In the SW it is possible to respect this additional damping as an option together with the damping functions A1, B1 and C1 (see functions A2, B2 and C2 in Figure 10). Further it is possible to choose a fixed value for the damping, that is used for all span length. If this value is left blank, no constant damping is used for the parameter study.

Note: It is under discussion to delete the additional damping from EN 1991-2 as experts found that the assumption behind this additional damping is not always valid.



Bridge Type	ζ Lower limit of percentage of critical damping [%]	
	Span L < 20m	Span $L \geq$ 20m
Steel and composite	$\zeta = 0{,}5 + 0{,}125\,(20 - L)$	$\zeta = 0{,}5$
Prestressed concrete	$\zeta = 1{,}0 + 0{,}07\,(20 - L)$	$\zeta = 1{,}0$
Filler beam and reinforced concrete	$\zeta = 1{,}5 + 0{,}07\,(20 - L)$	$\zeta = 1{,}5$

$$\Delta\zeta = \frac{0{,}0187L - 0{,}00064L^2}{1 - 0{,}0441L - 0{,}0044L^2 + 0{,}000255L^3}\,[\%]$$

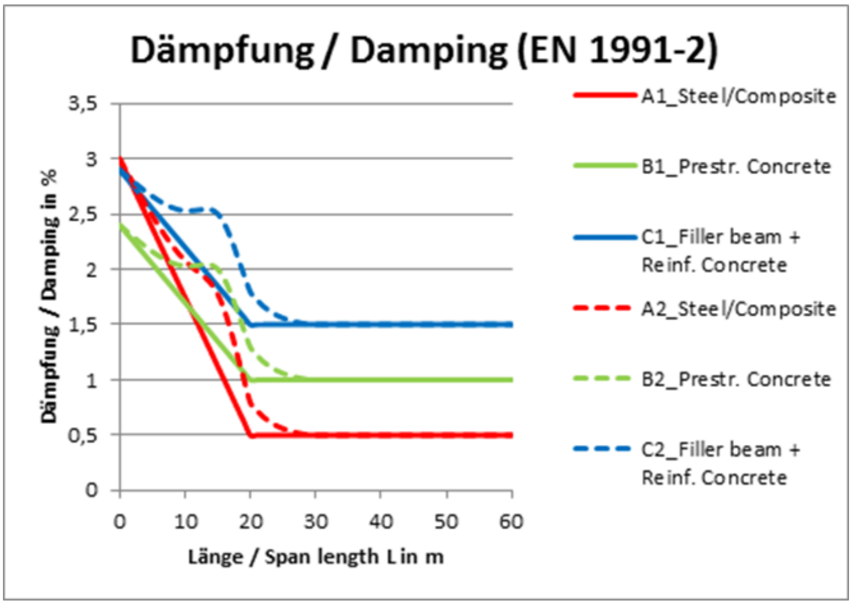


Figure 10: Damping functions based on functions in /4/

4.1.4 Mass per span length *m*, Stiffness *EI*

In the current version of the SW-tool a constant specific mass (mass per span length) m/L = 10 t/m is applied to all bridges. The stiffness *EI* is then determined by the natural frequency n_0.

Note: In a future version it is intended to vary this value to take account of values of existing bridges. This will be necessary to determine realistic accelerations and deflections. For a given pair of stiffness EI and natural frequency n_0, the mass per length m of the bridge m is determined by

$$m = \frac{\pi^2 EI}{4n_o^2 L^4} \qquad (27)$$

The stiffness of a bridge EI is further limited by the maximum deflection d caused by the static load of LM71. A pre-calculation gives a deflection d as a function of the stiffness and the length of the beam:

$$d = f(L,EI) \qquad (28)$$

For existing bridges a limit d_{lim} = L/600 applies, for new bridges a further speed dependent limitation is specified in EN 1990, A2.4.4.3.2 and DB uses another kind of speed depending limitation (see 4.3.3)

4.2 Time step width and vehicle speeds

To include all relevant dynamic effects according to the ÖBB rule /7/ one relevant wavelength shall be calculated in 20 steps.

The shortest relevant wavelength is defined by the maximum frequency of

- the excitation by axle distances, bogie distances and coach length and
- the natural frequency of the bridge

It is possible to choose whether only the first bending mode is included in the investigation or also the 2nd and 3rd order. The last option increases the simulation time significantly as the natural frequency of the third mode is nine times higher than the one of the first mode.

To optimise calculation time, the time step width is individually determined for each calculation:

The highest relevant excitation frequency n_{exc} is calculated with the speed of the train v and the shortest relevant wavelength of 4 m:

$$n_{exc} = \frac{v}{4\,m} \tag{29}$$

The highest relevant natural frequency $n_{i,\mathrm{relevant}}$ is given by the natural frequency of the first bending mode n_0 and the highest respected mode i of the beam:

$$n_{i,relevant} = i^2 n_0 \tag{30}$$

The shortest relevant period is then given by

$$T_{min,relevant} = \frac{1}{\max(n_{exc}\ ;\ n_{i,relevant})} \tag{31}$$

and this leads to a time step width

$$\Delta t = \frac{T_{min,relevant}}{n} = \frac{1}{n \cdot max\left(\frac{v}{4\,m}\ ;\ i^2 n_0\right)} \tag{32}$$

with

v – speed in m/s
i – order of the modes respected in the calculation (1 or 3)
n_0 - Natural frequency of 1st mode of the beam
$n_{\mathrm{i,relevant}}$ – relevant max. natural frequency of the beam
$T_{\mathrm{min,relevant}}$ - Shortest relevant period
n – number of time steps per period (Default: 20)

According to DB rule RIL 804.3301 for dynamic bridge design purposes, frequencies up to the 3rd bending mode shall be respected (9 times of the natural frequency of the first bending mode).

Note: It is expected, that for the chosen simplified model the third mode has only a very small impact on the result. If this can be verified, calculation time can be reduced significantly by restricting calculations to the 1st mode – especially for cases where two train designs are compared.

With a speed increment of 2 km/h as it is part of the DB-process, it is guaranteed that all narrow (low damped) natural frequencies of the bridge are excited sufficiently (The CALDINTAV Tutorial /8/ suggests to use a step width of 5 km/h which reduces the calculation time significantly with a small remaining uncertainty of the results at narrow resonance peaks).

4.3 Assessment quantities and references

The quantities that can be used to assess the results of the Time Step Calculation (TSC) are:

- max. bending moment at mid-span

- max. shear force
- max. vertical acceleration at mid span
- max. vertical deflection at mid span

Note: In the current version of the SW-tool, the evaluation of the max. shear force is not yet implemented.

The bending moment *M* is a combination of the static moment and the dynamic bridge response – both depend on the span *L*. The dynamic response depends on the natural frequency n_0 and the damping *D* which are also functions of *L.*

The sustainable moment M_{adm} of a bridge depend also on the span *L* and on a load model, amplified by dynamic enhancement factors. Therefore, an assessment of a vehicle design is based on the utilisation M / M_{adm} (see Figure 12).

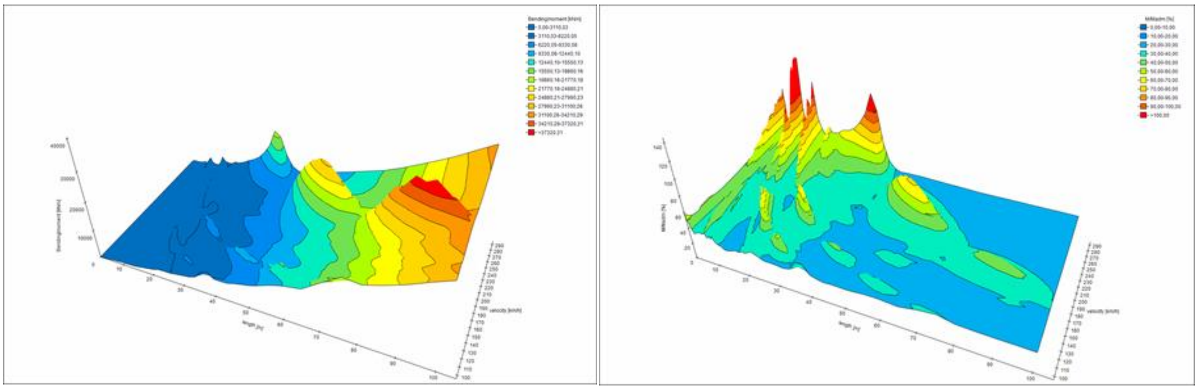


Figure 11: Example Moment *M* and utilisation *M* / *M*adm as function of span *L* and speed *v*

Typical load models which are implemented in the SW are

- the reference trains of a line category according to EN 15528, Annex A or
- the load model LM 71 according to EN 1991-2

The national German line category D4DB is a combination of the D4 load model according to EN 15528 and a series of 6-axle vehicles according to Figure 12.

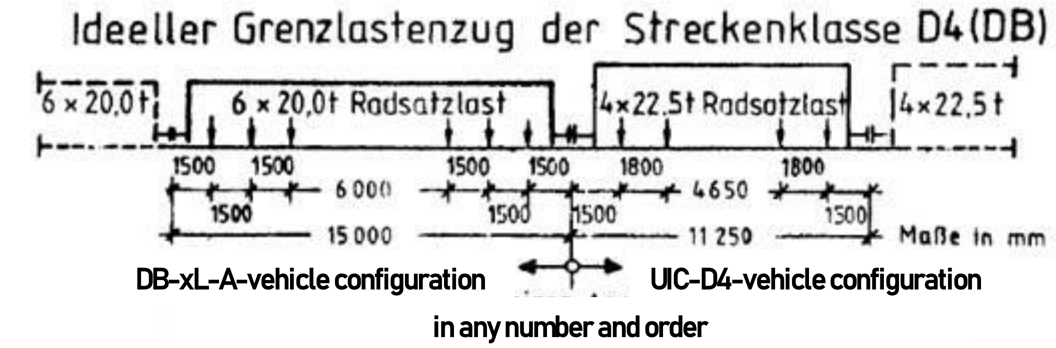


Figure 12: Load model of line category D4DB

The results obtained for the deflection and acceleration depend on the span *L* and assumptions taken for the stiffness *EI* and the mass per length *m* of the bridges. These results can be scaled for different stiffnesses and masses of certain bridges but cannot be compared directly with limit values. These quantities can only be used for comparison of different trains in terms of their excitation potential.

Note: On bridges with realistic parameters of mass per length (In the SW-tool 10 t/m are implemented for all spans), acceleration levels up to 3,5 m/s² are acceptable on bridges with ballast. On bridges without or with fixed ballast up to 6 m/s² may be acceptable. These values are indicated in the SW-tool for orientation but do not apply directly to bridges with realistic values of mass per length.

Note: In the public version of the SW-tool, TSC-results are only presented for the max. bending moment at mid-span, because a realistic specification of the mass per length and the stiffness is missing. Therefore, applicable limit values are missing for the other quantities. Only in Single-TSC-calculation limits are indicated for information.

4.3.1 Max. bending moment at mid-span

4.3.1.1 Bending Moment

The max. bending moment at mid span M is achieved from the result of the time step calculation M_{TSC} (see 3.2.1.2.2) superimposed with the static moment of the investigated train at mid span $M_{\mathrm{stat,trn}}$ (in the same load case used for the TSC) multiplied by the factor $a_0 \cdot \varphi''$ to take the effect of track irregularities etc. into account (see EN 1991-2, Annex C). For the calculation of φ'' the parameters of the calculated passage L, n_0 and v are used.

$$M(L, v, n_0, \zeta) = M_{TSC}(L, v, n_0, \zeta) + M_{stat,trn}(L) \cdot a_0 \varphi''(L, (v), n_0) \qquad (33)$$

Note: In the time step calculation of M_{TSC} and in the calculations of the static moments $M_{\mathrm{stat,trn}}$ of the investigated train the wheelset forces are distributed over three rail support points as suggested by EN 1991-2 Fig. 6.4 (see 3.2).

The diagrams of the time series on the Tab “Single TSC” show only the result of the time step calculation M_{TSC} (L,v,n_0,ζ) without any enhancement by φ'' while the admissible values given only for orientation are independent from this enhancement.

4.3.1.2 Utilisation

The bending moment is increasing with the span L. To assess it, it needs to be compared with the load bearing capacities M_{adm} of the bridges, which are also functions of the span. Therefore the utilisation M / M_{adm} is determined.

4.3.1.2.1 Utilisation of new bridges designed according to EN 1991-2

In cases, where the utilisation is determined for *new bridges*, designed according to EN 1991-2, the load bearing capacity M_{adm} is related to the static moment and shearforce of *LM71* enhanced by the traffic factor α and the dynamic factor $\Phi(L)$. $\Phi(L)$ can be chosen as Φ_2(L) (carefully maintained track, default) or Φ_3(L) (standard track maintenance), see EN 1991-2, 6.4.5.2.

$$M/M_{adm}(L, v, n_0, \zeta, \boldsymbol{\alpha LM71}) = \frac{M_{TSC}(L,v,n_0,\zeta) + M_{stat,trn}(L) \cdot a_0 \varphi''(L,(v),n_0)}{M_{stat,\alpha LM71}(L) \cdot \Phi(L)} \qquad (34)$$

Note 1: The dynamic factor Φ and therefore the capacity of a bridge that is designed according to LM 71 is independent from the speed and should cover all situations except resonance (see EN 1991-2, 6.4.5.2) – for new bridges up to 200 km/h.

Note 2: The static moment of LM 71 $M_{\mathrm{stat},\alpha\mathrm{LM71}}$ used for the load bearing capacity is determined at mid span without the distribution of the four single vertical wheelset forces over three rail support points each (see 3.2) in order to be consistent with the calculation method and the bridge design rules of DB Netz.

4.3.1.2.2 Utilisation of existing bridges checked for line categories

For *existing bridges*, which were only checked for a certain *line category* according to EN 15528, the load bearing capacity M_{adm} is the static moment of the reference train of the line category $M_{\mathrm{stat,LC}}$ increased by the factor $[1 + \varphi' + a_0\, \varphi'']$. This factor should consider the assumed dynamic response of a bridge under perfect track conditions (φ') and the effect of track irregularities etc. ($a_0 \cdot \varphi''$). Both factors φ' *and* φ'' are functions of the span length L, the natural frequency of the bridge n_0 and the speed v. Above 200 km/h both factors are not increased, because this method to quantify the capacity of bridges is not defined for higher speeds.

To determine φ' *and* φ'' the speed v^+ rounded to a full 10-km/h-step is used assuming that the line speed used for the design is defined in these steps. The abbreviations are explained in Table 1.

$$M/M_{adm}(L,v,n_0,\zeta,\boldsymbol{LC}) = \frac{M_{TSC}(L,v,n_0,\zeta) + M_{stat,trn}(L)\cdot a_0\varphi''(L,(v),n_0)}{M_{stat,LC}(L)\cdot[1+\varphi'(L,v^+,n_0) + a_0\cdot\varphi''(L,(v^+),n_0)]} \tag{35}$$

Note 1: For the calculations of the static moment $M_{\text{stat,LC}}$ of the reference train of a line category, the wheelset forces are distributed over three rail support points as suggested by EN 1991-2 Fig. 6.4 (see 3.2). This is consistent with the calculation method and the bridge design rules of DB Netz.

Note 2: EN 1991-2 requires for bridge design purposes, using the factors given by the natural frequency. If the frequency is not known, φ' shall be determined for the lower frequency line and φ“ for the upper frequency line. To study the influence on the compatibility the different assumptions for the natural frequency during the calculation of a bridge against a line category, the SW-tool allows to apply three options for the determination of the capacity of a bridge:

- **Min**imum values **of φ' and φ“**, achieved with either the upper or the lower frequency line and the speed rounded to the next full 10 km/h (n_{01}, n_{02}, v^+) - current DB-practice – probably unnecessarily demanding
- **Nominal** values of natural frequency and speed (n_0 and v) to determine φ' and φ“ - worst case according to EN 1991-2: no margins due to uncertainty about the natural frequency)
- **Max**imum values **of φ' and φ“**, achieved with either the upper or the lower frequency line and the speed rounded to the next full 10 km/h (n_{01}, n_{02}, v^+) - assuming that bridge design is generally assuming unknown natural frequencies

Figure 13 and Figure 14 show the dynamic factors φ' and φ'' for the two frequency lines n_{01}, n_{02} as functions of the span length L and the speed (for speeds above 80 km/h the factor φ'' is independent from the speed). Figure 13 contains also a presentation of the quotient between the maximum and the minimum values of φ'.

Finally Figure 15 shows the functions (1+ φ'+ 0,5 φ'') which are multiplied with the static moments of the reference trains of the line categories to cover the dynamic effects up to 200 km/h. They are compared with the factors Φ_2 and Φ_3 to be applied to the the more demanding Load model LM 71. The quotient between the maximum and the minimum values indicates the max. difference between the possible assumptions for the capacity of a bridge.

To take account for the requirement of EN 1991-2 to respect up to 120 % of the line speed for a compatibility check, another option (v^+ or $(v/1,2)^+$ allows to apply the capacity of a bridge that is determined with the factor $\varphi'(L,(v/1,2)^+,n_0)$ of the speed devided by 1,2 and rounded up to the next full 10 km/h.

Max of φ' and φ“:

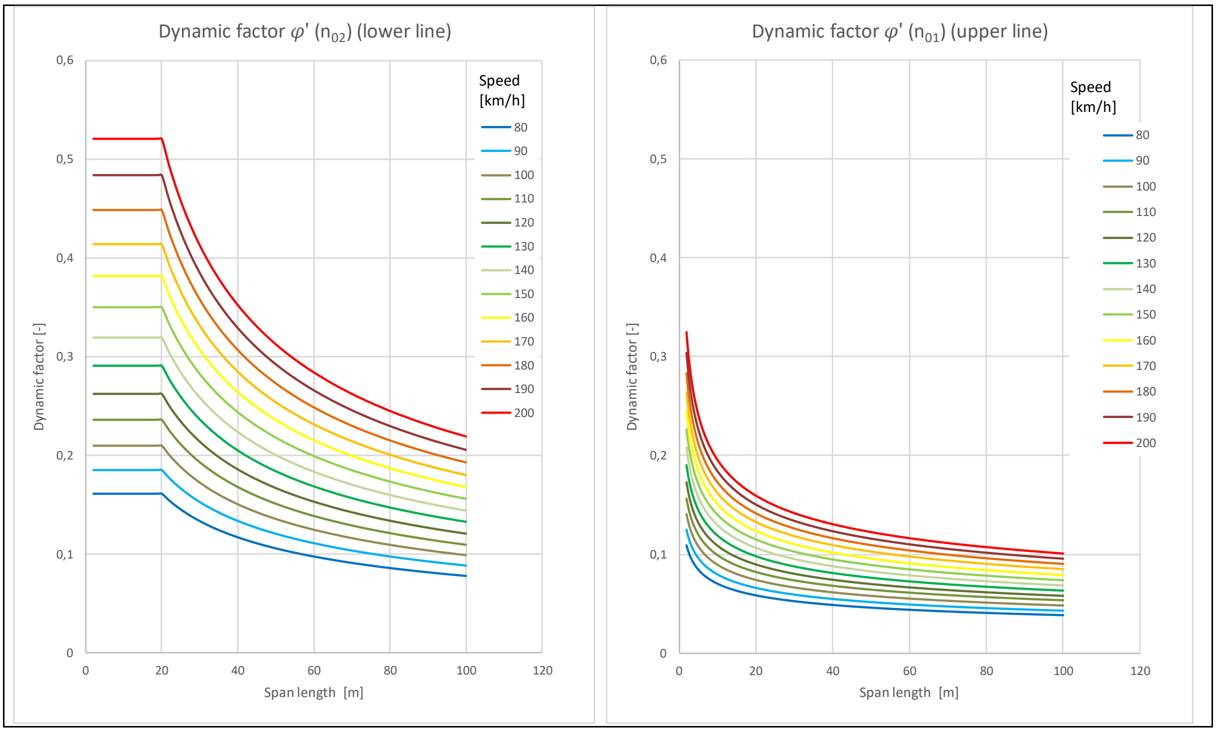
$$M/M_{adm}(L,v,n_0,\zeta,LC) = \frac{M_{TSC}(L,v,n_0,\zeta) + M_{stat,trn}\cdot a_0\varphi''(L,(v),n_0)}{M_{stat,LC}\cdot[1+\max\{\varphi'(L,v^+,n_{01});\varphi'(L,v^+,n_{02})\} + a_0\cdot\max\{\varphi''(L,(v^+),n_{01});\varphi''(L,(v^+),n_{02})\}]} \tag{36}$$

Min of φ' and φ“:

$$\frac{M}{M_{adm}(L,v,n_0,\zeta,LC)} = \frac{M_{TSC}(L,v,n_0,\zeta) + M_{stat,trn}\cdot a_0\varphi''(L,(v),n_0)}{M_{stat,LC}\cdot[1+\min\{\varphi'(L,v^+,n_{01});\varphi'(L,v^+,n_{02})\} + a_0\cdot\min\{\varphi''(L,(v^+),n_{01});\varphi''(L,(v^+),n_{02})\}]} \tag{37}$$

M / M_{adm}	Utilisation factor
M_{TSC}	Max. moment at mid-span determined by simulation for a train on a bridge
$M_{stat,trn}$	Max. static moment at mid-span of the simulated train
L	Span length of the simulated bridge (determinant length L_Φ EN 1991-2, C.6)
v	Speed of the train on the simulated bridge
n_0	Natural frequency of the simulated bridge
ζ	Damping of the simulated bridge
φ'	Dynamic factor for bridge oscillation according to EN 1991-2, Annex C
φ''	dynamic factor for track quality etc. according to EN 1991-2, Annex C
a_0	track maintenance factor (see EN 1991-2, C.1 and C.2) default value: a_0 = 0,5 for “carefully maintained track”. Other options (0 and 1) are possible to study the influence of this choice
$M_{stat,LC}$	Max. static moment at mid-span of a load model (Reference train of line category or $\alpha \cdot$ LM71 at the span length L of the simulated bridge)
LC	Load model of reference train of line category according to EN 15528 (A, B1, B2, C2, C3, C4, D2, D3, D4, D4xL, D4DB, E4, E5)
$M_{stat,\alpha LM71}$	Max. static moment at mid-span of the load model $\alpha \cdot$LM71
LM71	Load Model 71 according to EN 1991-2, Fig. 6.1
α	Design factor for application of load model LM71 according to the kind of traffic from the following values (see EN 1991-2, 6.3.2(3) 0,75 - 0,83 - 0,91 - 1,00 - 1,10 - 1,21 - 1,33 - 1.46 (default: α = 1,0)
v^+	Speed of the train on the simulated bridge rounded to the next full 10 km/h (assumed design rule), but limited to 200 km/h
$n_{01,2}$	Upper and lower design limit for natural frequency (function of L, see EN 1991-2, Fig. 6.10)
Φ	Dynamic factor used to enhance Moment and shear force of $\alpha \cdot$LM71 (see EN 1991-2, 6.4.5.2) • Φ_2 for carefully maintained track (Default) • Φ_3 for track with standard track maintenance

Table 1: Terms and abbreviations used for utilisation



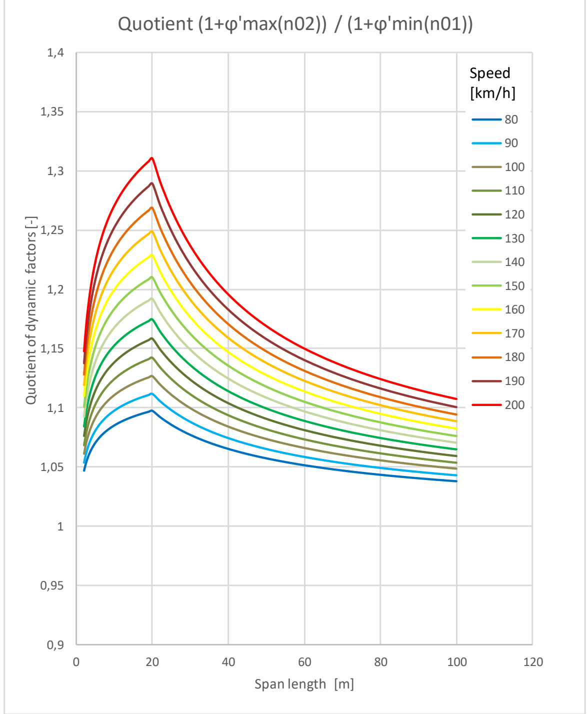


Figure 13: Dynamic factors $\varphi'(L,v,n_0)$ of lower (n_{02}) and upper (n_{01}) natural frequency function and Quotient of both (1+ φ') (see EN 1991-2, Annex C)

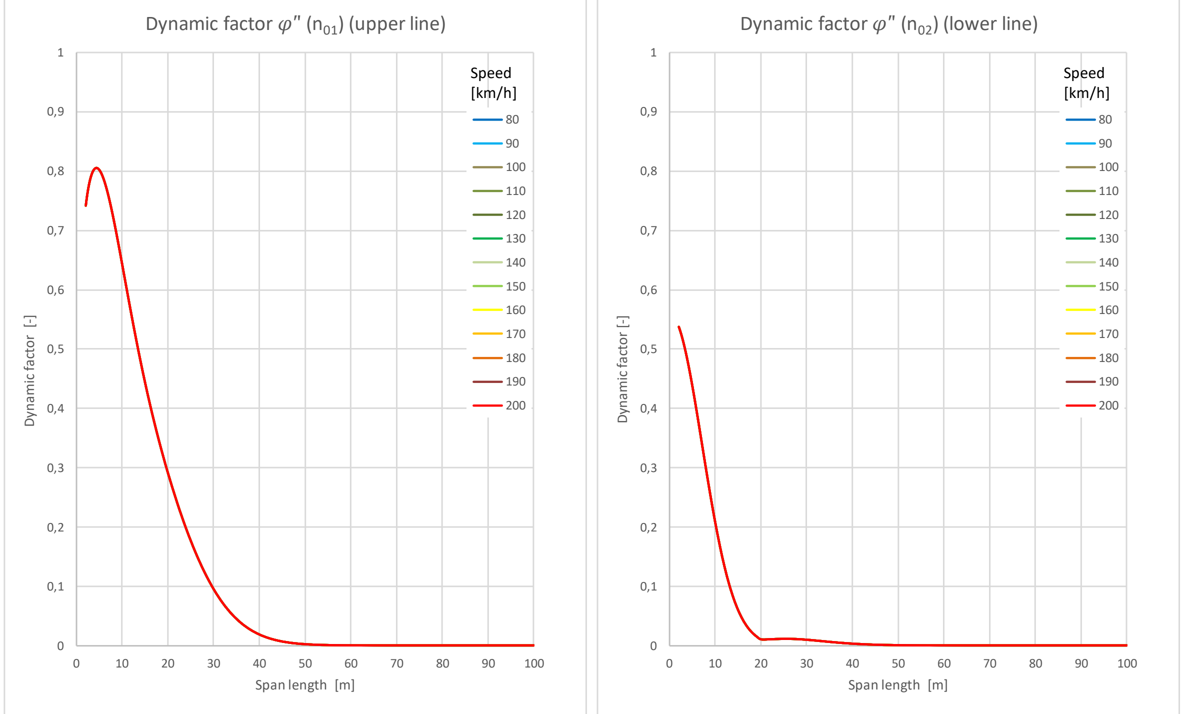


Figure 14: Dynamic factors $\varphi''(L,(v),n_0)$ of lower (n_{02}) and upper (n_{01}) natural frequency function and Quotient of both (see EN 1991-2, Annex C)

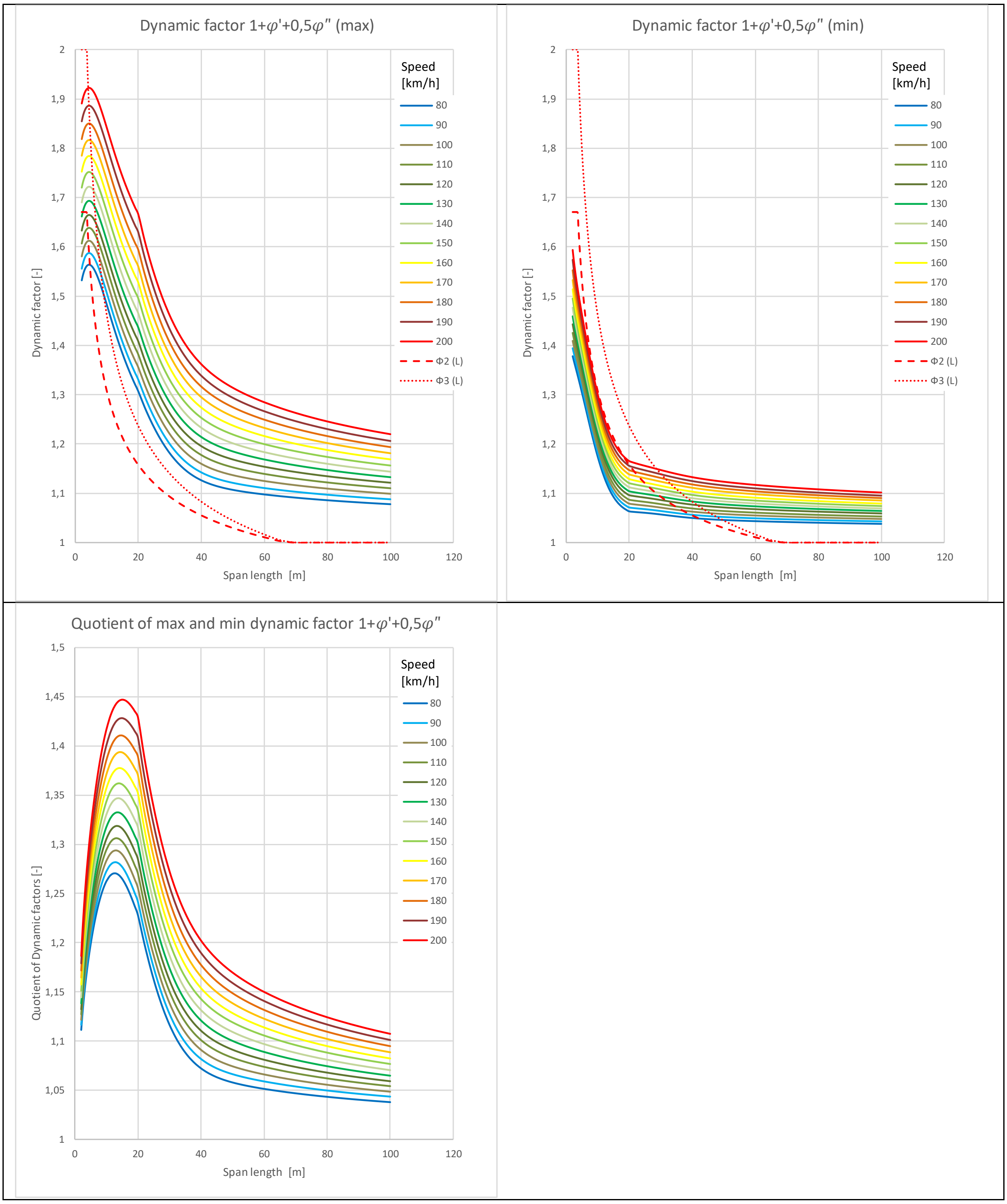


Figure 15: Max. and min. Dynamic factors 1 + $\varphi'(L,v,n_0)$ + 0,5 $\varphi''(L,(v),n_0)$ of upper and lower functions of natural frequency $n_{01}(L)$ and $n_{02}(L)$ and quotient of both (see EN 1991-2, Annex C) compared with dynamic factors Φ_2 and Φ_3 according to EN 1991-2, 6.4.5.2 to be used with $\alpha \cdot$ LM 71

4.3.1.2.3 Moments and utilisation used in Single TSC diagrams

The diagrams of the time series on the Tab “Single TSC” (see also chapter 3.2.1.3) show only the result of the time step calculation M_{TSC} (L,v,n_0,ζ) without any enhancement by phi’’ and the admissible moments presented in these diagrams are also neglecting the phi’’ enhancement.

Therefore, the single TSC diagrams give only a rough estimation if an acceptance criterion is met.

$$M_{adm,sgl,LM71} = M_{stat,LM71}(L) \cdot \Phi(L) \tag{38}$$

$$M_{adm,sgl,LC} = M_{stat,LC}(L) \cdot [1 + \varphi'(L, v, n_0)] \tag{39}$$

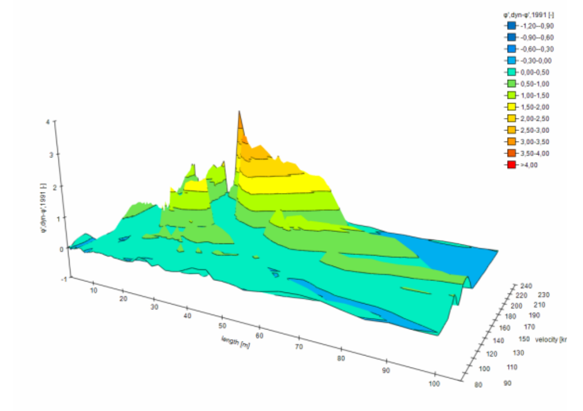
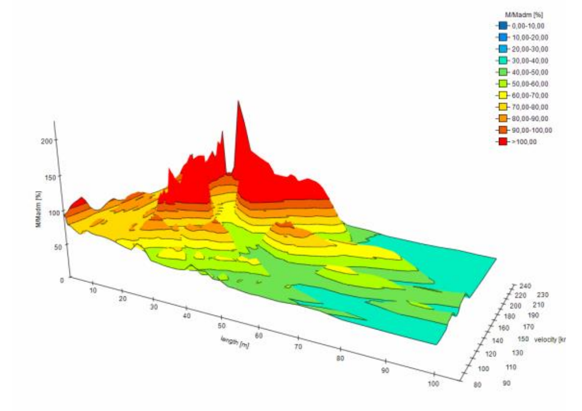
For the static moment of LM71 the distribution of the axle loads over three sleepers as suggested by EN 1991 is not implemented in order to be consistent with the DB-software. For further information about the distribution of the axle loads over 3 sleepers see chapter 3.2.

4.3.2 Dynamic Enhancement φ'_{dyn} and (φ'_{dyn} - φ'_{1991})

The dynamic enhancement φ'_{dyn} of a train passage is determined from the maximum bending moment M_{TSC} at mid-span achieved from the time step integration and the maximum static moment of the same train $M_{stat,trn}$ at mid span.

$$\varphi'_{dyn}(L, v, n_0, \zeta) = \frac{M_{TSC}(L, v, n_0, \zeta)}{M_{stat,trn}(L)} - 1 \tag{40}$$

Both moments are determined with the distribution of the loads over three sleepers as suggested by EN 1991-2 Fig. 6.4.

<table>
<tr><th>(φ'_{dyn} - φ'_{1991})</th><th>M/M_{adm} for line category D4DB</th></tr>
<tr><td colspan="2">Lower function of natural frequency $n_{02}(L)$</td></tr>
<tr><td>
</td><td>
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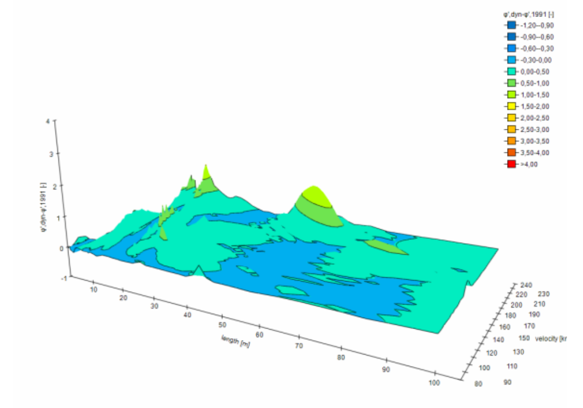
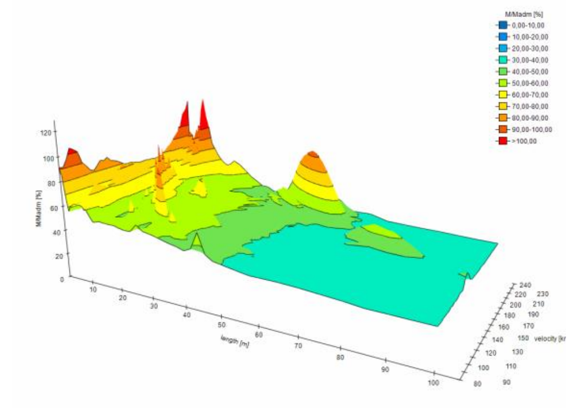
<tr><td colspan="2">Upper function of natural frequency $n_{01}(L)$</td></tr>
<tr><td>
</td><td>
</td></tr>
</table>

Figure 16: "Deficiency" of dynamic factor φ'_{dyn} - φ'_{1991} (left side) and utilisation of Moment related to line category D4DB for lower and upper functions of natural frequency $n_{02}(L)$ and $n_{01}(L)$, Example: HSLM-01 up to HSLM-10

To demonstrate which part of the dynamic enhancement is not covered by the static design rules of an existing bridge checked for a line category up to speeds of 200 km/h, the SW-tool provides also (φ'_{dyn} - φ'_{1991}), where φ'_{1991} is the dynamic factor for bridge oscillation according to EN 1991-2, Annex C (see also 4.3.1). Results (φ'_{dyn} - φ'_{1991}) > 0 indicate, that the dynamic enhancement of a train is not covered by the design rules for existing bridges.

Note: The values for φ' in EN 1991-2 were (under the assumption that no resonance effects occur below 200 km/h) determined for the passage of a single axle and confirmed for damping values significantly higher than stated in EN 1991-2. Therefore (φ'_{dyn} - φ'_{1991}) becomes often much greater than 0 also below 200 km/h. If bridges are only checked or designed for the reference train of a line category with the dynamic enhancement factor φ'_{1991}, compatibility can only be provided, if the static moments of the real trains remain far below the static moments of the reference train. Figure 16 shows as example of the "deficiency" (φ'_{dyn} - φ'_{1991}) between 80 km/h and 240 km/h (200 kmh +20% safety margin) results of the High Speed Load Models HSLM-01 up to HSLM-10.

4.3.3 Max. deflection at mid span

The max. deflection moment at mid span is achieved from the result of the time step calculation w_{TSC} (see 3.2.1.2.1) superimposed with the static deflection of the investigated train at mid span $w_{stat,trn}$ (in the same load case used for the TSC) multiplied by the factor $a_0 \cdot \varphi''$ to take the effect of track irregularities etc. into account (see EN 1991-2, Annex C). For the calculation of φ'' the parameters of the calculated passage L, n_0 and v are used.

$$w = w_{TSC}(L, v, n_0, \zeta) + w_{stat,trn} \cdot a_0 \varphi''(L, (v), n_0) \tag{41}$$

Note: In the public version of the SW-tool, TSC-results of the parameter max. deflection are not presented because a realistic specification of the mass per length and the stiffness and therefore applicable limit values are missing.

$$EI = \frac{4 n_0^2 L^4}{\pi^2} \cdot m; \quad m = \frac{\pi^2 EI}{4 n_0^2 L^4} \tag{42}$$

The diagrams of the time series on the Tab "Single TSC" show only the result of the time step calculation w_{TSC} (L, v, n_0, ζ) without any enhancement by φ''. The admissible values applied by DB Netz for their existing bridges are shown in Table 2. They are independent from this enhancement and are shown only for orientation.

	$v^+ \le 200$ km/h	$v^+ > 200$ km/h
L ≤ 25 m	L/600	L/800
25 m < L < 30 m	25/600+[(30/800-25/600)/5]*(L-25)	25/800+[(30/1000-25/800)/5]*(L-25)
L ≥ 30 m	L/800	L/1000

Table 2: Admissible values for deflection used by DB for real bridges

4.3.4 Max. acceleration at mid span

The max. acceleration at mid span is achieved from the result of the time step calculation a_{TSC} (see 3.2.1.2.1). The values presented in the TSC-3D and TSC-2D diagrams, are also enhanced as suggested by EN 1991-2, chapter 3 by $1 + a_0 \cdot \varphi''$ in order to be consistent with the presented moments:

$$a(L, v, n_0, \zeta) = a_{TSC}(L, v, n_0, \zeta) \cdot \left(1 + a_0 \cdot \frac{\varphi''(L, (v), n_0)}{1 + \varphi'_{dyn}(L, v, n_0, \zeta)}\right) \quad \text{with } \varphi'_{dyn} > 0 \tag{43}$$

The diagrams of the time series on the Tab “Single TSC” show only the result of the time step calculation a_{TSC} (L,v,n_0,ζ) without any enhancement by φ’’.

Note: The presentation of acceleration results is not implemented in the publich version of the SW-tool, because no applicable limit values are available for the constant .

4.3.5 Presentation of results

For each calculated train passage representing one span length, one speed, one damping function and one frequency level the maximum values of the assessment quantities are stored (max values stated in the diagrams of Figure 4). They can be presented as an envelope function of the span length and the speed (3D-diagram).

To study the influence of the calculated combinations (trains), frequency levels and damping functions, it is possible to filter the results to determine different envelope functions. Therefore, a pull-down menu in the 3-D-presentation allows to switch between “Envelope calculated results” and “Envelope chart filter”.

It is possible to present the envelopes of the maximum values of all described assessment quantities during the train passages.

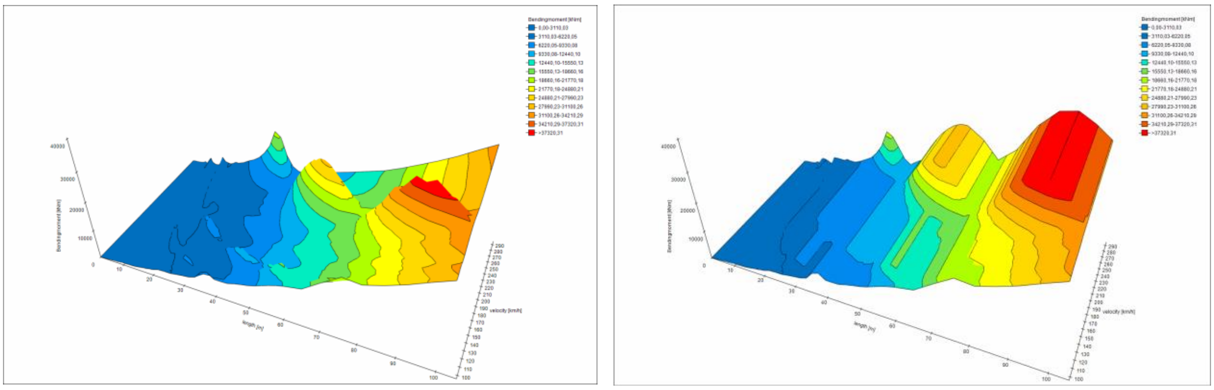


Figure 17: Example of bending moments in the absolute and the cumulated presentation

An option “cumulated” changes the presentation of the results: If at a certain span a certain assessment value is reached it is kept constant for all speed above until the TSC result is higher (see Figure 17). This type of presentation of the absolute assessment quantities (Moments, deflections and accelerations) can be used to define a reference surface of admissible values for a future version of the SW-tool: If a bridge is capable to resist a peak value of certain train or load model at a certain speed, this resistance is also available for higher speeds and can be used as admissible value.

The same results can also be presented in 2-D-diagrams as
- intersection along the speed axis for a certain span length
- envelope along the speed axis covering all span lengths
- intersection along the span axis for a certain speed
- envelope along the span axis up to a certain speed
- envelope along the span axis up to the max speed before 100 % of the limit is reached

Figure 18 illustrates these options.

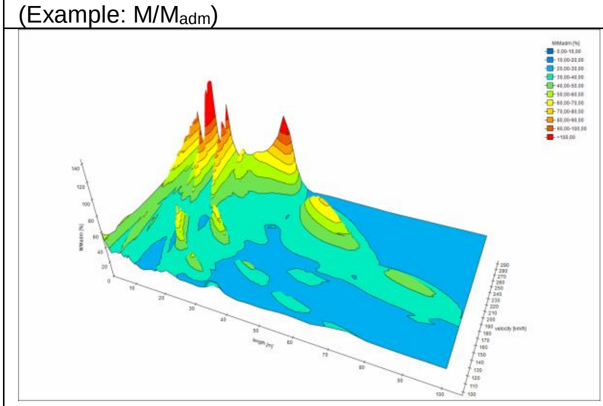
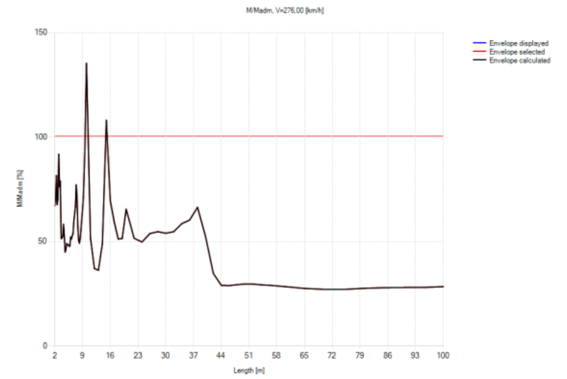
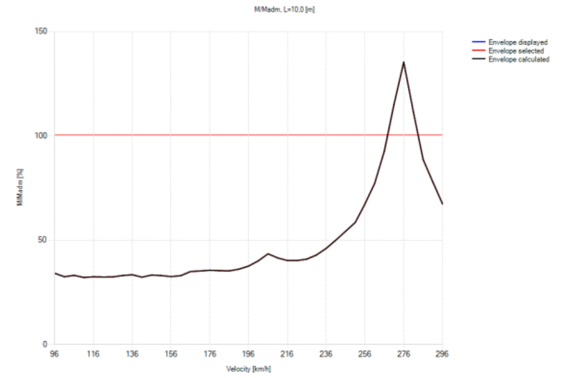
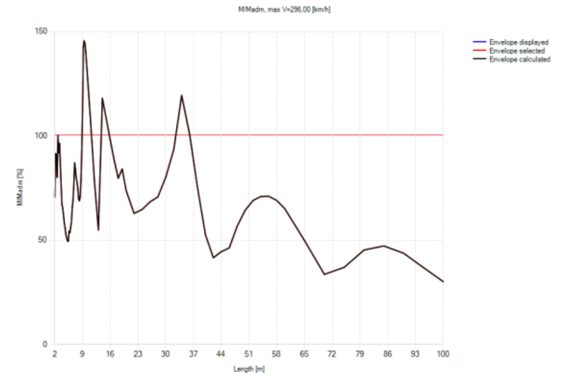
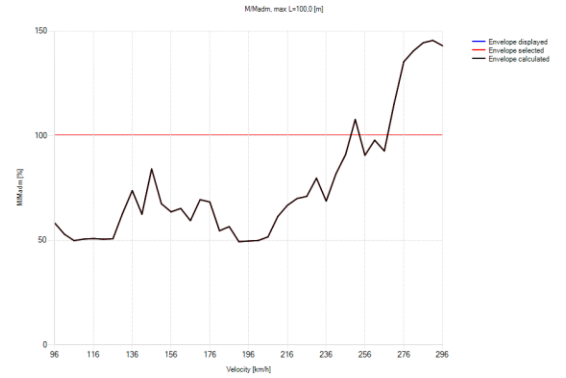
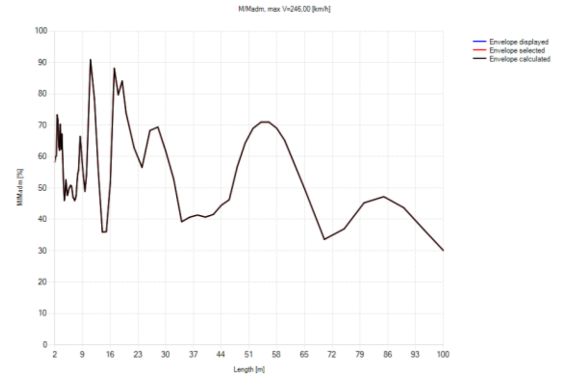
<table>
<tr><td>3-D-diagram
(Example: M/M_{adm})</td><td>Intersection along the span length axis
(Example at V = 276 km/h)</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Intersection along the speed axis
(Example at L=10 m)</td><td>Envelope along the span length axis
(Example covering all speeds up to 296 km/h)</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Envelope along the speed axis
covering all span lengths</td><td>Envelope along the span length axis up to the max. speed before 100 % of the limit is reached
(Example covering all speeds up to 246 km/h)</td></tr>
<tr><td>
</td><td>
</td></tr>
</table>

Figure 18: Examples of 2-D-presentations compared to a 3-D-presentation of the same utilisation results M/M_{adm}

5 User Manual

5.1 Hardware requirements

The SW requires a computer with an operating system higher than Windows 7.

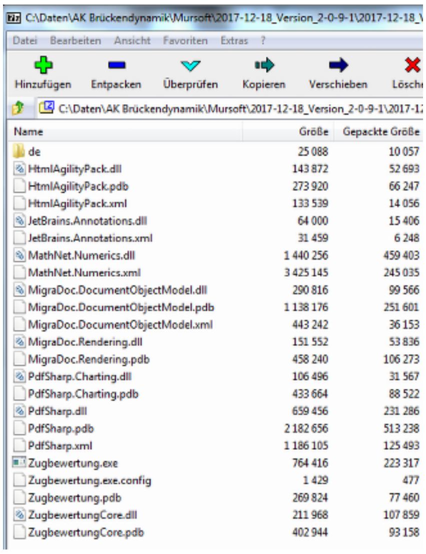
The SW was tested on a 64-bit-Windows 10 Pro-HP-Elite-book with a processor Intel® Core™ i5-73000 CPU @ 2,60 GHz and 16,0 GB RAM.

A screen with a resolution of 1920 x 1080 pixel is helpful but not necessary.

5.2 Installation

The SW-tool is delivered as a zip-file (see **Figure 19**), which must be unpacked into a folder to be specified by the user. Starting the file "Zugbewertung.exe" will start the program.

Note: It can be useful to create a link to the file "Zugbewertung.exe" on the desktop.



C:\Daten\AK Brückendynamik\Mursoft\2017-12-18_Version_2-0-9-1\2017-12-18_

C:\Daten\AK Brückendynamik\Mursoft\2017-12-18_Version_2-0-9-1\2017-1

Name	Größe	Gepackte Größe
de	25 088	10 057
HtmlAgilityPack.dll	143 872	52 693
HtmlAgilityPack.pdb	273 920	66 247
HtmlAgilityPack.xml	133 539	14 056
JetBrains.Annotations.dll	64 000	15 406
JetBrains.Annotations.xml	31 459	6 248
MathNet.Numerics.dll	1 440 256	459 403
MathNet.Numerics.xml	3 425 145	245 035
MigraDoc.DocumentObjectModel.dll	290 816	99 566
MigraDoc.DocumentObjectModel.pdb	1 138 176	251 601
MigraDoc.DocumentObjectModel.xml	443 242	36 153
MigraDoc.Rendering.dll	151 552	53 836
MigraDoc.Rendering.pdb	458 240	106 273
PdfSharp.Charting.dll	106 496	31 567
PdfSharp.Charting.pdb	433 664	88 522
PdfSharp.dll	659 456	231 286
PdfSharp.pdb	2 182 656	513 238
PdfSharp.xml	1 186 105	125 493
Zugbewertung.exe	764 416	223 317
Zugbewertung.exe.config	1 429	477
Zugbewertung.pdb	269 824	77 460
ZugbewertungCore.dll	211 968	107 859
ZugbewertungCore.pdb	402 944	93 158

Figure 19: Zip file of the delivered SW-tool

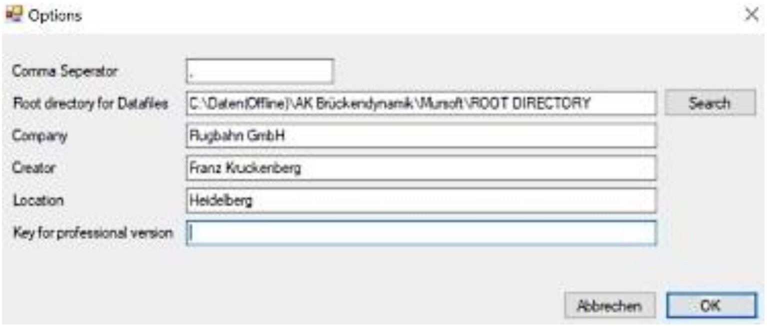
During the first use the SW-tool requires

- to specify a folder as root directory which will later be used to store rolling stock data, reference data and results;
- to define the decimal separator (comma or dot) used for copy / paste actions (it is recommended to use the same decimal separator as used in the MS-Excel-version installed on the same computer).
- to define information used as default for the definition of the output file title: Company, Author/Creator, Location

Note: These settings can be changed via the function "options" in the menu "Tools" (see Figure 20)

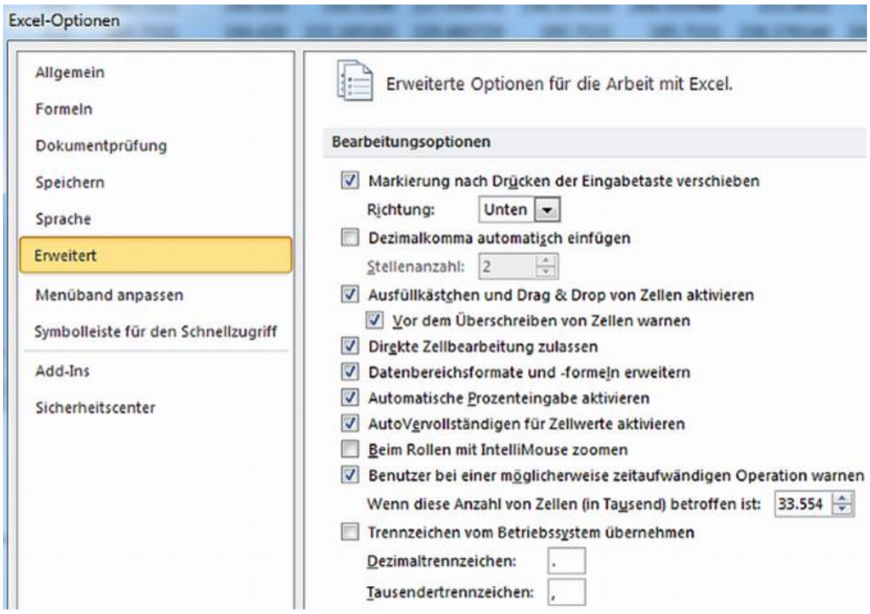
Note: In the German MS-Excel version a comma is used as default decimal separator.

For a "." specified in the SW-tool a MS-Excel setting D=".”and T="," (see Figure 21) is required. For a "," in the SW-tool the MS-Excel - settings have to be D="," and T=".".



Comma Seperator: .
Root directory for Datafiles: C:\Daten(Offline)\AK Brückendynamik\Munsoft\ROOT DIRECTORY
Company: Flugbahn GmbH
Creator: Franz Kruckenberg
Location: Heidelberg
Key for professional version:

Figure 20: Menu Tools – options



Erweiterte Optionen für die Arbeit mit Excel.

Bearbeitungsoptionen

☑ Markierung nach Drücken der Eingabetaste verschieben
Richtung: Unten
☐ Dezimalkomma automatisch einfügen
Stellenanzahl: 2
☑ Ausfüllkästchen und Drag & Drop von Zellen aktivieren
☑ Vor dem Überschreiben von Zellen warnen
☑ Direkte Zellbearbeitung zulassen
☑ Datenbereichsformate und -formeln erweitern
☑ Automatische Prozenteingabe aktivieren
☑ AutoVervollständigen für Zellwerte aktivieren
☐ Beim Rollen mit IntelliMouse zoomen
☑ Benutzer bei einer möglicherweise zeitaufwändigen Operation warnen
Wenn diese Anzahl von Zellen (in Tausend) betroffen ist: 33.554
☐ Trennzeichen vom Betriebssystem übernehmen
Dezimaltrennzeichen: .
Tausendertrennzeichen: ,

Figure 21: MS-Excel – Menu Options - Extended

5.3 Entering and saving vehicle data

For an easy input of data it is recommended to use the so called “harmonised vehicle data sheet” to collect the necessary vehicle data. This sheet is shown in Figure 22 and Figure 23.

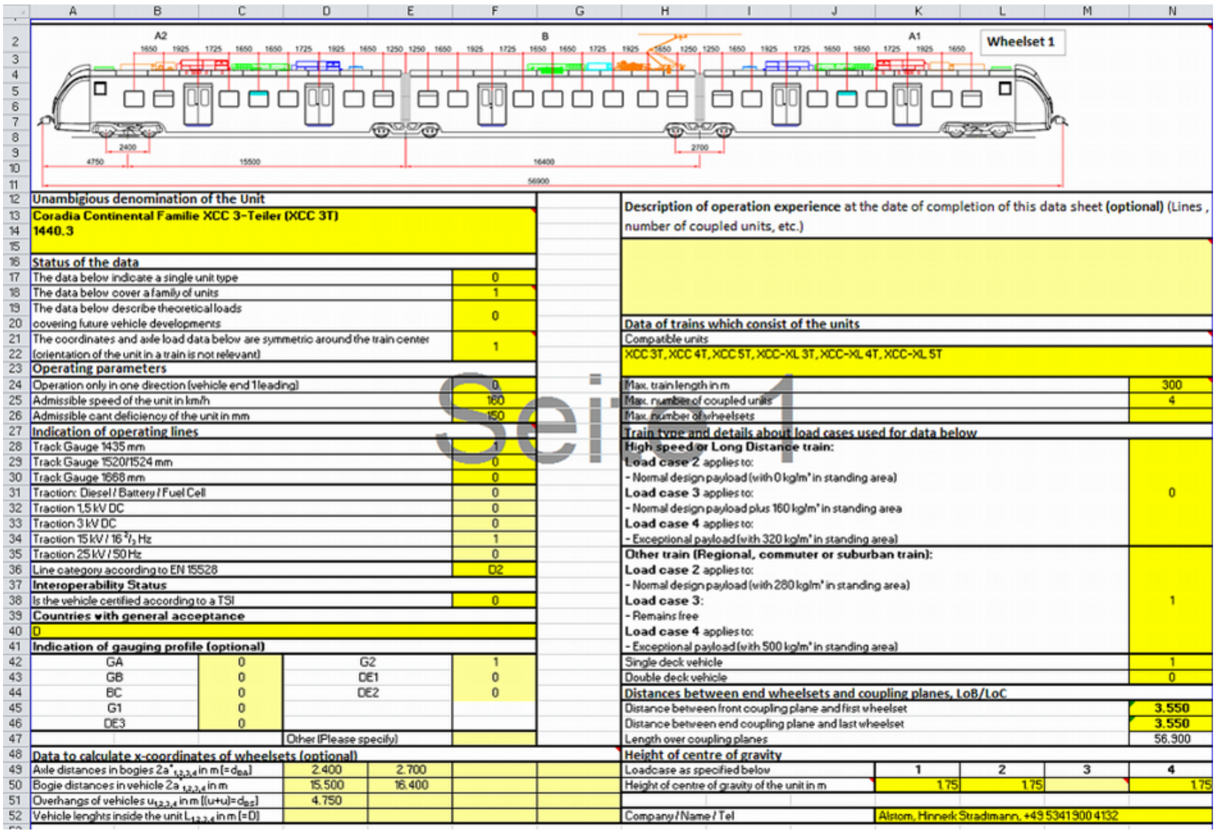
Figure 22 shows the upper part of the “harmonised vehicle data sheet” containing general information about the rolling stock and its operating conditions.

Figure 23 shows

- the lower part of the “harmonised vehicle data sheet” with the data related to the excitation of bridges,

and

- the corresponding “input vehicle data” table of the SW-tool to be used to enter vehicle data. The columns with the relevant data to be transferred from the “harmonised vehicle data sheet” into the SW-tool are marked.



Unambigious denomination of the Unit	
Coradia Continental Familie XCC 3-Teiler (XCC 3T) **1440.3**	
Status of the data	
The data below indicate a single unit type	0
The data below cover a family of units	1
The data below describe theoretical loads covering future vehicle developments	0
The coordinates and axle load data below are symmetric around the train center (orientation of the unit in a train is not relevant)	1
Operating parameters	
Operation only in one direction (vehicle end 1 leading)	0
Admissible speed of the unit in km/h	160
Admissible cant deficiency of the unit in mm	150
Indication of operating lines	
Track Gauge 1435 mm	1
Track Gauge 1520/1524 mm	0
Track Gauge 1668 mm	0
Traction: Diesel / Battery / Fuel Cell	0
Traction 1,5 kV DC	0
Traction 3 kV DC	0
Traction 15 kV / 16 $^2/_3$ Hz	1
Traction 25 kV / 50 Hz	0
Line category according to EN 15528	D2
Interoperability Status	
Is the vehicle certified according to a TSI	0
Countries with general acceptance	
D	

Indication of gauging profile (optional)

GA	0	G2	1
GB	0	DE1	0
BC	0	DE2	0
G1	0		
DE3	0		
		Other (Please specify)	

Data to calculate x-coordinates of wheelsets (optional)

Axle distances in bogies $2a^*_{1,2,3,4}$ in m [$=d_{BA}$]	2.400	2.700		
Bogie distances in vehicle $2a_{1,2,3,4}$ in m	15.500	16.400		
Overhangs of vehicles $u_{1,2,3,4}$ in m [$(u+u)=d_{BS}$]	4.750			
Vehicle lenghts inside the unit $L_{1,2,3,4}$ in m [$=D$]				

Description of operation experience at the date of completion of this data sheet **(optional)** (Lines , number of coupled units, etc.)

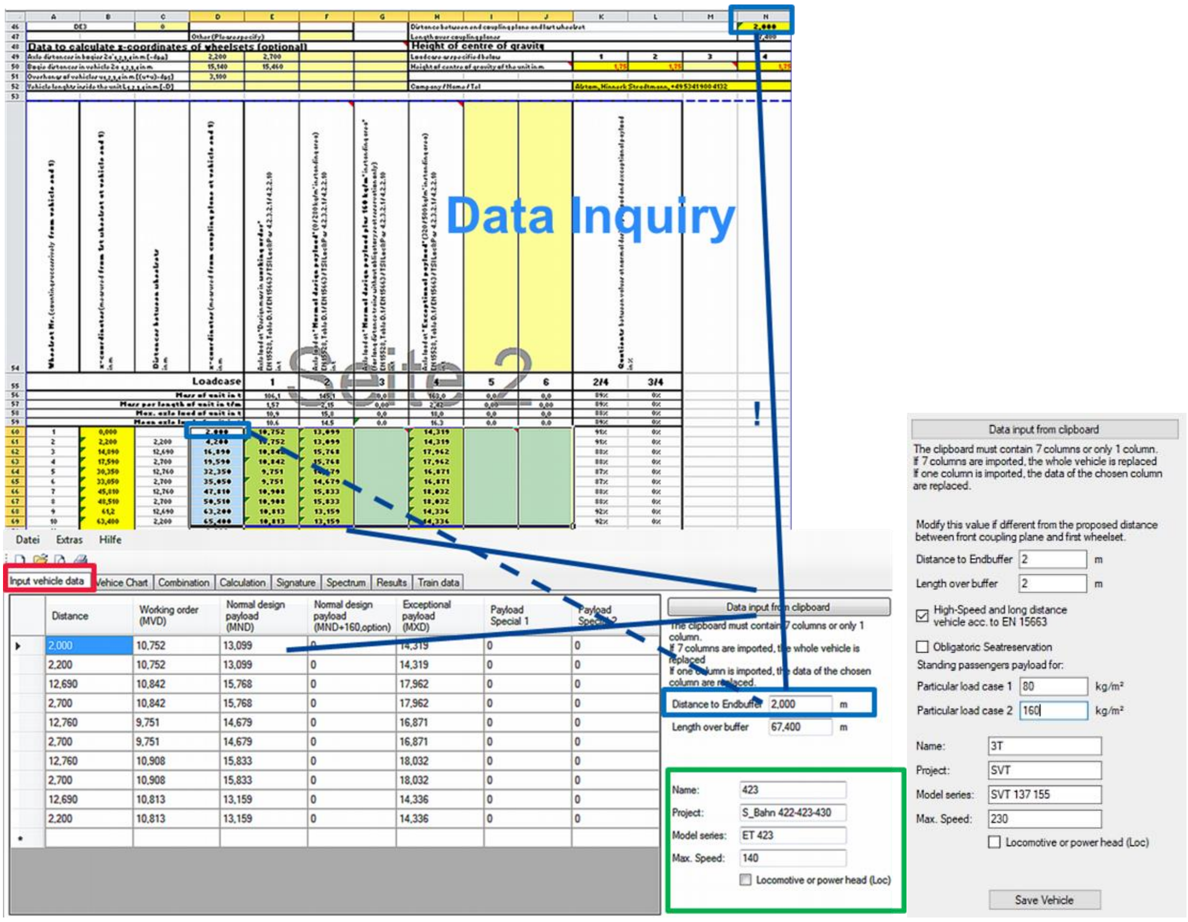
Data of trains which consist of the units	
Compatible units	
XCC 3T, XCC 4T, XCC 5T, XCC-XL 3T, XCC-XL 4T, XCC-XL 5T	
Max. train length in m	300
Max. number of coupled units	4
Max. number of wheelsets	
Train type and details about load cases used for data below	
High speed or Long Distance train: **Load case 2** applies to: - Normal design payload (with 0 kg/m² in standing area) **Load case 3** applies to: - Normal design payload plus 160 kg/m² in standing area **Load case 4** applies to: - Exceptional payload (with 320 kg/m² in standing area)	0
Other train (Regional, commuter or suburban train): **Load case 2** applies to: - Normal design payload (with 280 kg/m² in standing area) **Load case 3:** - Remains free **Load case 4** applies to: - Exceptional payload (with 500 kg/m² in standing area)	1
Single deck vehicle	1
Double deck vehicle	0
Distances between end wheelsets and coupling planes, LoB/LoC	
Distance between front coupling plane and first wheelset	**3.550**
Distance between end coupling plane and last wheelset	**3.550**
Length over coupling planes	56.900

Height of centre of gravity

Loadcase as specified below	**1**	**2**	**3**	**4**
Height of centre of gravity of the unit in m	1.75	1.75		1.75

Company / Name / Tel: Alstom, Hinnerk Stradmann, +49 5341 900 4132

Figure 22: Upper part of the “harmonised vehicle data sheet”



Distance	Working order (MVD)	Normal design payload (MND)	Normal design payload (MND+160,option)	Exceptional payload (MXD)	Payload Special 1	Payload Special 2
2,000	10,752	13,099	0	14,319	0	0
2,200	10,752	13,099	0	14,319	0	0
12,690	10,842	15,768	0	17,962	0	0
2,700	10,842	15,768	0	17,962	0	0
12,760	9,751	14,679	0	16,871	0	0
2,700	9,751	14,679	0	16,871	0	0
12,760	10,908	15,833	0	18,032	0	0
2,700	10,908	15,833	0	18,032	0	0
12,690	10,813	13,159	0	14,336	0	0
2,200	10,813	13,159	0	14,336	0	0

The clipboard must contain 7 columns or only 1 column.
If 7 columns are imported, the whole vehicle is replaced
If one column is imported, the data of the chosen column are replaced.

Distance to Endbuffer: 2,000 m
Length over buffer: 67,400 m

Name: 423
Project: S_Bahn 422-423-430
Model series: ET 423
Max. Speed: 140
☐ Locomotive or power head (Loc)

The clipboard must contain 7 columns or only 1 column.
If 7 columns are imported, the whole vehicle is replaced
If one column is imported, the data of the chosen column are replaced.

Modify this value if different from the proposed distance between front coupling plane and first wheelset.

Distance to Endbuffer: 2 m
Length over buffer: 2 m

☑ High-Speed and long distance vehicle acc. to EN 15663
☐ Obligatoric Seatreservation
Standing passengers payload for:
Particular load case 1: 80 kg/m²
Particular load case 2: 160 kg/m²

Name: 3T
Project: SVT
Model series: SVT 137 155
Max. Speed: 230
☐ Locomotive or power head (Loc)

Figure 23: Lower part of the “harmonised vehicle data sheet”, the seven column “input vehicle data” table of the SW-tool and additional necessary input data (distance to end coupler plane/end buffer plane, maximum permissible speed).

The first column to be imported from the “harmonised vehicle data sheet” shall contain the x-coordinates of the vehicle’s wheelsets in m (measured from the coupler-/end-buffer plane). The columns 2 to 7 shall contain the related axle loads in t for up to six different load cases. These axle loads shall be in accordance with the definitions in EN 15663 as follows:

1. design mass in working order (MVD)
2. design mass under normal payload (MND)
3. design mass under normal payload + 160 kg/m² (MND 160, only to be used for long distance and high speed trains without obligatory seat reservation)
4. design mass under exceptional payload (MXD)
5. user defined load case 1 (MU1)
6. user defined load case 2 (MU2)

Note 1: EN 15528, Annex D.1 requires using the load cases 2 (or 3) for dynamic calculations and the load case 4 for the (static) classification into the line categories. Load case 1 is specified in TSI Loc&Pas. It forms the basis for the validation of the theoretical mass management and enables to check the plausibility of the stated data. Load cases 5 and 6 can be used to indicate particular deviating load cases – for example load cases agreed with the operator.

Note 2: The coordinate of the first wheelset should not be zero. If this is given by the datasheet, the “Distance between front coupling plane and first wheelset” should be changed slightly. Usually, this does not appear by real trains and should not be necessary.

For locomotives only the load case “design mass in working order (MVD)” is relevant. The columns for the other 5 load cases may remain blank.

The easiest way to import **coordinates and loads** of wheelsets from the seven columns of the “harmonised vehicle data sheet” into the SW-tool is

- to copy them from the relevant seven columns into the clipboard (see upper part of Figure 23),
- to place the cursor somewhere into the table “Input Vehicle Data” of the SW-tool and
- to press the key “Enter data from clipboard” on the tab “Input Vehicle Data”.

In that case the “copied” data are inserted and any former data in the table of the SW-tool are replaced by the clipboard data.

Note: It is also possible to insert the data of one column if the content of the clipboard consists of one column only. The third option is to enter the data directly in the fields of the table. In that case the fields need to be completely empty before.

The input data from the seven columns in the “harmonised vehicle data sheet” do not contain the value of the **distance between the last axle and the coupling plane at the rear end** of the vehicle**.** This value shall be entered into the separate field “Distance to end buffer”. As default value the distance between the front end coupling plane and the first axle is proposed because in most cases this will be the correct value. In cases where the default value does not fit, it must be replaced by the correct value. Figure 23 shows also where to find this value in the “harmonised vehicle data sheet”. Furthermore, the maximum **permissible speed** of the vehicle shall be inserted in the field “Max. speed”. In case that the vehicle shall be handled as a **locomotive** (meaning that it will be respected only at the front end or rear end of a train), the tick box “Locomotive or power head (Loc)” shall be activated.

If particular load cases are specified for the vehicle the related standing passenger’s payload per m²shall be entered in the menu and will be saved with the vehicle data for later documentation in the output file.

To save the input vehicle data in the root directory for future use, names for a project” and a “model series” shall be specified as folder and subfolder names. These folders will be created automatically in the root directory.

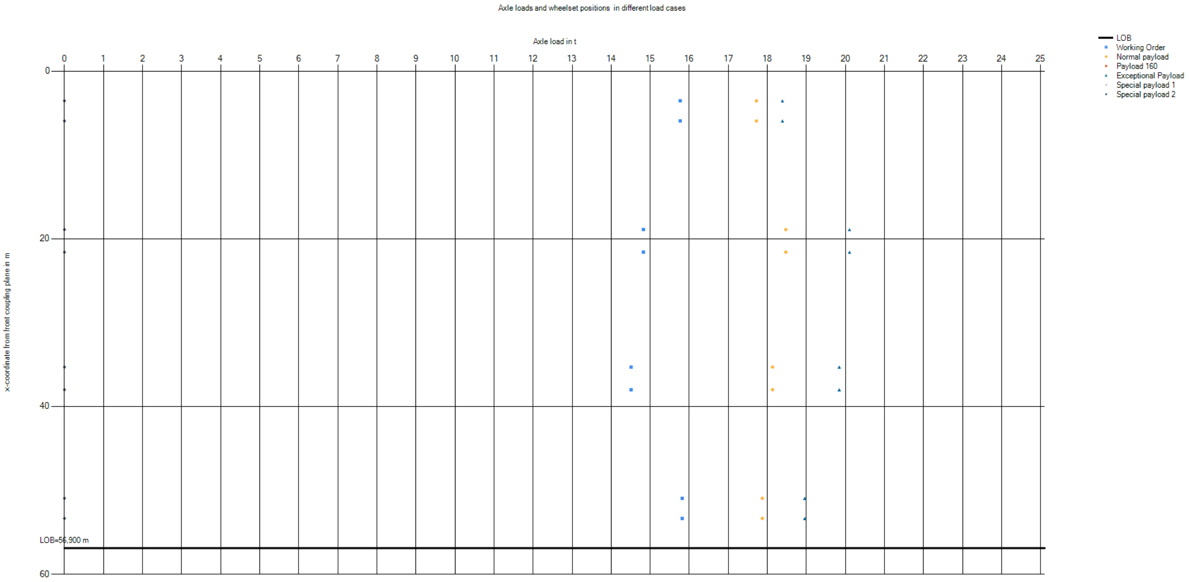


Figure 24: Graphical representation of vehicle data

At last the file name for the vehicle “Name” shall be specified. For further advice see chapter 5.4.

Note: It is recommended to use very short vehicle names, because they are used to create names of trains. If many vehicles are used to form a train, the resulting name of the train will consist of the combination of the names of all vehicles used for the train combination. Therefore. the SW-tool will give a warning message, if more than three characters are used as vehicle “Name”. The warning message can be ignored – but the consequence might be very long names for train combinations.

Note: A further sub-sub folder name “Vehicle” is set automatically as well as the file type “.veh” (or “.loc” in case of a locomotive).

The entered vehicle data can be checked graphically. The graph will be provided in the tab “Vehicle Chart” (see Figure 24). Vehicle data already stored by the SW-tool can be accessed via the SW-tool function “File – open”.

It is also possible to enter the data directly into the blank white fields of the table “Input vehicle data”. If a new line is chosen by the left mouse button, it is first filled with default values of distances and wheelset loads. These default values shall be modified. The data in the column “Abs. distance” will be calculated by the SW-tool.

A line can be deleted by marking it with the left arrow and the „delete“ button on the keyboard.

5.4 Data structure

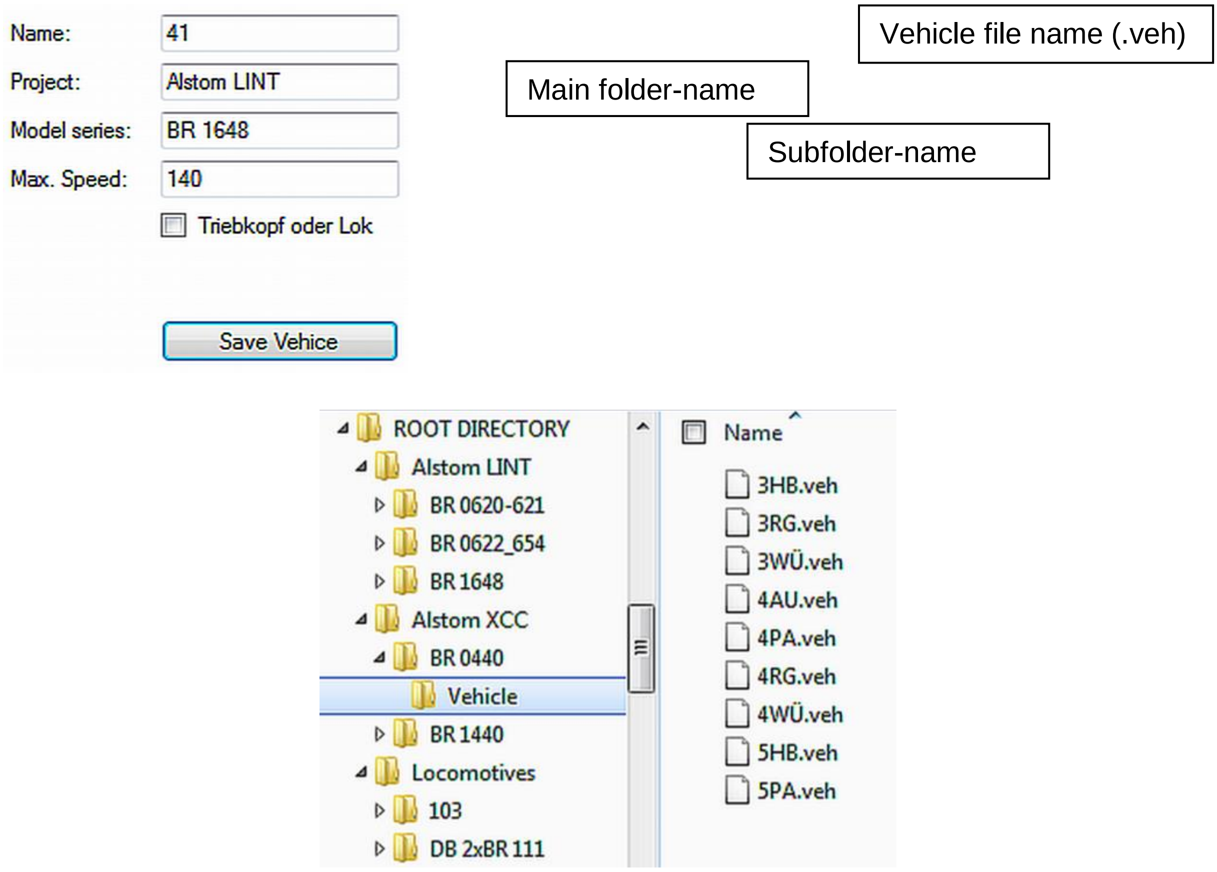

Name: 41
Project: Alstom LINT
Model series: BR 1648
Max. Speed: 140
☐ Triebkopf oder Lok

Figure 25: Data structure (Folder and file names) of vehicle data

A project name shall be chosen for the calculation series (usually one vehicle type, one vehicle family or a set of vehicles that is usually operated in a train).

Example: “Alstom LINT”. This project name is used as subfolder name in the “ROOT DIRECTORY”. A further subdirectory is named by the model-series. Example: “BR 1648”.

The vehicle data are always stored in subfolder “Vehicles”. The vehicle names to be chosen should be very short (recommendation: max. three letters or digits), as these names are used to indicate the train assembled with these vehicles. Example: “41.veh”, “54.veh” and “81.veh”.

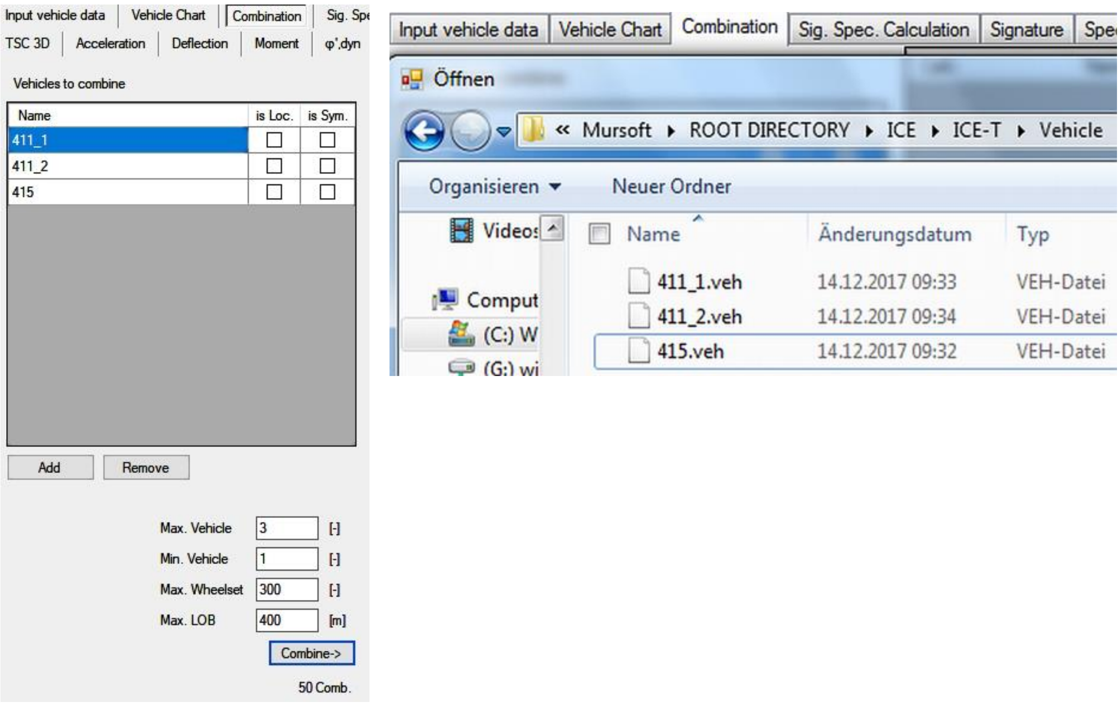
For some investigations it may be necessary to compare different types of units, e.g. an Intercity train with a Regional train. Due to the different kind of regulations it may be that not all columns (MVD, MND, MND+160, MXD, Payload Special 1, Payload Special 2) are filled in the datasheets. Since the choice of a column will be made for all trains together, the comparison is not possible without changing the data. For such an unusual project it is recommended to create a new folder in the ROOT directory, to save all units of interest there and to manipulate the given data in order to have the necessary axle loads stored in the same load column. To compare an Intercity train in MND+160 with a Regional train, which has no entries in this column, this column MND+160 of the regional has to be filled manually with the data of column MND. Keep in mind that this is a manipulation of the data and should not be used for any other calculations.

5.5 Train formation

In practice trains are often formed from several of the same, similar or different vehicles. Even if only a few vehicles are investigated, many possible combinations might occur. The SW-tool determines the wheelset coordinates and the wheelset loads of trains in all possible combinations of a set of vehicles, which can be chosen from the stored vehicle data.

To respect practical rules and limitations of real trains the SW-tool allows to apply filters related to the maximum and/or minimum number of vehicles, the maximum number of wheelsets and the maximum train length.

5.5.1 Vehicle combinations



Vehicles to combine

Name	is Loc.	is Sym.
411_1	☐	☐
411_2	☐	☐
415	☐	☐

Max. Vehicle 3 [-]
Min. Vehicle 1 [-]
Max. Wheelset 300 [-]
Max. LOB 400 [m]

50 Comb.

« Mursoft ▸ ROOT DIRECTORY ▸ ICE ▸ ICE-T ▸ Vehicle

Name	Änderungsdatum	Typ
411_1.veh	14.12.2017 09:33	VEH-Datei
411_2.veh	14.12.2017 09:34	VEH-Datei
415.veh	14.12.2017 09:32	VEH-Datei

Figure 26: Menu to choose vehicles to be combined

To form trains from vehicle data stored by the SW-tool before, the vehicles to be included in trains have to be chosen in the upper left field of the tab “Combination”. The button “Add” opens the explorer inside the specified root directory and allows to choose one or more vehicle files for the investigation. With the “Remove” button a chosen vehicle file can be excluded from the list of vehicles to be combined. Before starting the combination process, the default filter settings can be modified.

Note: At least one vehicle must be chosen as input for the combination process. This process is independent from the vehicle input process which is only used to create the vehicle data base.

In the example in Figure 26 one locomotive is chosen (the parameter “is.Loc” is set). This means that the locomotive will be considered only once at the front end or at the rear end of a train. From its data it was detected to be symmetric (the parameter “is.Sym” is set) and therefore it will be respected in one order only. The other three chosen vehicles are not symmetric and therefore these vehicles are respected in both orders (later indicated by an “i” behind the .veh file name for the inverse order).

If there are limitations for the resulting train compositions, they can be selected by setting limits to

• the maximum number of coupled vehicles (including a locomotive)	Default: 5
• the minimum number of coupled vehicles	Default: 1
• the maximum number of wheelsets of the train	Default: 300
• the maximum length over buffers/couplers	Default: 1000 m

After adjustment of these filter settings (if necessary) and pressing the “Combine” button the list of all possible trains matching the filter settings is shown in the right part of the screen including information about train length (LoB), number of wheelsets and vehicles (see Figure 27).

Note: The name of a train is composed by the names of the included vehicles (extended by an “i” indicating an inverse order) and is also used to indicate the calculation results and for documentation purposes. Calculations are made with the first vehicle of the combination name leading.

The boxes on the left side of this field (Column “Calc”) allow to exclude manually certain combinations from further calculations by removing the ticks from the relevant check boxes.

It is possible to take over the choice of trains from the Combination tab to the “TS Calculation” tab using the button “TS Calc update from combination” on the tab TSC. Other way round it is also possible to take over the choice of trains from “TS Calculation” into the “Combination” tab using the button “Calc update from TS Calc” on the tab “Combination”.

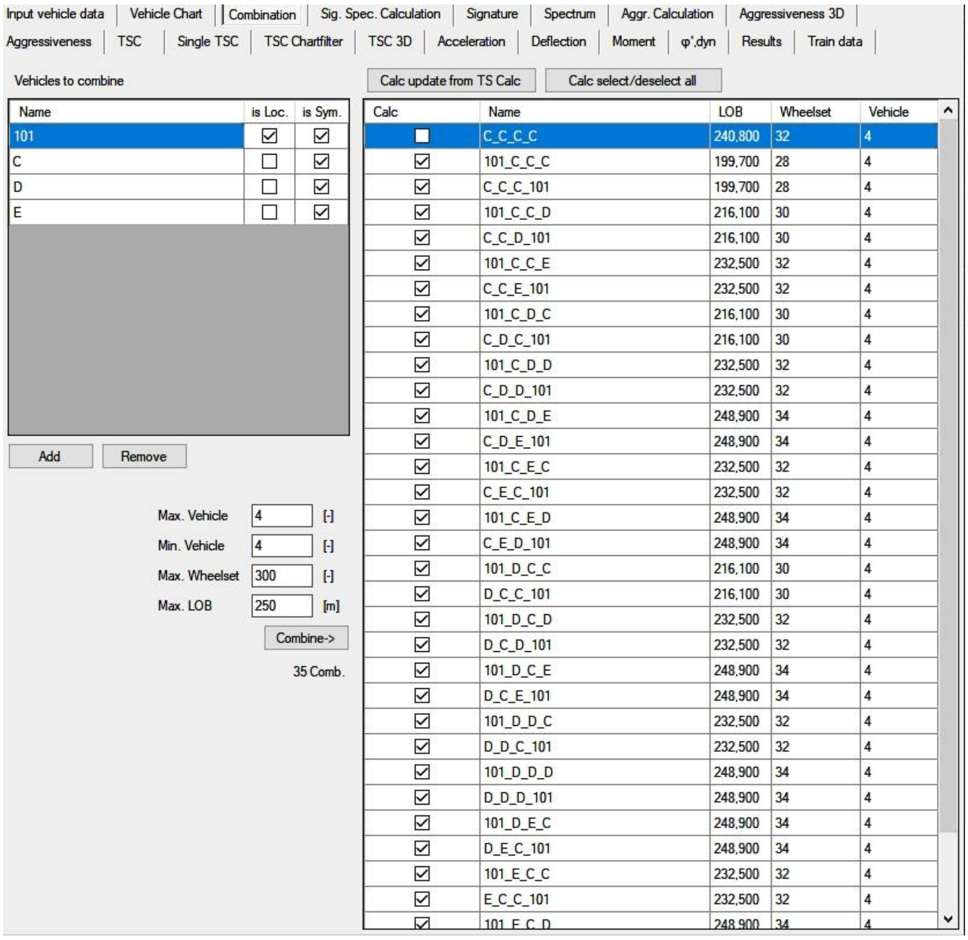
The total number of determined trains is indicated below the “Combine” button.

Note: The max. number of possible trains without filtering (if the load patterns of the vehicles are not symmetric) is given by

$N_{train} = \sum_{i=1}^{n}(2k)^{i}$ with *k* – number of vehicle variants to be investigated
n – Maximum number of coupled vehicles in one train

For further investigations performed by DB Netz, it is possible to export the data of the combinations in the DB Netz input format. The files “_dist_*DATE_TIME*.csv” and “_load_*DATE_TIME*.csv” are automatically created in the ROOT directory when the pdf-report (see 0) is created.

Note: The tick boxes in the column “Calc” are not relevant for the content of the export files. They contain the data of all created combinations.



Vehicles to combine

Name	is Loc.	is Sym.
101	☑	☑
C	☐	☑
D	☐	☑
E	☐	☑

Max. Vehicle 4 [-]

Min. Vehicle 4 [-]

Max. Wheelset 300 [-]

Max. LOB 250 [m]

35 Comb.

Calc	Name	LOB	Wheelset	Vehicle
☐	C_C_C_C	240,800	32	4
☑	101_C_C_C	199,700	28	4
☑	C_C_C_101	199,700	28	4
☑	101_C_C_D	216,100	30	4
☑	C_C_D_101	216,100	30	4
☑	101_C_C_E	232,500	32	4
☑	C_C_E_101	232,500	32	4
☑	101_C_D_C	216,100	30	4
☑	C_D_C_101	216,100	30	4
☑	101_C_D_D	232,500	32	4
☑	C_D_D_101	232,500	32	4
☑	101_C_D_E	248,900	34	4
☑	C_D_E_101	248,900	34	4
☑	101_C_E_C	232,500	32	4
☑	C_E_C_101	232,500	32	4
☑	101_C_E_D	248,900	34	4
☑	C_E_D_101	248,900	34	4
☑	101_D_C_C	216,100	30	4
☑	D_C_C_101	216,100	30	4
☑	101_D_C_D	232,500	32	4
☑	D_C_D_101	232,500	32	4
☑	101_D_C_E	248,900	34	4
☑	D_C_E_101	248,900	34	4
☑	101_D_D_C	232,500	32	4
☑	D_D_C_101	232,500	32	4
☑	101_D_D_D	248,900	34	4
☑	D_D_D_101	248,900	34	4
☑	101_D_E_C	248,900	34	4
☑	D_E_C_101	248,900	34	4
☑	101_E_C_C	232,500	32	4
☑	E_C_C_101	232,500	32	4
☑	101_E_C_D	248,900	34	4

Figure 27: Result of combination: List of trains

5.5.2 Handling of locomotives

A vehicle indicated as locomotive is considered only once in a train. If more than one locomotive is chosen, for any train only one locomotive per train is considered.

If more than one locomotive was chosen, they are handled separately with the other vehicles. It is not possible to combine different locomotives with each other.

Note 1: Two or more coupled locomotives should be handled as one vehicle. Therefore, they need to be entered and stored as one separate locomotive.

Note 2: To handle locomotives between coaches, partial trains including locomotive have to be saved as a vehicle. To support this method, it is foreseen for a later version of the SW-tool to save trains which are created by the “combination” button as a vehicle.

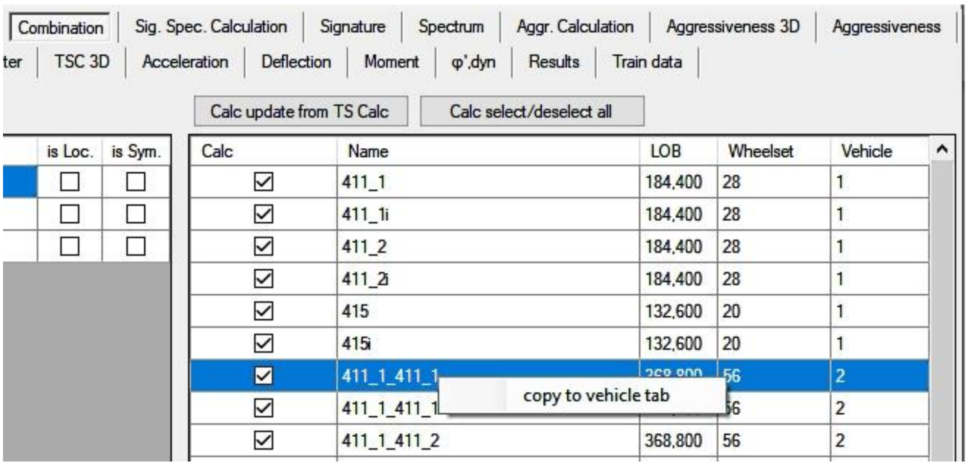
The axle loads of a locomotive are always chosen from the column “MVD” as no payload status is defined for them.

5.5.3 Coordinates of the wheelsets in a train

As all vehicle data sets contain the information about the distances between the first and last wheelset at their ends and the front and rear end coupling planes it is possible to determine the coordinates of trains. Therefore, the x-coordinate of the first wheelset of a train equals the distance between the front end coupling plane of the train and the first wheelset. The equations to determine the signatures, spectra and aggressiveness require a x-coordinate of 0 for the first wheelset of a train. For the calculations this offset is eliminated from all wheelset coordinates of the train internally in the SW-tool. This is not visible in the output data of train configurations.

5.5.4 Saving trains as vehicles or references

The trains composed by the tab “Combination” can be saved as a vehicle. Therefore one of the combinations can be chosen by the right mouse button to copy the data (coordinates, wheelset loads, distances to coupling plane and speed) to the tab “Input vehicle data” where they can be saved as a new vehicle as described in chapter 5.3.



is Loc.	is Sym.
☐	☐
☐	☐
☐	☐

Calc	Name	LOB	Wheelset	Vehicle
☑	411_1	184,400	28	1
☑	411_1i	184,400	28	1
☑	411_2	184,400	28	1
☑	411_2i	184,400	28	1
☑	415	132,600	20	1
☑	415i	132,600	20	1
☑	411_1_411_1	368,800	56	2
☑	411_1_411_1		6	2
☑	411_1_411_2	368,800	56	2

Figure 28: Option to copy data of a combination to the tab “Input vehicle data”

5.6 Saving a project

The work of a project can be saved in a cmz-file using the menu “File – Save as …”. The cmz-file includes

- all determined (train-) combinations,
- last calculation settings for the DER method,
- settings of last TSC calculation including the results of the Time step integration
- last TSC chart filter options

This allows to open the project later using the menu “File – Open” and to resume the work.

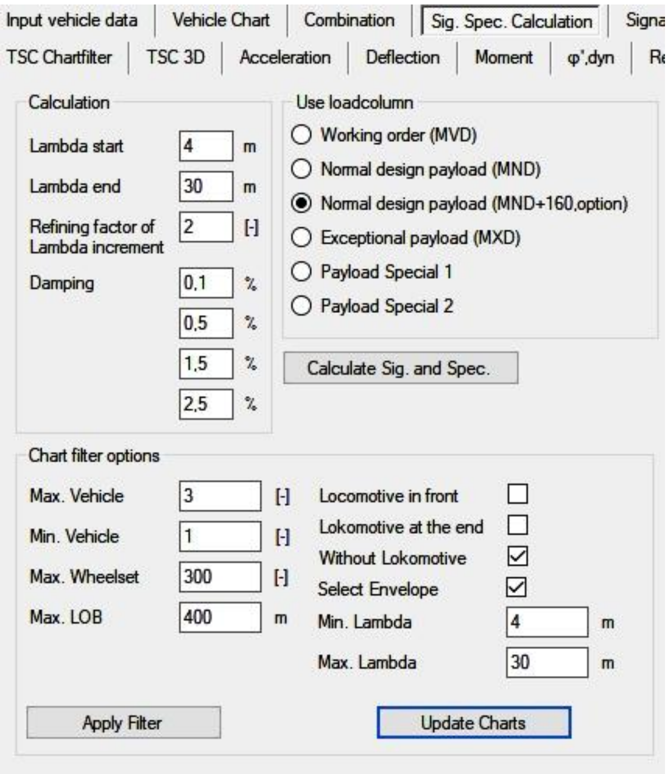
Note: The results of DER calculations are not saved in the cmz-file as they can be quickly repeated. Before creating an output pdf-file according to 0 from an opened cmz-file, it is necessary to repeat the Sig./Spec. and Aggr. calculations.

5.7 Calculation of signatures and spectra (DER-method)

5.7.1 Setting of calculation parameters

On the tab “Sig. Spec. Calculation” the parameters for DER calculations are to be set.

All parameters within this tab are pre-defined with default values. It is recommended to use these default values. But for the load case it is necessary to check, if the default load case MND is applicable for the design of the vehicles in question. More details are given in Note 1 and Note 2 below.



Calculation
Lambda start 4 m
Lambda end 30 m
Refining factor of Lambda increment 2 [-]
Damping 0,1 %
0,5 %
1,5 %
2,5 %

Use loadcolumn
○ Working order (MVD)
○ Normal design payload (MND)
● Normal design payload (MND+160,option)
○ Exceptional payload (MXD)
○ Payload Special 1
○ Payload Special 2

Chart filter options
Max. Vehicle 3 [-]
Min. Vehicle 1 [-]
Max. Wheelset 300 [-]
Max. LOB 400 m
Locomotive in front ☐
Lokomotive at the end ☐
Without Lokomotive ☑
Select Envelope ☑
Min. Lambda 4 m
Max. Lambda 30 m

Figure 29: DER calculation menu “Sig/Spec calculation”

Parameters to be set are divided into three different blocks:

a) **“Calculation”** (in the public version all default values are blocked), which contains
- the range of wavelengths to be regarded within the calculations, defined by “Lambda start” and “Lambda end”. Default values are 4 m and 30 m.
- the refining factor to refine the resolution of the wavelength compared to the minimum resolution which is set to (0,04 m between 4 m and 10 m, 0,2 m between 10 m and 20 m, 0,4 m between 20 m and 30 m). The default value for the refining factor is 2,
- a set of four different damping values which will be used for the spectra. The default values are 0,1 %, 0,5 %, 1,5 % and 2,5 %.

b) **“Use load column”**, where the loadcase has to be chosen which is used within the calculation

Note 1: According to EN 15528:2015, Table D.1 (which is also referred by DB Netz AG guideline 810.0200A81), the following load cases have to be used for dynamic checks:
- “Normal design payload (MND)” for high speed and long distance trains, if reservation is obligatory, and for all other trains (e,g. regional, commuter, suburban trains)
- “Normal design payload (MND+160.option)” for high speed and long distance trains, if reservation is **not** obligatory (common practice e.g. in German Intercity and ICE trains). For high speed and long distance trains **without obligatory seat reservation**, the **default setting** “Normal design payload (MND)” is **not applicable**.

Note 2: If available other load cases can be used for checking specific cases (for example: test runs in empty condition or in another defined loadcase).

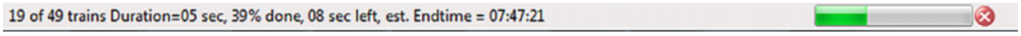
For further investigations performed by DB Netz, it is possible to export the data of the combinations in the DB Netz input format. The files “_dist_*DATE_TIME*.csv” and “_load_*DATE_TIME*.csv” are automatically created in the ROOT directory when the pdf-report (see 0) is created.

Note: The tick boxes in the column “Calc” are not relevant for the content of the export files. They contain the data of all created combinations.

By pressing the “Calculate Sig. and Spec.” button, the calculation of signatures and spectra of the trains, which were chosen in the tab “Combination” via the tick boxes, is started. The progress of the calculation is monitored at the bottom of the window (see Figure 30).

Note 3: All results are internally calculated from the vertical static wheelset forces P_{F0} in kN derived from the axle loads P_0 in the database which are given in tons:

$$P_{F0} = P_0 \cdot 9{,}81\ m/s^2$$



19 of 49 trains Duration=05 sec, 39% done, 08 sec left, est. Endtime = 07:47:21

Figure 30: Monitoring of calculation progress

c) **“Chart filter options”** allow to decide, which of the calculated results are presented in the diagrams on the tabs “Signature” and “Spectrum” (see chapter 5.7.2.1) as a red line (selected results). The black line in these diagrams represent always the envelope of all calculated results (calculated results).

5.7.2 Presentation of results

5.7.2.1 Choice of the results sent to diagrams

For the presentation of the results we need to distinguish between

- all *calculated* results,
- the results which are *selected* to be sent to the diagrams on the tabs “Signature” and “Spectrum” and
- the results which are *displayed* in the diagram after further exclusion of single train results on the tabs “Signature” and “Spectrum”.

On the tab “Sig. Spec. Calculation” in the field “Chart filter option” (see Figure 29) it is possible to choose the results which are sent to the diagrams (the envelope of all calculated results is always sent to the diagrams and is presented as a fat black line). Afterwards the “Update charts” button shall be pressed in order to send results to the diagrams presented on the tabs “Signature” and “Spectrum”, even if no “Chart filter options” settings are changed.

The settings of the chart filter options are predefined with the values set for the calculation in order to select generally all calculated combinations. Further the tick box “Select envelope” is activated. This means that only combinations are respected which contribute to the envelope of all calculated results. In order to minimize the number of combinations forming the envelope, each envelope section is represented by only one combination – in spite the fact that more than one combination could deliver the same values at a certain wavelength. This choice is made based on the length of the line that covers the envelope.

This selection of the presented results can be modified further using the tick boxes on the right side of the tab “Sig. Spec. Calculation” (except for the black envelope which always represents all calculated results). Here, a matrix of these tick boxes indicates which combinations are selected for graphical presentation of Signatures (Sig.), Spectra (Sp. *damping rate*) and Aggressiveness (A 3D). In a special column it is also indicated which combination is part of the envelope of the signatures (Is Env. S).

The number of active boxes in the columns (combinations shown in the diagrams) is indicated in the headlines of the columns in brackets.

Note 1: In the case that more than one combination is part of the envelope, only the combinations providing the longest part of the envelope are selected for presentation (indicated in the column (Is Env. S). The length of the contribution to the envelope of all combinations is indicated in the column #S for information. For the spectra, the same algorithm applies, but the information about the contribution of the combinations is not provided: An active box indicates after the calculation, that a combination is a necessary part of the envelope.

Note 2: In the non-public version, it is possible to steer the content of the diagrams by activating and deactivating the boxes in the columns “Sig.” and “Sp. *damping rate*”

The right part of the matrix gives information on the number of vehicles (Veh.) and wheelsets (W.set) and the length over buffer (LOB) for each combination.

5.7.2.2 Diagrams

The diagrams of the signatures on the tab “Signature” consist of all curves sent to the diagrams as defined in 5.7.2.1.

A fat black curve (called “*Envelope calculated*”) indicates the envelope of all calculated combinations, while a fat red curve (called “*Envelope selected*” indicates the envelope of the combinations specified by the chart filter (and the manual choice in the matrix of the tab “Sig. Spec. calculation” in case of the non-public version).
On the left side of the diagram a menu with list of all combinations sent to the diagram is shown. It is possible to deselect certain combinations leading to a third envelope of the displayed combinations (called “*Envelope displayed*”). This envelope is represented by a fat blue curve.

The possibility to modify the limits and the grid of the axes of the diagram enables also zooming in the diagrams.

To avoid a too small diagram in case of a large number of combinations it is possible to decide, whether the legend is shown inside or besides the diagram.

It is possible to indicate the coordinates of certain points of the curves in the diagram by clicking them with a mouse button. They can be removed by clicking them again.

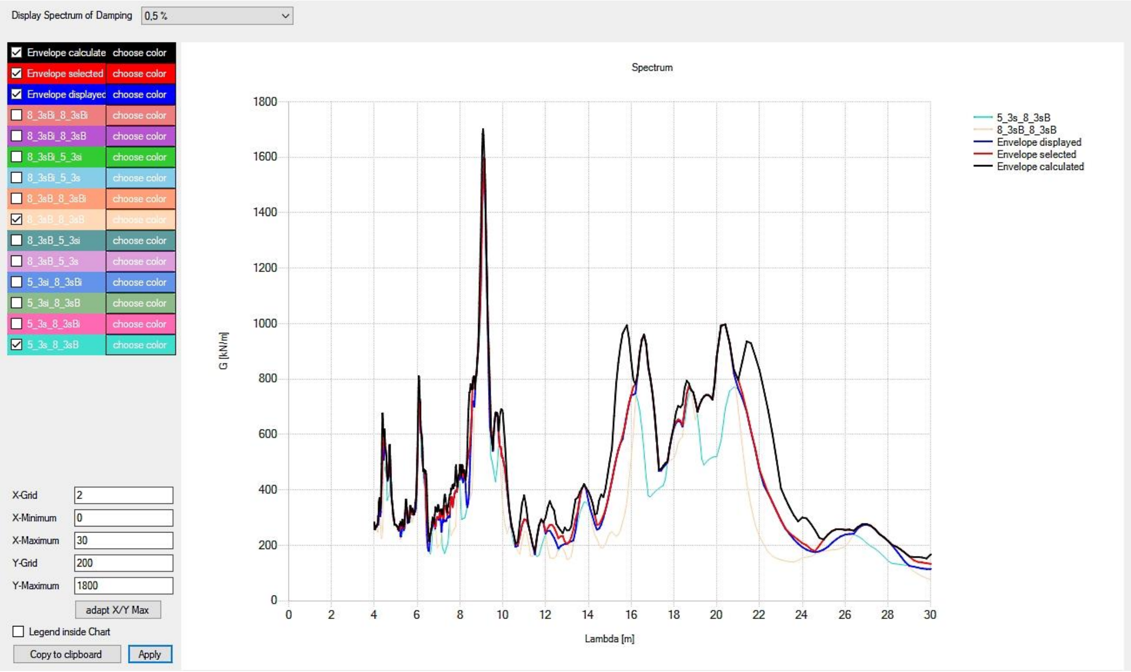
To use a diagram (including the indicated coordinates) inside other SW applications, it is possible to copy it to the clipboard by pressing the button “Copy to clipboard” on the lower left side or by using a field activated by clicking the right mouse button in the diagram.

5.7.3 Determination of combinations with relevant dynamic behaviour

As described in 3.2.2.2 it is possible to determine few combinations representing the dynamic behaviour of a huge number of combinations with a similar static axle load distribution using the spectra with the typical practical damping values of 0,5 %, 1,5 % and 2,5 %.

Figure 31 illustrates the process for this determination to choose the relevant combinations to be investigated by the parameter study using time step calculations (TSC).

In the example shown here for 0,5 % damping first the chart filter option on the tab “Sig. Spec. Calculation” was used to determine the red “selected” envelope. In this case the max. number of axles of the combinations was reduced from 42 (covered by the black “envelope calculated”) to 40. Afterwards on the tab “Spectrum” the menu on the left was used to investigate the influence of each single combination on the 0,5-%-spectrum. It was found that the envelope of two remaining combinations in the blue “displayed” envelope are a good representation of the “selected” red curve formed by all twelve combinations in the left menu. If these two combinations are also representing the red curves of the 1,5-%- and the 2,5-%-spectra, the time consuming TSC calculations can be restricted to the two remaining combinations. In some cases the spectra for the other damping values will require to add one or two more combinations.



Display Spectrum of Damping: 0,5 %

- ☑ Envelope calculate
- ☑ Envelope selected
- ☑ Envelope displayec
- ☐ 8_3sBi_8_3sBi
- ☐ 8_3sBi_8_3sB
- ☐ 8_3sBi_5_3si
- ☐ 8_3sBi_5_3s
- ☐ 8_3sB_8_3sBi
- ☑ 8_3sB_8_3sB
- ☐ 8_3sB_5_3si
- ☐ 8_3sB_5_3s
- ☐ 5_3si_8_3sBi
- ☐ 5_3si_8_3sB
- ☐ 5_3s_8_3sBi
- ☑ 5_3s_8_3sB

X-Grid: 2
X-Minimum: 0
X-Maximum: 30
Y-Grid: 200
Y-Maximum: 1800

☐ Legend inside Chart

Figure 31: Determination of relevant combinations for TSC calculations

5.8 Calculation of Aggressiveness

5.8.1 Definition

The aggressiveness is defined as the product of the spectrum $G_{aggr}(\lambda,L,\zeta)$ and the Amplification factor $A(L/\lambda)$ described below. It represents the acceleration level. The acceleration level can be calculated by another multiplication with a factor that depends only on the mass per length (see chapter 3.2.2.3).

Note: For this operation the spectrum $G_{aggr}(\lambda,L,\zeta)$ according to equation 5.7 of ERRI D214, RP6, part A is used (Devided by the span length *L* in order to remain consistent with the mass factor of the simplified approach in equation 5.8 of ERRI D214, RP6, part A which is the factor of equation 5.8 multiplied by L) , that does not take into account the simplification used for the definition of $G(\lambda,\zeta)$ (see chapter 3.2.2.3). The duration of the passage of the train is correctly represented by train length plus the span length instead of the train length only.

$$G_{aggr}(\lambda, L) = \frac{Max}{i=0;N-1}\left\{\frac{1}{\zeta(x_{i+L)}}\sqrt{\left[\sum_{k=0}^{i} P_k cos\left(\frac{2\pi x_k}{\lambda}\right)\right]^2+\left[\sum_{k=0}^{i} P_k sin\left(\frac{2\pi x_k}{\lambda}\right)\right]^2}\left[1-e^{-2\pi\zeta\frac{x_i+L}{\lambda}}\right]\right\}$$

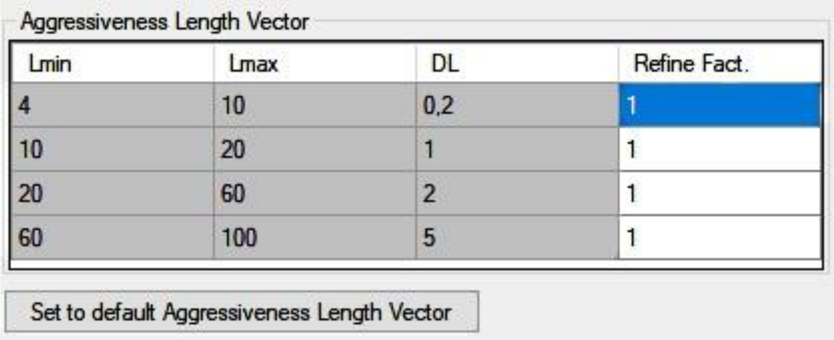
$$A\left({}^{L}/_{\lambda}\right) = \left|\frac{cos\left(\frac{\pi L}{\lambda}\right)}{\left(\frac{2L}{\lambda}\right)^2-1}\right| \tag{44}$$

5.8.2 Setting of calculation parameters

As the aggressivity is calculated for each span length *L*, the latter must be introduced as an additional parameter and it needs to be specified how it is varied.

The interval *DL* of the “Aggressiveness Length Vector” is given in a table which defines four subsets of the range of span lengths between 4 m and 100 m.

Note: The (integer) factor “*Refine. Fact.*” in the last column describes for each line the number of substeps. In the current version it is always set to 1 and can no longer be modified

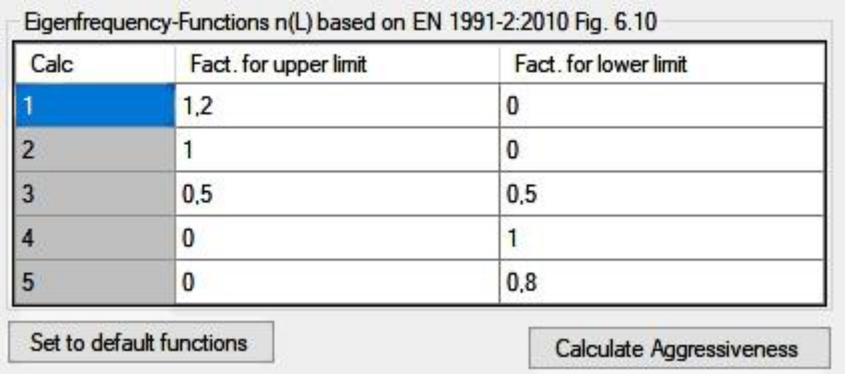


Lmin	Lmax	DL	Refine Fact.
4	10	0,2	1
10	20	1	1
20	60	2	1
60	100	5	1

Figure 32: Menu to control span-length vector for aggressiveness calculation

Furthermore, the natural frequency functions n(L) of the bridges which shall be taken into account during the calculation have to be defined (compare 4.1.2). Up to 5 different natural frequency functions can be described as a linear combination of those given in Fig. 6.10 of EN 1991-2:2010, using the table shown in Figure 33,
The table should be read as follows:

- Function #2 in this example is identical to the upper limit function of EN1991-2 (=> 1 x upper limit, 0 x lower limit)
- Function #4 is identical to the lower limit function of EN1991-2 (=> 0 x upper limit, 1 x lower limit)
- Function #3 is the mean of both limit functions of EN1991-2 (=> 0.5 x upper limit + 0.5 x lower limit)
- Function #1 has 20% higher natural frequencies compared to the upper limit function (=> 1.2 x upper limit, 0 x lower limit)
- Function #5 has 20% lower natural frequencies compared to the lower limit function (=> 0 x upper limit, 0.8 x lower limit)



Calc	Fact. for upper limit	Fact. for lower limit
1	1,2	0
2	1	0
3	0,5	0,5
4	0	1
5	0	0,8

Figure 33: Menu to control the natural frequency functions (also called eigenfrequency functions) for aggressiveness calculation

The five functions described above are the default function set within the software. However, other functions can be defined by adjusting the entries in the table. If both factors in a line are set to ”0”, this function is not used within the calculation.

E.g. if a network is considered which contains only new built bridges, it could be possible to neglect bridges with natural frequencies lower than given in EN 1991-2. In this case use the default setting, but without function #5 (entry “0” “0” in line #5).

The damping D is varied in four steps using the values specified for the calculation of spectra on the tab “Sig. Spec. Calculation” (see 5.7.1).

5.8.3 Three-dimensional presentation of aggressiveness

The aggressivity is a function of the span-length L, the wavelength λ and the Damping D. On the tab “Aggressiveness 3D” the results of all calculated trains are presented as an envelope over λ and L. The damping can be chosen from a dropdown list which contains the damping values used for the calculation.

The vertical axis can be scaled using the entry “Scale to max A*G”.

Pointing with the mouse into the diagram returns the values for L, λ and A*G of the respective point.

5.8.4 Two-dimensional presentation of aggressiveness

The results of aggressiveness as a function can be also presented as intersection of the three-dimensional presentation in 5.8.3. Therefore, the tab “Aggressiveness” provides the following possibilities:

- Choosing the results of one or more train combinations for a certain damping or choosing the results as a comparison of the different damping values, the latter either for all calculated envelopes or for all displayed and selected envelopes.
- Choosing these results for a certain span length, with the wavelength λ on the x-axis, or for a certain lambda value, with the span length on the x-axis. These options correlate to different intersections of the three-dimensional aggressiveness plot.
- Alternatively, choosing the velocity instead of the wavelength λ on the x-axis, scaled using one of the five different Eigenfrequency functions (here called velocity functions) defined on the “Aggr. Calc“ tab *(*see 3.2.2.3).

The diagram can be zoomed by entering values for X-Minimum, X-Maximum and/or Y-Maximum. Furthermore, both X- and Y-Grid can be adopted, and the legend can be positioned inside or besides the diagram. After the choice the “Apply” button must be pressed. The „adapt X/Y Max“ button establishes the automatic scale.
Finally, the diagram can be copied to the clipboard, e.g. to paste it in a technical report.

5.9 Time step calculation (TSC)

5.9.1 Parameter Study

The parameter study allows to investigate the dynamic behaviour of a set of simple single beam bridges covering a representative field of parameters (see 4.1) during the passage of one or more trains. The train data can be chosen from the combinations created before from vehicle data on the “Combination” Tab.

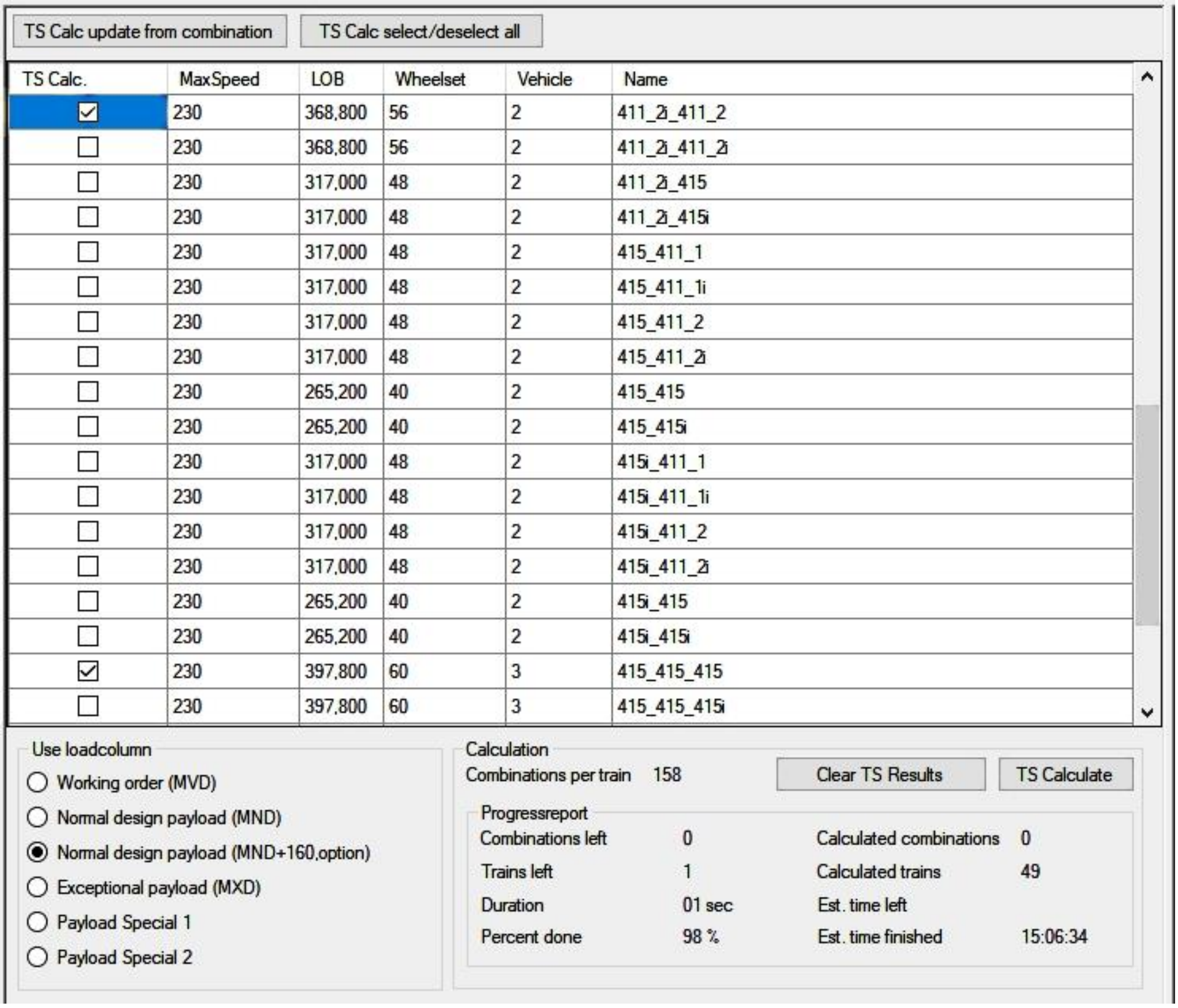
5.9.1.1 Choice of investigated trains

Figure 34 shows the menu for the choice of trains. All trains achieved by the “combination” process (see 5.5) are listed indicating max. speed, LoB and the numbers of wheelsets and vehicles. A ticked box indicates, if a train will be included in the time step calculations. To simplify the handling, the buttons “TS Calc update from combination” (taking over the activated trains from the “Combination” tab, see Figure 27) and “TS Calc select / deselect all” are available.

The load case is per default set to the case used for the “Sig. Spec. Calculation” but can be varied if necessary.

In the left field below the table of combinations, the load column of the vehicle data must be chosen (MND is the default setting).

Note: Please ensure, that the vehicle data of vehicles being part of the combination have the relevant wheelset loads in the same load column.



TS Calc.	MaxSpeed	LOB	Wheelset	Vehicle	Name
☑	230	368,800	56	2	411_2i_411_2
☐	230	368,800	56	2	411_2i_411_2i
☐	230	317,000	48	2	411_2i_415
☐	230	317,000	48	2	411_2i_415i
☐	230	317,000	48	2	415_411_1
☐	230	317,000	48	2	415_411_1i
☐	230	317,000	48	2	415_411_2
☐	230	317,000	48	2	415_411_2i
☐	230	265,200	40	2	415_415
☐	230	265,200	40	2	415_415i
☐	230	317,000	48	2	415i_411_1
☐	230	317,000	48	2	415i_411_1i
☐	230	317,000	48	2	415i_411_2
☐	230	317,000	48	2	415i_411_2i
☐	230	265,200	40	2	415i_415
☐	230	265,200	40	2	415i_415i
☑	230	397,800	60	3	415_415_415
☐	230	397,800	60	3	415_415_415i

Use loadcolumn
○ Working order (MVD)
○ Normal design payload (MND)
● Normal design payload (MND+160,option)
○ Exceptional payload (MXD)
○ Payload Special 1
○ Payload Special 2

Calculation
Combinations per train 158

Progressreport

Combinations left	0	Calculated combinations	0
Trains left	1	Calculated trains	49
Duration	01 sec	Est. time left	
Percent done	98 %	Est. time finished	15:06:34

Figure 34: Menu to choose trains and load case to be investigated

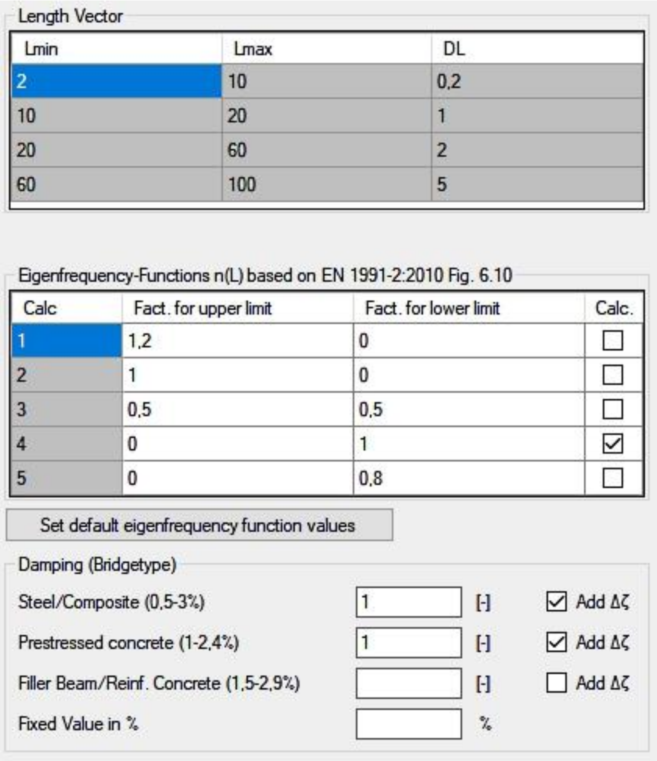
5.9.1.2 Setting of bridge parameters

The bridge parameters included in the study consist of the length vector (see 4.1.1), the function of natural frequency (see 4.1.2), the damping function (see 4.1.3).

The menu from the Tab “TSC” shown in Figure 35 controls the bridge parameters included into the study.

First the <u>*span length vector*</u> (cannot be varied) is shown.

Afterwards the characteristics of five *functions of natural frequency* (Eigenfrequency functions) is specified by factors to be multiplied with the upper and the lower frequency limit for new bridges given in EN 1991-2 (see Figure 10). The settings for a proof calculation are shown in Figure 35 covering an extended range between 80 % of the lower and 120 % of the upper limit of EN 1991-2 in five steps. Line 2 and 4 of the menu table in Figure 35 reflect the upper and the lower limit of Figure 8, Line 3 is the mean frequency between the limit. Line1 reflects a higher stiffness than required, while line 5 covers a representative range of existing bridges designed before introduction of EN 1991-2.



Length Vector

Lmin	Lmax	DL
2	10	0,2
10	20	1
20	60	2
60	100	5

Eigenfrequency-Functions n(L) based on EN 1991-2:2010 Fig. 6.10

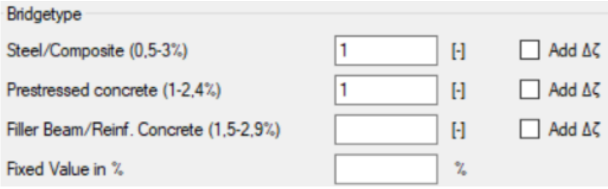
Calc	Fact. for upper limit	Fact. for lower limit	Calc.
1	1,2	0	☐
2	1	0	☐
3	0,5	0,5	☐
4	0	1	☑
5	0	0,8	☐

Damping (Bridgetype)

Steel/Composite (0,5-3%)	1	[-]	☑ Add Δζ
Prestressed concrete (1-2,4%)	1	[-]	☑ Add Δζ
Filler Beam/Reinf. Concrete (1,5-2,9%)		[-]	☐ Add Δζ
Fixed Value in %		%	

Figure 35: Menu to control bridge parameters of the parameter study using Time step calculation (TSC)

In the last step the three *damping functions* specified in EN 1991-2 can be included in the study (multiplied with a scaling factor) – with the option to respect the additional damping $\Delta\zeta$ (see 4.1.3). As a further option a fixed damping valued for spans can be included. Figure 36 shows the SW menu for the damping functions included in the investigation. To deactivate a damping function, the field for the scaling factor shall be empty or zero.



Bridgetype

Steel/Composite (0,5-3%)	1	[-]	☐ Add Δζ
Prestressed concrete (1-2,4%)	1	[-]	☐ Add Δζ
Filler Beam/Reinf. Concrete (1,5-2,9%)		[-]	☐ Add Δζ
Fixed Value in %		%	

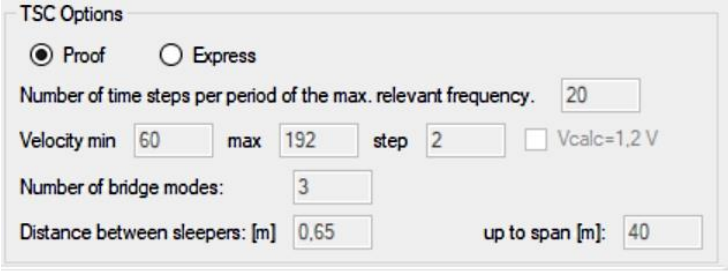
Figure 36: Menu for damping functions with scaling factors and a fixed damping value

5.9.1.3 Calculation parameters

Figure 37 shows the SW-menu for setting the calculation parameters.

The TSC calculation in its required full extent is quite time consuming. If the mode “proof” is chosen, such a calculation is performed for a defined set of bridge parameters. The “Express” mode allows a quick overview over the behaviour of the vehicle with reduced accuracy. Further it allows to study the influence of some parameters which cannot be modified in the proof mode.

Table 3 shows the fixed values used in the Proof Mode and default values proposed in the Express Mode.



TSC Options

● Proof ○ Express

Number of time steps per period of the max. relevant frequency. 20

Velocity min 60 max 192 step 2 ☐ Vcalc=1,2 V

Number of bridge modes: 3

Distance between sleepers: [m] 0,65 up to span [m]: 40

Figure 37: Menu "TSC Options" to control of time step width, speed range, speed increment and number of respected bridge modes

	Express	Proof
Number of time steps per period	*15*	**20**
Min. velocity	*96*	**60**
Max. velocity	*120% of the highest max. speed of the chosen combinations*	**120% of the highest max. speed of the chosen combinations**
Velocity increment	*5 km/h*	**2 km/h**
Vcalc = 1,2 (120 % speed margin internally handled)	*no*	**no**
Number of Bridge modes (see 4.2)	*1*	**3**
Distance between sleepers for load distribution (see 3.2)	*0,65 m*	**0,65 m**
Up to span (upper limit for application of load distribution)	*40 m*	**40 m**
Eigenfrequency functions	*Lines 2, 3, 4*	**Lines 1, 2, 3, 4**
Damping functions	*Line 1 (steel / composite) with "1" and $\Delta\delta$*	**Lines 1, 2, 3 with "1" and $\Delta\delta$**

Table 3: Calculation parameters in "Express" and "Proof" mode (*default values that can be modified* / **fix values**)

The use of the default values of the express mode leads to a significant acceleration of the calculation with uncertainties in the results:

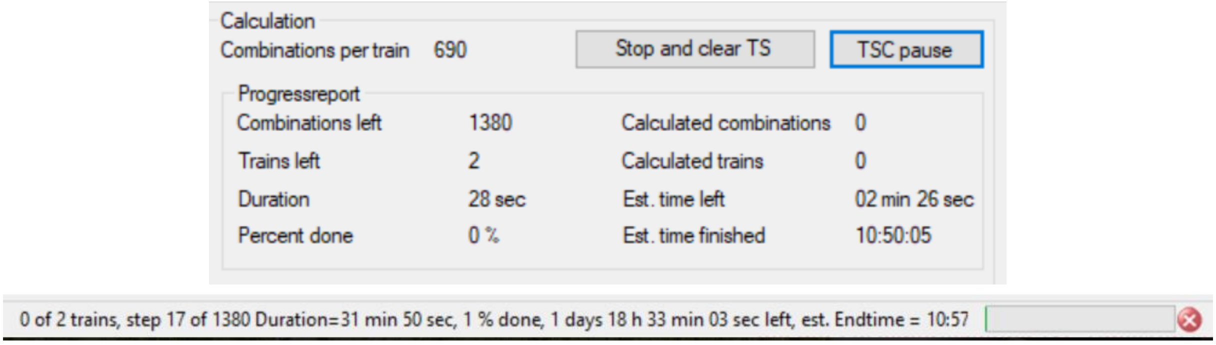
- With a low *number of time steps* per period of the highest relevant frequency (see 4.2) not all peaks are properly found,
- For compatibility checks with low line categories it is necessary to include *small velocities* in the investigation
- With a big *velocity step,* not all peaks are properly found
- The limitation of the investigated *bending modes* to the first order leads to an uncertainty up to 10 % compared to the 3rd order. The calculation is roughly 9 times quicker.
- The *distribution of the wheelset loads on three sleepers* is necessary for short bridges; for spans above 40 m there is no influence.

- Generally, the lowest *natural frequencies* lead to the most critical results. To describe the behaviour on different bridges also higher frequencies should be regarded. The function 5 of natural frequencies (80% of the lower function specified in EN 1991-2) is roughly covered by the velocity margin of 20 %.
- The *damping function* 1 (steel / composite) provides the lowest damping values for spans below 10 m while a combination of the functions 1 and 2 (steel / composite and prestressed concrete) cover all minimum damping values specified in EN 1991-2 (see 4.1.3)

The maximum velocity is set automatically to its default value of 120 % of the maximum of the admissible speeds V_{adm} of the trains (combinations) chosen for the parameter study. If a deviating speed range is wanted for the calculation, this needs to be entered after the final choice of the trains and before starting the calculation.

5.9.1.4 Performing the calculation

After setting of all parameters, the calculation is started by the button “TS calculate” in the field “calculation” on the “TSC” tab (see Figure 35). Once the calculation is started, a progress report is shown in the “calculation” field (see Figure 38). Further two buttons allow to pause the calculation or to stop the calculation and clear the storage. In case of a pause, the calculation can be resumed later, in case “stop and clear” a new calculation with other parameters can be started afterwards.



Combinations per train 690

Combinations left	1380	Calculated combinations	0
Trains left	2	Calculated trains	0
Duration	28 sec	Est. time left	02 min 26 sec
Percent done	0 %	Est. time finished	10:50:05

0 of 2 trains, step 17 of 1380 Duration=31 min 50 sec, 1 % done, 1 days 18 h 33 min 03 sec left, est. Endtime = 10:57

Figure 38: Calculation field on TSC tab after starting the calculation including the progress report, the buttons to pause and to stop the calculation and the status bar

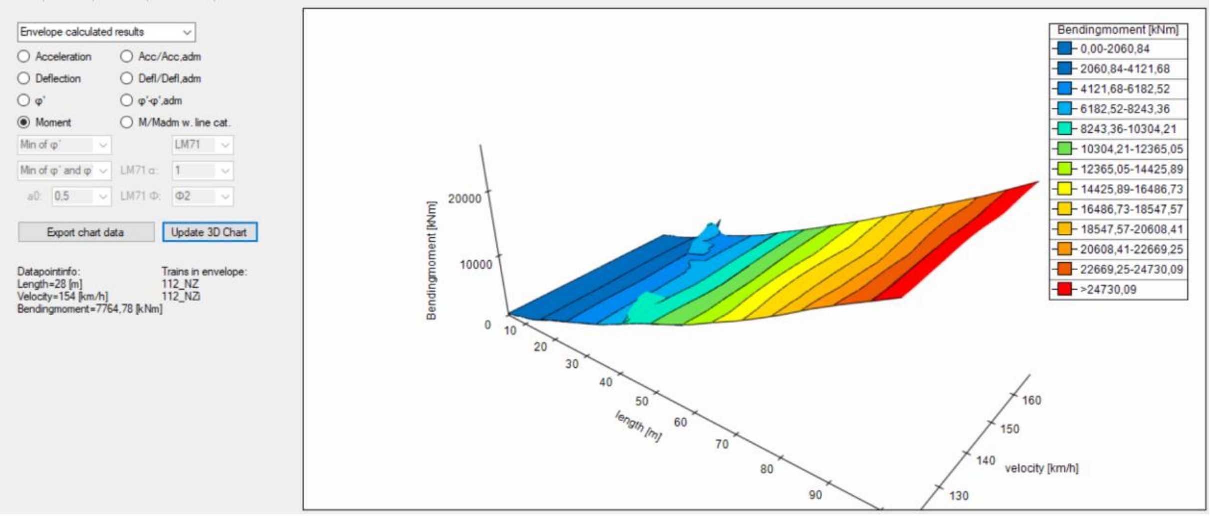
A bar at the lower left of the TSC tab show the status of the calculation. Here it is also indicated if the calculation is finished.

Note: On some computers after a while of calculation the progress cannot be displayed until the calculation is finished. In that case patience is necessary. In proof mode this can take several hours per chosen combination.

It is recommended to save the project including the TSC results as cmz-file (see 5.6) directly after finishing the calculation. This allows to re-open the results and to evaluate them later under several aspects. Different chart filter options and views of diagrams described in the following chapters are available using the same moments M_{TSC}, deflections w_{TSC} and accelerations a_{TSC} determined by the times step calculations of the parameter study.

5.9.1.5 3-D-presentation of results

The results of the TSC calculations are presented on the “TSC 3D” Tab to understand the behaviour. In these 3-D-Diagrams all relevant quantities (to be chosen in the menu on the left) are presented as envelope functions of span length and speed covering all calculated (or chosen) cases.



Envelope calculated results

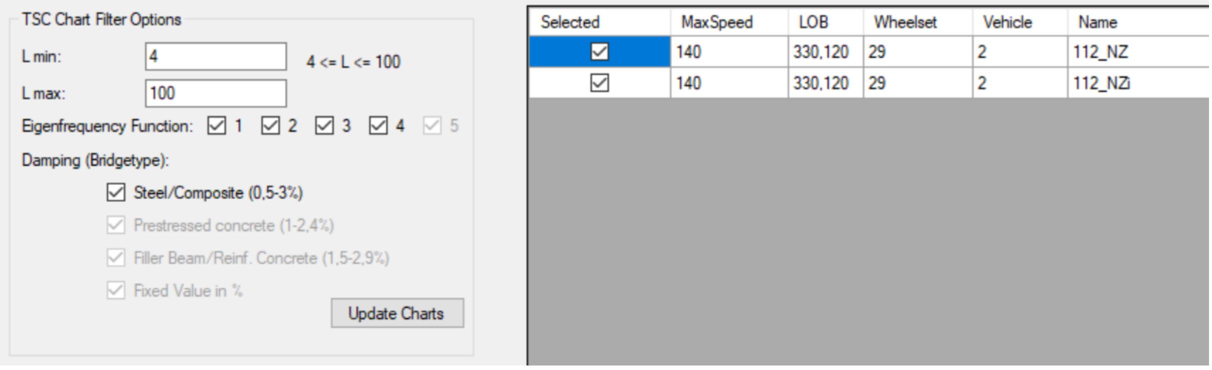
● Moment

Datapointinfo:
Length=28 [m]
Velocity=154 [km/h]
Bendingmoment=7764,78 [kNm]

Trains in envelope:
112_NZ
112_NZi

Figure 39: Example of 3-D-presentation of calculated bending moments

In a scroll down menu (see Figure 39, upper left) it can be decided, whether the envelope of all "*calculated results*" is shown or the envelope of a reduced set of "*selected*" calculation parameters. The definition of the reduced parameter set is controlled by the "TSC chartfilter" tab (see Figure 40). If some options on the "TSC chartfilter" tab were not calculated, they are deactivated without any choice. In that case the related fields are shown in "grey".



L min: 4
L max: 100
4 <= L <= 100
Eigenfrequency Function: ☑ 1 ☑ 2 ☑ 3 ☑ 4 ☑ 5
Damping (Bridgetype):
☑ Steel/Composite (0,5-3%)
☑ Prestressed concrete (1-2,4%)
☑ Filler Beam/Reinf. Concrete (1,5-2,9%)
☑ Fixed Value in %

Selected	MaxSpeed	LOB	Wheelset	Vehicle	Name
☑	140	330,120	29	2	112_NZ
☑	140	330,120	29	2	112_NZi

Figure 40: Chartfilter tab with menu to specify the "selected" results for graphic presentations

On the "TSC 3D" tab (see Figure 39) a diagram is drawn according to the settings of the menu field on the left side (and, if chosen, according to the Tab "TSC chartfilter") after pressing the button "update chart". The chosen combinations (trains) respected in the diagram are indicated at the lower end of the left side bar.

To modify the 3-D-view it possible to pick inside the diagram and rotate the diagram.

It is possible to indicate the coordinates of certain points of the curves in the diagram by clicking them with a mouse button. The result is shown in the lower part of the left side bar.

To use a diagram (including the indicated coordinates) inside other SW applications, it is possible to copy it to the clipboard by using a field activated by clicking the right mouse button in the diagram.

Note: The button "Export chart data" data writes all data shown on the chart into a csv-file with a name containing the shown quantity with the names of the vehicles used in the "Combination" tab

separated by "-", followed by the actual date and time "*_YYYY-MM-DD_hh-mm*"). The file is stored in the ROOT directory and contains in the first lines all information of the settings of the "TSC 3D" Tab and the "TSC chartfilter".
In case of the quantity M/M_{adm} a second file "Madm*_vehicle-list_YYYY-MM-DD_hh-mm.csv*" is written containing the admissible moments. For additional information the first line of the exported data (indicated by a velocity = 0) contain the envelope of the static moments $M_{stat,trn}$ (L) of the combinations shown in the diagram and the second line the static moment of the reference line category/load model $M_{stat,LC}$ (L) resp. $M_{stat,1,0\cdot LM71}$ (L).

The following choices of output quantities are available:

Acceleration
In the diagram the max. accelerations achieved by the time step calculation is increased by a term respecting the effects of track defects according to EN 1991-2:

$$a(L,v,n_0,\zeta) = a_{TSC}(L,v,n_0,\zeta)\cdot\left(1+a_0\cdot\frac{\varphi''(L,(v),n_0)}{1+\varphi'_{dyn}(L,v,n_0,\zeta)}\right)\quad \text{with } \varphi'\text{dyn} > 0 \tag{45}$$

Acc/Acc$_{.adm}$
In this diagram the above accelerations are divided by an admissible acceleration a_{adm} = 6 m/s² which is used as a preliminary reference. Because a fixed value of 10 t/m for the linear mass of all bridges was used for the time step calculation, the results must be interpreted with real data of linear masses.

Deflection
In the diagram the max. deflections achieved by the time step calculation is increased by a term respecting the effects of track defects according to EN 1991-2:

$$w = w_{TSC}(L,v,n_0,\zeta) + w_{stat,trn}\cdot a_0\varphi''(L,(v),n_0) \tag{46}$$

Defl/Defl$_{.adm}$
In this diagram the above deflections are divided by admissible deflections w_{adm} (see also 4.3.3)

φ'_{dyn}
In this diagram the dynamic amplification factor determined from the results of the time step integration and the static moment of the chosen combinations (trains) is presented.

$$\varphi'_{dyn}(L,v,n_0,\zeta) = \frac{M_{TSC}(L,v,n_0,\zeta)}{M_{stat,trn}(L)} - 1 \tag{47}$$

φ'_{dyn} - φ'_{1991}
In this diagram the excess of the dynamic amplification factor φ'_{1991} specified in EN 1991-2 (see Figure 13) by factors φ'_{dyn} determined for the investigated combinations is presented (see also 4.3.2).

Moment
In this diagram the max. bending moment achieved by the time step calculation is increased by a term respecting the effects of track defects (see also 4.3.1.1).

$$M(L,v,n_0,\zeta) = M_{TSC}(L,v,n_0,\zeta) + M_{stat,trn}(L)\cdot a_0\varphi''(L,(v),n_0) \tag{48}$$

M/M$_{adm}$

In this diagram the above Moments are divided by admissible Moments M$_{adm}$ depending on the line category LC / the load model LM71 (see also 4.3.1.2)

$$M/M_{adm}(L,v,n_0,\zeta,\boldsymbol{\alpha LM71}) = \frac{M_{TSC}(L,v,n_0,\zeta) + M_{stat,trn}(L)\cdot a_0\varphi''(L,(v),n_0)}{M_{stat,\alpha LM71}(L)\cdot\Phi(L)} \tag{49}$$

Note 1: In the non-published SW the following values can be chosen from the menu on the left to vary the capacity of bridges checked or designed for LM 71:

- Sleeper distance: d=0 or d=0,65 m with d=0 as default
- α: 0,75 – 1,46 with a default value 1,0
- Φ: Φ_2 or Φ_3 with Φ_2 as default

$$M/M_{adm}(L,v,n_0,\zeta,\boldsymbol{LC}) = \frac{M_{TSC}(L,v,n_0,\zeta) + M_{stat,trn}(L)\cdot a_0\varphi''(L,(v),n_0)}{M_{stat,LC}(L)\cdot[1+\varphi'(L,v^+,n_0)+a_0\cdot\varphi''(L,(v^+),n_0)]} \tag{50}$$

Note 2: In the non-published SW the following values can be chosen from the menu on the left to vary the capacity of bridges checked or designed for a line category:

- Sleeper distance: d=0 or d=0,65 m with d=0,65 as default
- α0: 0 – 1,0 with a default value 0,5
- φ'(n0) and φ''(n0): Minimal, nominal or maximum values in the field of eigenfrequencies according to EN 1991-2 with the minimum values as default, see Figure 8) This does not affect the term respecting track quality by φ''(n0) in the numerator, where always the nominal value of φ'' is used with a_0=0,5.

Note 3: The static moments of LM71 and the line categories ($M_{stat,\alpha LM71}(L)$ and $M_{stat,LC}(L)$) are maximum moments at mid span and were evaluated in very small calculation steps. The functions are therefore deviating from the ones used for line categorisation in EN 15528 where it is required to use maximum moments along the span evaluated in defined but larger calculation increments.

5.9.1.6 2-D-presentation of results

As explained in chapter 4.3.5 it is possible to create several 2-D-charts from the results on the tabs “Moment”, “Acceleration”, “Deflection”, and “φ'$_{,dyn}$”. While the 3-D-presentations contain only the envelope of all results, or of a subset of results chosen by the chart filter, the 2-D presentations contain curves for

- the envelope of all calculated results (“envelope calculated”, fat black curve),
- the envelope defined by the chart filter setting (“envelope selected”, fat red curve)
- the envelopes of the single combinations (trains) chosen in the chart filter (thin curves)
- the envelope of the combinations (trains) activated in the menu (“envelope displayed”, fat blue curve)

2D-diagrams can be created

- with a speed axis for certain spans or as an envelope over all spans,
- with a span axis
    - as an “intersection” at a certain speed
    - as an “envelope up to” a certain speed *v*
    - as an “envelope calculated, selected or displayed 100%” up to the speed, that gives a result just below the specified limit value for the investigated quantity. In that case the speed is indicated in the headline of the diagram

All diagrams can be exported by the button “copy to clipboard” located on the lower left of the tab and are also available when pressing the right mouse button inside the diagram.

Figure 41illustrates possible menu settings for useful views as 2-D-chart which are also used for the pdf-output-file.

○ Moment ● M/Madm Line Cat. D4DB X-Axis ○ Velocity ● Length Envelope 336 km/h Envelope up to v Update chart Export chart
Min of φ' and φ'' a0: 0.5 LM71 α: 1.00 LM71 Φ: Φ2

○ Moment ● M/Madm Line Cat. D4DB X-Axis ○ Velocity ● Length Envelope Envelope calculated 100% Envelope up to v Update chart Export chart
Min of φ' and φ'' a0: 0.5 LM71 α: 1.00 LM71 Φ: Φ2

○ Moment ● M/Madm Line Cat. D4DB X-Axis ○ Velocity ● Length Envelope Envelope selected 100% Envelope up to v Update chart Export chart
Min of φ' and φ'' a0: 0.5 LM71 α: 1.00 LM71 Φ: Φ2

○ Moment ● M/Madm Line Cat. D4DB X-Axis ● Velocity ○ Length Envelope Envelope selected 100% Envelope up to v Update chart Export chart
Min of φ' and φ'' a0: 0.5 LM71 α: 1.00 LM71 Φ: Φ2

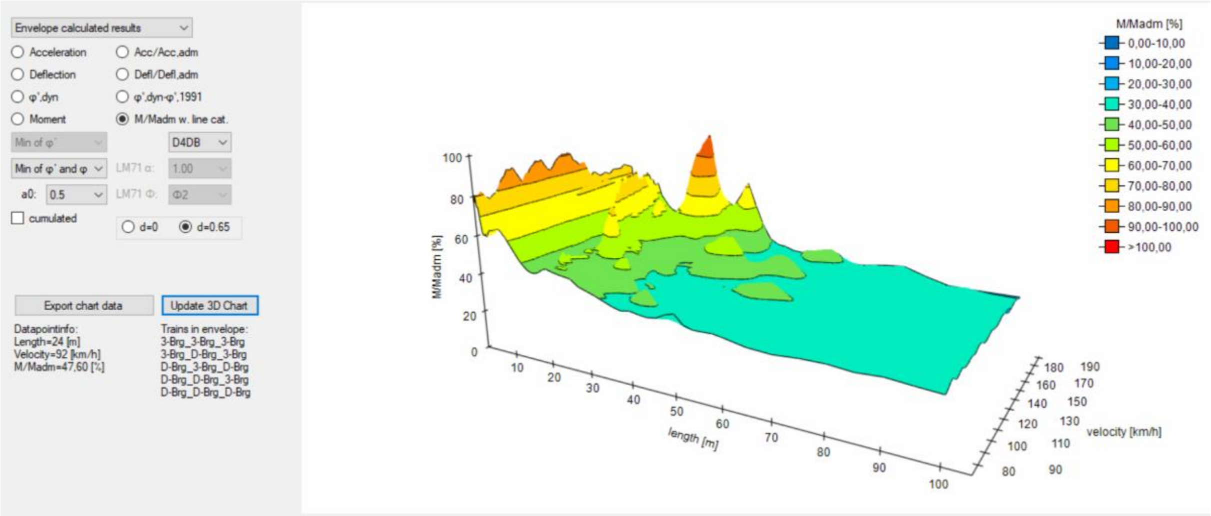
○ Moment ● M/Madm Line Cat. LM71 X-Axis ○ Velocity ● Length Envelope 336 km/h Envelope up to v Update chart Export chart
Min of φ' and φ'' a0: 0.5 LM71 α: 1.00 LM71 Φ: Φ2

○ Moment ● M/Madm Line Cat. LM71 X-Axis ○ Velocity ● Length Envelope Envelope calculated 100% Envelope up to v Update chart Export chart
Min of φ' and φ'' a0: 0.5 LM71 α: 1.00 LM71 Φ: Φ2

○ Moment ● M/Madm Line Cat. LM71 X-Axis ○ Velocity ● Length Envelope Envelope selected 100% Envelope up to v Update chart Export chart
Min of φ' and φ'' a0: 0.5 LM71 α: 1.00 LM71 Φ: Φ2

○ Moment ● M/Madm Line Cat. LM71 X-Axis ● Velocity ○ Length Envelope Envelope selected 100% Envelope up to v Update chart Export chart
Min of φ' and φ'' a0: 0.5 LM71 α: 1.00 LM71 Φ: Φ2

Figure 41: 2-D presentation: Examples of suggested menu settings for M/Madm with line category D4DB as reference and view options for “intersection”, “envelope up to v” and “envelope 100%”



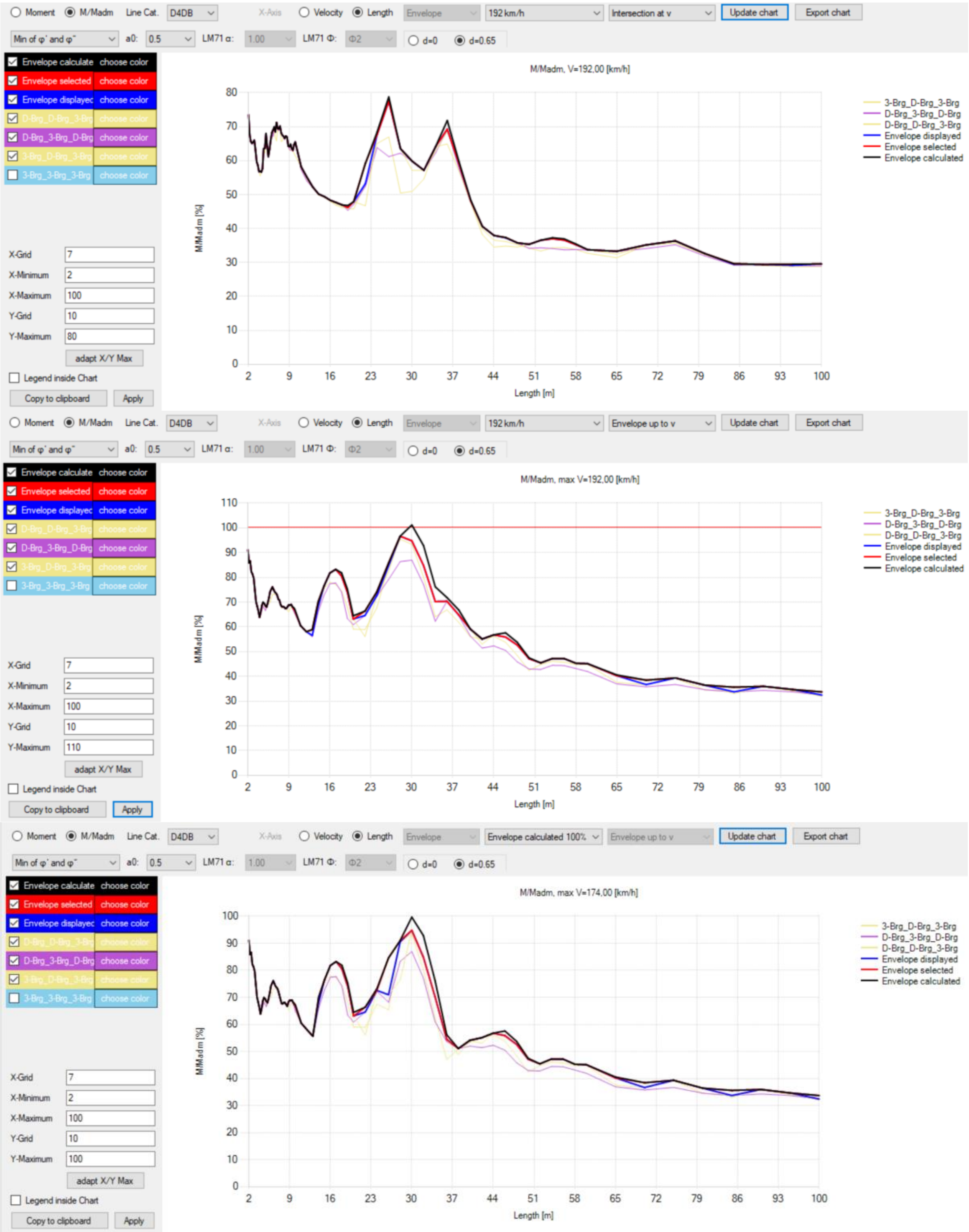
Envelope calculated results
○ Acceleration ○ Acc/Acc,adm
○ Deflection ○ Defl/Defl,adm
○ φ',dyn ○ φ',dyn-φ',1991
○ Moment ● M/Madm w. line cat.
Min of φ' D4DB
Min of φ' and φ LM71 α: 1.00
a0: 0.5 LM71 Φ: Φ2
☐ cumulated ○ d=0 ● d=0.65

Export chart data Update 3D Chart

Datapointinfo:
Length=24 [m]
Velocity=92 [km/h]
M/Madm=47,60 [%]

Trains in envelope:
3-Brg_3-Brg_3-Brg
3-Brg_D-Brg_3-Brg
D-Brg_3-Brg_D-Brg
D-Brg_D-Brg_3-Brg
D-Brg_D-Brg_D-Brg

Figure 42: 3D-chart of the results presented in Figure 43 as 2D-charts: *M/M*$_{adm}$ with line category D4DB



○ Moment ● M/Madm Line Cat. D4DB X-Axis ○ Velocity ● Length Envelope 192 km/h Intersection at v
Min of φ' and φ'' a0: 0.5 LM71 α: 1.00 LM71 Φ: Φ2 ○ d=0 ● d=0.65
☑ Envelope calculate
☑ Envelope selected
☑ Envelope displayec
☑ D-Brg_D-Brg_3-Brg
☑ D-Brg_3-Brg_D-Brg
☑ 3-Brg_D-Brg_3-Brg
☐ 3-Brg_3-Brg_3-Brg
X-Grid 7
X-Minimum 2
X-Maximum 100
Y-Grid 10
Y-Maximum 80
☐ Legend inside Chart

○ Moment ● M/Madm Line Cat. D4DB X-Axis ○ Velocity ● Length Envelope 192 km/h Envelope up to v
Min of φ' and φ'' a0: 0.5 LM71 α: 1.00 LM71 Φ: Φ2 ○ d=0 ● d=0.65
☑ Envelope calculate
☑ Envelope selected
☑ Envelope displayec
☑ D-Brg_D-Brg_3-Brg
☑ D-Brg_3-Brg_D-Brg
☑ 3-Brg_D-Brg_3-Brg
☐ 3-Brg_3-Brg_3-Brg
X-Grid 7
X-Minimum 2
X-Maximum 100
Y-Grid 10
Y-Maximum 110
☐ Legend inside Chart

○ Moment ● M/Madm Line Cat. D4DB X-Axis ○ Velocity ● Length Envelope Envelope calculated 100% Envelope up to v
Min of φ' and φ'' a0: 0.5 LM71 α: 1.00 LM71 Φ: Φ2 ○ d=0 ● d=0.65
☑ Envelope calculate
☑ Envelope selected
☑ Envelope displayec
☑ D-Brg_D-Brg_3-Brg
☑ D-Brg_3-Brg_D-Brg
☑ 3-Brg_D-Brg_3-Brg
☐ 3-Brg_3-Brg_3-Brg
X-Grid 7
X-Minimum 2
X-Maximum 100
Y-Grid 10
Y-Maximum 100
☐ Legend inside Chart

Figure 43: 2-D chart: Example for M/M$_{adm}$ over span with line category D4DB as reference and view options for “intersection”, “envelope up to v” and “envelope calculated 100%”

The 2D-charts in Figure 43 demonstrate the options for presentation of the results as function of the span. The examples are based on the 3D-chart of all calculated shown in Figure 42. In this diagram it is not easy to locate the small excess at a span of 30 m and a speed between 174 km/h and 176 km/h. The 2-D-diagramms allow to analyse the behaviour in detail.

In the first diagram an intersection at the max. investigated speed of 192 km/h is shown. The second diagram shows an envelope up to the max. investigated speed of 192 km/h indicating an excess of the limit value by the envelope of all calculated results (black line). In the third diagram the envelope up the last speed for which the limit value is not exceeded (174 km/h) by all calculated results (black line) is shown.

Figure 44 presents the same data as a function of speed and envelope over all spans. The excess of the limit value slightly above 174 km/h by the black line (all calculated results) is clearly visible.

In this example the black line (all "*calculated"* results) exceeds the reference Moment M_{adm} at a span of 30 m between 174 km/h and 176 km/h while the red line (results "*selected"* by the chart filter and indicated in the complete menu list on the left side of the tab) remains below the limit. In this example the longest calculated train combination was filtered out by the chart filter. The blue line indicates the "*displayed*" results without the combination "3Brg-3Brg-3Brg" which is deactivated in the left menu.

Note: The "*displayed*" results (blue line) are not available in the 3-D-view and the output pdf-file.

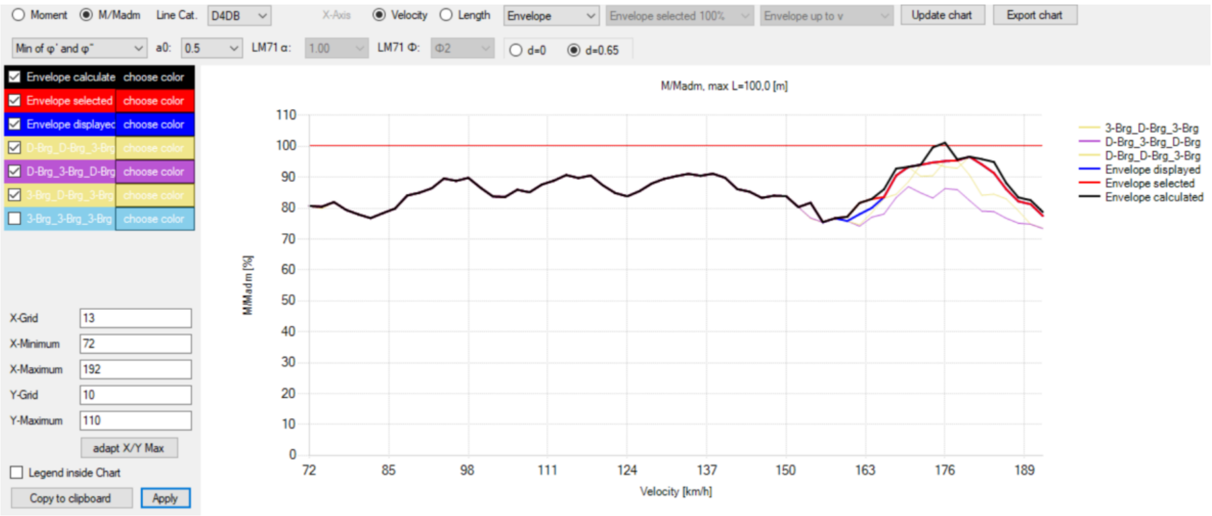

○ Moment ● M/Madm
Line Cat. D4DB
X-Axis ● Velocity ○ Length
Envelope
Envelope selected 100%
Envelope up to v
Min of φ' and φ"
a0: 0.5
LM71 α: 1.00
LM71 Φ: Φ2
○ d=0 ● d=0.65
☑ Envelope calculate
☑ Envelope selected
☑ Envelope displayed
☑ D-Brg_D-Brg_3-Brg
☑ D-Brg_3-Brg_D-Brg
☑ 3-Brg_D-Brg_3-Brg
☐ 3-Brg_3-Brg_3-Brg
X-Grid 13
X-Minimum 72
X-Maximum 192
Y-Grid 10
Y-Maximum 110
☐ Legend inside Chart

Figure 44: 2-D chart: Example for M/M_{adm} over speed with line category D4DB as reference and view option "envelope"

In each 2-D-chart it is possible to indicate the coordinates of certain points of the curves by clicking them with a mouse button. They can be removed by clicking them again.

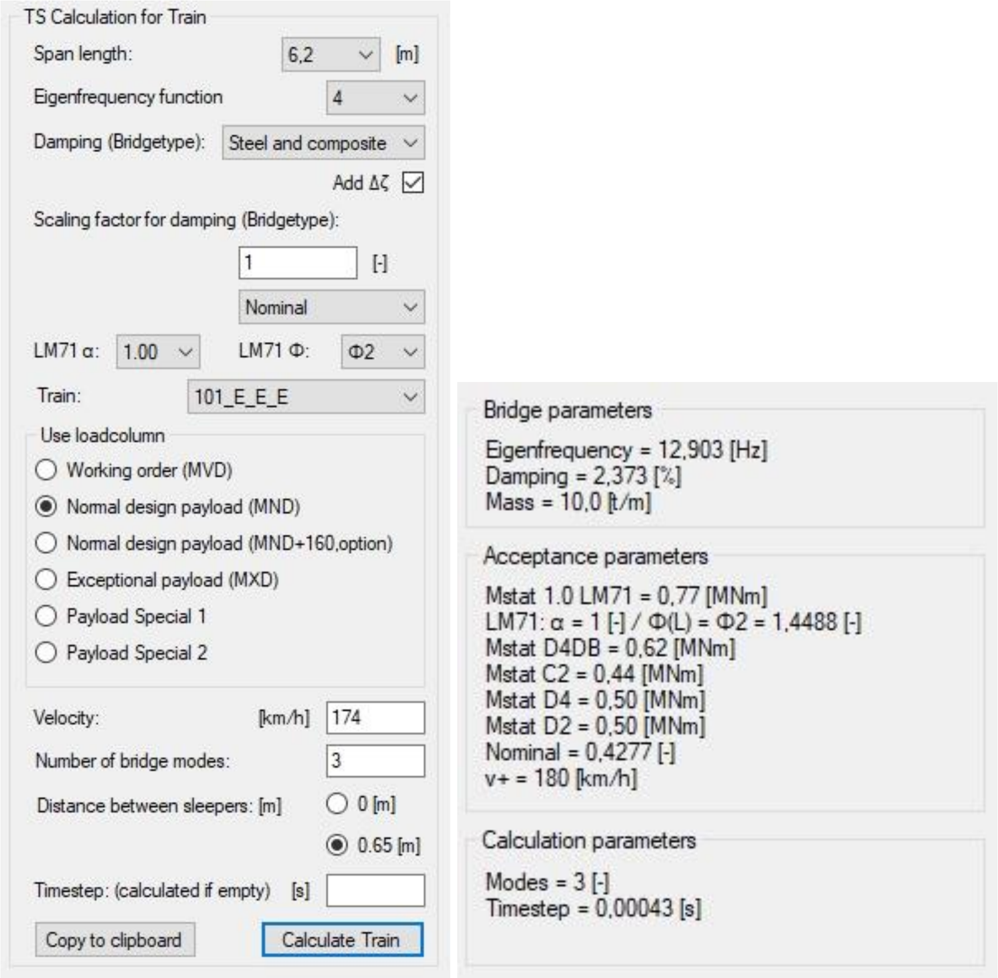
To use a diagram (including the indicated coordinates) inside other SW applications, it is possible to copy it to the clipboard by pressing the button "Copy to clipboard" on the lower left side or by using a field activated by clicking the right mouse button in the diagram.

5.9.2 Single TSC

The Tab "Single TSI" allows to investigate a single passage of a train passing a bridge with defined parameters. Such calculations are the basis for the parameter study described in 5.9.1.

In the example shown in Figure 45 the train 101_E_E_E (consisting of a locomotive "101" with three vehicles "E", loaded with normal design payload) passes a bridge with a span of 6,2 m and a natural frequency according to frequency function 4 (lower bound of frequency range according to EN 1991-2, in this case: 12,903 Hz). The damping stated for steel and composite bridges in EN 1991-2 is taken into account (in this case 2,373 %). The mass per length is set to 10 t/m. The chosen speed is 174 km/h.

The results in time domain $a_{\mathrm{TSC}}(t)$, $w_{\mathrm{TSC}}(t)$ and $M_{\mathrm{TSC}}(t)$ are shown in YYYYY (without any enhancement due to track quality by φ'').


TS Calculation for Train

Span length: 6,2 [m]
Eigenfrequency function 4
Damping (Bridgetype): Steel and composite
Add Δζ ☑
Scaling factor for damping (Bridgetype): 1 [-]
Nominal
LM71 α: 1.00 LM71 Φ: Φ2
Train: 101_E_E_E

Use loadcolumn
○ Working order (MVD)
● Normal design payload (MND)
○ Normal design payload (MND+160,option)
○ Exceptional payload (MXD)
○ Payload Special 1
○ Payload Special 2

Velocity: [km/h] 174
Number of bridge modes: 3
Distance between sleepers: [m] ○ 0 [m] ● 0.65 [m]
Timestep: (calculated if empty) [s]

Bridge parameters

Eigenfrequency = 12,903 [Hz]
Damping = 2,373 [%]
Mass = 10,0 [t/m]

Acceptance parameters

Mstat 1.0 LM71 = 0,77 [MNm]
LM71: α = 1 [-] / Φ(L) = Φ2 = 1,4488 [-]
Mstat D4DB = 0,62 [MNm]
Mstat C2 = 0,44 [MNm]
Mstat D4 = 0,50 [MNm]
Mstat D2 = 0,50 [MNm]
Nominal = 0,4277 [-]
v+ = 180 [km/h]

Calculation parameters

Modes = 3 [-]
Timestep = 0,00043 [s]

Figure 45: Single TSC Menu and parameter control table

For orientation some reference values are indicated:

For the *accelerations* the references 3,5 m/s² and 6 m/s² are indicated. Please note, that always a fixed value of 10 t/m for the mass per length is used and that therefore the results and the reference values can only be interpreted together with real data of linear masses.

As reference *Moments* the Load Model LM 71 and the Line categories D4DB, C2, D4 and D2 are available.

The reference moment M_{adm} of *LM 71* at mid span (see 4.3.1.2.3 and 5.9.1.5) can be scaled with the factors *α* and *Φ* (in the example $\alpha = 1{,}0$ and $\Phi = \Phi_2$) and is used without a load distribution on three sleepers.

$$M_{adm,sgl,LM71} = M_{stat,LM71}(L) \cdot \Phi(L) \tag{51}$$

Note 1: As the enhancement of M_{TSC} by $M_{stat,trn} \cdot a0 \cdot \varphi''$ is not included in the shown time history of M_{TSC}, the margin to LM 71 can be larger than in the parameter study.

The reference moments M_{adm} of the *Line Categories* at midspan (see 4.3.1.2.3 and 5.9.1.5) can be modified by variation of φ'.

$$M_{adm,sgl,LC} = M_{stat,LC}(L) \cdot [1 + \varphi'(L, v, n_0)] \tag{52}$$

To be consistent with the DB parameter study, "*Min of φ*" is the right choice – assuming that the bridge was checked with the quite low dynamic enhancement factor specified for a stiff bridge (according to the upper frequency function given in EN 1991-2). Further options are the use of the "*Nominal*" values specified in EN 1991-2 for each frequency of a bridge or the use of "*Max of φ*". The wheelset loads of the reference trains of the line categories are distribution on three sleepers with a sleeper distance *d* = 0,65 m.

Note 2: As the enhancement of M_{TSC} by $M_{stat,trn} \cdot a_0 \cdot \varphi''$ and the even higher enhancement of M_{adm} by $M_{stat,LC} \cdot$ a0 φ'' are not included in the diagrams, the margin to the line categories can be a little bit smaller than in the parameter study.

Figure 46 shows the time histories resulting from a single TSC calculation. These results are not included in the output pdf-file. The "copy to clipboard" button in the Single TSC Menu allows to export the results as graphical presentation.

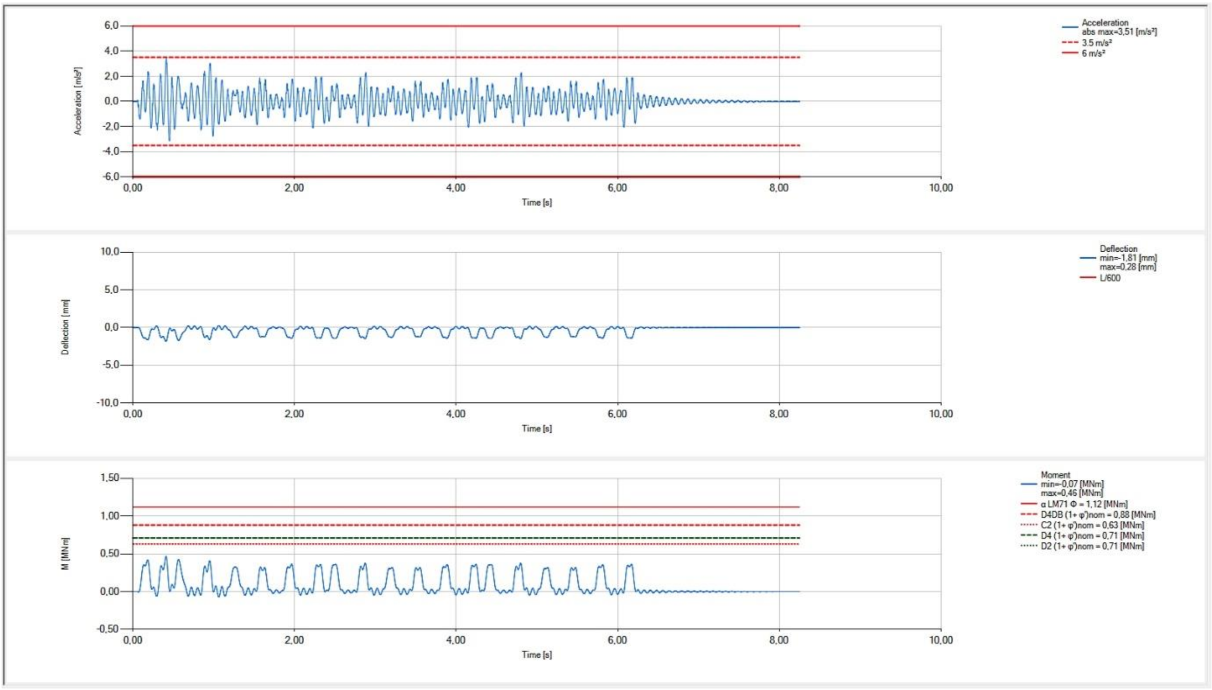
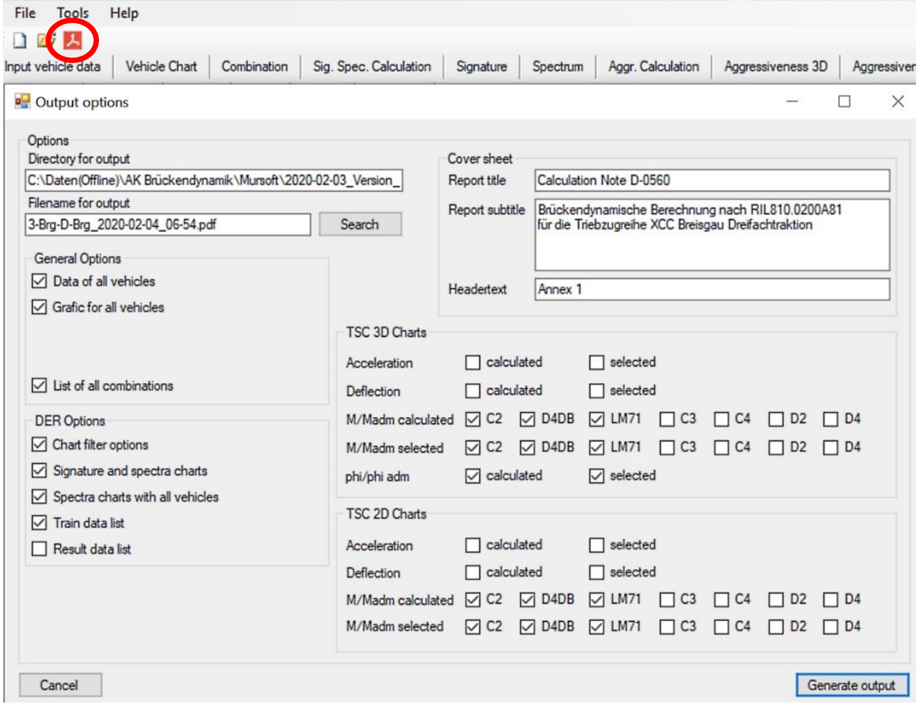


Figure 46: Single TSC result

5.10 PDF-Report

A pdf report and additional csv output files can be created automatically using the “Create PDF” button in the shortcut bar above the tabs. It is also available in the menu “File”.
Clicking on this button opens a control menu (Figure 47), which offers the following options:



Options

Directory for output: C:\Daten(Offline)\AK Brückendynamik\Mursoft\2020-02-03_Version_

Filename for output: 3-Brg-D-Brg_2020-02-04_06-54.pdf

Cover sheet

Report title: Calculation Note D-0560

Report subtitle: Brückendynamische Berechnung nach RIL810.0200A81
für die Triebzugreihe XCC Breisgau Dreifachtraktion

Headertext: Annex 1

General Options
- ☑ Data of all vehicles
- ☑ Grafic for all vehicles
- ☑ List of all combinations

DER Options
- ☑ Chart filter options
- ☑ Signature and spectra charts
- ☑ Spectra charts with all vehicles
- ☑ Train data list
- ☐ Result data list

TSC 3D Charts

Acceleration ☐ calculated ☐ selected
Deflection ☐ calculated ☐ selected
M/Madm calculated ☑ C2 ☑ D4DB ☑ LM71 ☐ C3 ☐ C4 ☐ D2 ☐ D4
M/Madm selected ☑ C2 ☑ D4DB ☑ LM71 ☐ C3 ☐ C4 ☐ D2 ☐ D4
phi/phi adm ☑ calculated ☑ selected

TSC 2D Charts

Acceleration ☐ calculated ☐ selected
Deflection ☐ calculated ☐ selected
M/Madm calculated ☑ C2 ☑ D4DB ☑ LM71 ☐ C3 ☐ C4 ☐ D2 ☐ D4
M/Madm selected ☑ C2 ☑ D4DB ☑ LM71 ☐ C3 ☐ C4 ☐ D2 ☐ D4

Figure 47: Menu to control the content of the output pdf-file

- Selection of a **directory** to save the report and the output files (the root directory or the directory which was used before during the recent session will be proposed);
- Entering a **filename** (a name will be proposed, containing the names of the vehicles used in the “Combination” tab separated by “-“ followed by the actual date and time “_YYYY-MM-DD_hh-mm”);
- Entering **information for title sheet** (Company, name, author and date are cosen automatically using information from the settings during SW-installation, see 5.2)
- Choosing the **extent of input data and results** to be documented **in the pdf-report**:
  - **Data of all vehicles** (always chosen):
    - Content of the “Input vehicle data” tab for each vehicle which was used for the combination
  - **Graphics for all vehicles**:
    - Content of the “Vehicle Chart” tab for all vehicles which were used for the combination,
  - List of all **combinations** (chosen by default):
    - Content of the “Combination” tab,
  - **Chart filter options** (chosen by default):
    - Setting for the diagrams of signature and spectra on the “Sig. Spec. Calculation” tab,
  - Resulting **signature and spectra charts** (chosen by default):
    - All signatures and envelopes which can be displayed on the “Signature” tab,
    - The envelopes of all calculated spectra according to the “Spectrum” tab,
    - The envelopes of all displayed and selected spectra according to the “Spectrum” tab,
  - Resulting **spectra** charts with **all vehicles**:
    - All calculated spectra and their envelopes, one diagram for each different damping value,

  - Resulting **3-D- and 2-D-charts of time step calculations** (TSC) including a table concluding the results (admissible speeds depending on line category and M/M_{adm} together with the utilisation at 120 % of maximum train speed)
    - distinguished for all **“calculated”** and/or **“selected”** cases based on the chart filter setting that is also documented. A possible manual choice “displayed” is not taken into account for the output pdf file.
    - The 2D-charts M/Madm are always produced as
      - envelopes over span of “calculated” and “selected” results up to the max. calculated v
      - envelopes over span over span of “calculated” and “selected” results up to 100 % for all calculated results
      - envelopes over span of “calculated” and “selected” results up to 100 % for the selected results (chart filter)
      - envelopes over speed of “calculated” and “selected” results

- Choosing the **extend of data** to be stored as **csv files**
  - Train data list:
    - List of absolute and relative axle distances and the respective wheelset loads for all calculated trains (content of the „Train data“ tab),
  - Result data list:
    - List of the signature and spectra data for all calculated trains (content of the “Result” tab).

In Figure 47 the default setting when using the menu the first time after starting the SW-tool is shown. During later calls of the menu, the last choice of output options is provided as default.

Pressing the “**Generate output” button** will write:
- the chosen content into a pdf file
  (filename as given above, amended by “.pdf”);
- the train data, if chosen, into a csv file
  (filename as given above, amended by “_TrainData.csv”);
- the result data list, if chosen, into a csv file
  (filename as given above, amended by “_Results.csv”);
- the train data of all combinations into two csv-files for the wheelset loads and coordinates in the DB-format (always produced)
  (filenames as given above, amended by “_DB_dist_*date_time*.csv” and “_DB_load_*date_time*.csv”)

Note: Before creating an output pdf-file from an opened cmz-file (see 5.6), it is necessary to repeat the Sig./Spec. and Aggr. Calculations because the results of DER calculations are not saved in the cmz-file.

For a traceable documentation of the performed calculations, it is necessary to use at minimum the default settings.

Note: The output file does not contain results of interactive settings (“displayed” results). If such results need to be documented, the clipboard functions and / or data export functions shall be used to create manually a separate document.

6 Bibliography

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7 Table of Annexes

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