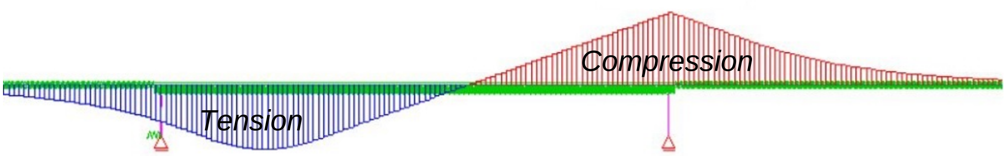
DEGREE PROJECT

Railway bridges with floating slab track systems

Numerical modelling of rail stresses

Dependence on properties of floating slab mats



Rail stresses from a temperature rise in a bridge deck

Daniel Kostet

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Luleå University of Technology
Department of Civil, Environmental and Natural Resources Engineering

The figure on the cover shows rail stresses caused by a temperature rise in the bridge deck model.

Preface

This Master of Science Project was initiated by WSP Bridges and Hydraulic Design in Luleå. It was carried out during the summer and fall of 2017. It was supervised by Mr. Lars Öström, M.Sc., Department Manager, and Dr. Anders Bennitz, bridge specialist.

Dr. Lennart Elfgren, Senior Professor in Structural Engineering at Luleå University of Technology, acted as Examiner.

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Daniel Kostet

Abstract

The increased use of continuously welded rails in the railway systems makes it necessary to increase the control of the rail stresses to avoid instability and damages of the rails. Large stresses are especially prone to appear at discontinuities in the railway systems, such as bridges, due to the interaction between the track and the bridge. The interaction leads to increased horizontal forces in the rails due to the changed stiffness between the embankment and the bridge, temperature variations, bending of the bridge structure because of vertical traffic loads and braking and traction forces. If the compressive rail stresses become too high it is necessary to use costly and maintenance-requiring devices such as rail expansion joints and other rail expansion devices. These devices increase the railway systems life cycle cost and should if possible be avoided.

The use of non-ballasted track on high-speed railways, tramways and subways, has increased since this kind of track requires less maintenance and according to some investigations have a lower life cycle cost compared to ballasted track. The non-ballasted track is usually made of a track slab to which the rails are connected through fastenings. The track slab is connected to the bridge structure and held in place by shear keys. When non-ballasted tracks are used in populated areas it is sometimes necessary to introduce some vibration and noise damping solution. One of the possible solutions is to introduce a floating slab mat (elastic mat) under the track slab on the bridge.

The influence of the floating slab mats properties on the rail stresses is investigated in this degree project. The investigation was performed through a numerical modelling of two railway bridges using the finite element software SOFiSTiK. The results from the investigation showed that there was a small reduction of the compressive rail stresses by approximately 3 – 7% (depending on the stiffness of the elastic support, load positions and the properties of the mat) when a mat was installed under the track slab. The results from the investigation also showed that there was a small reduction (up to approximately 1 %) of the compressive stresses in the rail when the thickness of the mat was increased, and the stiffness of the mat was reduced. This reduction of the compressive stresses is assumed to be caused by the mat being mounted on the sides of the shear keys. The lower stiffness of the mat allows the track slab and the bridge deck to move more freely parallel to each other in the horizontal direction. This leads to a decrease of the stresses in the rail due to a lower interaction between the track and the bridge. It was also shown that the rail stresses increased if the friction between the slab mat and the bridge deck was considered. This is because of an increase of the interaction between the track and the bridge due to the mats horizontal stiffness.

Keywords: *ballasted track, bridge, elastic mat, expansion, finite element method (FEM), finite element analysis (FEA), floating slab mat, interaction, International union of railways (UIC), non-ballasted track, SOFiSTiK*

Sammanfattning

Den ökade användningen av kontinuerligt svetsade räler i järnvägsnäten i världen leder till en ökad kontroll av rälsspänningarna för att undvika instabilitet och skador på rälsen. Särskilt vid en diskontinuit i järnvägssystemet, som vid broar, kan stora tillskottspänningar i rälsen uppstå till följd av interaktionen mellan spår och bro. Interaktion leder till ökade horisontella krafter som verkar på rälsen och beror på den förändrade styvheten mellan järnvägsbank och bro, temperaturvariationer, nedböjning av bron på grund av vertikala trafiklaster samt broms- och accelerationskrafter. Om spänningarna i rälsen blir för stora behöver kostsamma och underhållskrävande dilatationsfogar införas. Dessa dilatationsfogar ökar järnvägssystemets livscykelkostnad och är något som ska undvikas att införas i den mån det är möjligt.

Användningen av ballastfritt spår för höghastighetsjärnvägar, spårvägar och tunnelbanor ökar på grund av att dessa spår kräver mindre underhåll och har enligt vissa undersökningar en lägre livscykelkostnad i jämförelse med ballasterat spår. Ballastfritt spår består oftast av en betongplatta till vilken rälsen är kopplad genom befästningar. Plattan är i sin tur kopplad till underbyggnaden genom skjuvförbindare som håller plattan på plats. När ballastfritt spår används i bebodda områden är det ibland nödvändigt att ta till vibrations- och ljuddämpande åtgärder. En åtgärd som används på brokonstruktioner för att minska vibrationer och ljudföroreningar är att montera en vibrationsdämpande matta, som är tillverkad av ett elastiskt material, mellan betongplattan och broöverbyggnaden.

I detta examensarbetet undersöks hur den vibrationsdämpande mattans egenskaper påverkar rälsspänningarna. Resultaten från undersökningen visar att spänningarna i rälsen minskar med cirka 3–7 % (beroende på det elastiska stödets styvhet, lastpositioner och mattans egenskaper) när en elastisk matta installeras under spårplattan i jämförelse med när ingen matta används. När mattans tjocklek ökar och när styvheten sänks minskar spänningarna med cirka 1 % i jämförelse mellan den tjockaste och tunnaste mattan. Denna minskning av spänningarna antas bero på att den vibrationsdämpande mattan som är monterad på sidan av skjuvförbindarna ger en möjlighet för spåret och bron att förskjutas fritt parallellt varandra innan en interaktion mellan spår och bro uppstår. Det visade sig även att om friktionen mellan mattan och broöverbyggnaden medräknas ökar spänningarna i rälsen. Detta beror på att mattan då skapar en större interaktion mellan spåret och bron gentemot fallet då mattans horisontella styvhet inte beaktas.

Nyckelord: *ballasterat spår, ballastfritt spår, bro, dilatationsfogar, finita elementmetoden (FEM), finit elementanalys (FEA), fixerat spår, interaktion, Internationella järnvägsunionen (UIC), SOFiSTiK, vibrationsdämpande matta*

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Nomenclature

Latin uppercase letters

A	Area	[m^2]
A_{60}	Total area for the track, two UIC60 rail cross sections	[m^2]
A_{cs}	Cross section area	[m^2]
E	Young's modulus / modulus of elasticity	[MPa]
$F_{braking}$	Horizontal braking force	[kN/m]
F_l	Longitudinal / horizontal support reaction	[kN]
$F_{support}$	Longitudinal / horizontal support reaction	[kN]
$F_{vertical}$	Vertical train load	[kN/m]
H	Height	[m]
I	Moment of inertia	[m^4]
$I_{y,slab}$	Moment of inertia for the track slab	[m^4]
$I_{y,rail}$	Total moment of inertia for the rails, two UIC60 rail cross sections	[m^4]
L_{span}	Span length	[m]
L_{train}	Train length	[m]
N_{rail}	Normal forces acting in the longitudinal direction of the rails	[kN]

Latin lowercase letters

b_{mat}	Breadth of the floating slab mat	[m]
b_{shear}	Breadth of the shear keys	[m]
b_{slab}	Breadth of the track slab	[m]
d_{node}	Distance between each node	[m]
d_{spring}	Distance between each spring	[m]
h	Height	[m]
h_{shear}	Height of the shear keys	[m]
h_{slab}	Height of the track slab	[m]
$k_{bm,mat,h}$	The mats horizontal stiffness / static horizontal bedding modulus	[kN/m^3]
$k_{bm,mat,v}$	The mats vertical stiffness / static vertical bedding modulus	[kN/m^3]
$k_{elastic,loaded}$	Elastic displacement resistance for the loaded track	[kN/m^2]
$k_{elastic,unloaded}$	Elastic displacement resistance for the unloaded track	[kN/m^2]
k_{long}	Longitudinal / horizontal support stiffness	[kN/m]
$k_{plastic}$	Plastic displacement resistance	[kN/m]

$k_{plastic,loaded}$	Plastic displacement resistance for the loaded track	[kN/m]
$k_{plastic,unloaded}$	Plastic displacement resistance for the unloaded track	[kN/m]
t_{mat}	Thickness of the floating slab mat	[m]
u_0	Displacement between the elastic and plastic zones	[mm]
x_{cg}	Center of gravity from the bottom of the bridge cross section	[m]
$x_{cg,deck}$	Center of gravity of the deck from the bottom of the bridge cross section	[m]
$x_{cg,slab}$	Center of gravity of the track slab from the bottom of the bridge cross section	[m]
z	Train position	[m]

Greek uppercase letters

ΔT_{deck}	Temperature variation of the deck	[°C]
ΔT_{rail}	Temperature variation of the rails	[°C]

Greek lowercase letters

α	Thermal expansion coefficient	[1/K]
α_{deck}	Thermal expansion coefficient for the deck	[1/K]
α_{rail}	Thermal expansion coefficient for the rails	[1/K]
δ_{deck}	Absolute displacement of the top of the deck	[mm]
δ_h	Displacement of the foundation	[m]
δ_p	Bending of the pier caused by elastic deformation	[m]
δ_φ	Rotation of the foundation	[m]
ν_{mat}	Poisson's ratio of the mat material	[-]
σ_{rail}	Rail stress	[MPa]

Abbreviations

CDB	Central data base
CWR	Continuously welded rails
FE	Finite element
FEA	Finite element analysis
UIC	International Union of Railways - Union Internationale des Chemins de fer

1 Introduction

This chapter presents the background, aim and scope, methodology and the limitations of this degree project.

1.1 Background

Non-ballasted tracks (slab tracks) are being more common to use due to that it has a lower maintenance cost compared to ballasted tracks. Also, some investigations indicate that non-ballasted track have a lower life cycle cost compared to ballasted tracks. When non-ballasted tracks are used in populated areas it is sometimes necessary to introduce some vibration and noise damping solution. One of the possible solutions is to introduce an elastic mat (also called floating slab mat) under the track slab, (PORR Group, 2017; Esveld, 2001; Xin & Gao, 2011; PANDROL, 2017; edilon sedra, 2017a).

Bridges acts like a discontinuity in the railway system due to a change of stiffness properties compared to the adjacent embankment track. The bending of the bridge structure, the temperature variation and the braking and traction forces also influence the rail stresses. These track – bridge interaction effects cannot be neglected for continuously welded rails (CWR) due to the risk of high compressive rail stresses that may lead to track instability. If the compressive rail stresses are too high it is necessary to use costly and maintenance-requiring rail expansion devices such as expansion joints, see section 2.2.1 for an explanation of how these devices work. It is therefore of interest to try to decrease the compressive rail stresses to be able to avoid the use of these devices and therefore reduce the total life cycle cost of the railway system, (Ruge & Birk, 2006; Esveld, 2001; Kumar & Upadhyay, 2012; Strauss, et al., 2015).

1.2 Aim and scope

The goal with the master project is to develop a finite element model of a simple span railway bridge which fulfills the requirements stated by UIC Code 774-3R (2001). The model should be used to simulate the track - bridge interaction for a railway bridge with non-ballasted track to be able to answer the following research questions:

- How does the use of an elastic mat influence the compressive rail stresses? The mat is placed under a slab track and may have different thicknesses and stiffnesses.
- How does the horizontal shear stiffness of the elastic mat influence the compressive rail stresses?

1.3 Methodology

First a literature study was performed to learn how to use the finite element analysis (FEA) software SOFiSTiK. At the same time, the theory was studied for track and bridge interaction and how to model this phenomena in a FEA-software.

Thereafter a validation was performed of the software and of the choice of a FE-model for ballasted tracks which meets the requirements set by UIC Code 774-3R (2001). The chosen model was then modified to fit non-ballasted tracks (slab tracks) with and without a mat under the track slab. The results from the model with and without a floating slab mat was then compared to see how different mat properties influence the compressive rail stresses.

1.4 Limitations

The following limitations have been chosen:

- Only single span bridges with a single noncurved track are considered in this degree project.
- Different load cases according to SS-EN 1991-2 (2010) are not considered in this project. Standardized test cases with already defined loads from UIC Code 774-3R (2001) are used.

2 Literature review

The performed literature review is presented in this chapter.

2.1 Track and bridge interaction – theory and requirements

2.1.1 Introduction

The interaction between the bridge and the track occurs because of the connection between them, this means that the behavior of the track influences the bridge behavior and vice versa. These interaction effect leads to displacement of the track and the bridge, forces in the rails, the bearings of the bridge and in the deck. Interaction occurs regardless if ballasted or non-ballasted tracks are used. (UIC Code 774-3R, 2001; SS-EN 1991-2, 2010; Esveld, 2001; Ruge & Birk, 2006; Strauss, et al., 2015).

The bridge and the track will continue to fulfil their functions if these interaction effects are under control. If these effects are not checked properly, the track may be damaged. Examples of damages which may occur are rail fractures and disruption of the fastening between the bridge and the track which may lead to instability of the track. Large longitudinal compression forces on the rail may lead to rail buckling, whereas longitudinal tensile forces may lead to rail failure, (UIC Code 774-3R, 2001; Esveld, 2001).

The interaction between the track and the bridge should be checked in the ultimate limit state for the rail and for the strength of the substructure and bearings. The bridge displacement should be checked in the serviceability limit state during the design process, (UIC Code 774-3R, 2001; SS-EN 1991-2, 2010).

The general theory of the use of continuous welded rails on embankments is summarized in section 2.1.2. The theory behind the track and bridge interaction phenomena is explained in section 2.1.3 - 2.1.7.

2.1.2 Continuous welded rails (CWR) on embankments

When continuous welded rails (CWR) are used on embankments the rails are often fixed to the sleepers by elastic fastenings. The elastic fastenings secure the rails to the sleepers through a predefined clamping force which transmits the longitudinal movements of the rails to the sleepers. Longitudinal forces act on the rails when the ballast prevents the free movements of the rails when the rails are exposed to traffic and thermal forces (UIC Code 774-3R, 2001).

According to UIC Code 774-3R (2001) the contraction and the expansion of the CWR are prevented in a zone called the “central zone”. In each end of the CWR two expansion zones are located. The thermal effects for the rail can be seen in Figure 2.1, (UIC Code 774-3R, 2001).

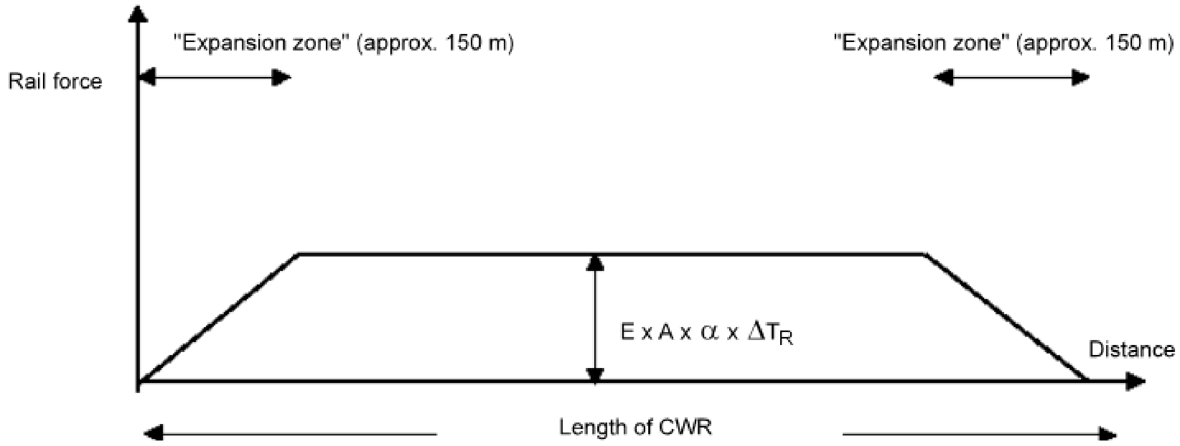


Figure 2.1 Forces in a continuous welded rail (CWR) for a temperature change of ΔT_R , (UIC Code 774-3R, 2001).

The parameters in Figure 2.1 are:

$\alpha = \alpha_{rail}$ is the coefficient of thermal expansion for the rails [1/K]

$\Delta T_R = \Delta T_{rail}$ is the temperature variation of the rails [°C]

E is the Young's modulus for steel [Pa]

A is the combined cross-section of two rail cross sections [m^2]

F is the normal force in the rails [kN]

2.1.3 Continuous welded rails (CWR) on bridges

When a CWR track is resting on a bridge, displacements of the track are induced. These displacements occur because of the movements and deformations of the bridge. Any displacement or force that acts on either the track or the bridge will develop forces in the other one. In other words, the track (rails, fastenings, sleepers, ballast, slab etc.) and the bridge will jointly resist the longitudinal forces from traction (force created by the pulling or pushing capability of the locomotive) and braking if the rails are continuous over discontinuities in the support of the track (e.g. between an embankment and the bridge structure). The longitudinal forces will be partly transmitted by the bearings and the substructure to the foundations and partly to the embankment behind the abutment by the rails, (SS-EN 1991-2, 2010; UIC Code 774-3R, 2001).

Longitudinal forces are generated in the fixed bridge bearings and in the rails in the cases where the CWR prevents the movement of the bridge deck produced by the braking forces, vertical loading, thermal variation of the bridge deck, creep and shrinkage, (SS-EN 1991-2, 2010).

Figure 2.2 shows an example of a rail stress curve due to temperature variation of the bridge deck. Compressive rail stresses will occur at the movable support because it is in this direction the bridge deck will expand during the increase of temperature. The fixed support prevents the expansion of the deck in that direction.

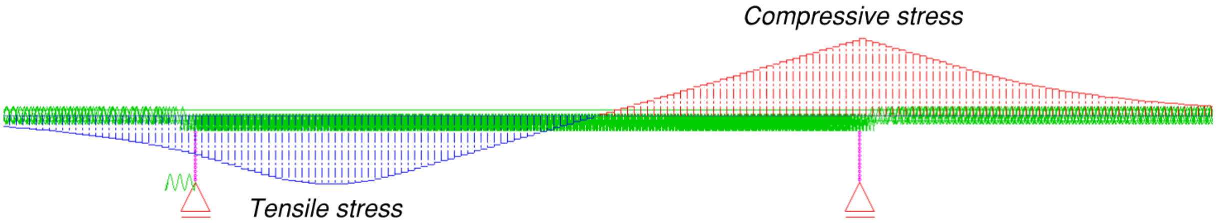


Figure 2.2 Rail stresses due to an increase of the temperature in the bridge deck. Tensile stress at the fixed support and compressive stress at the movable support.

2.1.4 Parameters that affect the interaction between the track and the bridge

Different track and bridge parameters influence the track and bridge interaction phenomenon. SS-EN 1991-2 (2010) and UIC Code 774-3R (2001) prescribes that the track and bridge parameters in section 2.1.4.1 and section 2.1.4.2 shall be considered in a complete analysis of the interaction effects.

In section 2.1.5 and section 2.1.6 is the most important parameters from section 2.1.4.1 and section 2.1.4.2 for the study performed in this degree project described together with an explanation of how they influences the behavior of the track and the bridge.

2.1.4.1 Track parameters

Parameters from the arrangement of the track which must be considered in a complete interaction analysis:

- Location of rail expansion devices.
- Non-ballasted or ballasted track systems.
- Vertical distance between the neutral axis of the rails and the top of the deck.

Properties of the track which must be considered in a complete interaction analysis:

- The tracks resistance per unit length to longitudinal displacement as a function of the relative displacement between the rails and the deck, see section 2.1.5.
- The axial stiffness of the rail.
- The thermal expansion coefficient for the rail.

2.1.4.2 Bridge parameters

Parameters from the arrangement of the bridge structure which must be considered in a complete interaction analysis:

- Expansion length L_T between the end of the deck and the thermal fixed point, see Figure 2.7.
- The location of the thermal fixed point (fixed bearing(s)).
- Length of each deck and the number of separate decks.
- Continuous beams, simply supported beams, or a sequence of beams.

Properties of the bridge structure which must be considered in a complete interaction analysis:

- The total longitudinal stiffness, which means that the longitudinal stiffnesses of the foundations, substructure and bearings are summarized into a total stiffness, see the explanation in section 2.1.6.
- The decks vertical stiffness.
- Longitudinal displacement of the end of the deck because of angular rotation generated from the structural configuration at the bearings.
- The vertical distance from the top of the deck and the neutral axis of the deck.
- The vertical distance from the top of the deck and the axis of rotation of the bearing.
- The thermal expansion coefficient for the bridge deck.

2.1.5 Behavior of the track

2.1.5.1 Track behavior

The most important track parameters from section 2.1.4.1 are described in this section together with an explanation of how they influence the behavior of the track.

The behavior of the track depends on the type of track used (ballasted or non-ballasted track). The force and displacement relationship for each type of track depends on the tracks maintenance level, the structure of the track, how often the track is exposed to loads, the vertical load applied and if the track has any defects, (UIC Code 774-3R, 2001).

The general behavior of the tracks resistance against longitudinal displacement relative to its supporting structure expressed as a function can be seen in Figure 2.3 and Figure 2.4. From Figure 2.3 it is possible to see that the resistance increases fast when the displacement is low, but, at a certain degree of displacement the resistance will reach a plateau and remain constant, (UIC Code 774-3R, 2001).

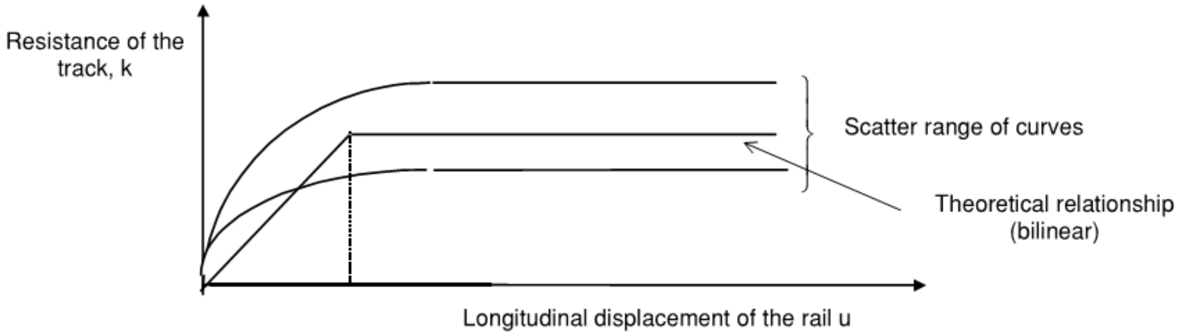
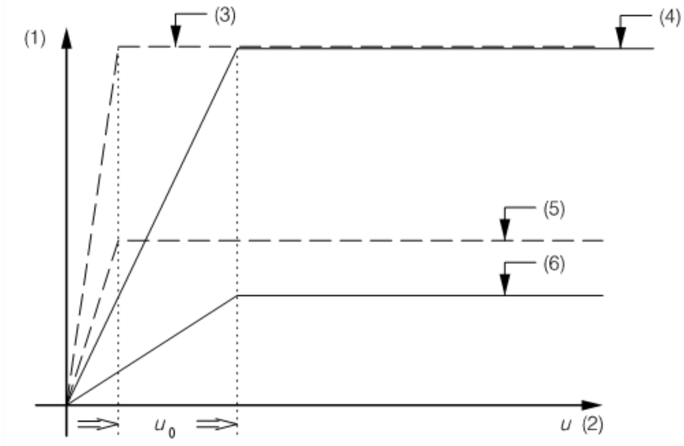


Figure 2.3 Example curve that shows the resistance to longitudinal displacement of the track as a function of the longitudinal displacement, (UIC Code 774-3R, 2001).



Key
(1) Longitudinal shear force in the track per unit length
(2) Displacement of the rail relative to the top of the supporting deck
(3) Resistance of the rail in sleeper (loaded track)
(frozen ballast or track without ballast with conventional fastenings)
(4) Resistance of sleeper in ballast (loaded track)
(5) Resistance of the rail in sleeper (unloaded track)
(frozen ballast or track without ballast with conventional fastenings)
(6) Resistance of sleeper in ballast (unloaded track)

Figure 2.4 Simplified bilinear functions for the resistance to longitudinal displacement of the track, (SS-EN 1991-2, 2010).

A bilinear theoretical relationship between the resistance to longitudinal displacement of the track as a function of the longitudinal displacement is introduced to be able to simplify the calculations, see Figure 2.3 and Figure 2.4. Different relationships between the resistance and the displacement are used for different kind of track properties (i.e. loaded or unloaded track, ballasted or non-ballasted track, frozen or unfrozen ballast), see Figure 2.4, (UIC Code 774-3R, 2001; SS-EN 1991-2, 2010).

In the bilinear model the first part of the bilinear curve is called the elastic zone. The resistance increases until it reaches the displacement $u_0 = v_{pl}$, the part of the curve after that point is called the plastic zone. When the track is modelled as nonlinear springs in a finite element software the bilinear relationship between the resistance and the longitudinal displacement will be used as the stiffness of the springs. The nonlinear spring behavior can be seen in Figure 2.5 and can be described as: If the displacement is larger than u_0 the spring will be unloaded as an elastic spring in that point of the curve. The displacement in that point will be used as the new initial value for the displacement in the future loadings of the spring, (Esveld, 2001).

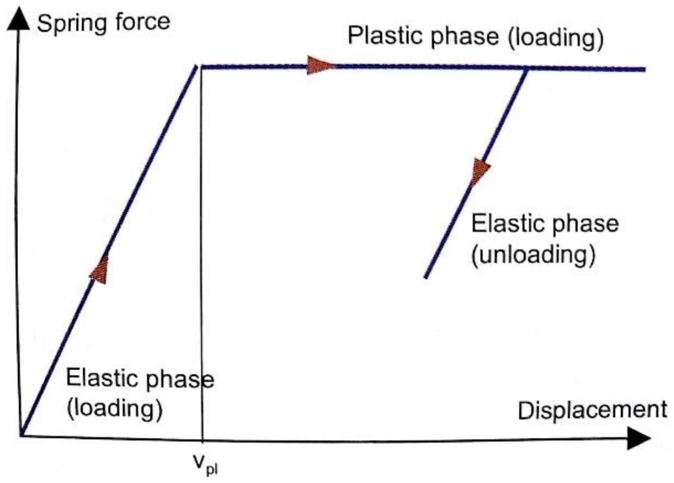


Figure 2.5 The bilinear behavior of a nonlinear spring, (Esveld, 2001).

2.1.5.1.1 Ballasted track behavior

According to UIC Code 774-3R (2001) the resistance against longitudinal displacement for a ballasted track is dependent on the following parameters:

- The ability of the rail fastenings to counteract the rails displacement relative to the sleeper, which is dependent on the clamping action efficiency.
- The friction between the ballast and the deck and the ballast abilities to counteract displacements of the rail and sleeper relative to the deck.

UIC Code 774-3R (2001) recommends the values for u_0 and $k_{plastic}$ in Table 2.1 to be used in the interaction analysis for a ballasted track.

Table 2.1 u_0 and $k_{plastic}$ for a ballasted track, (UIC Code 774-3R, 2001).

u_0 and $k_{plastic}$ for a ballasted track	**Value**	**Unit**
Resistance of sleeper in ballast (unloaded track), moderate maintenance, $k_{plastic}$	12	kN/m
Resistance of sleeper in ballast (unloaded track), good maintenance, $k_{plastic}$	20	kN/m
Resistance of loaded track or track with frozen ballast, $k_{plastic}$	60	kN/m
u_0 for the resistance of the rail to sliding relative to the sleeper	0,5	mm
u_0 for the resistance of the sleeper in the ballast	2	mm

2.1.5.1.2 Non-ballasted track behavior

According to UIC Code 774-3R (2001) the same bilinear function described above can be used for non-ballasted tracks, i.e. when the rail is fastened directly to the bridge deck or to a track slab with rail fastenings.

UIC Code 774-3R (2001) recommends the values for u_0 and $k_{plastic}$ in Table 2.2 to be used in the interaction analysis for a non-ballasted track.

Table 2.2 u_0 and $k_{plastic}$ for a non-ballasted track, (UIC Code 774-3R, 2001).

u_0 and $k_{plastic}$ for a non-ballasted track	**Value**	**Unit**
Resistance for unloaded track, $k_{plastic}$	40	kN/m
Resistance for loaded track, $k_{plastic}$	60	kN/m
Displacement u_0 in the beginning of the plastic zone	0,5	mm

2.1.6 Behavior of the bridge

This section describes the most important bridge parameters from section 2.1.4.2 for the study performed in this degree project together with an explanation of how they influence the behavior of the bridge.

According to UIC Code 774-3R (2001) the following features should be considered in the track and bridge interaction analysis:

- The bridges static arrangement.
- The bearings behavior.
- The supports behavior and the total support stiffness.
- The decks bending behavior.

Each of these features are described in section 2.1.6.1 – 2.1.6.3.

2.1.6.1 The static arrangement of the bridges

The following parameters are according to UIC Code 774-3R (2001) the most important parts of the static arrangement of the bridge:

- Length(s) of the span(s).
- The expansion length(s), L_T, see Figure 2.7.
- The location(s) of rail expansion devices if there are any.
- The movable and fixed supports locations.
- The number of decks.
- The number of supports per deck (including any shared supports).

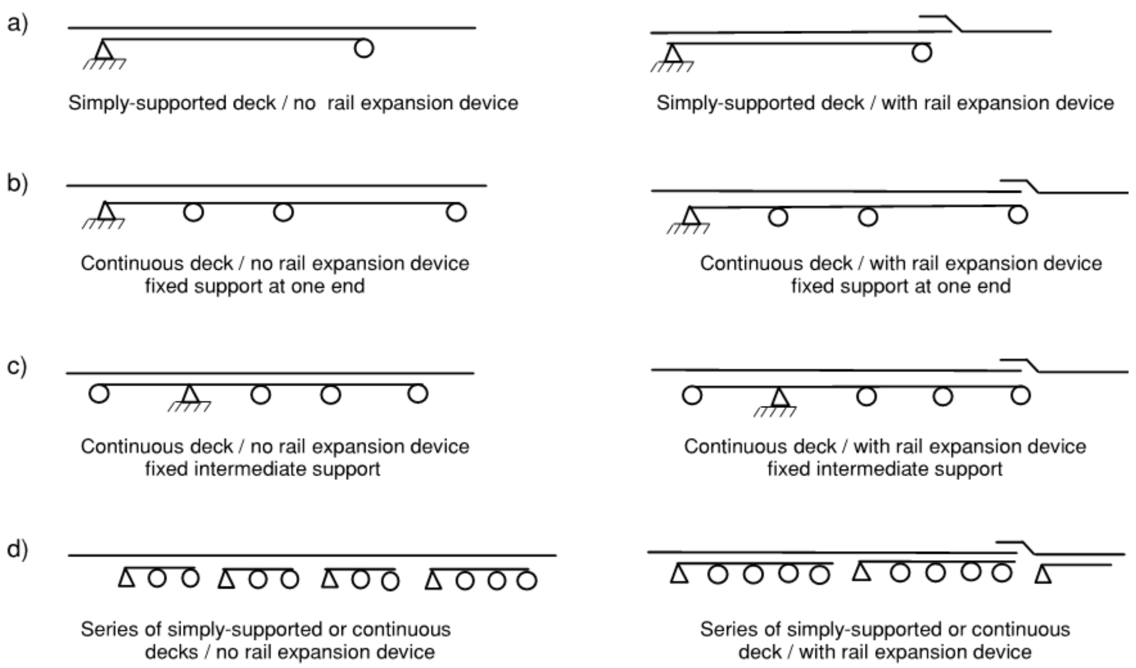


Figure 2.6 The most common static arrangements, (UIC Code 774-3R, 2001).

Some of the most common static arrangements mentioned before are shown in Figure 2.6. In this degree project the arrangement a) in Figure 2.6 is considered.

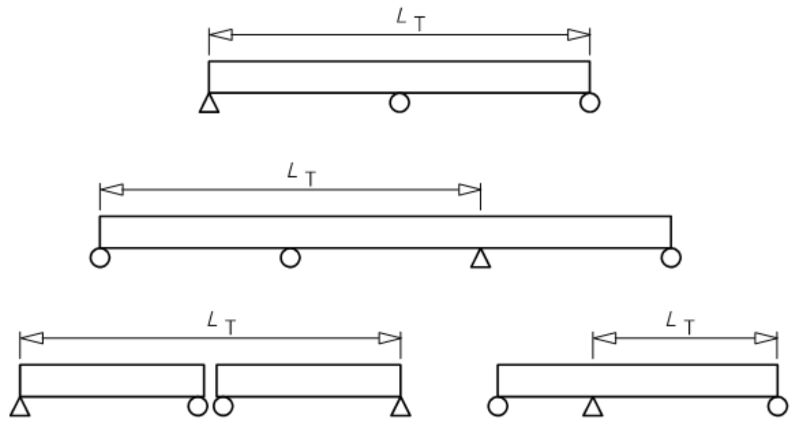


Figure 2.7 Different expansion lengths L_T, (SS-EN 1991-2, 2010).

2.1.6.2 The supports resistance against horizontal displacement

The displacement of the deck is highly influenced by the bearings longitudinal stiffnesses, especially the stiffness of the fixed bearing which is influenced by the stiffness of the subgrade. The stiffness of the movable bearing is only considered in more detailed analysis models, (UIC Code 774-3R, 2001).

The different kinds of parameters that influences the stiffness of the fixed support are shown in Figure 2.8.

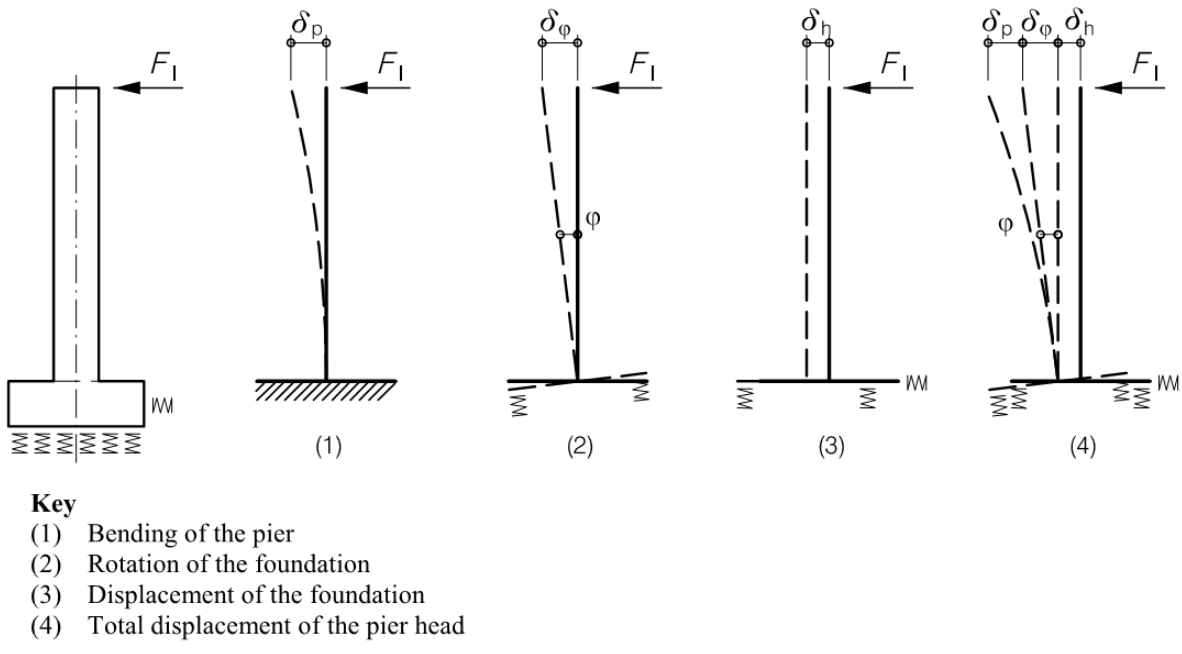


Figure 2.8 "Example of the determination of the equivalent longitudinal stiffness at the bearings", (SS-EN 1991-2, 2010).

According to SS-EN 1991-2 (2010) the total longitudinal stiffness k_{long} of one pier/support is calculated as:

$$k_{long} = \frac{F_l}{\delta_p + \delta_\varphi + \delta_h} \tag{2.1}$$

where

F_l is the longitudinal / horizontal support reaction [kN]

δ_p is the bending of the pier caused by elastic deformation [m]

δ_φ is the rotation of the foundation [m]

δ_h is the displacement of the foundation [m]

2.1.6.3 The bending behavior of the deck

The bending of the deck is generated by the vertical train load and generates a longitudinal displacement of the top of the deck end, which in turn leads to interaction between the track and the deck. The interaction effects are primarily influenced by the stiffness of the deck and the position of the decks neutral axis but are also dependent on the deck height and the fixed supports stiffness. These interaction effects create horizontal forces in the support and in the rails. Figure 2.9 shows the deck ends response to the bending of the deck, (UIC Code 774-3R, 2001).

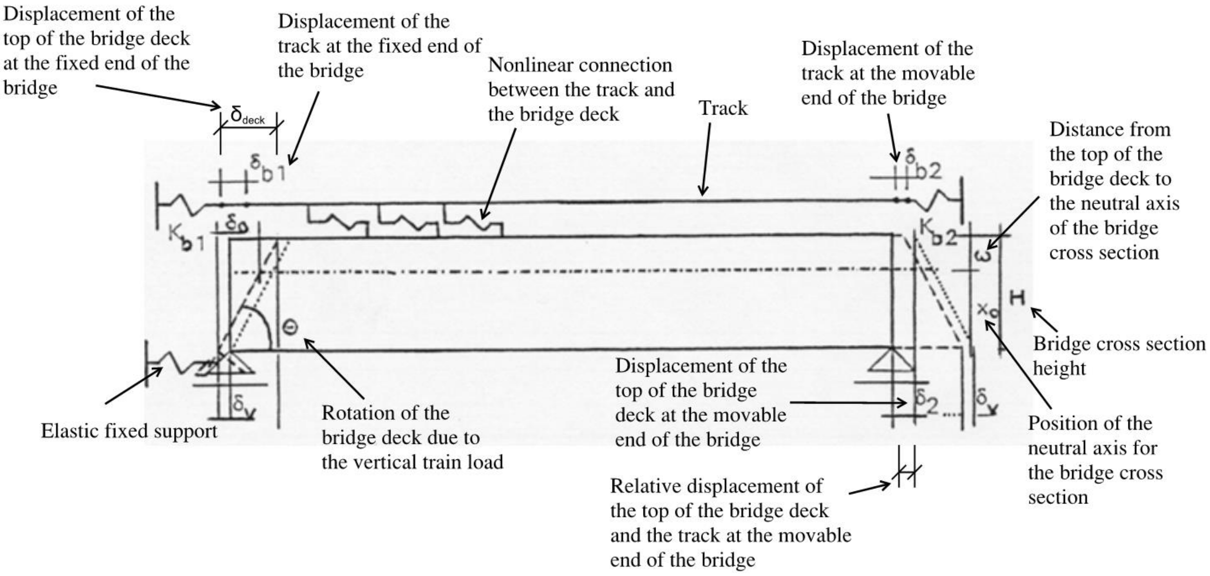


Figure 2.9 The end sections response, (UIC Code 774-3R, 2001).

2.1.7 Actions to be considered in the track and bridge interaction analysis

According to SS-EN 1991-2 (2010) and UIC Code 774-3R (2001) the following actions generate relative displacements between the deck and the rails and should therefore be considered in the analysis of the interaction effects:

- Horizontal braking and traction forces.
- When an expansion device is used, the thermal effects should be considered from the temperature variation of the rail and the deck.
- When continuous welded rails (CWR) are used only the thermal effects from the temperature variation of the deck should be considered.
- Vertical traffic loads (vertical bending of the bridge).
- The deformation of the structure and the supports due to vertical temperature gradient, creep and shrinkage should be considered where relevant.

The first four actions described above are those that often are of most importance for the bridge design. Two different methods that could be used to sum up the effects from them are described in section 2.6, (UIC Code 774-3R, 2001).

2.2 Continuous welded rail (CWR)

2.2.1 General information and principles about rails and CWR

According to UIC Code 774-3R (2001) a large percentage of the track on all railways now consists of continuous welded rails (CWR). This is especially true for high and very high-speed track. The largest advantage of CWR in front of non-welded tracks is that there is no need to use joints to connect the rails together. These joints require a lot of maintenance and decreases the service life of all track components which result in a higher life cycle cost, (Esveld, 2001).

The use of CWR and its behavior on embankment and on bridges are described in section 2.1.2 and section 2.1.3.

According to Esveld (2001) the rails, which is the most important part of the track structure, should provide the following functions:

- Take up the wheel loads and distribute them over the sleepers.
- Distribute the braking and traction forces through friction.
- Provide a smooth-running surface.
- Guide the wheel in the lateral direction.
- Distribute the horizontal transverse forces that acts on the rail head to the sleepers and supports.

There exist several different rail profile types and some of them are shown in Figure 2.10. In this degree project the UIC 60 rail profile for standard rail track is used, see Figure 2.11.

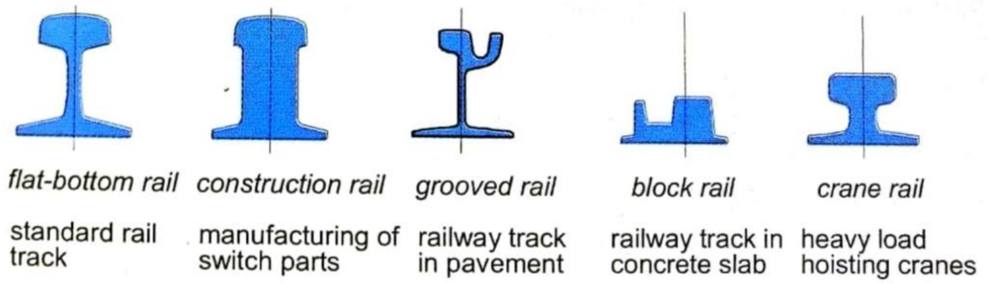


Figure 2.10 Different rail profile types, (Esveld, 2001).

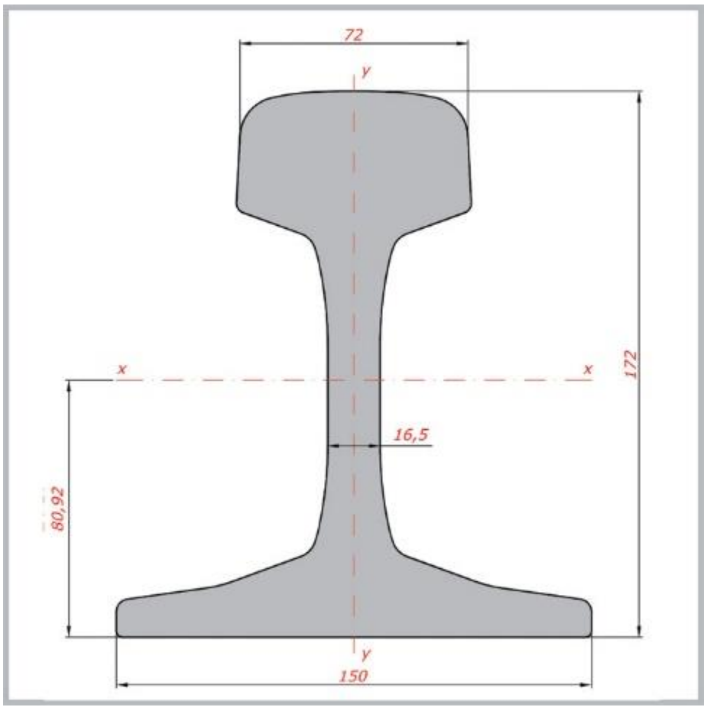


Figure 2.11 UIC 60 rail profile, (VALENTE SPA, 2017).

When CWR is used on bridges large rail stresses are induced due to the large displacement of the bridge structure with respect to the adjacent track. To avoid these rail stresses, which can result in track instability, are rail expansion joints and rail expansion devices used in those cases when the stresses are too high. The expansion joints and expansion devices are expensive and requires a lot of maintenance, (Esveld, 2001).

Expansion joints are used at the movable bearings of large structures, at the end of CWR tracks and where a change of structure occur at bridges, crossings and switches. The expansion joint shown in Figure 2.12 allows an axial displacement of 120 mm and is constructed with non-standard rails, but can also be constructed with standard rails, (Esveld, 2001).

In Figure 2.13 an expansion device is shown. Expansion devices are used for CWR on structures with a large expansion length and allows a maximum displacement of the blade parallel to the stock rail of 220 mm, (Esveld, 2001).

Figure 2.12 Expansion joint, (Esveld, 2001).

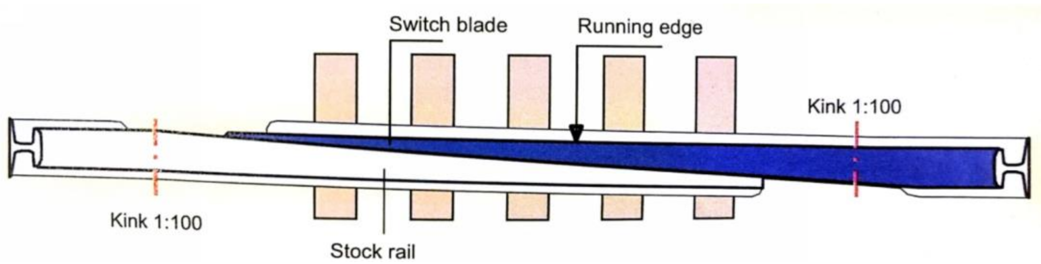


Figure 2.13 Rail expansion device, (Esveld, 2001).

2.3 Ballasted track on railway bridges

The behavior of the ballasted track on railway bridges is described in section 2.1.5, whereas the general principles and functions of the ballasted track components are described in this section.

2.3.1 General information about ballasted tracks

The ballasted track structure consists of the rail, fastenings, sleepers and ballast on top of a subgrade or a bridge, see Figure 2.14 and Figure 2.15. Each component of the ballasted track and its functions are described in section 2.3.1.1 – 2.3.1.3. The functions and the general principles of the rail have already been described in section 2.2.

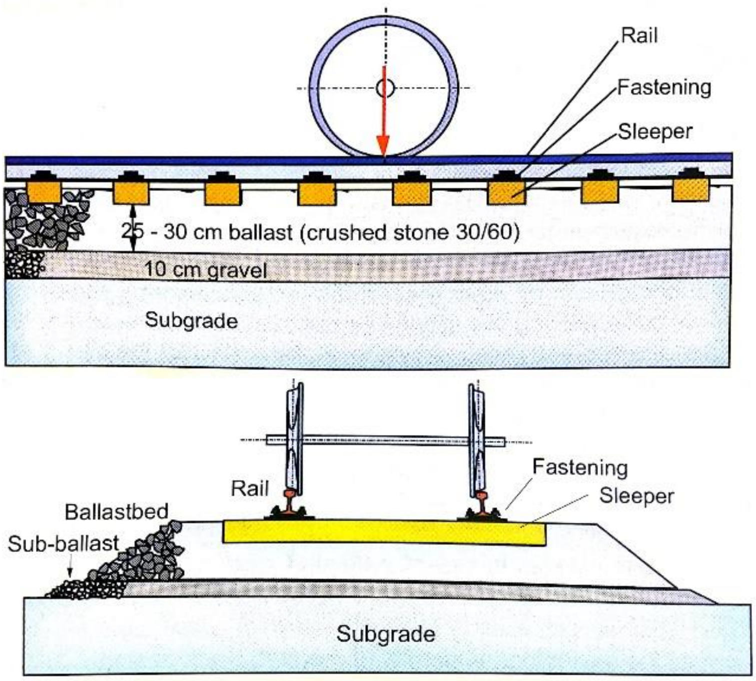


Figure 2.14 Ballasted track structure on a subgrade. Top: longitudinal section view. Bottom: cross section view, (Esveld, 2001).

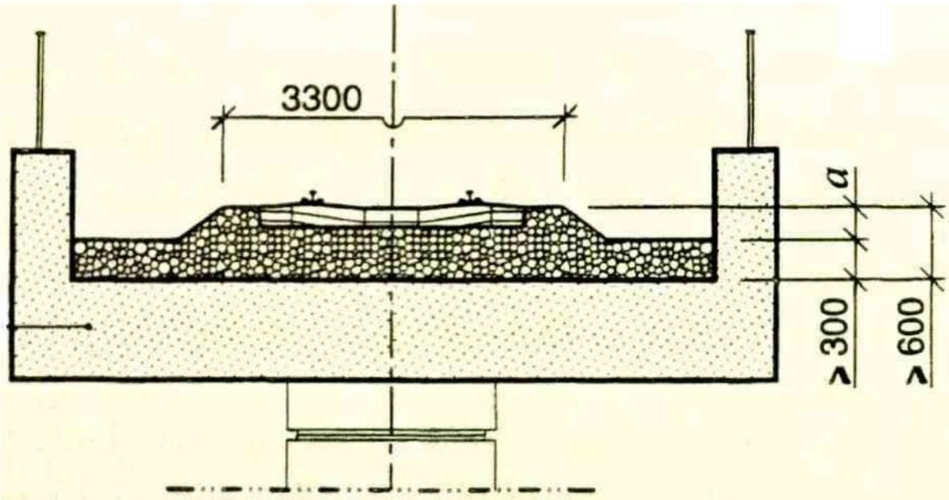


Figure 2.15 Ballasted track structure on a concrete bridge, (Sundqvist & Sahlin, 2000).

Esveld (2001). Lichtberger (2005) and AGICO GROUP (2017) gives the following pros and cons of ballasted tracks compared to the slab tracks:

- Pros
  - Low initial investment cost.
  - Good drainage performance.
  - Usually quick and easy to lay.
  - Easy to repair.

- Cons
  - Bridge and viaduct structures must be stronger, heavier and more expensive due to the higher and heavier track structure.
  - The track starts to move in both the lateral and longitudinal direction after a time.
  - The rail and wheels are damaged due to particles from the pulverization of the ballast beds grains.
  - The wear of the ballast, contamination and incursion of fine particles from the subgrade shrinks the permeability of the ballast bed.
  - The speed of the train is limited on ballasted tracks.
  - Passengers may feel uncomfortable due to the low train speed and the banged sound from the track.
  - Higher maintenance and traffic hindrance costs due to the necessity of a routine maintenance scheme to replace and clean ballast and to restore the track alignment.
  - Poor service life expectation (30 – 40 years).
  - More expensive if a life cycle cost comparison is performed.
  - The ballasted track will lose attractiveness in favor of slab track systems due to the high life cycle cost.

There are also investigations indicating that the differences in life cycle costs are small or negligible for ballasted and non-ballasted track and that more research must be performed on this subject, (Giunta & Praticò, 2017; Capacity for Rail, 2014; In 2 Rail, 2017)

2.3.1.1 Fastening systems

According to Esveld (2001) and Sundqvist (2003) the main functions of the chosen fastening system are the following:

- Reduce the impact and vibrations from the traffic loads.
- Elastically transmit the forces from the rail to the sleeper and subgrade.
- Maintain the track gauge (distance between the rails) and the inclination of the rail.

When CWR is used fastenings with a greater amount of elasticity should be used to reduce the impacts from the traffic loads. Elastic fastenings are especially a necessity for concrete sleepers as they are vulnerable to impacts. The general principle for elastic fastenings is that the spring displacement is large, this means that a considerable elastic spring displacement in the vertical direction is created due to the clamping force, (Lichtberger, 2005; Esveld, 2001).

In Figure 2.16 two different kinds of elastic fastening systems for ballasted track is shown, one fastening system from the manufacturer Pandrol and one fastening system from the manufacturer Vossloh.

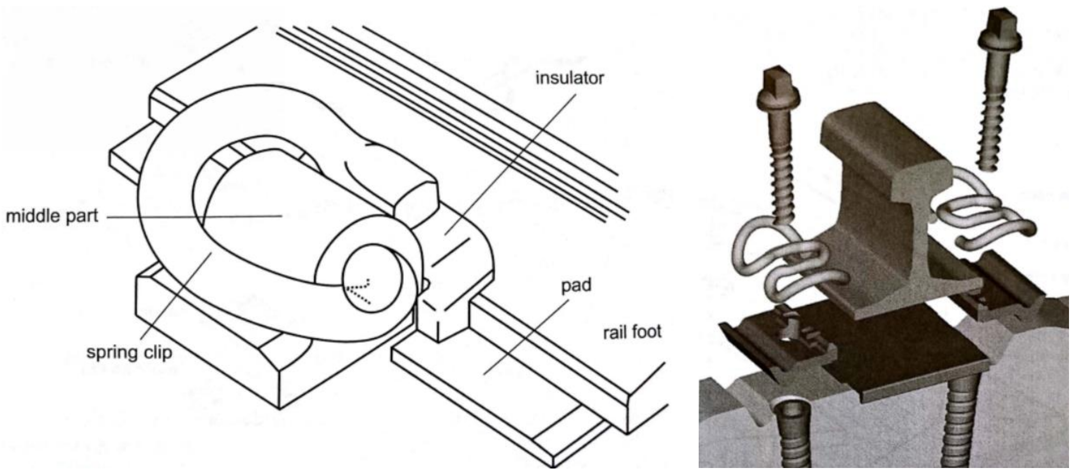


Figure 2.16 Left: Pandrol e-clip fastening system. Right: Vossloh W14 fastening system. (Lichtberger, 2005).

2.3.1.2 Sleepers

According to Esveld (2001) and Lichtberger (2005) the main functions of the sleepers are:

- Distribute and transfer the vertical, longitudinal and horizontal centrifugal forces to the ballast bed.
- Establish and maintain the track gauge (distance between the rails) and the inclination of the rail.
- Reduce rail vibrations, impact waves and noise pollution.

To meet these requirements sleepers made of steel, timber or reinforced concrete are used, (Esveld, 2001; Lichtberger, 2005).

2.3.1.3 The ballast bed

According to Esveld (2001) and Lichtberger (2005) the main functions of the ballast bed are:

- Provide a good drainage capacity to maintain the bearing capacity of the subgrade.
- Transmit the pressure from the sleepers to the subgrade or the bridge deck as uniformly as possible. A thickness of 25 – 30 cm has been proven to provide this function, see Figure 2.14.
- The ballast bed should have a high resistance against lateral and longitudinal sleeper displacements.
- Ensure the elasticity of the track to avoid large dynamic forces.

The choice of the ballast beds cross section, thickness and material properties influences these functions and requirements, (Lichtberger, 2005).

Continuous ballast beds can be used on short bridges and viaducts that cannot move. This means that discontinuities in the transition between the structure and the embankment can be avoided if the ballast bed on the adjacent embankments are continuous over the bridge or viaduct. When continuous ballasted beds are used it is necessary to add more elasticity to the track through a ballast mat under the ballast bed, also, an increased elasticity of the rail fastenings is necessary, (Esveld, 2001).

2.4 Slab track on railway bridges

The general principles and functions of the slab tracks components and the floating slab mat (elastic mat) are described in this section.

2.4.1 General information about slab tracks

For non-ballasted track the ballast bed is replaced by a rigid concrete track slab. This concrete track slab provides track stability and transfers the load. In Figure 2.17 a slab track system is shown on an embankment, (britpave, 2017).

The application of the slab track is growing since the slab track is a strong substitute for the ballasted track to limit the track maintenance. The most common slab track systems are the prefabricated systems as they provide and ensures high quality. Slab tracks are especially a better alternative for high-speed railways than ballasted tracks. Ballasted track on high-speed railways tends to need more maintenance. This is mainly due to that particles from the ballast bed are churned up because of the high-speed of the trains. These particles damage the rails and the wheels which leads to an increased amount of continuous maintenance. The continuous need of maintenance leads to a low availability of the track for running trains and a higher life cycle cost. Due to this has the slab tracks popularity increased, (Esveld, 2001; Jang, et al., 2017).

The different slab track systems are especially used on civil structures, light rail (subways and tramways) and on high-speed lines (Esveld, 2001).


Figure 2.17 Slab track system on embankment - Open section, (PORR Group, 2017).

Esveld (2001), Lichtberger (2005) and AGICO GROUP (2017) give the following pros and cons of slab track compared to the ballasted track:

- Pros
  - Almost maintenance free with a maintenance of 20-30% of the maintenance costs of ballasted track.
  - Almost no traffic hindrance due to maintenance works.
  - Almost full replacement at the end of the service life.
  - High train speed and makes the passengers feel comfortable.
  - The expected service life is 50 – 60 years instead of the expected service life of 30 – 40 years for ballasted track.
  - Slab track is much competitive from the cost point of view if a life cycle cost study is performed.
  - Low structure height and low weight allows bridge and viaducts to be less heavy and expensive.
  - High-speed trains passing do not cause any drag forces in the ballast.
  - Creates a better environment in the areas close to the track due to that no dust from the ballast bed are whirled up.
  - Easier for road vehicles to assess the track.
  - Use of electro-magnetic wheel brakes.
  - Can be designed as a floating slab track to meet the requirements in areas that are sensitive to ground-borne vibrations and vibration nuisance.

- Cons
  - Higher initial investment cost.
  - Cannot be laid in earthquake areas.
  - If a derailment happens, it will take more effort and time to repair the track compared to a ballasted track.
  - Greater airborne noise reflection.
  - Relatively small adaptively to larger displacement of the embankment.
  - The foundation must be well prepared with homogenous sublayers which are capable to withstand the imposed loads without any larger settlements.

There are also investigations indicating that the differences in life cycle costs are small or negligible for ballasted and non-ballasted track and that more research must be performed on this subject, (Giunta & Praticò, 2017; Capacity for Rail, 2014; In 2 Rail, 2017).

A floating slab track system with shear keys on bridges from the manufacturer ÖBB-PORR are considered in this master thesis. This system is described more deeply in section 2.4.2.

Other types of slab track systems from different projects are summarized in Table 2.3. An overview of these systems can be found in Esveld (2001) and Lichtberger (2005).

Table 2.3 Examples of other slab track systems used in different projects, (britpave, 2017).

Project	Country	Slab track system – Track form
Shinkansen	Japan	Shinkansen
Duerne	The Netherlands	Embedded Rail
Best	The Netherlands	Embedded Rail
Crewe-Kidsgrove	UK	BBEST Embedded Rail
High Speed Line HSL-Zuid	The Netherlands	Rheda 2000
Cologne-Frankfurt High Speed Line	Germany	Rheda Züblin
Hibel & Prestbury Tunnels	UK	Rheda 2000
Nuremberg-Ingolstadt High Speed Line	Germany	Rheda 2000FF-Bögl
Taipei and Kaohsiung High Speed Rail	Taiwan	Rheda 2000
Eje Atlantico	Spain	Rheda 2000
Perpignan-Figueras	Spain	Rheda 2000
Guadarrama Tunnel	Spain	Rheda 2000
Beijing-Tianjin Intercity Railway	China	Rheda 2000
TGV Méditerranée	France	Sateba booted sleeper
Channel Tunnel	UK/France	Sonneville block
Channel Tunnel Rail Link Phase II	UK	Booted sleeper
Gotthard Tunnel	Switzerland	Booted sleeper
St. Pancras	UK	Resilient baseplate
Docklands Light Railway	UK	Resilient baseplate
Athens Attiko Metro	Greece	Booted sleeper
Hong Kong MRT	Hong Kong	Resilient baseplate Floating track slab
Kuala Lumpur Star LRT	Malaysia	Resilient baseplate
London Underground	UK	Resilient baseplate
Tramway de Grenoble	France	Booted sleeper
Nottingham Express Transit	UK	Embedded Rail
Sheffield Supertram	UK	Embedded Rail

In Figure 2.18 an elastic fastening system (Vossloh 300) is shown which is frequently used for slab tracks on high-speed railways. The purpose of fastenings systems for non-ballasted tracks is the same as for the fastenings system for ballasted tracks described in section 2.3.1. The difference is that a fastening with a higher vertical elasticity must be used due to the higher stiffness of the track slab compared to the ballast bed, (Lichtberger, 2005).

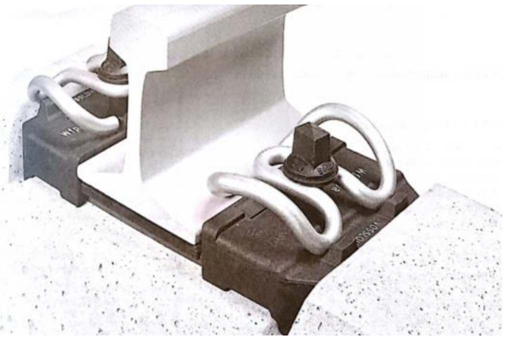
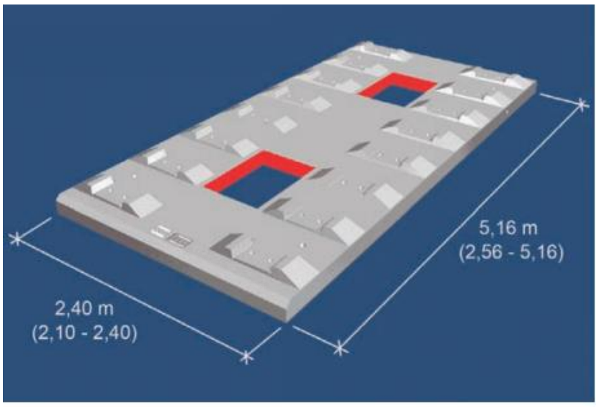


Figure 2.18 Vossloh 300 fastening system for non-ballasted track, (Lichtberger, 2005).

2.4.2 *Floating slab track systems on railway bridges*

In this section the floating slab track system ÖBB-PORR is described. It is an elastically supported track base plate with shear keys. This system has been used in the construction of bridges in Germany since 2001 and is the obligatory system in Austria since 1995. Over 100 km of tracks are in operation and the oldest sections have been in operation for over 17 years without any service costs or maintenance, (PORR Group, 2017).

The concrete track plate (slab) with un-tensioned reinforcement from ÖBB-PORR is prefabricated before it is installed at the construction site. Every 65 cm is a pair of the fastening system Vossloh 300-1 installed. The track-base-plate-system ÖBB-PORR and its geometry and properties can be seen in Figure 2.19 (PORR Group, 2017).



TRACK BASE PLATE SYSTEM ÖBB–PORR	
Length	5,16 m (2,56 up to 5,16m)
Width	2,40 m (2,10 up to 2,40m)
Depth	16 cm (16 / 24 cm)
Openings	91 x 64 cm (top) 87 x 60 cm (bottom)
Weight:	50,00 KN (gross) 51,40 KN (using Vossloh 300-1)
Types:	Linear (R>3697 m) Radii (R=200 up to 3697m) Railway/suburban railway/underground Rail: 60E1 (E2) / S54 / S48U

Figure 2.19 Track base plate system ÖBB-PORR properties, (PORR Group, 2017).

Floating slab track systems is especially useful in populated areas with strict regulations for vibrations and noise. When track slab systems are used on bridges the top of the bridge deck is used as a direct base for the track slab where the bottom of the track slab lies on an elastic mat, (also called floating slab mat), see Figure 2.20 and Figure 2.21. The purpose of the floating slab mat is to reduce the slab track vibrations into the bridge structure (foundation) and the structure borne noise created from the dynamic effects of rail traffic. The noise and vibrations are reduced due to the reduced support stiffness of the track. This system is called a light mass-spring-system, (Kraśkiewicz, et al., 2016; Xin & Gao, 2011; PORR Group, 2017; edilon sedra, 2017b).

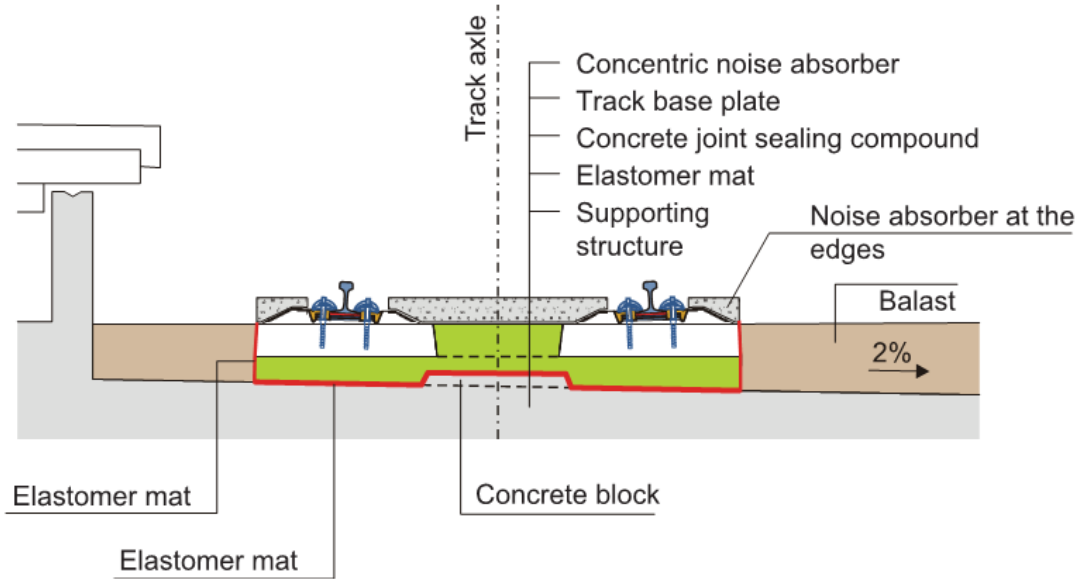


Figure 2.20 Floating slab track system on a bridge structure, (PORR Group, 2017).

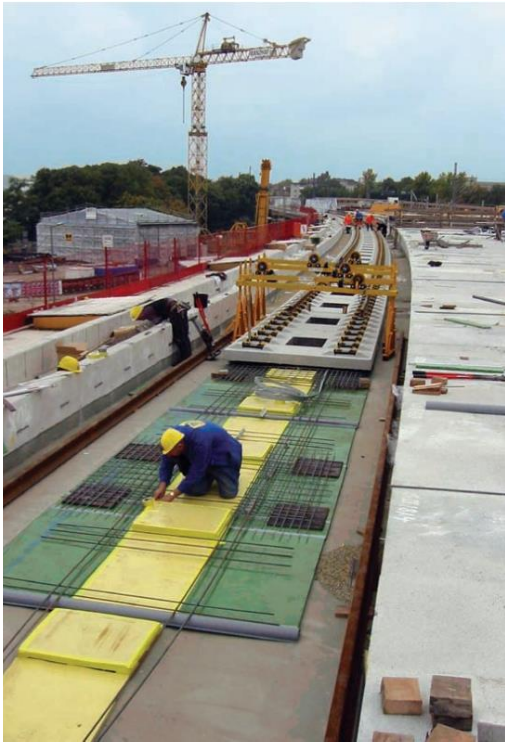


Figure 2.21 Application of floating slab track on a bridge structure, (PORR Group, 2017).

The concrete blocks (shear keys) shown in Figure 2.20 are used to transfer the horizontal forces and pressures into the bridge structure. The floating slab mat is installed on top and on the sides of the shear keys. To avoid punching a mat with a lower stiffness is applied on the top area of the shear keys unlike on the side areas of the shear keys, (PORR Group, 2017; Jang, et al., 2017).

On bridges unacceptable high compression rail stresses can occur at joints. These stresses are caused by the deformations created from settlements, temperature variations, traffic loads, creep and shrinkage.

To avoid these stresses, it is in some cases necessary to install special track-crossing constructions. In Figure 2.22 an example of a track-crossing construction is shown. It is used for continuous bridges, (PORR Group, 2017).

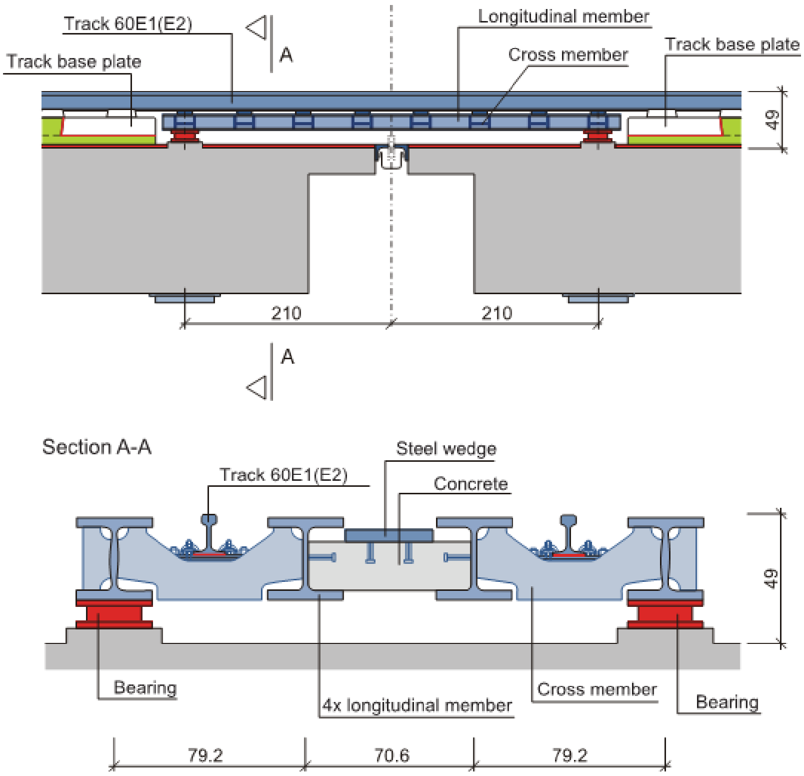


Figure 2.22 Track-crossing construction, (PORR Group, 2017).

One of the manufactures of floating slab mats is Pandrol. Figure 2.23 shows a Pandrol floating slab mat type CDM-FSM. This mat can be used for all types of track and rail systems (metros, main and high-speed lines), (PANDROL, 2017).

Figure 2.23 Floating slab mat CDM-FSM, (PANDROL, 2017).

The static bedding modulus properties for a floating slab mat (TRACKELAST STM / RPU / Blue) from the manufacturer edilon sedra are used in this degree project, see Figure 2.24. This mat is made of the elastomer based on polyurethane and was developed to be used for floating slab tracks for heavy rail (freight and passenger trains, including high speed trains) and light rail (metros and trams). Table 2.4 summarizes the mats vertical static bedding modulus for different mat thicknesses, (edilon sedra, 2017a).

Mats with a low vertical static bedding modulus or stiffness gives higher stresses in the rail due to the increased vertical deflection of the railway track. The static bedding modulus of the mat is dependent on the thickness of the mat, material, type of structure and the load value in which the bedding modulus is defined and load frequency for dynamic modulus (edilon sedra, 2017b; Kraśkiewicz, et al., 2016).

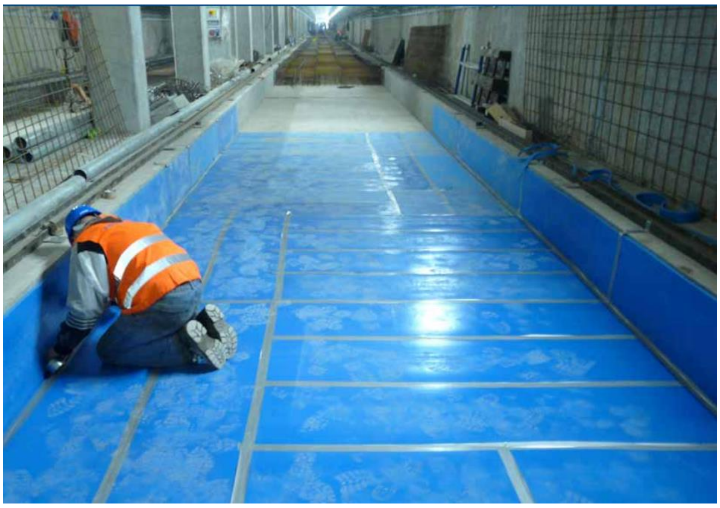


Figure 2.24 Application of a floating slab mat – (Trackelast STM/RPU/Blue) from edilon sedra in a tunnel, (edilon sedra, 2017a).

Table 2.4 Static bedding modulus for the floating slab mat edilon sedra Trackelast STM / RPU / Blue, (edilon sedra, 2017b)

Mat thickness, t_{mat} [mm]	**Static vertical bedding modulus, $k_{bm,mat,v}$ [kN/m^3]**
12,0	10000,0
15,0	8000,0
20,0	6000,0
25,0	5000,0
28,0	4000,0
30,0	4000,0
35,0	3000,0

2.5 SOFiSTiK

2.5.1 General information about the software

The software used for the Finite Element Analysis (FEA) in this project is SOFiSTiK. SOFiSTiK is a FEA-software developed to especially be used by civil and structural engineers. A modular structure of programs builds up the core of the software through a Central Data Base (CDB). Each program gets its input from a graphical user interface or from text files. The programs exchange information between each other through the CDB. The program structure with the different modules/programs and their functions can be seen in Figure 2.25, (SOFiSTiK AG, 2016).

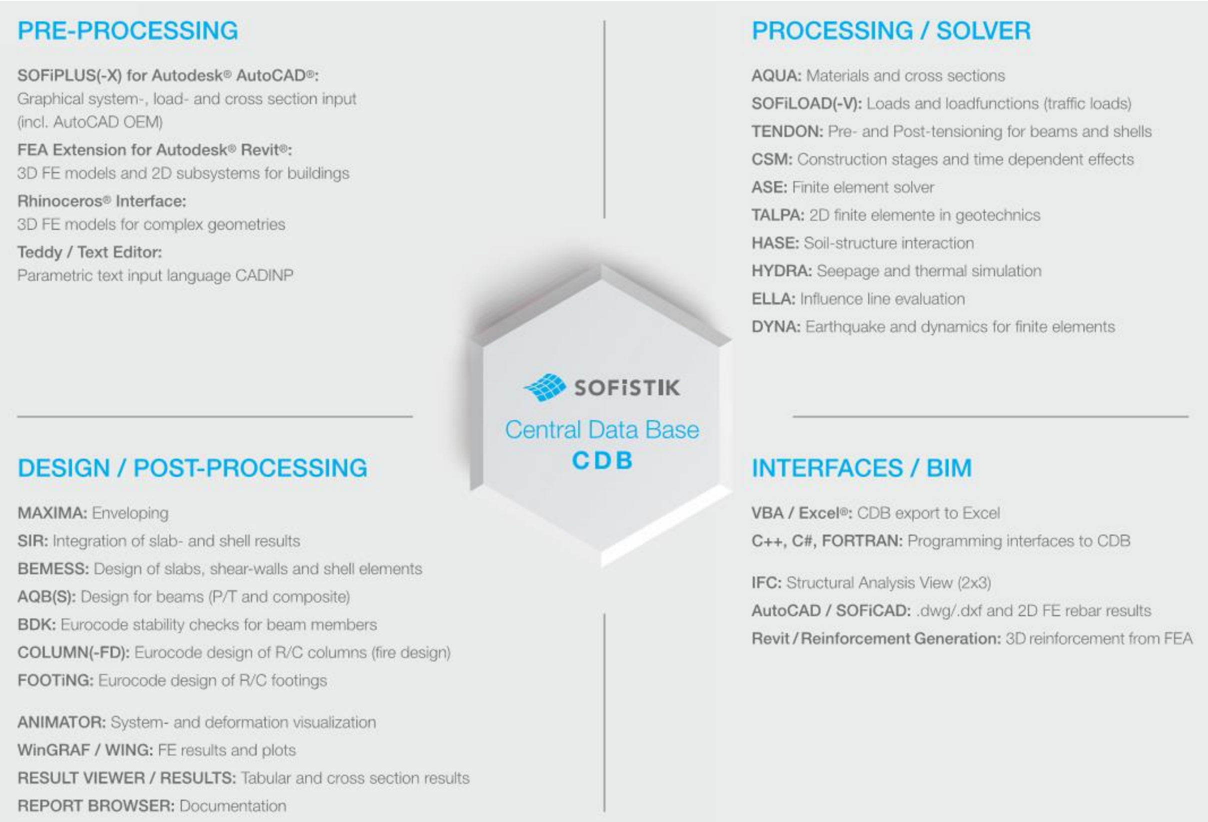


Figure 2.25 SOFiSTiK program structure, (SOFiSTiK AG, 2016).

The most powerful way to use the software is through the parametric text input language CADINP which is a programmable macro-language. With this programming language it is possible for the user to produce macros and to keep all secondary information in formulas and comments, (SOFiSTiK AG, 2016).

The analysis is according to SOFiSTiK AG (2008) performed in three steps:

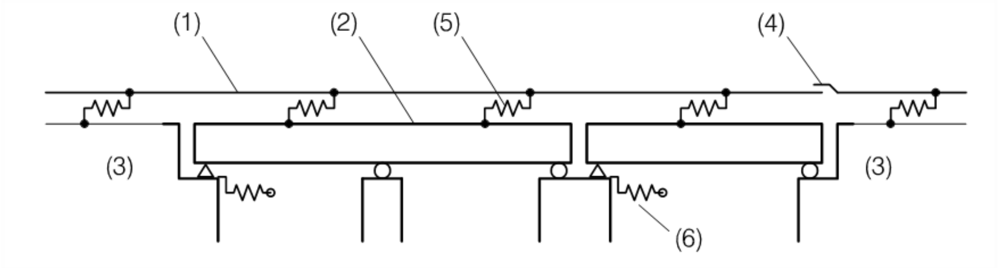
- Preprocessing – Input of structural system, loads, materials etc.
- Processing / Solver– Structural analysis of the system (computation of the support forces, deformations, stress resultants etc.).
- Postprocessing – Design of reinforced concrete or steel, graphical or numerical output.

In this degree project the preprocessing is performed with the text editor Teddy. The parametric text input language CADINP is used in Teddy to call the other modules used in the degree project:

- Preprocessing:
  - Teddy – Text editor
- Processing:
  - AQUA –Materials and cross sections
  - SOFiMSHA – Import and export of finite elements and beam structures
  - SOFiLOAD – Input of loads and load functions
- Solver:
  - ASE – used for general static analysis of finite element structures
- Postprocessing:
  - Result Viewer / RESULTS: used for graphical and tabular finite element postprocessing
  - WiNGRAF / WING – used for graphical representation of finite elements and beam structures

2.6 General recommendations for computer-assisted track/bridge interaction analysis according to Eurocode and the International Union of Railways (UIC)

According to SS-EN 1991-2 (2010) and UIC Code 774-3R (2001) a structural model as the one shown in Figure 2.26 could be used in the finite element analysis model (FEA-model) to determine the interaction effects of interest (rail stresses, support reactions, relative and absolute displacements of the track and the deck). The parameters and actions described in section 2.1 should be used in the model.



Key
(1) Track
(2) Superstructure (a single deck comprising two spans and a single deck with one span shown)
(3) Embankment
(4) Rail expansion device (if present)
(5) Longitudinal non-linear springs reproducing the longitudinal load/ displacement behaviour of the track
(6) Longitudinal springs reproducing the longitudinal stiffness K of a fixed support to the deck taking into account the stiffness of the foundation, piers and bearings etc.

Figure 2.26 Combined track/structure model, (SS-EN 1991-2, 2010).

UIC Code 774-3R (2001) gives the following recommendations for the FEA-model:

- Rigid elements could be used to simulate the connection between the deck elements and the supports, see Figure 2.27.
- Rigid elements could be used to simulate the connection between the deck elements and the track elements.
- For simplicity the track elements can be placed in the same position as the top of the deck.
- The horizontal stiffness of the fixed support should be modelled as springs with a linear behavior, see Figure 2.26.
- The connection between the track and the deck should be modelled through nonlinear springs, see Figure 2.26 and Figure 2.27.
- The track and the deck could be modelled as discrete elements with a maximum element length of 2.0 meters to guarantee accurate results.
- At least 100 meters of embankment track on both sides of the bridge should be included in the model.
- For single span bridges the train loads should only be applied on the bridge and the embankment on one side of the bridge. If the train is placed on both embankments an overestimation of the effects could occur.
- When CWR are used the thermal variation of the rail should be assumed to be zero as it does not affect the interaction effects of interest between the track and the deck.
- In the case of expansion devices, the thermal variation of the rail should be considered since relative displacement will occur between the track and the deck. Also, it is necessary to check if the displacement of the rail is larger than the maximum displacement of the device, see Figure 2.12 and Figure 2.13 in section 2.2.1.

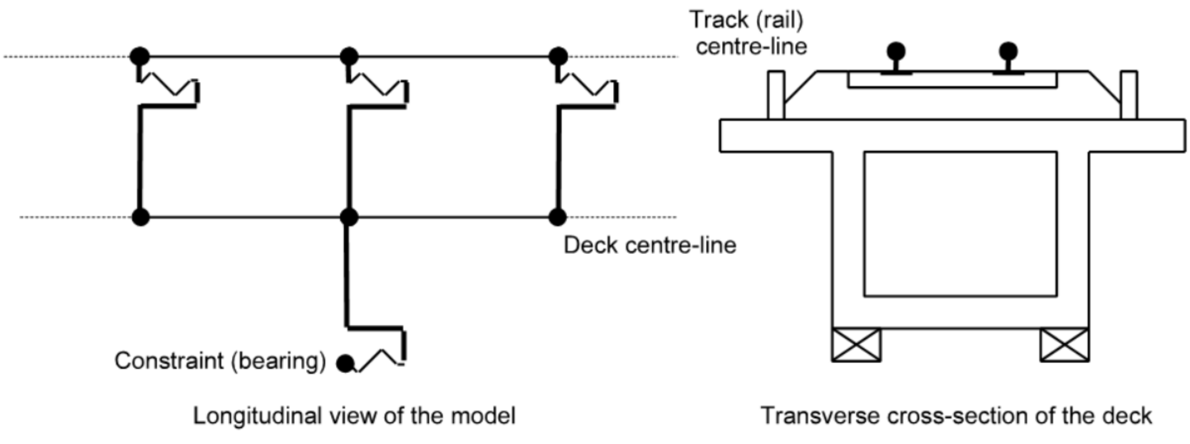


Figure 2.27 "Typical model of the track – deck-bearing system", (UIC Code 774-3R, 2001).

Two different types of interaction analyses can according to UIC Code 774-3R (2001) be carried out:

- Complete analysis method: A model where the train travels over the bridge through an algorithm where the nonlinear springs reactions for every load step are saved to be able to see the combined effect of the thermal variations and the braking, traction and vertical forces. All loads are combined in the same load case. An explanation of the nonlinear springs behavior when different load steps influence on each spring are saved after each iteration is presented in section 2.1.5 and Figure 2.5.

- Simplified analysis method: Separate analyses of each action (the thermal variations, the braking, traction and vertical forces). Each action is considered as one separate load case. The results from each analysis (load case) are then combined through a linear superposition.

The train loads can be used as static loads and the nonlinear behavior of the connection between the track and the deck should be considered in both interaction analyses methods. The choice of interaction analysis depends on how accurate the user wants the results to be. (UIC Code 774-3R, 2001).

The simplified analysis method with separate analyses is used in this degree project.

3 Choice of system and software validation

3.1 Precomputed test cases from UIC – ballasted track on railway single span bridges

3.1.1 Test cases from UIC 774-3R

Two test cases - E1-3 and F4-6 from UIC Code 774-3R (2001, Appendix D) was used in the validation of the software and in the choice of FEA-model for the project. The test case configuration can be seen in Figure 3.1. According to UIC Code 774-3R (2001) the following parameters and assumptions were used:

- Ballasted track.
- 300 m of embankment on each side of the bridge, see Figure 3.1.
- The horizontal resistance is 20 kN/m when the track is unloaded.
- The horizontal resistance is 60 kN/m when the track is loaded with a vertical train load with a magnitude of 80 kN/m.
- Thermal variation for the deck: 35 °C.
- Thermal variation for the rails: 50 °C.
- Vertical train load: 80 kN/m.
- Horizontal braking force: 20 kN/m.
- Train length: 300 m.
- The position of the rails center of gravity is considered to overlap with the top of the slab.
- The direction of travel for test case E1-3 is from the fixed support towards the movable support whereas the direction of travel for test case F4-6 is in the reverse direction.

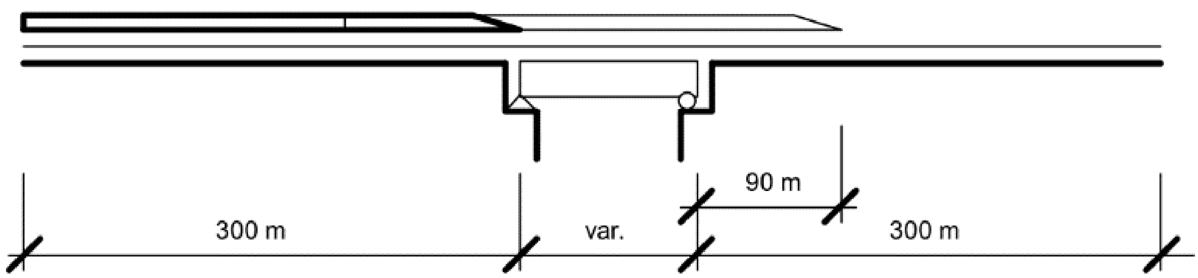


Figure 3.1 Test case configuration, (UIC Code 774-3R, 2001).

The cross-section parameters in Table 3.1 are based on the deck type shown in Figure 3.2.

Table 3.1 Input parameters for the different test cases, (UIC Code 774-3R, 2001).

Test case	Span length, L_{span} [m]	Horizontal support stiffness, k_{long} [kN/m]	Young's modulus, E [GPa]	Moment of inertia, I [m^4]	Height, H or h [m]	Cross section area, A_{cs} [m^2]	Center of gravity, x_{cg} [m]
E1-3	60	600000	210	2,59	6	0,74	4,79
F4-6	60	120000	210	2,59	6	0,74	4,79

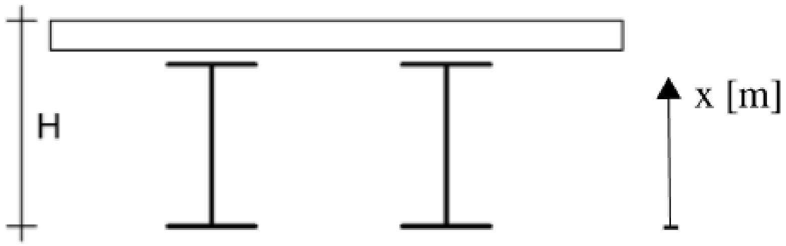


Figure 3.2 Deck type used for the test cases E1-3 and F4-6, (UIC Code 774-3R, 2001).

The following interaction parameters which influences the rail stresses, the horizontal reaction force in the fixed bearing and the displacements of the deck and the rail are considered and determined for each model in this thesis and are compared to the results from UIC Code 774-3R (2001, Appendix D):

- Thermal variation of the deck.
- Braking forces.
- End rotations due to the vertical train load.

The effects of the interaction between the rail and the deck are according to UIC Code 774-3R (2001) given through:

- Additional rail stresses. See Figure 5.3 and Figure 5.4 to see examples of the additional normal forces that causes these additional rail stresses.
- Relative displacement between the track and the top of the deck at the movable end of the bridge. See Figure 3.3 for explanations and Appendix 2 (p.30 – 33, p.36 – 39 and p.42 – 45) for examples of displacements caused by each interaction parameter.
- Absolute displacement of the top of the deck in the fixed end of the bridge. See Figure 3.3 for explanations and Appendix 2 (p.30 – 33, p.36 – 39 and p.42 – 45) for examples of displacements caused by each interaction parameter.
- Horizontal support reactions at the fixed support. See Appendix 2 (p.29, p.35 and p.41) for examples of horizontal forces at the fixed support caused by each interaction parameter.

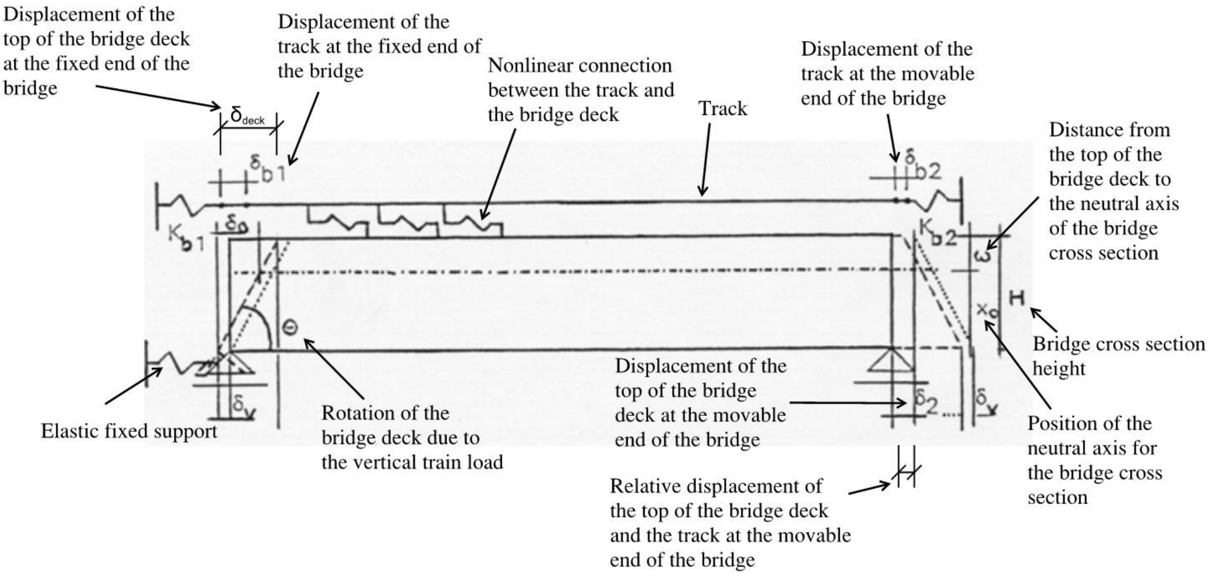


Figure 3.3 Interaction behavior, (UIC Code 774-3R, 2001).

A hand calculation of the support reaction, absolute displacement of the deck and the rail stresses for each interaction parameter was performed for the two test cases described in this section. The results from the hand calculation are summarized in Table 3.2 and Table 3.3. The interested reader can find the whole hand calculation process in Appendix 1.

Table 3.2 Hand calculation results for test case E1-3.

Load case	N_{rail} [kN]	Rail stress, σ_{rail} [MPa]	Top of the deck - abs.disp, δ_{deck} [mm]	Support reaction, $F_{support}$ [kN]
Temperature variation - deck	-461,16	-30,00	-1,17	700,00
Braking	-284,38	-18,50	1,01	-603,33
Vertical bending - end rot	-390,45	-25,40	1,84	1106,67
Sum:		**-73,90**	**1,68**	**1203,34**

Table 3.3 Hand calculation results for test case F4-6.

Load case	N_{rail} [kN]	Rail stress, σ_{rail} [MPa]	Top of the deck - abs.disp, δ_{deck} [mm]	Support reaction, $F_{support}$ [kN]
Temperature variation - deck	-384,30	-25,00	-4,08	490,00
Braking	-461,16	-30,00	-2,33	280,00
Vertical bending - end rot	-155,26	-10,10	4,43	532,00
Sum:		**-65,10**	**-1,98**	**1302,00**

The results from the computer analysis made by UIC gave the results in Table 3.4 and Table 3.5.

Table 3.4 Results from the computer analysis performed by UIC for test case E1-3, (UIC Code 774-3R, 2001).

Load case	N_{rail} [kN]	Rail stress, σ_{rail} [MPa]	Top of the deck - abs.disp, δ_{deck} [mm]	Support reaction, $F_{support}$ [kN]
Temperature variation - deck	-471,46	-30,67	-1,69	700,12
Braking	-252,41	-16,42	1,36	-813,22
Vertical bending - end rot	-261,02	-16,98	3,77	977,70
Sum:		**-64,07**	**3,44**	**864,60**

Table 3.5 Results from the computer analysis performed by UIC for test case F4-6, (UIC Code 774-3R, 2001).

Load case	N_{rail} [kN]	Rail stress, σ_{rail} [MPa]	Top of the deck - abs.disp, δ_{deck} [mm]	Support reaction, $F_{support}$ [kN]
Temperature variation - deck	-399,21	-25,97	-4,35	482,92
Braking	-393,22	-25,58	-3,19	383,07
Vertical bending - end rot	-157,26	-10,23	2,29	436,75
Sum:		**-61,78**	**-5,25**	**1302,74**

UIC Code 774-3R (2001) also performed a computer analysis of the temperature variation of the rails and got the same compressive rail stress for both test cases, σ_{rail} = -126 MPa.

The model and the software are according to UIC Code 774-3R (2001) considered to be validated if the following criteria are meet in a comparison to the results from the computer analyses performed by UIC:

- If the error is less than 10% on the single effects and on the sum of the effects.
- An error up to 20% can be accepted if the error is on the safe side.

3.2 SOFiSTiK validation FEA-models

3.2.1 Common parameters and assumptions for the test models

The common assumptions and input parameters for the three test models presented in section 3.2.2 – 3.2.4 are described in this section. Since the recommendations for computer assisted analysis from UIC and Eurocode in section 2.6 not gave all necessary information about how the model should be constructed was three different test models used to see how they influence the results. The difference between each test model is how the bridge is connected from the center of gravity of the bridge cross section to the supports and how the nonlinear springs attaches the track elements to the bridge structure.

The three test models are based on the recommendations for computer assisted analysis described in section 2.6 with some modifications. A 2D-plane frame system is used for the models where the cross-section properties from Table 3.1 and Table 3.6 are entered as parameters without any information about the cross-sections geometry and dimensions. Both the track and the bridge deck are modelled with elastic 2D beam elements.

Table 3.6 Input parameters and loads.

Input parameters and loads	**Value**	**Unit**
Distance between each node, d_{node}	0,6	m
Distance between each spring, d_{spring}	0,6	m
Plastic displacement resistance for the unloaded track, $k_{plastic,unloaded}$	20	kN/m
Plastic displacement resistance for the loaded track, $k_{plastic,loaded}$	60	kN/m
Displacement between the elastic and plastic zones, u_0	2	mm
Elastic displacement resistance for the loaded track, $k_{elastic,unloaded}$	16666	kN/m^2
Elastic displacement resistance for the unloaded track, $k_{elastic,loaded}$	50000	kN/m^2
Thermal variation for the deck, ΔT_{deck}	35	°C
Thermal expansion coefficient for the deck, α_{deck}	$1{,}00\times10^{-5}$	1/K
Total area for the track, two UIC60 rail cross-sections, A_{60}	$1{,}537\times10^{-2}$	m^2
Total moment of inertia for the rail, $I_{y,rail}$	$6{,}077\times10^{-5}$	m^4
Train length, L_{train}	300	m
Vertical train load, $F_{vertical}$	80	kN/m
Horizontal braking force, $F_{braking}$	20	kN/m
Thermal variation for the rails, ΔT_{rail}	50	°C
Thermal expansion coefficient for the rail, α_{rail}	$1{,}2\times10^{-5}$	1/K

It seems like UIC Code 774-3R (2001) has performed the calculation for an equivalent cross section where the concrete has been converted into steel, therefore the thermal expansion coefficient for steel was used for the whole cross section.

The temperature variation of the rails was first tested with the thermal expansion coefficient for steel ($1{,}00\times10^{-5}$ 1/K) to see if the model with coupled nodes described in section 3.2.4 gave the same rail stress result as the computer analysis performed by UIC Code 774-3R (2001). It was determined that the use of $1{,}00\times10^{-5}$ 1/K gave an incorrect compressive rail stress. Frýba (2006) suggests that the value of $1{,}2\times10^{-5}$ 1/K should be used as the thermal expansion coefficient for the rails to get results that are on the safe side. The value suggested by Fryba (2006) was used in the second test and gave the correct compressive rail stress, σ_{rail} = -126 MPa. The normal force diagram for the second test can be seen in Figure 3.4. The behavior of the normal force from the temperature variation is exactly as it should be, see Figure 2.1 and the explanation in section 2.1.2.

This is a possible source of error as it is not stated anywhere in UIC Code 774-3R (2001) what dimensions of the bridge cross sections and thermal expansion coefficients they have used for the bridge and the rail materials.

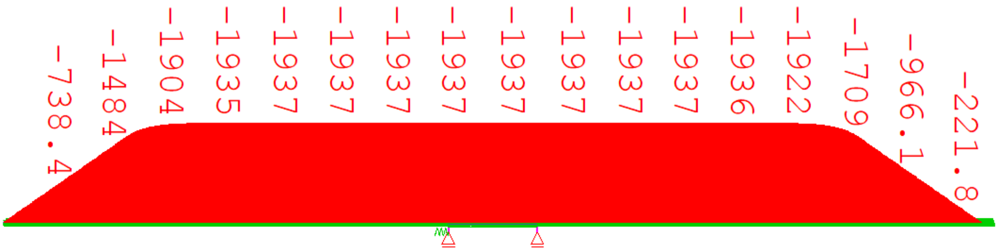


Figure 3.4 Compressive normal force in the rail from the temperature variation of the rails, [kN].

The center of gravity of the track is assumed to coincide with the top of the bridge deck in all cases, therefore the beam elements that simulates the track are placed in the same height as the top of the bridge deck in the models.

The bridge configuration shown in Figure 3.5 is from the model where the supports are coupled to the center of gravity of the cross section through two coupled nodes. Nevertheless, the support conditions and the connection between the deck and the track are the same for all three models described in the following sections.

The connection between the bridge deck and the track is modelled through nonlinear springs with the same stiffness against displacements in the vertical and horizontal direction, see Figure 3.5. The choice of spring stiffness in the vertical direction was based on tests. From the tests it was determined that the same spring stiffness in both the horizontal and vertical direction gave the most realistic results for the three load cases in comparison with the computer calculated results from UIC Code 774-3R (2001).

The distance between each node and spring is assumed to be 0.6 meters which is the same as the most common distance between the sleepers, (Esveld, 2001).

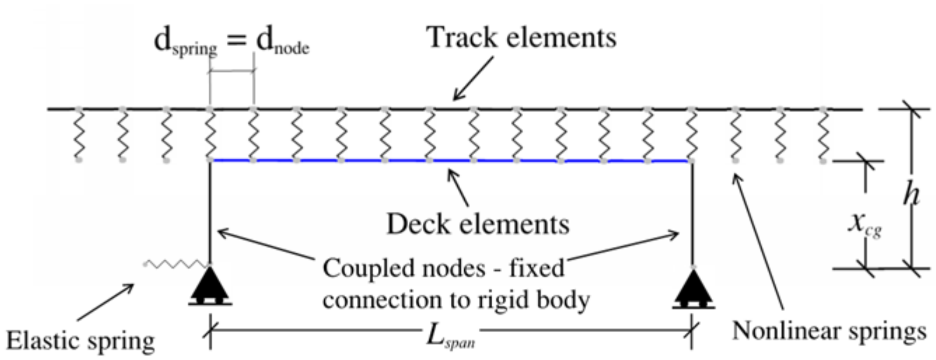


Figure 3.5 Support conditions and the connection between the deck and the track.

On both sides of the bridge 300 m of the embankment with track is included, see Figure 3.1. The connection between the embankment and the track is simulated through the same type of nonlinear springs as for the connection between the bridge and the track. The support nodes are fixed in the vertical direction and an elastic spring is used to simulate the horizontal stiffness of the fixed support, see Figure 3.5.

The three different load cases considered in the simplified analyses are the thermal variation of the deck, the braking force and the vertical train load. The loads in Table 3.6 was used as static loads. Different spring stiffnesses were used for different parts of the models for the three different load cases. In the temperature variation load case the spring stiffness for the unloaded track was used in the whole model, whereas different spring stiffnesses were used for the unloaded and loaded parts of the track for the braking force and the vertical train load.

The compressive rail stresses were combined with the simplified analysis method described in section 2.6 to be able to find where the largest combined compressive rail stresses occur in the model. Detailed results and diagrams for each model and test case can be found in Appendix 2.

UIC Code 774-3R (2001) appears to have used the recommendations for the combination of the loads for the hand calculation in the simplified analysis method to find the largest and most conservative value of the rail stresses from the braking load case. The recommendations below will therefore be used for the rail stresses from the braking load case in the validation of the software.

The following recommendation is given in UIC Code 774-3R (2001) for the load combination of the load case effects determined through the hand calculation method:

- The determined support reaction and rail stresses at the supports due to temperature variation and braking forces should be taken with both the negative and positive signs to find the worst case. The sign for the support reaction and rail stresses due to the vertical load is given with the correct sign directly.

The elastic displacement resistances $k_{elastic,i}$ in Table 3.6 are calculated as:

$$k_{elastic,i} = \frac{k_{plastic,i}}{d_{spring} \times u_0} \tag{3.1}$$

where

$k_{plastic,i}$ is the plastic displacement resistance for the track [kN/m]

d_{spring} is the distance between each spring in the model [m]

u_0 is the displacement between the elastic and plastic zones [mm]

The temperature variation of the deck causes relative displacements between the deck and the track and is therefore considered in the thermal variation load case, see Figure 3.6. The temperature variation of the rail does not generate relative displacements between the deck and the track for continuous welded rails without an expansion device and are therefore not considered in the further analyses of the rail stresses, (UIC Code 774-3R, 2001).

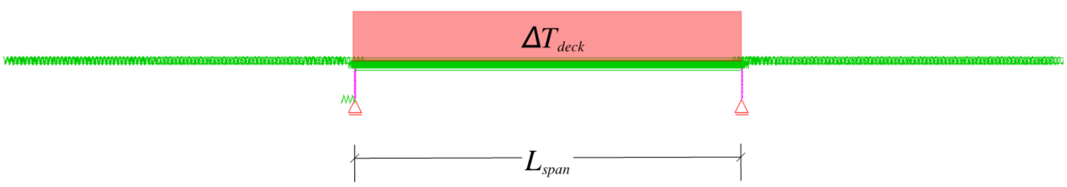


Figure 3.6 Temperature variation load case for E1-3 respectively F4-6.

The recommendations from UIC Code 774-3R (2001) described in section 2.6 state that the train only should be located on the bridge and on one of the adjacent embankments in case of a single span bridge to give accurate results. For the braking and vertical load case the train was therefore positioned as in Figure 3.7 to give the largest combined compressing rail stresses for the two different test cases. These positions and directions of the braking load were validated to give the largest compressive rail stresses through the method described in section 3.3.

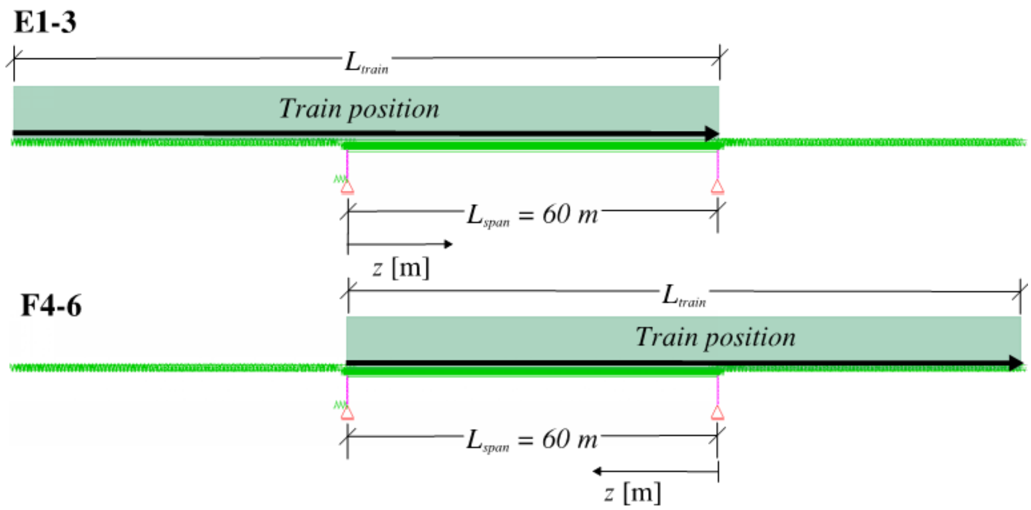


Figure 3.7 Train position for the braking force load case and the vertical load case for test case E1-3 respectively F4-6.

The rail stresses σ_{rail} in the result tables in chapter 5 are calculated as:

$$\sigma_{rail} = \frac{N_{rail}}{A_{60}} \tag{3.2}$$

where

A_{60} is the total area for the track, two UIC60 rail cross sections [m^2]

N_{rail} is the normal forces acting in the longitudinal direction of the rails [kN]

3.2.2 Center of gravity directly on the supports

The model is based on the assumptions and input parameters described in section 3.2.1, but, the center of gravity of the cross section is placed directly on the supports to be able to see how the position of the center of gravity influences the results. The system configuration can be seen in Figure 3.8. This model is only used to see how the position of the center of gravity influences the behavior of the normal forces.

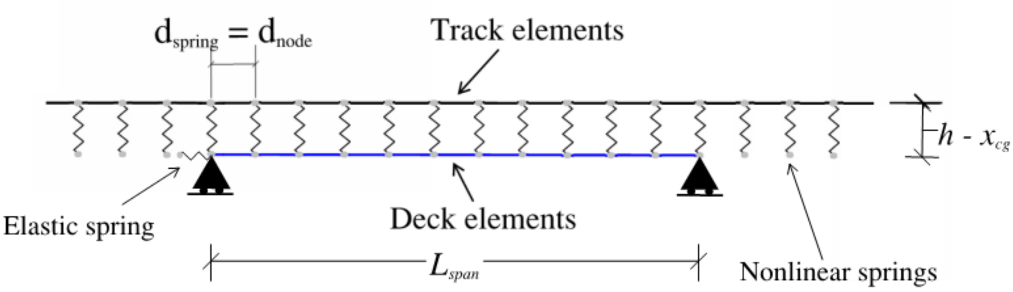


Figure 3.8 System configuration - center of gravity placed directly on the supports.

3.2.3 Center of gravity with an eccentricity from the supports

The model is based on the assumptions and input parameters described in section 3.2.1, but in this model, the deck elements are placed with an eccentricity from the support nodes equal to the distance x_{cg} from the bottom of the cross section to its center of gravity. The nonlinear springs that ties the track to the bridge is connected from the track nodes to the bottom nodes, see Figure 3.9.

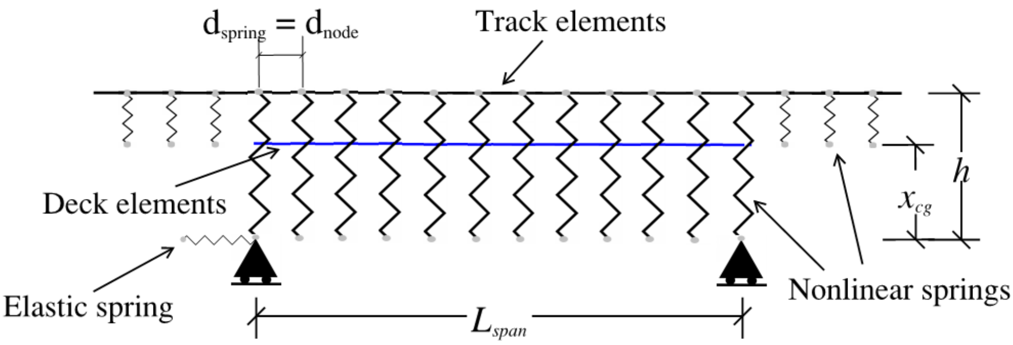


Figure 3.9 System configuration - center of gravity positioned with an eccentricity from the supports.

3.2.4 Center of gravity coupled to the supports with two coupled nodes

The model is based on the assumptions and input parameters described in section 3.2.1. The center of gravity of the cross section is coupled to the support nodes through coupling nodes that is simulating a rigid connection. The springs that connects the track to the bridge are connected from the track nodes to the nodes located in the center of gravity of the cross section. The system configuration can be seen in Figure 3.10.

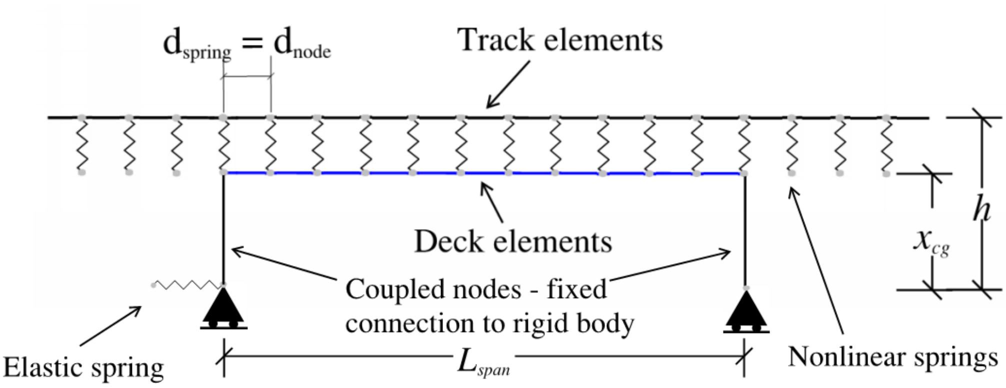


Figure 3.10 System configuration - center of gravity coupled to the supports with two coupled nodes.

3.2.5 Choice of system

After a comparison of the results from each test model with the results gained from the hand calculation in Appendix 1 and the computer calculation from UIC Code 774-3R (2001) the model with the center of gravity coupled to the supports with two coupled nodes was chosen as the system to be used in the rest of the project. The results and the analysis are presented in section 5.1.3 and 5.1.4. In Appendix 5 the CADINP code for the chosen model can be seen.

3.3 Determination of the largest compressive rail stresses and the worst train position

The train loads were moved over the bridge in the model with the coupled nodes to be able find the train position that gives the largest combined compressing rail stresses in some part of the rail. For test case F4-6 both travel directions were considered for the braking force load case for every train position.
Different spring stiffnesses was used in the loaded and unloaded part of the model for all positions. The results and the worst position of the train are presented in section 5.2.

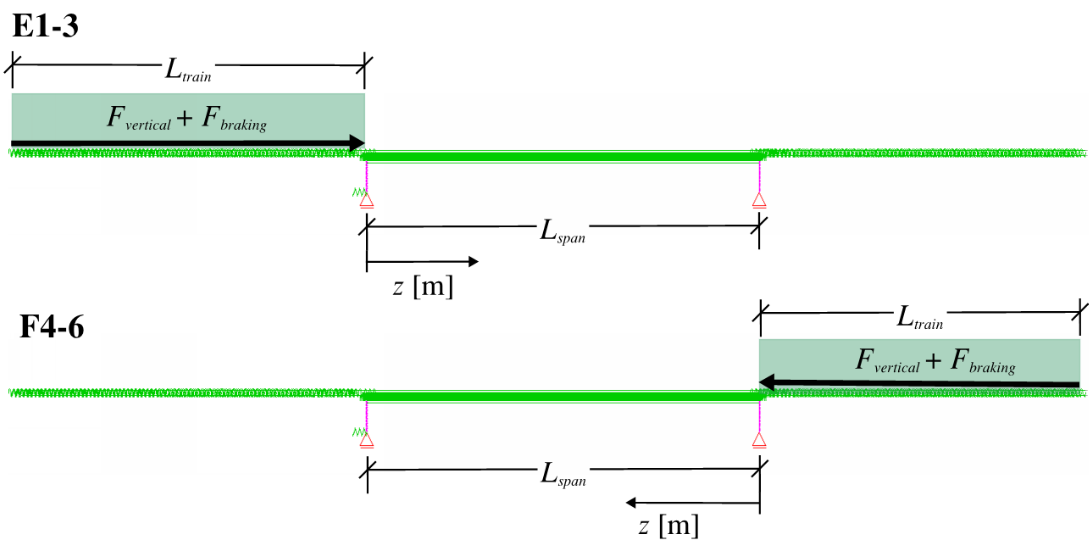


Figure 3.11 Load position illustration for the braking force load case respectively the vertical load case.

4 SOFiSTiK model – non-ballasted track on railway bridges

4.1 Simple span bridge with non-ballasted track - model descriptions

The chosen FEA-model described in section 3.2.4 for the bridge with ballasted track is modified to work for non-ballasted track bridges. Two different models are used to be able to compare the results, one model without a floating slab mat under the track slab and one model with a floating slab mat under the track slab.

The CADINP code for the models described in section 4.1.2 and section 4.1.3 can be found in Appendix 5.

4.1.1 Common parameters and assumptions for the two non-ballasted track models

The same train positions and load cases that were used for the ballasted track in chapter 3 are used for both models. The compressive rail stresses at the movable support are compared. The illustration of the train positions is shown in Figure 3.7

Only the floating slab mats influence on the compressive rail stresses are of interest at the movable support. The support reaction and the absolute displacement of the deck are therefore not considered.

The same input parameters for the two test cases from Table 3.1 are used in the models together with the input parameters in Table 4.1, Table 4.2, section 4.1.2 and section 4.1.3 for respectively test case, with and without a floating slab mat.

The recommended values from UIC Code 774-3R (2001) for non-ballasted tracks are used, see Table 4.1.

Table 4.1 Input parameters and loads to the slab track models.

Input parameters and loads	Value	Unit
Distance between each node, d_{node}	0,6	m
Distance between each spring, d_{spring}	0,6	m
Plastic displacement resistance for the unloaded track, $k_{plastic,unloaded}$	40	kN/m
Plastic displacement resistance for the loaded track, $k_{plastic,loaded}$	60	kN/m
Displacement between the elastic and plastic zones, u_0	0,5	mm
Thermal variation for the deck, ΔT_{deck}	35	°C
Thermal expansion coefficient for the deck, α_{deck}	$1{,}00\times10^{-5}$	1/K
Total area for the track, two UIC60 rail cross-sections, A_{60}	$1{,}537\times10^{-2}$	m^2
Total moment of inertia for the rail, $I_{y,rail}$	$6{,}077\times10^{-5}$	m^4
Train length, L_{train}	300	m
Vertical train load, $F_{vertical}$	80	kN/m
Horizontal braking force, $F_{braking}$	20	kN/m

The assumed geometry and the properties of the track slab used in the analyses are shown in Figure 4.1 respectively Table 4.2.

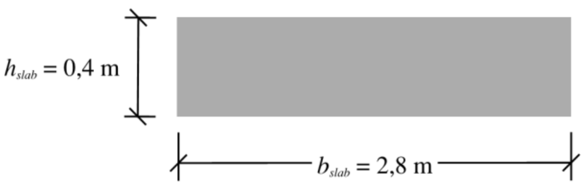


Figure 4.1 Assumed track slab geometry.

Table 4.2 Slab track properties.

Track slab properties	**Value**	**Unit**
Track slab area, A_{slab}	1,12	m^2
Total moment of inertia for the track slab, $I_{y,slab}$	0,0149	m^4
Concrete	C30/37	-

Both models are based on the system configuration shown in Figure 4.2 which is an evolution of the model described in section 3.2.4. The connection between the rail and the track slab is modelled through nonlinear springs with the same stiffness in the vertical and horizontal direction, whereas the connection between the track slab and the deck is modelled through elastic springs with different stiffnesses in the vertical and horizontal direction. The track slab, the rails and the bridge deck are modelled as elastic 2D beam elements. More detailed information of how the model is configured for each model with and without the floating slab mat are described in section 4.1.2 and section 4.1.3.

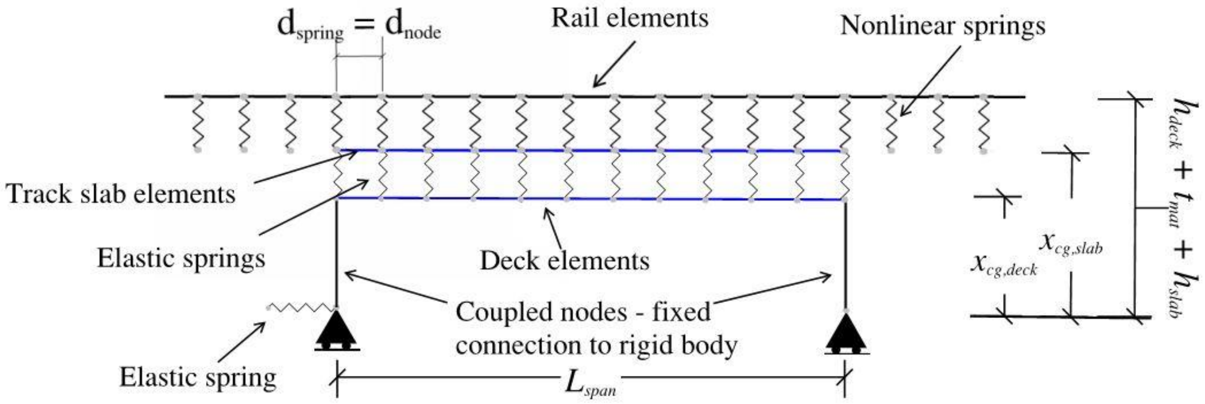


Figure 4.2 Slab track model.

4.1.2 Model without a floating slab mat (elastic mat) under the track slab

In this model it is assumed that the shear keys take up all the horizontal forces and transfer them to the bridge structure directly. The stiffness of the elastic springs is therefore chosen to be infinitely large in the CADINP code. This assumption is used in the model seen in Figure 4.2 together with the input data from Table 3.1, Table 4.1 and Table 4.2.

4.1.3 Model with a floating slab mat (elastic mat) under the track slab

The floating slab mat is assumed to be installed on the sides and on the top of the shear keys, see Figure 4.3 and Figure 4.4.

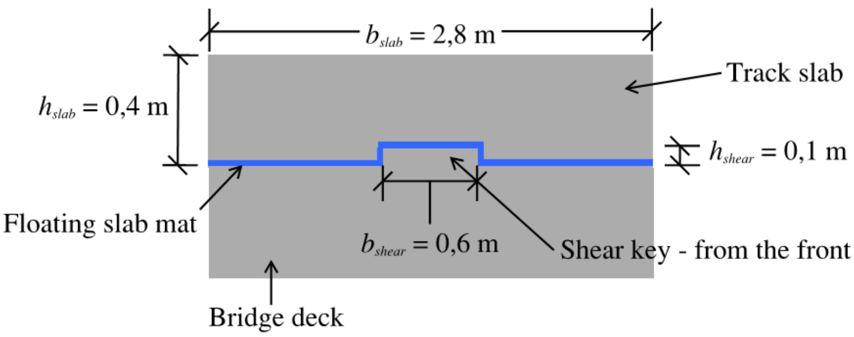


Figure 4.3 Front view of the track slab with a floating slab mat. Not in scale.

It is assumed that there is a shear key every three meter between the track slab and the bridge deck, see Figure 4.4.

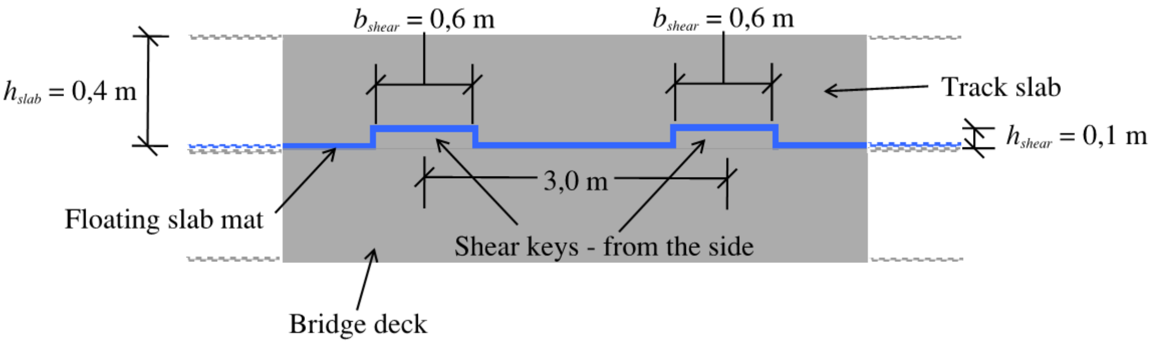


Figure 4.4 Side view of the track slab with a floating slab mat. Not in scale.

A simplification is made where the floating slab mats force-displacement behavior is assumed to be linear elastic. The elastic springs that simulates the shear keys are inserted every three meters in the model shown in Figure 4.2. The shear key springs have one vertical and one horizontal stiffness simulating the floating slab mats stiffness on top of and on the sides of the shear keys. Between these shear key springs, the springs that simulates the slab mat are placed. Two different cases for mat springs are considered to see how the horizontal stiffness of the mat influences the rail stresses. In one of the cases it is assumed that the mat springs have a horizontal stiffness and in the second case the mat springs horizontal stiffness is assumed to be zero due to lack of friction between the mat and the bridge deck. This means that the shear keys in the second case does not have any help from the floating slab mat to withstand the longitudinal forces.

The mats horizontal stiffness for different mat thicknesses in Table 4.3 is calculated as:

$$k_{bm,mat,h} = \frac{k_{bm,mat,v}}{2(1+\nu_{mat})} \tag{4.1}$$

where

$k_{bm,mat,v}$ is the slab mats vertical stiffness [kN/m^3]

ν_{mat} is the Poisson's ratio of the mat material [-]

Equation (4.1) are the relation between slab mats vertical and horizontal stiffnesses. The interested reader can find the derivation of equation (4.1) in Appendix 6.

Equation 4.1 together with the Poisson's ratio for polyurethane (rubber) $\nu_{mat} = 0{,}5$ and the different vertical stiffnesses $k_{bm,mat,v}$ in Table 4.3 gives the horizontal stiffnesses in Table 4.3.

The values in Table 4.3 are multiplied with different reference areas in the model to give the stiffness in kN/m, see the comments in the input code for the system in Appendix 5 for an explanation.

The input data in Table 3.1, Table 4.1 – Table 4.4 and Figure 4.3 – Figure 4.4 together with the assumptions presented in this section are used in the slab track model seen in Figure 4.2.

Table 4.3 Static bedding modules for the elastic mat Trackelast STM / RPU / Blue from edilon sedra, (edilon sedra, 2017b).

Mat thickness, t_{mat} [mm]	**Static vertical bedding modulus, $k_{bm,mat,v}$ [kN/m^3]**	**Static horizontal bedding modulus, $k_{bm,mat,h}$ [kN/m^3]**
12,0	10000,0	3333,3
15,0	8000,0	2666,7
20,0	6000,0	2000,0
25,0	5000,0	1666,7
28,0	4000,0	1333,3
30,0	4000,0	1333,3
35,0	3000,0	1000,0

Table 4.4 Input parameters to the slab track model with a slab mat.

Input parameters to the model with a slab mat	**Value**	**Unit**
Shear key breadth, b_{shear}	0,6	m
Shear key height, h_{shear}	0,1	m
Floating slab mat breadth, b_{mat}	2,8	m

5 Results and analysis

5.1 Choice of system and software validation

5.1.1 Center of gravity directly on the supports

The results from the model with the center of gravity directly on the supports are not considered in the comparison between the models due to the strange behavior of the normal force in the vertical load case. If one compare the normal force diagram from the vertical load case in Figure 5.1 and Figure 5.2 with the other two models results from the same load case in Figure 5.3 and Figure 5.4 it is easy to see that this behavior is incorrect. It is also a logical consequence that the model reacts in this way as the center of gravity of the deck is not in its correct position in the model. More detailed results and diagrams are presented in Appendix 2.

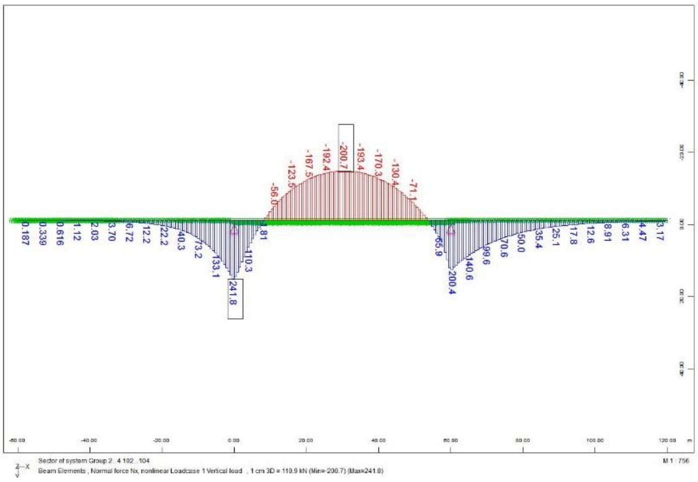


Figure 5.1 E1-3. Normal force diagram for the vertical load case from the model with the center of gravity directly on the supports.

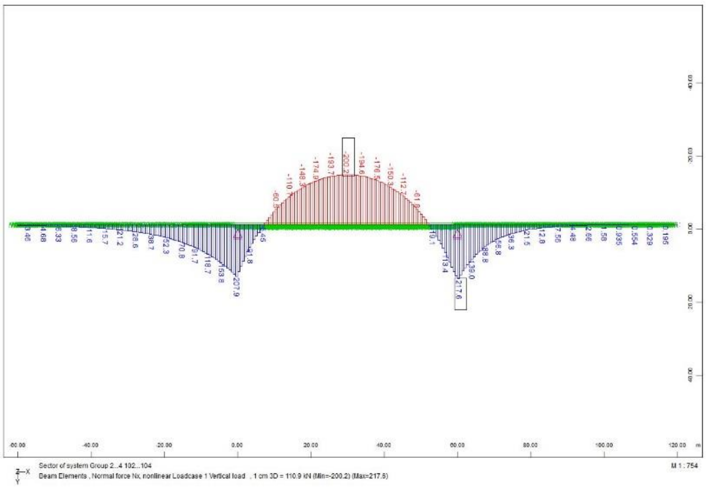


Figure 5.2 F4-6. Normal force diagram for the vertical load case from the model with the center of gravity directly on the supports.

5.1.2 *Center of gravity with an eccentricity from the supports*

Use of the model described in section 3.2.3 with the two test cases described in section 3.1.1 together with the load cases from section 3.2.1 gave the results in Table 5.1 and Table 5.2. The normal force diagrams from which the normal force values in Table 5.1 and Table 5.2 have been taken from can be found in Appendix 2.

From each load case the compressive rail stress at the movable support was combined through a linear superposition to get the total rail stress, see the discussion in section 5.1.3.

Table 5.1 Test case E1-3 - SOFiSTiK output for the model with the center of gravity positioned with an eccentricity from the supports.

Load case	N_{rail} **[kN]**	**Rail stress,** σ_{rail} **[MPa]**	**Top of the deck - abs.disp,** δ_{deck} **[mm]**	**Support reaction,** $F_{support}$ **[kN]**
Temperature variation - deck	-464,60	-30,22	-2,23	678,50
Braking	-259,80	-16,90	1,14	-683,70
Vertical bending - end rot	-305,40	-19,87	5,11	1004,00
Sum:		**-66,99**	**4,02**	**998,80**

Table 5.2 Test case F4-6 - SOFiSTiK output for the model with the center of gravity positioned with an eccentricity from the supports.

Load case	N_{rail} **[kN]**	**Rail stress,** σ_{rail} **[MPa]**	**Top of the deck - abs.disp,** δ_{deck} **[mm]**	**Support reaction,** $F_{support}$ **[kN]**
Temperature variation - deck	-398,00	-25,89	-4,78	461,60
Braking	-485,90	-31,61	-2,64	316,20
Vertical bending - end rot	-129,60	-8,43	3,36	479,80
Sum:		**-65,93**	**-4,06**	**1257,60**

5.1.3 *Center of gravity coupled to the supports with two coupled nodes*

Use of the model described in section 3.2.4 with the two test cases described in section 3.1.1 together with the load cases from section 3.2.1 gave the results in Table 5.3 and Table 5.4. From each load case the rail stress at the movable support was chosen and combined through a linear superposition to get the total rail stress. The compressive rail stresses at the movable support was used because it is in that position the largest combined compressive rail stresses occur, see section 5.2. The normal force diagrams from which the normal force values in Table 5.3 and Table 5.4 have been taken can be seen in Figure 5.3, Figure 5.4 and in Appendix 2 where detailed results and diagrams are presented.

Table 5.3 Test case E1-3 - Sofistik output for the model with the center of gravity coupled to the supports with two coupled nodes.

Load case	N_{rail} **[kN]**	**Rail stress,** σ_{rail} **[MPa]**	**Top of the deck - abs.disp,** δ_{deck} **[mm]**	**Support reaction,** $F_{support}$ **[kN]**
Temperature variation - deck	-493,20	-32,08	-1,28	768,30
Braking	-249,80	-16,25	1,19	-711,40
Vertical bending - end rot	-312,90	-20,36	4,89	1102,00
Sum:		**-68,69**	**4,80**	**1158,90**

Table 5.4 Test case F4-6 - Sofistik output for the model with the center of gravity coupled to the supports with two coupled nodes.

Load case	N_{rail} **[kN]**	**Rail stress,** σ_{rail} **[MPa]**	**Top of the deck - abs.disp,** δ_{deck} **[mm]**	**Support reaction,** $F_{support}$ **[kN]**
Temperature variation - deck	-419,10	-27,26	-4,66	496,60
Braking	-498,00	-32,40	-2,54	304,50
Vertical bending - end rot	-87,20	-5,67	3,17	496,40
Sum:		**-65,33**	**-4,03**	**1297,50**

5.1.4 Choice of system and software validation

The result from the models for the two test cases are summarized in Table 5.5 respectively Table 5.7. In Table 5.6 and Table 5.8 the percentage error are summarized for the results from the test models and the results from the computer calculation made by UIC Code 774-3R (2001) and the hand calculation performed in Appendix 1. The comparison is also presented in Appendix 2 with detailed results and normal force diagrams which shows where the normal forces that creates the rail stresses in Table 5.5 and Table 5.7 are taken from for every load case.

Table 5.5 Summary of the results for test case E1-3.

Test case E1-3	Load case	Rail stress, σ_{rail} [MPa]	Top of the deck - abs.disp, δ_{deck} [mm]	Support reaction, $F_{support}$ [kN]
Hand calculation	Temperature variation - deck	-30,00	-1,17	700,00
	Braking	-18,50	1,01	-603,33
	Vertical bending - end rot	-25,40	1,84	1106,67
	Sum:	**-73,90**	**1,68**	**1203,34**
UIC Computer calculation	Temperature variation - deck	-30,67	-1,69	700,12
	Braking	-16,42	1,36	-813,22
	Vertical bending - end rot	-16,98	3,77	977,70
	Sum:	**-64,07**	**3,44**	**864,60**
Sofistik Eccentric center of gravity	Temperature variation - deck	-30,22	-2,23	678,50
	Braking	-16,90	1,14	-683,70
	Vertical bending - end rot	-19,87	5,11	1004,00
	Sum:	**-66,99**	**4,02**	**998,80**
Sofistik Coupled nodes	Temperature variation - deck	-32,08	-1,28	768,30
	Braking	-16,25	1,19	-711,40
	Vertical bending - end rot	-20,36	4,89	1102,00
	Sum:	**-68,69**	**4,80**	**1158,90**

Table 5.6 Comparison of the error, calculated as a percentage, between the sums determined through each test model against the sums from the hand calculation and the computer calculation performed by UIC for test case E1-3.

Test case E1-3 - error against the sums from the hand calculation	Rail stress, σ_{rail} [%]	Top of the deck - abs.disp, δ_{deck} [%]	Support reaction, $F_{support}$ [%]
Sofistik Eccentric center of gravity	-9,3	139,3	-17,0
Sofistik Coupled nodes	-7,1	185,7	-3,7
Test case E1-3 - error against the sums from UIC's computer calculation	**Rail stress, σ_{rail} [%]**	**Top of the deck - abs.disp, δ_{deck} [%]**	**Support reaction, $F_{support}$ [%]**
Sofistik Eccentric center of gravity	4,6	16,9	10,3
Sofistik Coupled nodes	7,2	39,5	34,0

Figure 5.3 presents the normal force diagrams for test case E1-3 from the model with coupled nodes, more detailed normal force diagrams from the models in Table 5.5 can be found in Appendix 2.

The combined compressing normal force at the movable support from the diagrams in Figure 5.3 have been used in the linear superposition of the rail stresses in Table 5.3 and Table 5.5.

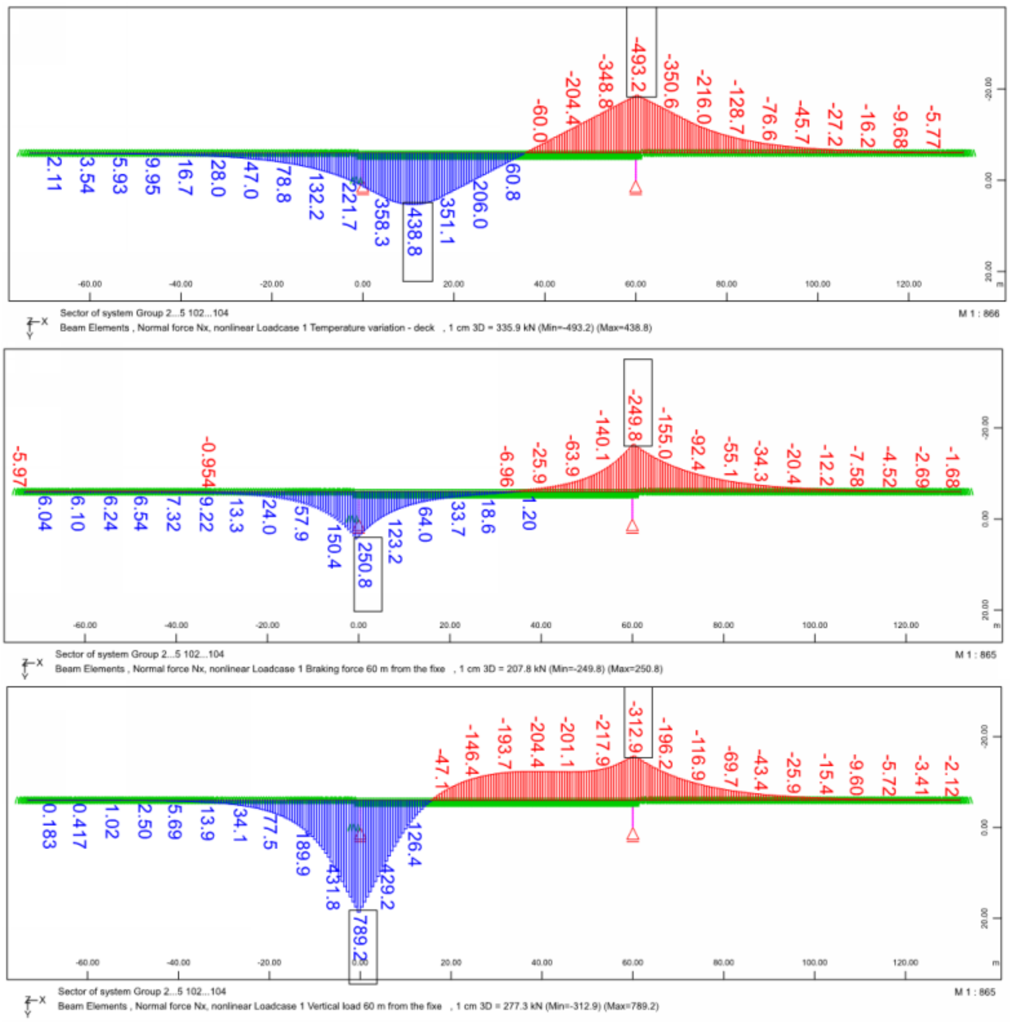


Figure 5.3 E1-3. Normal force diagrams from the model with coupled nodes. Top: Temperature variation for the deck. Middle: Braking load case. Bottom: Vertical load case.

Table 5.7 Summary of the results for test case F4-3.

Test case F4-6	**Load case**	**Rail stress, σ_{rail} [MPa]**	**Top of the deck - abs.disp, δ_{deck} [mm]**	**Support reaction, $F_{support}$ [kN]**
Hand calculation	Temperature variation - deck	-25,00	-4,08	490,00
	Braking	-30,00	-2,33	280,00
	Vertical bending - end rot	-10,10	4,43	532,00
	Sum:	**-65,10**	**-1,98**	**1302,00**
UIC Computer calculation	Temperature variation - deck	-25,97	-4,35	482,92
	Braking	-25,58	-3,19	383,07
	Vertical bending - end rot	-10,23	2,29	436,75
	Sum:	**-61,78**	**-5,25**	**1302,74**
Sofistik Eccentric center of gravity	Temperature variation - deck	-25,89	-4,78	461,60
	Braking	-31,61	-2,64	316,20
	Vertical bending - end rot	-8,43	3,36	479,80
	Sum:	**-65,93**	**-4,06**	**1257,60**
Sofistik Coupled nodes	Temperature variation - deck	-27,26	-4,66	496,60
	Braking	-32,40	-2,54	304,50
	Vertical bending - end rot	-5,67	3,17	496,40
	Sum:	**-65,33**	**-4,03**	**1297,50**

Table 5.8 Comparison of the error, calculated as a percentage, between the sums determined through each test model against the sums from the hand calculation and the computer calculation performed by UIC for test case F4-6.

Test case F4-6 - error against the sums from the hand calculation	Rail stress, σ_{rail} [%]	Top of the deck - abs.disp, δ_{deck} [%]	Support reaction, $F_{support}$ [%]
Sofistik Eccentric center of gravity	1,3	105,1	-3,4
Sofistik Coupled nodes	0,4	103,5	-0,3

Test case F4-6 - error against the sums from UIC's computer calculation	Rail stress, σ_{rail} [%]	Top of the deck - abs.disp, δ_{deck} [%]	Support reaction, $F_{support}$ [%]
Sofistik Eccentric center of gravity	6,7	-22,7	-3,5
Sofistik Coupled nodes	5,8	-23,2	-0,4

Figure 5.4 gives the normal force diagrams for test case F4-6 from the model with coupled nodes, more detailed diagrams with the normal forces from the models in Table 5.7 can be found in Appendix 2.

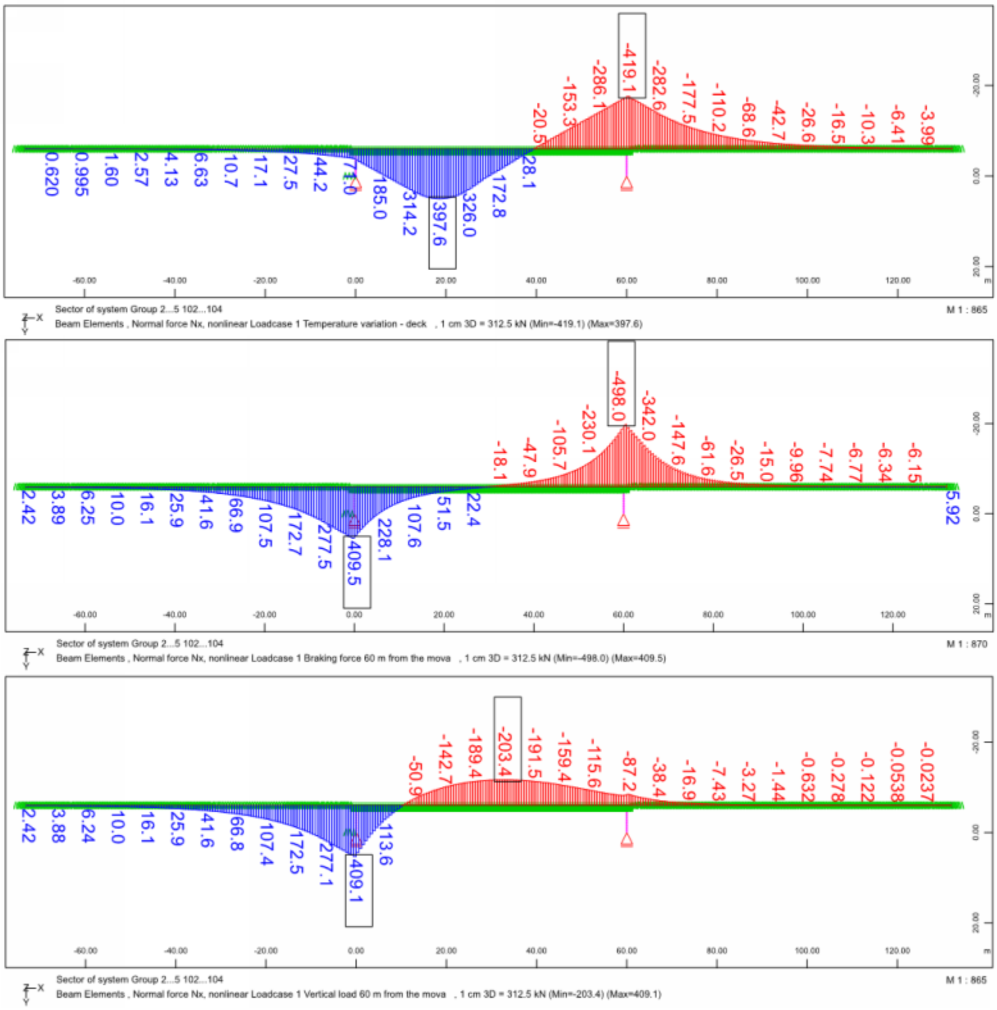


Figure 5.4 F4-6. Normal force diagrams from the model with coupled nodes. Top: Temperature variation for the deck. Middle: Braking load case. Bottom: Vertical load case.

The compressive normal forces at the movable support from the diagrams in Figure 5.4 have been used in the linear superposition of the rail stresses in Table 5.4 and Table 5.7. The largest compressive rail stress was produced when the braking force was directed towards the movable support (change of sign of the results from the braking force according to the recommendation explained in section 3.2.1).

After a comparison of the results in Table 5.5 – Table 5.8 the model with the coupled nodes is chosen as the model that best simulates the track and bridge interaction behavior. The choice of this model is based on the following conclusions from the test calculations:

- The model is the system that is most like the system configuration that UIC Code 774-3R (2001) and SS-EN 1991-2 (2010) recommends, see section 2.6.
- The results for the rail stresses are closest to both the hand calculated results and the computer calculated results performed by UIC Code 774-3R (2001) for most of the cases compared to the model with an eccentric center of gravity.
- The results for the rail stresses from the model are on the safe side for both test cases when it is compared to the computer calculation performed by UIC Code 774-3R (2001).
- The percentage error for the rail stresses compared to both the hand calculation and the computer calculated results performed by UIC Code 774-3R (2001) is small and within acceptable limits for this model. The acceptable limits can be seen in section 3.1.1.

The error of the sums of the compressive rail stresses is within the acceptable error of 10 % for both test cases when the simplified method is used, the software is therefore considered validated for the rail stresses, see Table 5.6 and Table 5.8. The purpose of this model is to investigate how the rail stresses are influenced so no further parameter study will be performed to get a better accuracy of the results from the other interaction effects.

5.2 Determination of the largest compressive rail stresses and the worst train position

From the detailed diagrams in Appendix 2 and Appendix 3 it is possible to determine that the largest combined compressive rail stresses with the simplified method occurs at the movable support for both test cases. Therefore the compressive rail stress at the movable support for different train positions is presented in Figure 5.5 and Figure 5.6. For both test cases the largest combined compressive rail stresses occur when the train is positioned at position z = 60 m in each model, see Table 5.9 and Table 5.10.

5.2.1 *E1-3 – Summary of the results*

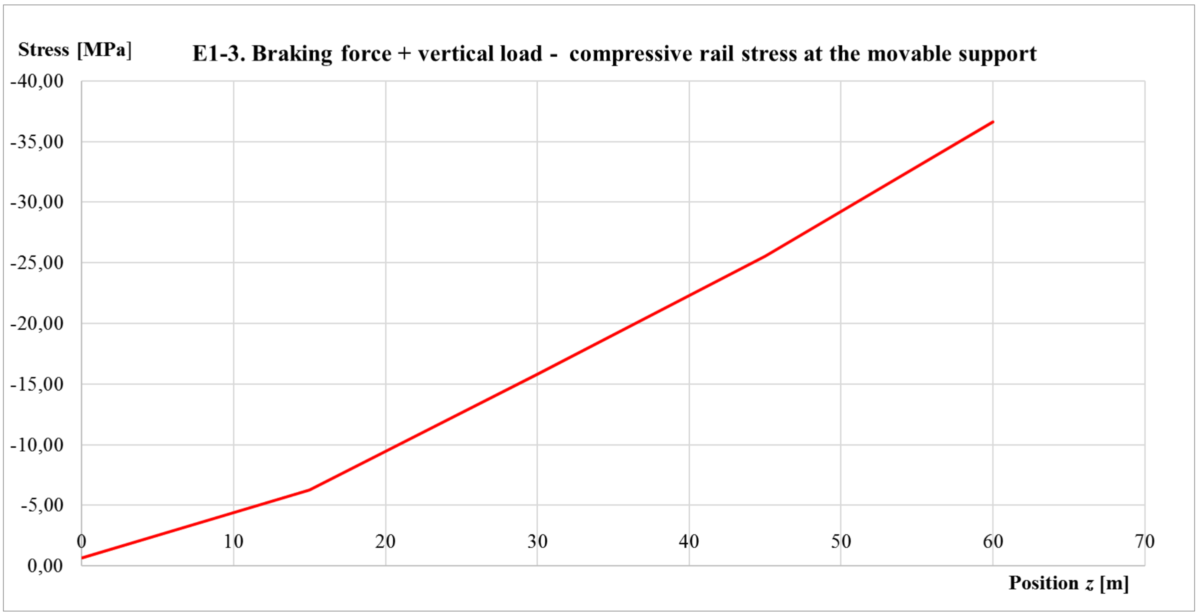


Figure 5.5 E1-3. Braking force + vertical load - compressive rail stress at the movable support for different train position z from the fixed support, see Figure 3.11 for an illustration of the train positions.

Table 5.9 combines the largest compressive rail stresses from the traffic loads with the rail stress from the temperature variation of the deck. The normal forces used in Table 5.9 can be seen in Figure 5.3.

Table 5.9 E1-3. Total compressive rail stress at the movable support, train position z = 60 m from the fixed support.

Load case	N_{rail} **[kN]**	**Rail stress,** σ_{rail} **[MPa]**
Temperature variation - deck	-493,20	-32,08
Braking	-249,80	-16,25
Vertical bending - end rot	-312,90	-20,36
Sum:		**-68,69**

5.2.2 *F4-6 – Summary of the results*

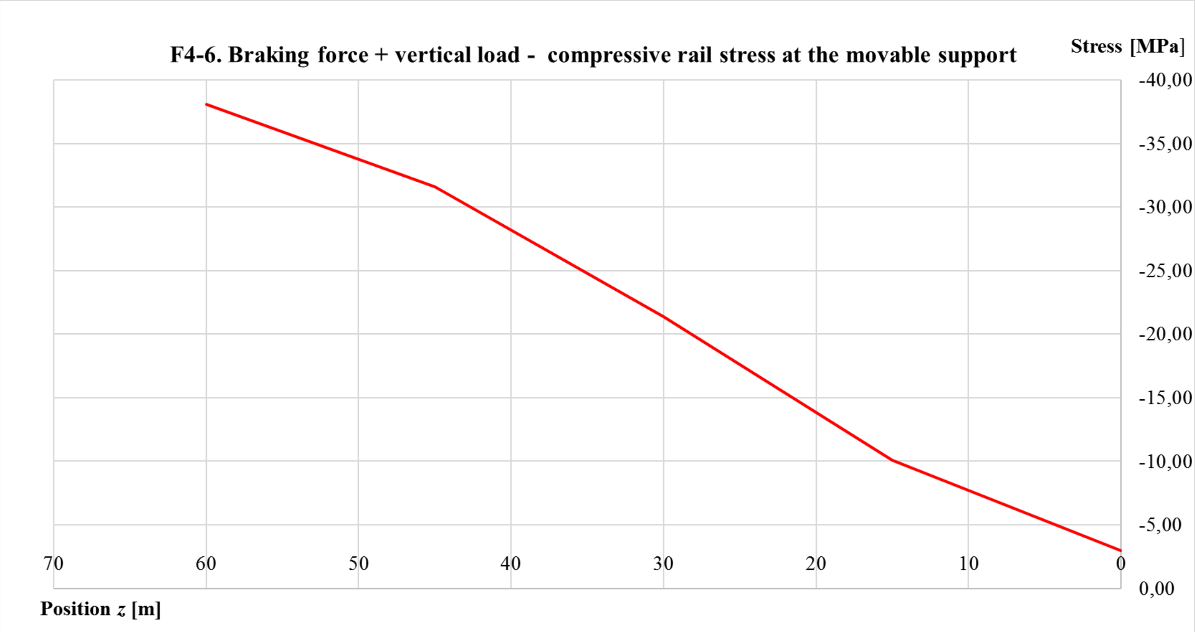


Figure 5.6 F4-6. Braking force + vertical load - compressive rail stress at the movable support for different train position z from the movable support, see Figure 3.11 for an illustration of the train positions.

The largest total compressive rail stress at the movable support is created when the braking force acts from the fixed support towards the movable support. The compressive rail stresses at the movable support for different train positions is shown in Table 5.10.

Table 5.10 combines the compressive rail stresses from the traffic loads with the rail stress from the temperature variation of the deck. The normal forces used in Table 5.10 can be seen in Figure 5.4.

Table 5.10 F4-6. Total compressive rail stress at the movable support, train position z = 60 m from the movable support.

Load case	N_{rail} **[kN]**	**Rail stress,** σ_{rail} **[MPa]**
Temperature variation - deck	-419,10	-27,26
Braking	-498,00	-32,40
Vertical bending - end rot	-87,20	-5,67
Sum:		**-65,33**

5.3 Simple span bridge with non-ballasted track - results

Detailed results from the two models with and without a floating slab mat are presented in Appendix 4 for both test cases. A comparison of the compressive rail stresses at the movable support from the models with and without a floating slab mat under the slab track is performed in section 5.3.1 and section 5.3.2.

5.3.1 E1-3 – Comparison of the results from the slab track models with and without a floating slab mat under the track slab

The compressive rail stresses at the movable support from the models with and without a floating slab mat are summarized in Table 5.11.

Table 5.11 E1-3. Compressive rail stresses at the movable support from the models with and without a floating slab mat.

	E1-3 floating slab mat with a horizontal stiffness			E1-3 floating slab mat without a horizontal stiffness		
Mat thickness [mm]	**Load case**	**N_{rail} [kN]**	**Rail stress, σ_{rail} [MPa]**	**Load case**	**N_{rail} [kN]**	**Rail stress, σ_{rail} [MPa]**
No mat 0,0	Temperature variation - deck	-887,0	-57,7	Temperature variation - deck	-887,0	-57,7
	Braking	-336,5	-21,9	Braking	-336,5	-21,9
	Vertical bending - end rot	-409,2	-26,6	Vertical bending - end rot	-409,2	-26,6
	Sum:		**-106,2**	**Sum:**		**-106,2**
12,0	Temperature variation - deck	-816,2	-53,1	Temperature variation - deck	-810,2	-52,7
	Braking	-339,3	-22,1	Braking	-339,5	-22,1
	Vertical bending - end rot	-367,8	-23,9	Vertical bending - end rot	-363,7	-23,7
	Sum:		**-99,1**	**Sum:**		**-98,5**
15,0	Temperature variation - deck	-815,3	-53,0	Temperature variation - deck	-813,8	-52,9
	Braking	-339,3	-22,1	Braking	-339,5	-22,1
	Vertical bending - end rot	-366,4	-23,8	Vertical bending - end rot	-363,1	-23,6
	Sum:		**-98,9**	**Sum:**		**-98,6**
20,0	Temperature variation - deck	-817,7	-53,2	Temperature variation - deck	-813,8	-52,9
	Braking	-339,3	-22,1	Braking	-339,4	-22,1
	Vertical bending - end rot	-361,9	-23,5	Vertical bending - end rot	-362,1	-23,6
	Sum:		**-98,8**	**Sum:**		**-98,6**
25,0	Temperature variation - deck	-812,6	-52,9	Temperature variation - deck	-809,1	-52,6
	Braking	-339,3	-22,1	Braking	-339,4	-22,1
	Vertical bending - end rot	-363,3	-23,6	Vertical bending - end rot	-361,1	-23,5
	Sum:		**-98,6**	**Sum:**		**-98,2**
28,0	Temperature variation - deck	-811,7	-52,8	Temperature variation - deck	-809,0	-52,6
	Braking	-339,3	-22,1	Braking	-339,4	-22,1
	Vertical bending - end rot	-362,3	-23,6	Vertical bending - end rot	-360,5	-23,5
	Sum:		**-98,4**	**Sum:**		**-98,2**
30,0	Temperature variation - deck	-811,7	-52,8	Temperature variation - deck	-809,0	-52,6
	Braking	-339,3	-22,1	Braking	-339,4	-22,1
	Vertical bending - end rot	-361,9	-23,5	Vertical bending - end rot	-360,1	-23,4
	Sum:		**-98,4**	**Sum:**		**-98,1**
35,0	Temperature variation - deck	-813,2	-52,9	Temperature variation - deck	-813,2	-52,9
	Braking	-339,3	-22,1	Braking	-339,3	-22,1
	Vertical bending - end rot	-359,1	-23,4	Vertical bending - end rot	-359,1	-23,4
	Sum:		**-98,3**	**Sum:**		**-98,3**

Figure 5.7 and Figure 5.8 show the compressive rail stresses at the movable support from the models with and without a floating slab mat.

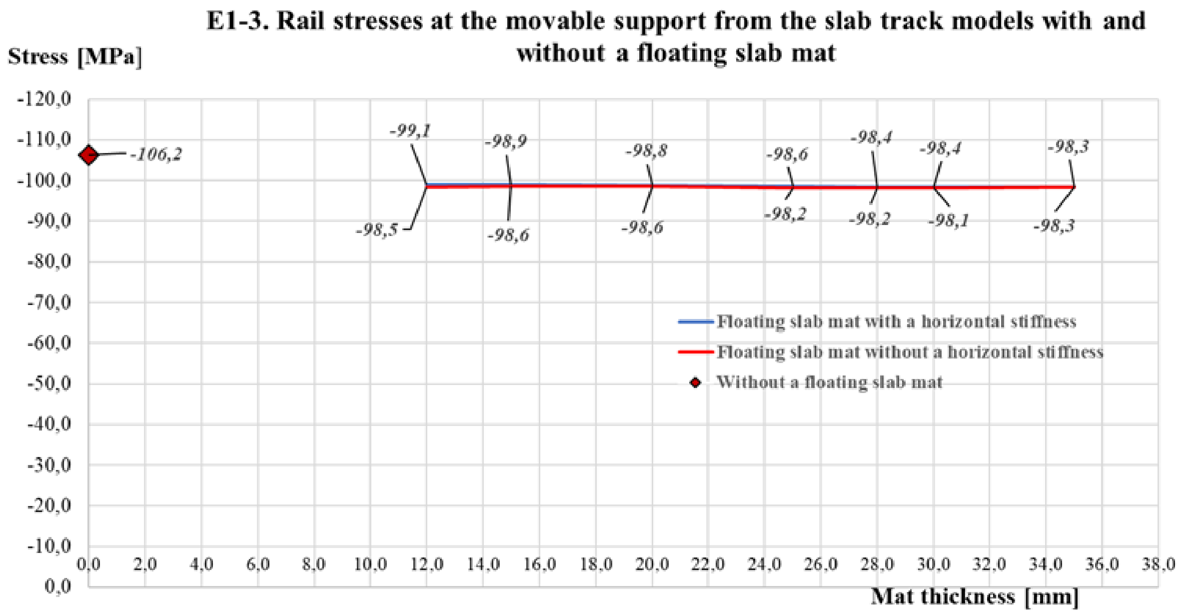


Figure 5.7 E1-3. Rail stresses at the movable support from the slab track models with and without a floating slab mat.

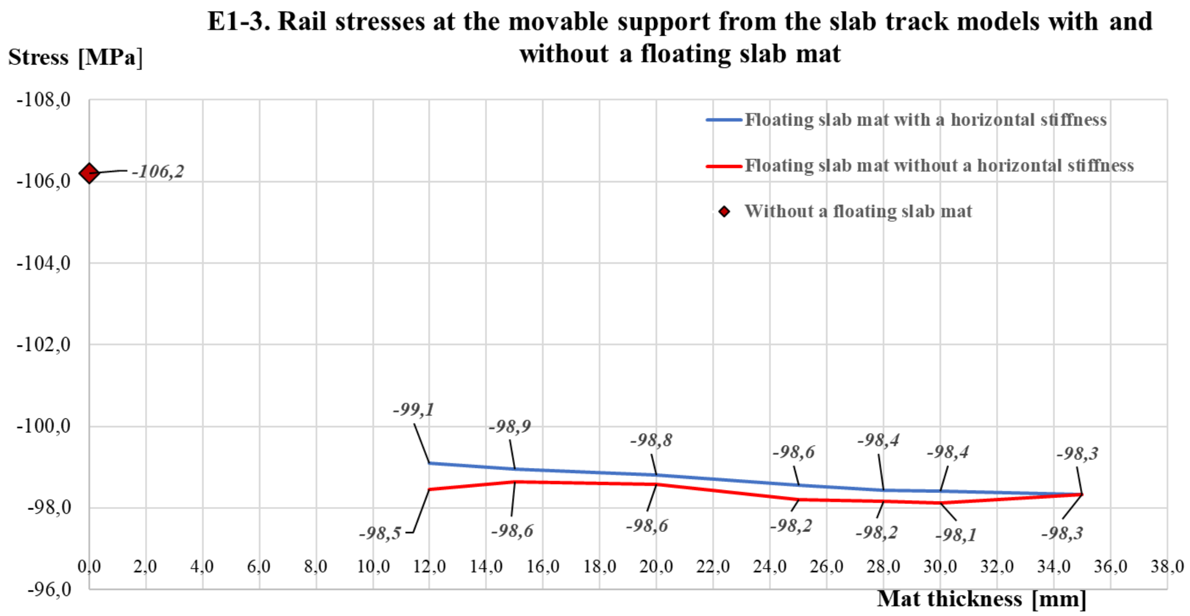


Figure 5.8 E1-3. Zoomed in - Rail stresses at the movable support from the slab track models with and without a floating slab mat.

From Table 5.11 and the diagrams in Figure 5.7 and Figure 5.8 it is possible to see that the use of a floating slab mat under the track slab does not affect the rail stresses to any significant extent (a reduction by approximately 7 %). It can also be seen that the horizontal stiffness of the floating slab mat slightly increases the rail stresses in comparison with the assumption that there is no friction between the bridge deck and the mat between the shear keys.

The decrease of the compressive rail stresses is assumed to be due to that the mat that is placed on the sides of the shear key acts like a damper which allows the track slab and the bridge to move more freely parallel to each other (decreased interaction between the track and the bridge). If the thickness of the mat is increased the stiffness of the mat will decrease, this leads to a larger damping effect and a reduction of the stresses. When the horizontal stiffness of the slab mat between the shear keys is considered the interaction between the track and the bridge is increased due to the friction between the mat, the track slab and the bridge deck. This leads to slightly higher compressive rail stresses for this case.

5.3.2 F4-6 – Comparison of the results from the slab track models with and without a floating slab mat under the track slab

The compressive rail stresses at the movable support from the models with and without a floating slab mat are summarized in Table 5.12.

Table 5.12 F4-6. Compressive rail stresses at the movable support from the models with and without a floating slab mat.

	F4-6 floating slab mat with a horizontal stiffness			F4-6 floating slab mat without a horizontal stiffness		
Mat thickness [mm]	**Load case**	**N_{rail} [kN]**	**Rail stress, σ_{rail} [MPa]**	**Load case**	**N_{rail} [kN]**	**Rail stress, σ_{rail} [MPa]**
No mat 0	Temperature variation - deck	-661,00	-43,00	Temperature variation - deck	-661,00	-43,00
	Braking	-504,20	-32,80	Braking	-504,20	-32,80
	Vertical bending - end rot	60,00	3,90	Vertical bending - end rot	60,00	3,90
	Sum:		**-71,9**	**Sum:**		**-71,9**
12	Temperature variation - deck	-681,30	-44,32	Temperature variation - deck	-684,30	-44,52
	Braking	-505,00	-32,85	Braking	-505,00	-32,85
	Vertical bending - end rot	117,40	7,64	Vertical bending - end rot	129,40	8,42
	Sum:		**-69,5**	**Sum:**		**-69,0**
15	Temperature variation - deck	-682,30	-44,39	Temperature variation - deck	-681,60	-44,34
	Braking	-505,00	-32,85	Braking	-505,00	-32,85
	Vertical bending - end rot	121,00	7,87	Vertical bending - end rot	129,40	8,42
	Sum:		**-69,4**	**Sum:**		**-68,8**
20	Temperature variation - deck	-681,60	-44,34	Temperature variation - deck	-683,20	-44,44
	Braking	-505,00	-32,85	Braking	-505,00	-32,85
	Vertical bending - end rot	123,00	8,00	Vertical bending - end rot	130,30	8,48
	Sum:		**-69,2**	**Sum:**		**-68,8**
25	Temperature variation - deck	-681,50	-44,33	Temperature variation - deck	-683,20	-44,44
	Braking	-504,70	-32,83	Braking	-504,70	-32,83
	Vertical bending - end rot	128,80	8,38	Vertical bending - end rot	131,10	8,53
	Sum:		**-68,8**	**Sum:**		**-68,7**
28	Temperature variation - deck	-683,00	-44,43	Temperature variation - deck	-681,60	-44,34
	Braking	-504,70	-32,83	Braking	-504,70	-32,83
	Vertical bending - end rot	129,90	8,45	Vertical bending - end rot	131,60	8,56
	Sum:		**-68,8**	**Sum:**		**-68,6**
30	Temperature variation - deck	-681,70	-44,35	Temperature variation - deck	-674,80	-43,90
	Braking	-507,70	-33,03	Braking	-504,70	-32,83
	Vertical bending - end rot	129,70	8,44	Vertical bending - end rot	131,90	8,58
	Sum:		**-68,9**	**Sum:**		**-68,1**
35	Temperature variation - deck	-681,30	-44,32	Temperature variation - deck	-682,40	-44,39
	Braking	-504,70	-32,83	Braking	-504,70	-32,83
	Vertical bending - end rot	131,10	8,53	Vertical bending - end rot	132,80	8,64
	Sum:		**-68,6**	**Sum:**		**-68,6**

Figure 5.9 and Figure 5.10 show the compressive rail stresses at the movable support from the models with and without a floating slab mat.

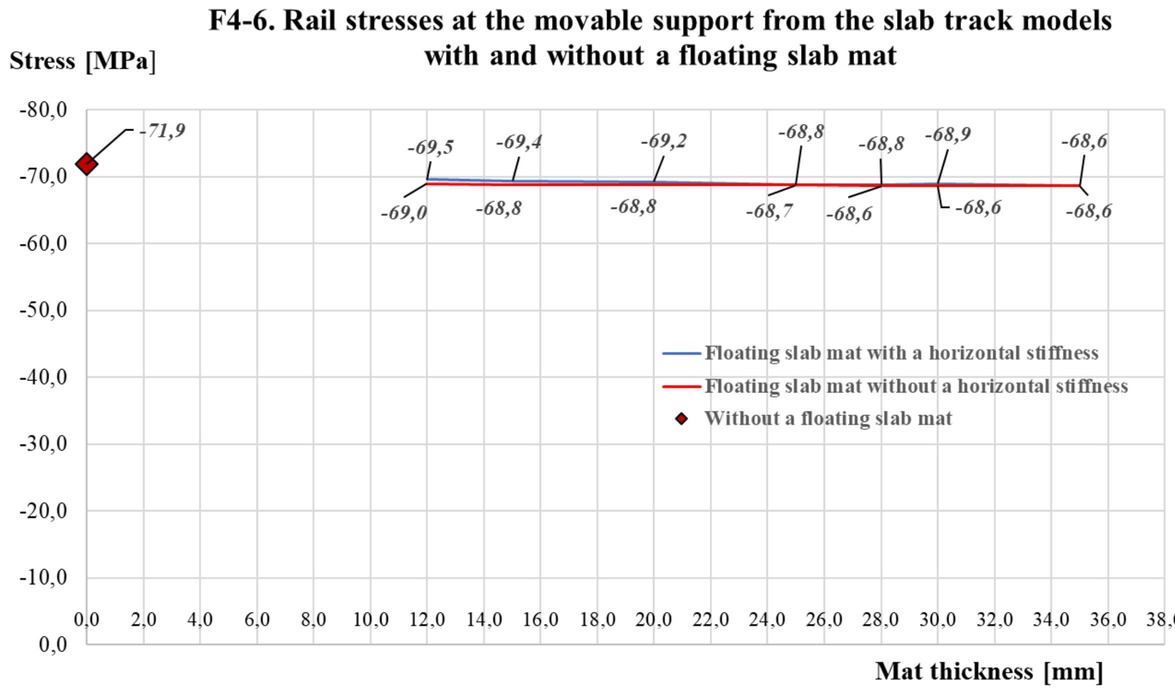


Figure 5.9 F4-6. Rail stresses at the movable support from the slab track models with and without a float-ing slab mat.

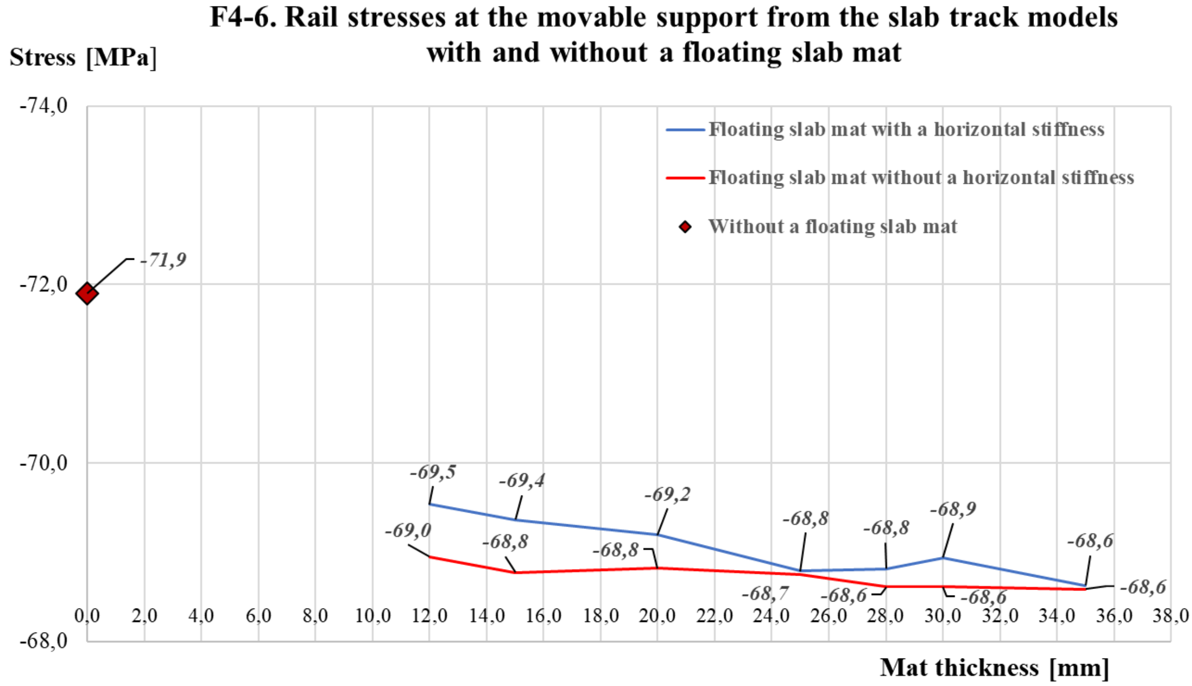


Figure 5.10 F4-6. Zoomed in - Rail stresses at the movable support from the slab track models with and without a floating slab mat.

From Table 5.12 and the diagrams in Figure 5.9 and Figure 5.10 it is possible to see that the use of a floating slab mat under the track slab does not affect the rail stresses to any significant extent (a reduction by approximately 3 – 5%). It can also be seen that the horizontal stiffness of the floating slab mat slightly increases the rail stresses in comparison with the assumption that there is no friction between the bridge deck and the mat between the shear keys.

The decrease of the compressive rail stresses is assumed to be due to that the mat that is placed on the sides of the shear key acts like a damper which allows the track slab and the bridge to move more freely parallel to each other (decreased interaction between the track and the bridge). If the thickness of the mat is increased the stiffness of the mat will decrease, this leads to a larger damping effect and a reduction of the stresses. When the horizontal stiffness of the slab mat between the shear keys is considered the interaction between the track and the bridge is increased due to the friction between the mat, the track slab and the bridge deck. This leads to slightly higher compressive rail stresses for this case.

6 Discussion and conclusions

6.1 Discussion

From the results in section 5.3 it can be seen that the compressive rail stresses are influenced by the floating slab mat with a small degree. The results from the investigation showed that there was a small reduction of the compressive rail stresses by approximately 3 – 7% (depending on the stiffness of the elastic support, load positions and the properties of the mat) when a mat was installed under the track slab. The results from the investigation also showed that there was a small reduction (up to approximately 1 %) of the compressive stresses in the rail when the thickness of the mat was increased, and the stiffness of the mat was reduced.

The decrease of compressive rail stresses is assumed to be due to the lower stiffness that is created by the floating slab mat placed on the sides of the shear keys, see Figure 4.3 and Figure 4.4. The mat acts as a damper which allows the track slab and the bridge to move more freely parallel to each other. This reduces the interaction between the track and the bridge, therefore, also compressive rails stresses are reduced. If the thickness of the mat is increased the stiffness of the mat will decrease, this leads to a larger damping effect and a reduction of the stresses. Without the mat all forces will be directly transferred into the shear keys. This results in an increased interaction between the track and the bridge and larger compressive rail stresses. If the horizontal stiffness of the mat is considered the interaction between the track and the bridge is increased due to the friction between the mat, the track slab and the bridge deck. This will lead to slightly higher compressive rail stresses than in the case when the friction between the mat, track slab and the bridge deck is neglected. It is therefore on the safe side to assume that the floating slab mat also transfer some of the horizontal forces into the bridge structure.

The results in chapter 5 are valid for the models and test cases described in chapter 3 and chapter 4. Some assumptions have been made which may influence the results and create some uncertainties about the accuracy of the results for all possible cases that may occur in the reality. Examples of assumptions, simplifications and lack of information from UIC Code 774-3R (2001) that may have influenced the investigation results are:

- The geometry of the cross sections that UIC Code 774-3R (2001) has used in their test cases are not realistic, the height of the cross sections are very large compared to the cross sections that are used in reality.
- UIC Code 774-3R (2001) does not state anywhere what dimensions they have used for the bridge cross sections.
- UIC Code 774-3R (2001) does not state anywhere what thermal expansion coefficients they have used for the deck and the rails.
- UIC Code 774-3R (2001) does not state anywhere what vertical stiffness of the track they have used.
- It is not clear in the recommendations from UIC Code 774-3R (2001) where and in which direction they have placed the train loads when they use the simplified analysis method in the test models.
- It is not clear in the recommendations from UIC Code 774-3R (2001) where they have performed the linear superposition of the rail stresses when they use the simplified analysis method in the test models.
- The lack of accuracy for the absolute displacement of the top of the deck for the validation models. The error does not meet the acceptable validation limits. See the analysis and discussion about this simplification in section 5.1.4.

- The assumption that the track has the same stiffness in both the vertical and horizontal direction.
- The assumption that the floating slab mats material acts in a linear elastic way. Rubber cannot be infinitely compressed.
- The assumption that the mat has the same thickness everywhere in the model. According to PORR Group (2017) a mat with a lower stiffness should be applied on the top area of the shear keys to avoid punching. On the side areas of the shear keys a mat with a higher stiffness could be used.
- The assumed geometry and properties of the track slab and the shear keys.

6.2 Conclusions

The conclusion and answer to the research questions are that a small decrease occur of the compressive rail stresses if floating slab mats are used under the track slab on railway bridges. When the thickness of the mat is increased the vertical and horizontal stiffness of the mat will decrease. The lower stiffness of the mat that is wrapped around the sides of the shear keys lead to a reduction by approximately 3 – 7 %, depending on the stiffness of the elastic support, load positions and the properties of the mat, of the rail stresses due to a lower interaction between the track and the bridge. The rail stresses increase if the friction between the slab mat and the bridge deck is considered. This is due to that the interaction between the track and the bridge is increased by the horizontal stiffness of the mat. A reduction by approximately 1 % of the rail stresses can be seen in a comparison between the thinnest and the thickest mat.

These conclusions are valid for the models described in this master thesis and may change for other models.

6.3 Suggestions for further research

Further research in this area may be based on the following suggestions:

- Further develop the models and try to make a more complete parameter study to get better accuracy for all interaction effects.
- Try to find more information about the nonlinear behavior of the mat and use that information in the model to see how the results are affected.
- Use different thicknesses of the mat in different parts of the model to see how this influences the rail stresses.
- Try to use and develop these models to be able to test different bridge types to see if the results and conclusions also are valid for those cases.
- Try to get this model to work for the complete analysis method described in section 2.6 which takes the loading history into account to see how the results are affected if all nonlinear effects are considered.
- Create a more advanced 3D FEA-model of an existing railway bridge with slab track to see how the compressive rail stresses are influenced if a floating slab mat is introduced under the track slab.

The CADINP codes for the models are attached in Appendix 5 and is free to use and develop further if the user refers to this degree project in his or her work.

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Appendix 1
Hand calculation of the validation examples from UIC 774-3R

Table of Contents

1 Introduction and model description

The hand calculation examples in this document is based on the two test cases E1-3 and F4-6 from UIC Code 774-3R (2001, Appendix D). The model configuration is shown in figure 1 and the cross section considered in the test cases and the hand calcucations can be seen in figure 2.

According to UIC Code 774-3R (2001) was the following assumptions made in the calculations of the test cases:

- Ballasted track
- 300 m of embankment on each side of the bridge, see figure 1
- Resistance when the track is unloaded: 20 kN/m
- Resistance when the track is loaded with a vertical load of 80 kN/m: 60 kN/m
- Thermal variation for the deck: 35 °C
- Thermal variation for the rails: 50 °C
- Vertical load: 80 kN/m
- Horizontal braking force: 20kN/m
- Train length: 300 m
- The position of the rails center of gravity is considered to overlap with the top of the RC slab.

The direction of travel and the braking forces acts in the direction from the fixed support towards the movable support for test case E1-3, (direction 1). The direction for test case F4-6 is in the reverse direction (direction 2), see figure 1.
The horizontal forces and the horizontal displacements are defined as positive in the direction from the fixed support towards the movable support (direction 1).
The direction of travel influences the sign of the horizontal support reaction in the fixed support. When the train travels in direction 1 are the horizontal force that acts on the fixed support negative, and positive when the train travels in direction 2, (UIC Code 774-3R, 2001).

The graphs used for the design is evaluated for one track bridges with one simply-supported deck and a fixed support in one end, (UIC Code 774-3R, 2001).

In the hand calculations are the influence of the following parameters on the rail stresses, support reaction for the fixed bearing and the deformations considered:

- Temperature variations in the rail
- Temperature variations in the deck
- Braking actions
- End rotations

The effects of the interaction between the rail and the deck are according to UIC Code 774-3R (2001) given through:

- Additional rail stresses
- Relative displacement between the rail and deck
- Absolute displacement of the deck
- Horizontal reactions / horizontal forces at the fixed support

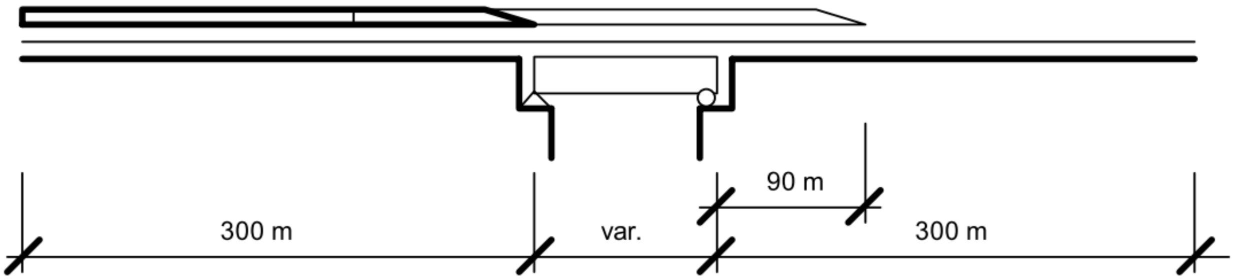


Figure 1. Model configuration, (UIC Code 774-3R, 2001).

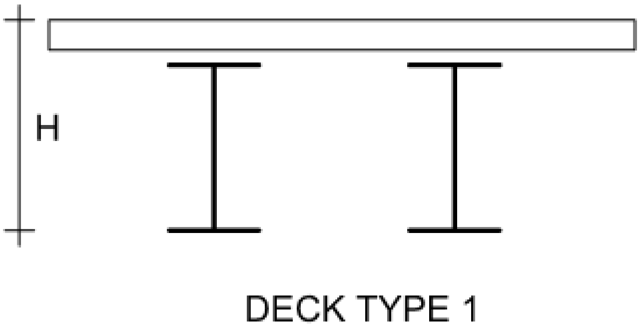


Figure 2. Deck type, (UIC Code 774-3R, 2001).

2 Hand calculation of test case E1-3 from Appendix D in UIC 774-3

The hand caclulation followed the same procedure as the hand calculation example "C-2 - Example 1a Simply-supported deck bridge with one elastic fixed support (deck slab bridge) / no expansion device" found in UIC Code 774-3R (2001, Appendix C).

Input data:

Simply-supported deck

One track

Deck length: $L := 60\ m$

Horizontal stiffness for the fixed support: $K_{fixed} := 600000\ \frac{kN}{m}$ $K_{fixed} = 600\ \frac{kN}{mm}$

$K_{10} := 10 \cdot L$

No friction in the movable bearing

Deck bridge with a cross section according to figure 2 with the following parameters:

Young's modulus: $E := 210\ GPa$ $E = \left(2.1 \cdot 10^{8}\right)\ \frac{kN}{m^2}$

Moment of inertia: $I := 2.590\ m^4$

Area: $A := 0.74\ m^2$

Height: $H := 6\ m$

Center of gravity / neutral axis: $x_{cg} := 4.79\ m$

Distance from the upper surface of the slab to the decks neutral axis, (positive direction downwards): $\omega := H - x_{cg} = 1.2\ m$

ω/H value used in calibrating diagrams found in UIC Code 774-3R (2001, Appendix B): $\gamma := \frac{\omega}{H} = 0.2$

Displacement of the slab due to the rotation of the end section of the deck for deck bridges, load model 71 [LM71]: $\theta H := 8\ mm$

UIC 60 continuous welded rails ---> $A_{60} := 15.372 \cdot 10^{-3}\ m^2$ / track

Horizontal resistance k of the connection between the track and the structure/embankment:

- Resistance for the unloaded track: a displacement of 2 mm between the elastic zone and the plastc zone and a resistance of 20 kN/m in the plastic phase: $k_{rail\_unloaded} := 20\ \frac{kN}{m}$

- Resistance for the loaded track (vertical load 80 kN/m): a displacement of 2 mm between the elastic zone and the plastc zone and a resistance of 40 kN/m in the plastic phase: $k_{rail\_loaded} := 60\ \frac{kN}{m}$

Coefficient of thermal expansion: $\alpha := 1.0 \cdot 10^{-5}$

Thermal variation for the deck: $\Delta T_{deck} := -35\ °C$

$\Delta T_{deck} := 35\ °C$

Thermal variation for the rail: $\Delta T_{rail} := -50\ °C$

$\Delta T_{rail} := 50\ °C$

Horizontal braking force: $F_{braking} := 20\ \frac{kN}{m}$

Vertical load: $F_{vertical} := 80\ \frac{kN}{m}$

Direction of travel: From the fixed support towards the movable support (direction 1), see figure 1.

2.1 Effects due to temperature variation

In figure 3 and 4 are the diagrams for the stresses in the rail due to the temperature variation for the case without an expansion device shown.
In figure 5 is the support reaction due to the temperature variation for the case without an expansion device shown.

Temperature interaction effects parameters:

$\Delta T_{deck} = 35\ °C$

$L = 60\ m$

$K_{fixed} = 600\ \frac{kN}{mm}$ ---> $K_{10} := 10 \cdot L$

Unloaded track: ---> $k_{20} := k_{rail\_unloaded} = 20\ \frac{kN}{m}$

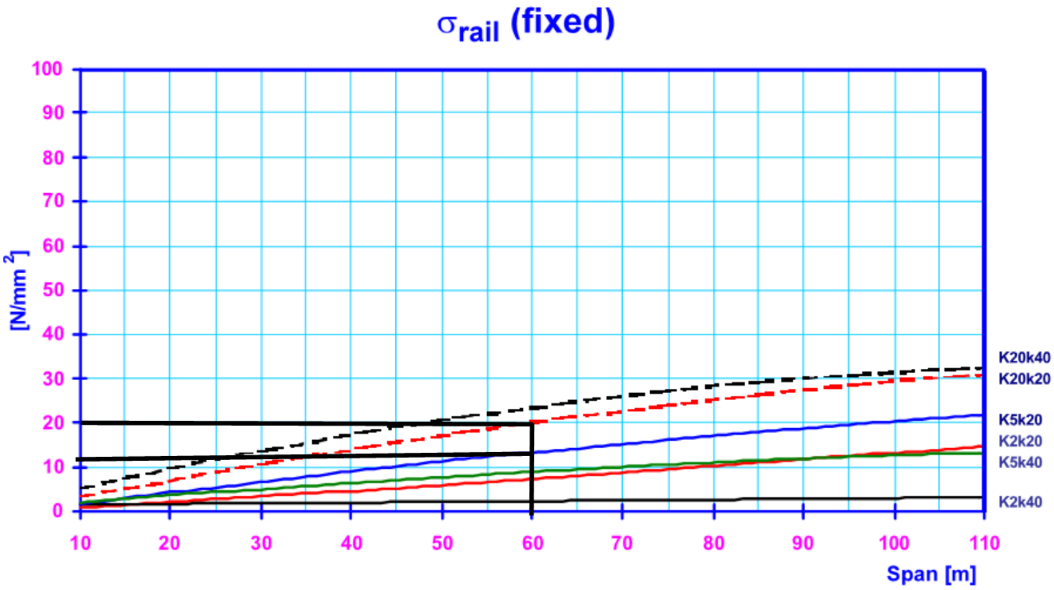


Figure 3. Temperature - variation load-case ($\Delta T_{deck} = 35\ °C$) (stresses in the fixed support), (UIC Code 774-3R, 2001).

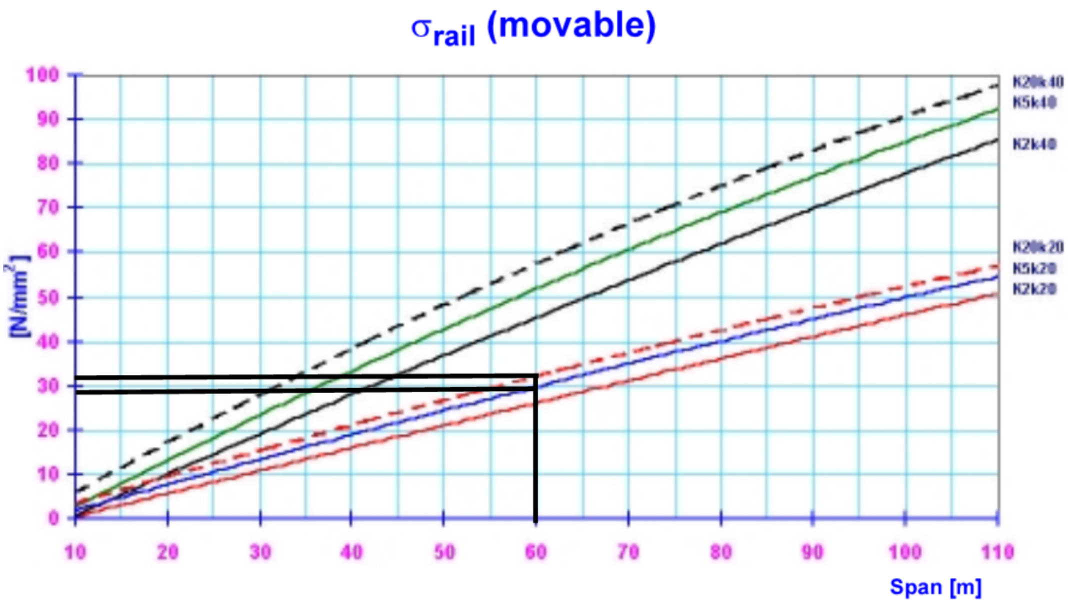


Figure 4. Temperature - variation load-case (ΔT_{deck} = 35 °C) (stresses in the movable support), (UIC Code 774-3R, 2001).

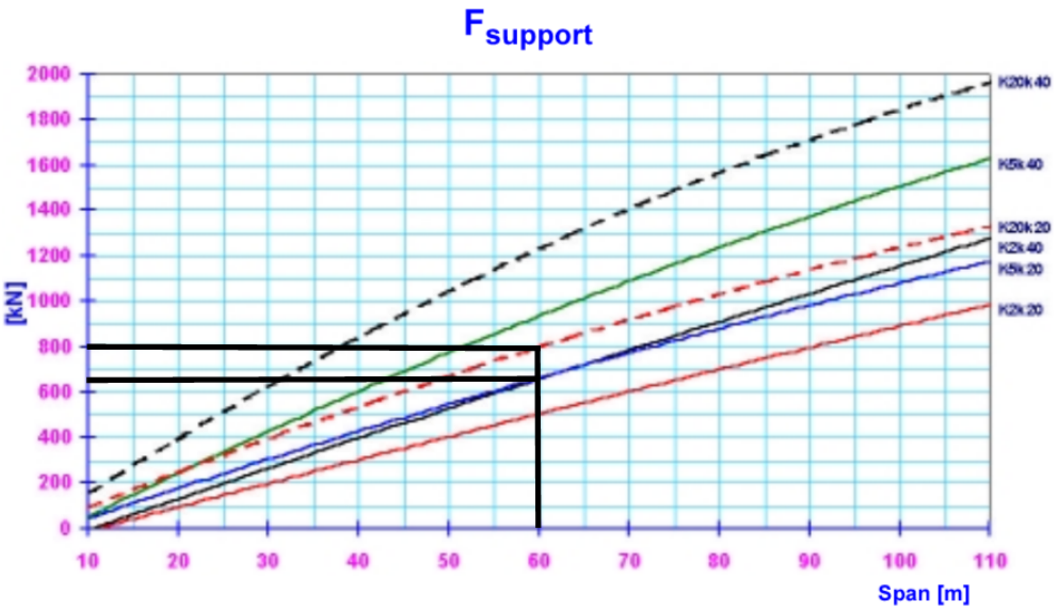


Figure 5. Temperature - variation load-case (ΔT_{deck} = 35 °C) (support reaction), (UIC Code 774-3R, 2001).

An linear interpolation between $K_5\ k_{20}$ and $K_{20}\ k_{20}$ is performed to get the stresses in the rail and the support reaction for $K_{10}\ k_{20}$ from the diagrams in figure 3, 4 and 5.

Fixed support, stresses in the rail due to temperature variation according to figure 3:

$K_5\ k_{20}$: $x_1 := 5$ $y_1 := 12\ \frac{N}{mm^2}$

$K_{20}\ k_{20}$: $x_2 := 20$ $y_2 := 20\ \frac{N}{mm^2}$

$K_{10}\ k_{20}$: $x := 10$

$$y := y_1 + \frac{(x - x_1) \cdot (y_2 - y_1)}{x_2 - x_1} \xrightarrow{explicit, ALL} 12\ \frac{N}{mm^2} + \frac{(10-5) \cdot \left(20\ \frac{N}{mm^2} - 12\ \frac{N}{mm^2}\right)}{20-5} = 14.7\ \frac{N}{mm^2}$$

Stresses in the rail at the fixed support: $\sigma_{rail\_fixed\_\Delta T} := y = 14.7\ \frac{N}{mm^2}$

Movable support, stresses in the rail due to temperature variation according to figure 4:

$K_5\ k_{20}$: $x_1 := 5$ $y_1 := 29\ \frac{N}{mm^2}$

$K_{20}\ k_{20}$: $x_2 := 20$ $y_2 := 32\ \frac{N}{mm^2}$

$K_{10}\ k_{20}$: $x := 10$

$$y := y_1 + \frac{(x - x_1) \cdot (y_2 - y_1)}{x_2 - x_1} \xrightarrow{explicit, ALL} 29\ \frac{N}{mm^2} + \frac{(10-5) \cdot \left(32\ \frac{N}{mm^2} - 29\ \frac{N}{mm^2}\right)}{20-5} = 30\ \frac{N}{mm^2}$$

Stresses in the rail at the movable support: $\sigma_{rail\_movable\_\Delta T} := y = 30\ \frac{N}{mm^2}$

Support reaction due to temperature variation according to figure 5:

$K_5\ k_{20}$: $x_1 := 5$ $y_1 := 650\ kN$

$K_{20}\ k_{20}$: $x_2 := 20$ $y_2 := 800\ kN$

$K_{10}\ k_{20}$: $x := 10$

$$y := y_1 + \frac{(x - x_1)\cdot(y_2 - y_1)}{x_2 - x_1} \xrightarrow{explicit, ALL} 650\ kN + \frac{(10-5)\cdot(800\ kN - 650\ kN)}{20-5} = 700\ kN$$

Support reaction: $F_{support\_\Delta T} := y = 700\ kN$

2.2 Effects due to braking

In figure 6 and 7 are the diagrams for the stresses in the rail due to braking for the case without an expansion device shown.
In figure 8 is the support reaction due to braking for the case without an expansion device shown.

Braking interaction effects parameters:

$L = 60\ m$

$K_{fixed} = 600\ \frac{kN}{mm}$ ---> $K_{10} := 10 \cdot L$

Loaded track: ---> $k_{60} := k_{rail\_loaded} = 60\ \frac{kN}{m}$

An linear interpolation between $K_5\ k_{60}$ and $K_{20}\ k_{60}$ is performed to get the stresses in the rail and the support reaction for $K_{10}\ k_{20}$ from the diagrams in figure 6, 7 and 8.

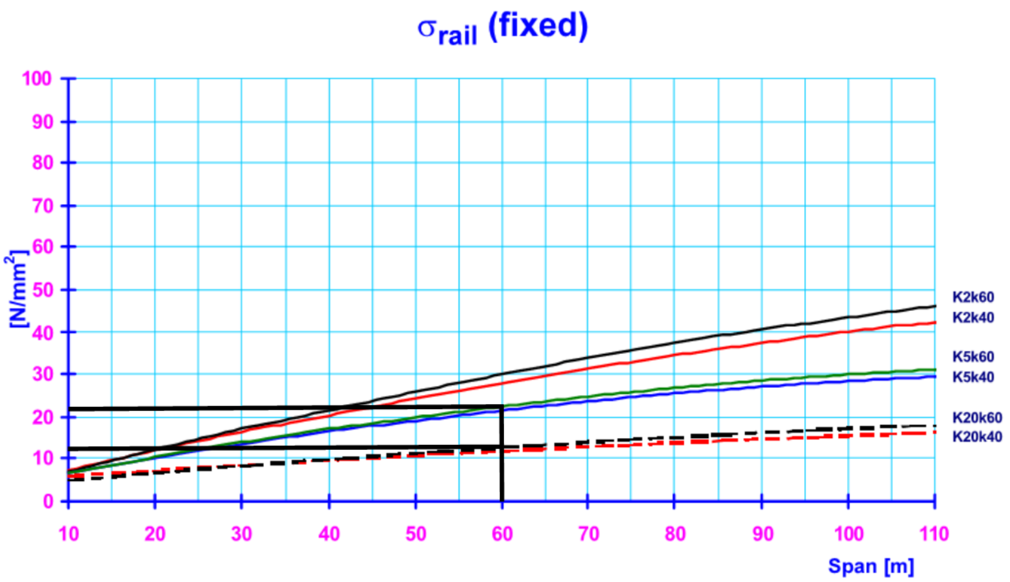


Figure 6. Braking load-case (fixed support) (20 kN/m), (UIC Code 774-3R, 2001).

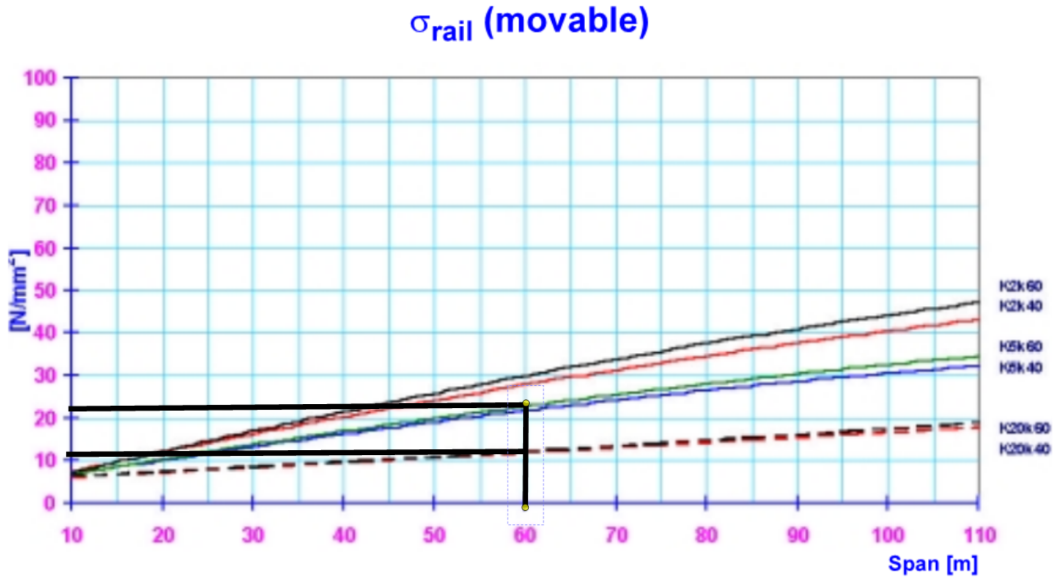


Figure 7. Braking load-case (movable support) (20kN/m), (UIC Code 774-3R, 2001).

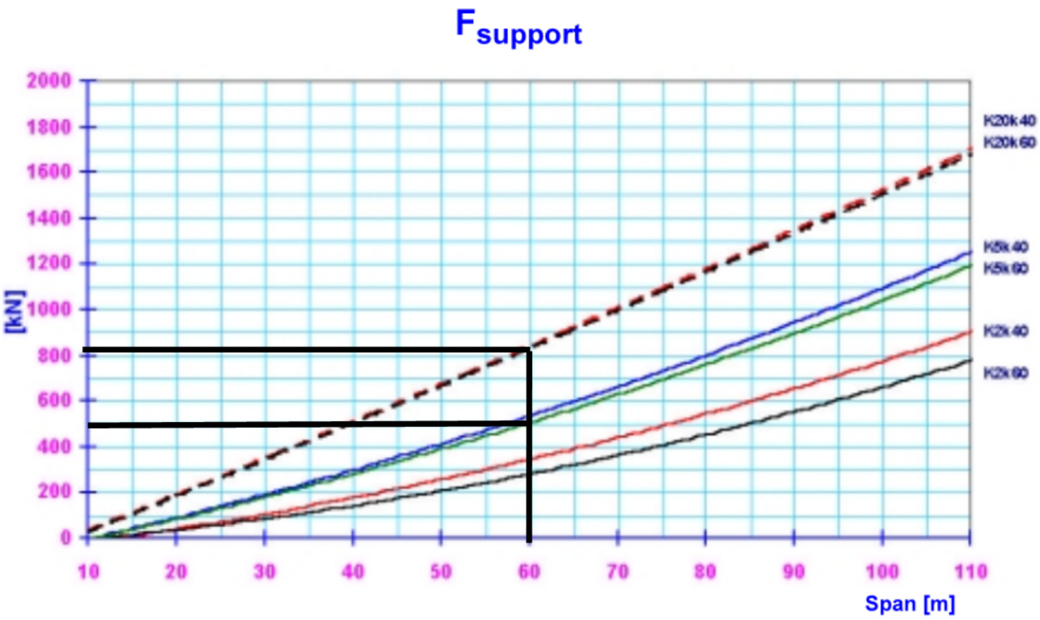


Figure 8. Braking - load-case (support reaction) (20kN/m), (UIC Code 774-3R, 2001).

Fixed support, stresses in the rail due to braking according to figure 6:

$K_5\ k_{60}$: $x_1 := 5$ $y_1 := 22\ \frac{N}{mm^2}$

$K_{20}\ k_{60}$: $x_2 := 20$ $y_2 := 11.5\ \frac{N}{mm^2}$

$K_{10}\ k_{60}$: $x := 10$

$$y := y_1 + \frac{(x - x_1) \cdot (y_2 - y_1)}{x_2 - x_1} \xrightarrow{explicit, ALL} 22\ \frac{N}{mm^2} + \frac{(10-5) \cdot \left(11.5\ \frac{N}{mm^2} - 22\ \frac{N}{mm^2}\right)}{20-5} = 18.5\ \frac{N}{mm^2}$$

Stresses in the rail at the fixed support: $\sigma_{rail\_fixed\_braking} := y = 18.5\ \frac{N}{mm^2}$

Movable support - stresses in the rail due to braking according to figure 7:

$K_5\ k_{60}$: $x_1 := 5$ $y_1 := 22\ \frac{N}{mm^2}$

$K_{20}\ k_{60}$: $x_2 := 20$ $y_2 := 11.5\ \frac{N}{mm^2}$

$K_{10}\ k_{60}$: $x := 10$

$$y := y_1 + \frac{(x - x_1) \cdot (y_2 - y_1)}{x_2 - x_1} \xrightarrow{explicit, ALL} 22\ \frac{N}{mm^2} + \frac{(10-5) \cdot \left(11.5\ \frac{N}{mm^2} - 22\ \frac{N}{mm^2}\right)}{20-5} = 18.5\ \frac{N}{mm^2}$$

Stresses in the rail at the movable support: $\sigma_{rail\_movable\_braking} := y = 18.5\ \frac{N}{mm^2}$

Support reaction due to braking according to figure 8:

$K_5\ k_{20}$: $x_1 := 5$ $y_1 := 490\ kN$

$K_{20}\ k_{20}$: $x_2 := 20$ $y_2 := 830\ kN$

$K_{10}\ k_{20}$: $x := 10$

$$y := y_1 + \frac{(x - x_1) \cdot (y_2 - y_1)}{x_2 - x_1} \xrightarrow{explicit, ALL} 490\ kN + \frac{(10 - 5) \cdot (830\ kN - 490\ kN)}{20 - 5} = 603.3\ kN$$

Support reaction: $F_{support\_braking} := y = 603.3\ kN$

The train moves in the direction from the fixed support against the movable support,
see figure 1, therefore is the braking force that acts on the fixed support negative:

Support reaction: $F_{support\_braking} := -F_{support\_braking} = -603.3\ kN$

2.3 Effects due to vertical bending

In figure 9 and 10 are the diagrams for the stresses in the rail due to vertical bending for the case without an expansion device shown.
In figure 11 is the support reaction due to vertical bending for the case without an expansion device shown.

Vertical bending interaction effects parameters:

Deck bridge

$\theta H = 8\ mm$

$L = 60\ m$

$K_{fixed} = 600\ \frac{kN}{mm}$ ---> $K_{10} := 10 \cdot L$ $\gamma = 0.2$

UIC60 --> A_{60}

An linear interpolation is performed to get the stresses in the rail and the support reaction for $\gamma = 0.2 / K_{10}$ from the diagrams in figure 9, 10 and 11.

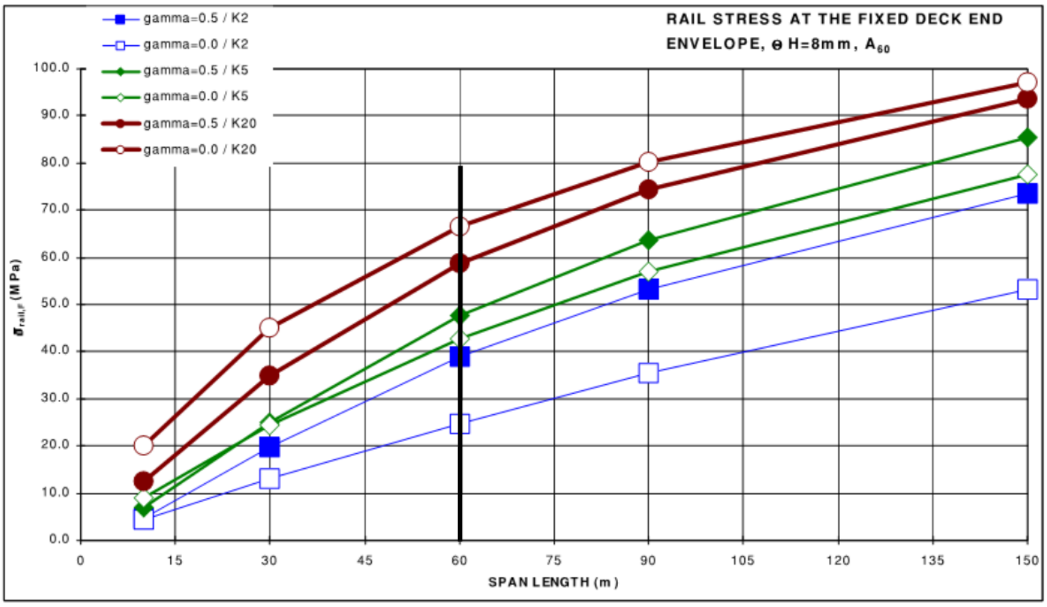


Figure 9. Vertical bending (fixed support), (UIC Code 774-3R, 2001).

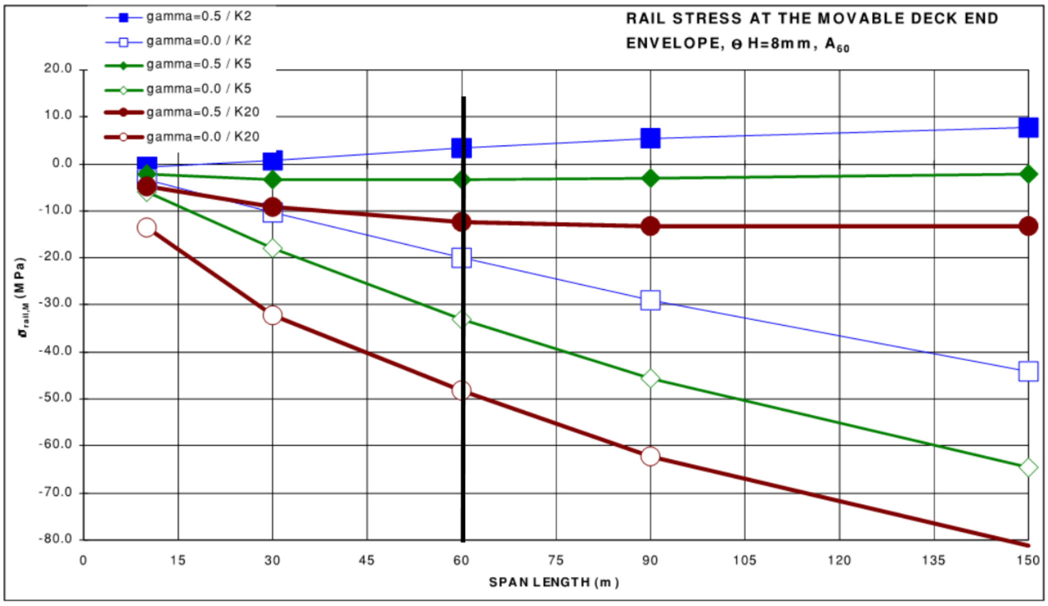


Figure 10. Vertical bending (movable support), (UIC Code 774-3R, 2001).

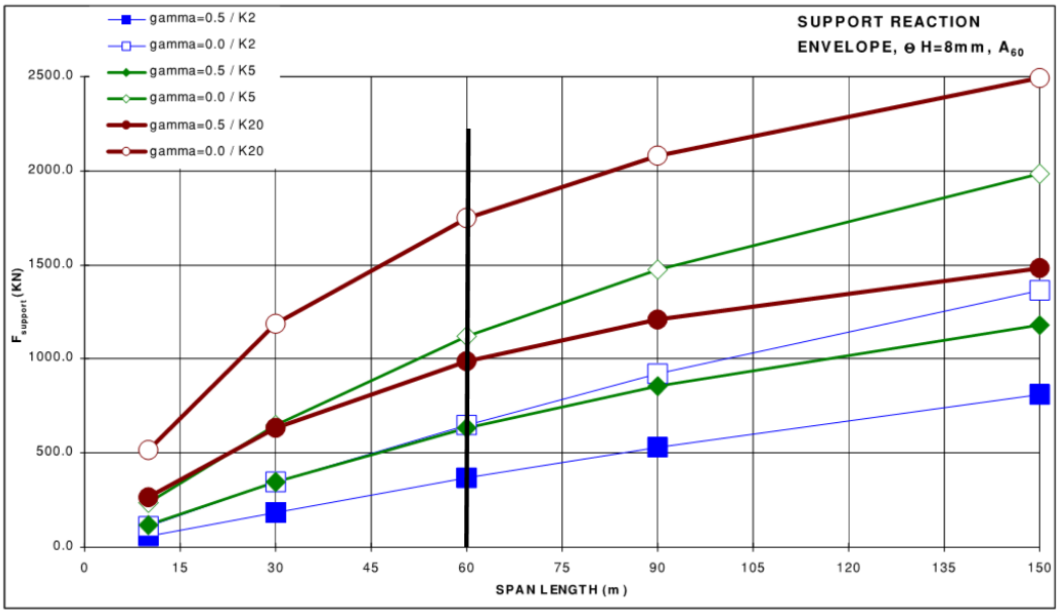


Figure 11. Vertical bending (support reaction), (UIC Code 774-3R, 2001).

Fixed deck end - stresses in the rail according figure 9:

Linear interpolation to get the stress in the rail for $\gamma = 0.2/K_5$:

$\gamma = 0.5/K_5$: $x_1 := 0.5$ $y_1 := 48 \dfrac{N}{mm^2}$

$\gamma = 0.0/K_5$: $x_2 := 0.0$ $y_2 := 43 \dfrac{N}{mm^2}$

$\gamma = 0.2/K_5$: $x := 0.2$

$$y := y_1 + \frac{(x - x_1) \cdot (y_2 - y_1)}{x_2 - x_1} \xrightarrow{explicit, ALL} 48 \frac{N}{mm^2} + \frac{(0.2 - 0.5) \cdot \left(43 \frac{N}{mm^2} - 48 \frac{N}{mm^2}\right)}{0.0 - 0.5} = 45 \frac{N}{mm^2}$$

$\gamma = 0.2/K_5$: $y_{0.2\_K5} := y = 45 \dfrac{N}{mm^2}$

Linear interpolation to get the stress in the rail for $\gamma = 0.2/K_{20}$:

$\gamma = 0.5/K_{20}$: $x_1 := 0.5$ $y_1 := 67 \dfrac{N}{mm^2}$

$\gamma = 0.0/K_{20}$: $x_2 := 0.0$ $y_2 := 59 \dfrac{N}{mm^2}$

$\gamma = 0.2/K_{20}$: $x := 0.2$

$$y := y_1 + \frac{(x - x_1) \cdot (y_2 - y_1)}{x_2 - x_1} \xrightarrow{explicit, ALL} 67 \frac{N}{mm^2} + \frac{(0.2 - 0.5) \cdot \left(59 \frac{N}{mm^2} - 67 \frac{N}{mm^2}\right)}{0.0 - 0.5} = 62.2 \frac{N}{mm^2}$$

$\gamma = 0.2/K_{20}$: $\quad y_{0.2\_K20} := y = 62.2 \frac{N}{mm^2}$

Linear interpolation to get the stress in the rail for $\gamma = 0.2/K_{10}$*:*

$\gamma = 0.2/K_5$: $\quad x_1 := 5 \quad y_1 := y_{0.2\_K5} = 45 \frac{N}{mm^2}$

$\gamma = 0.2/K_{20}$: $\quad x_2 := 20 \quad y_2 := y_{0.2\_K20} = 62.2 \frac{N}{mm^2}$

$\gamma = 0.2/K_{10}$: $\quad x := 10$

$$y := y_1 + \frac{(x - x_1) \cdot (y_2 - y_1)}{x_2 - x_1} \xrightarrow{explicit, ALL} \frac{45 \cdot N}{mm^2} + \frac{(10 - 5) \cdot \left(\frac{62.2 \cdot N}{mm^2} - \frac{45 \cdot N}{mm^2}\right)}{20 - 5} = 50.7 \frac{N}{mm^2}$$

$\gamma = 0.2/K_{10}$: $\quad y_{0.2\_K10} := y = 51 \frac{N}{mm^2}$

Rail stress at the fixed deck end: $\quad \sigma_{rail\_fixed\_\theta H} := y_{0.2\_K10} = 51 \frac{N}{mm^2}$ tension

According to UIC Code 774-3R (2001) should the stress due to rotation/vertical bending be taken as 0 when it has the opposite sign to the values of the stresses from the temperature variation and braking. In this case is the stress due to rotation a tensile stress, while the stresses from the temperature variation and braking is compressive stresses. Therefore should the stress from the vertical bending be taken equal to 0.

Representative value, additional compressive rail stress at the fixed deck end due to rotation: $\quad \sigma_{rail\_fixed\_\theta H} := 0 \frac{N}{mm^2}$

Movable deck end - stresses in the rail according to figure 10:

Linear interpolation to get the stress in the rail for $\gamma = 0.2/K_5$:

$\gamma = 0.5/K_5$: $x_1 := 0.5$ $y_1 := -3 \dfrac{N}{mm^2}$

$\gamma = 0.0/K_5$: $x_2 := 0.0$ $y_2 := -33.5 \dfrac{N}{mm^2}$

$\gamma = 0.2/K_5$: $x := 0.2$

$$y := y_1 + \frac{(x - x_1) \cdot (y_2 - y_1)}{x_2 - x_1} \xrightarrow{explicit, ALL} -3 \frac{N}{mm^2} + \frac{(0.2 - 0.5) \cdot \left(-33.5 \frac{N}{mm^2} - -3 \frac{N}{mm^2}\right)}{0.0 - 0.5} = -21.3 \frac{N}{mm^2}$$

$\gamma = 0.2/K_5$: $y_{0.2\_K5} := y = -21.3 \dfrac{N}{mm^2}$

Linear interpolation to get the stress in the rail for $\gamma = 0.2/K_{20}$:

$\gamma = 0.5/K_{20}$: $x_1 := 0.5$ $y_1 := -12 \dfrac{N}{mm^2}$

$\gamma = 0.0/K_{20}$: $x_2 := 0.0$ $y_2 := -48 \dfrac{N}{mm^2}$

$\gamma = 0.2/K_{20}$: $x := 0.2$

$$y := y_1 + \frac{(x - x_1) \cdot (y_2 - y_1)}{x_2 - x_1} \xrightarrow{explicit, ALL} -12 \frac{N}{mm^2} + \frac{(0.2 - 0.5) \cdot \left(-48 \frac{N}{mm^2} - -12 \frac{N}{mm^2}\right)}{0.0 - 0.5} = -33.6 \frac{N}{mm^2}$$

$\gamma = 0.2/K_{20}$: $y_{0.2\_K20} := y = -33.6 \dfrac{N}{mm^2}$

Linear interpolation to get the stress in the rail for $\gamma = 0.2/K_{10}$:

$\gamma = 0.2/K_5$: $x_1 := 5$ $y_1 := y_{0.2\_K5} = -21.3 \dfrac{N}{mm^2}$

$\gamma = 0.2/K_{20}$: $x_2 := 20$ $y_2 := y_{0.2\_K20} = -33.6 \dfrac{N}{mm^2}$

$\gamma = 0.2/K_{10}$: $x := 10$

$$y := y_1 + \frac{(x - x_1)\cdot(y_2 - y_1)}{x_2 - x_1} \xrightarrow{explicit, ALL} -\frac{21.3 \cdot N}{mm^2} + \frac{(10-5)\cdot\left(-\frac{33.6 \cdot N}{mm^2} - -\frac{21.3 \cdot N}{mm^2}\right)}{20-5} = -25.4\ \frac{N}{mm^2}$$

$\gamma = 0.2 / K_{10}$: $y_{0.2\_K10} := y = -25\ \frac{N}{mm^2}$

Rail stress at the movable deck end: $\sigma_{rail\_movable\_\theta H} := y_{0.2\_K10} = -25.4\ \frac{N}{mm^2}$ ***compression***

Representative value, additional compressive rail stress at the fixed deck end due to rotation: $\sigma_{rail\_movable\_\theta H} := -\sigma_{rail\_movable\_\theta H} = 25.4\ \frac{N}{mm^2}$

Support reaction due to the vertical bending according to figure 11:

Linear interpolation to get the support reaction for $\gamma = 0.2 / K_5$*:*

$\gamma = 0.5 / K_5$: $x_1 := 0.5$ $y_1 := 635\ kN$

$\gamma = 0.0 / K_5$: $x_2 := 0.0$ $y_2 := 1125\ kN$

$\gamma = 0.2 / K_5$: $x := 0.2$

$$y := y_1 + \frac{(x - x_1)\cdot(y_2 - y_1)}{x_2 - x_1} \xrightarrow{explicit, ALL} 635\ kN + \frac{(0.2 - 0.5)\cdot(1125\ kN - 635\ kN)}{0.0 - 0.5} = 929\ kN$$

$\gamma = 0.2 / K_5$: $y_{0.2\_K5} := y = 929\ kN$

Linear interpolation to get the support reaction for $\gamma = 0.2 / K_{20}$*:*

$\gamma = 0.5 / K_{20}$: $x_1 := 0.5$ $y_1 := 1000\ kN$

$\gamma = 0.0 / K_{20}$: $x_2 := 0.0$ $y_2 := 1770\ kN$

$\gamma = 0.2 / K_{20}$: $x := 0.2$

$$y := y_1 + \frac{(x - x_1) \cdot (y_2 - y_1)}{x_2 - x_1} \xrightarrow{explicit, ALL} 1000\ kN + \frac{(0.2 - 0.5) \cdot (1770\ kN - 1000\ kN)}{0.0 - 0.5} = 1462\ kN$$

$\gamma = 0.2/K_{20}$: $y_{0.2\_K20} := y = 1462\ kN$

Linear interpolation to get the support reaction for $\gamma = 0.2/K_{10}$:

$\gamma = 0.2/K_5$: $x_1 := 5$ $y_1 := y_{0.2\_K5} = 929\ kN$

$\gamma = 0.2/K_{20}$: $x_2 := 20$ $y_2 := y_{0.2\_K20} = 1462\ kN$

$\gamma = 0.2/K_{10}$: $x := 10$

$$y := y_1 + \frac{(x - x_1) \cdot (y_2 - y_1)}{x_2 - x_1} \xrightarrow{explicit, ALL} 929 \cdot kN + \frac{(10 - 5) \cdot (1462 \cdot kN - 929 \cdot kN)}{20 - 5} = 1106.7\ kN$$

$\gamma = 0.2/K_{10}$: $y_{0.2\_K10} := y = 1106.7\ kN$

Support reaction: $F_{support\_\theta H} := y_{0.2\_K10} = 1106.7\ kN$

2.4 Absolute displacements

Absolute displacement of the deck due to braking:

$$\delta_{deck\_fixed\_braking} := \frac{-F_{support\_braking}}{K_{fixed}} = 1.01\ mm$$

If the following condition is fullfiled is also the ***relative displacement*** between the rail and the deck on the safe side, (UIC Code 774-3R, 2001):

$$Verification := \begin{array}{l} \text{if } \delta_{deck\_fixed\_braking} < 5\ mm \\ \quad \| \text{“OK!”} \\ \text{else} \\ \quad \| \text{“Not OK!”} \end{array} = \text{“OK!”}$$

Absolute displacement of the deck due to temperature variation:

$$\delta_{deck\_fixed\_\Delta T} := \frac{-F_{support\_\Delta T}}{K_{fixed}} = -1.17\ mm$$

Absolute displacement of the deck due to rotation / vertical bending: $\delta_{deck\_fixed\_\theta H} := \frac{F_{support\_\theta H}}{K_{fixed}} = 1.84\ mm$

2.5 Combination of the load-case effects for test case E1-3

Interaction due to the temperature variation:	*Interaction due to braking:*	*Interaction due to vertical bendning:*
$\sigma_{rail\_fixed\_\Delta T} = 14.7\ MPa$	$\sigma_{rail\_fixed\_braking} = 18.5\ MPa$	$\sigma_{rail\_fixed\_\theta H} = 0\ MPa$
$\sigma_{rail\_movable\_\Delta T} = 30\ MPa$	$\sigma_{rail\_movable\_braking} = 18.5\ MPa$	$\sigma_{rail\_movable\_\theta H} = 25.4\ MPa$
$F_{support\_\Delta T} = 700\ kN$	$F_{support\_braking} = -603.3\ kN$	$F_{support\_\theta H} = 1106.7\ kN$

According to UIC Code 774-3R (2001) should the values of the rail stresses and support reactions obtained from the graphs be taken with both the positive and negative signs in the combinations to find the worst case. The signs for the rail stresses and the support reactions from the vertical bending are given directly from the graphs, (UIC Code 774-3R, 2001).

Combination factors according to UIC Code 774-3R (2001):

$\alpha := 1.0$ $\beta := 1.0$ $\gamma := 1.0$

Total stress in the rail - fixed support:

$$\sigma_{railfixed} := \alpha \cdot \sigma_{rail\_fixed\_\Delta T} + \beta \cdot \sigma_{rail\_fixed\_braking} + \gamma \cdot \sigma_{rail\_fixed\_\theta H} = 33.2\ MPa$$

Total stress in the rail - movable support:

$$\sigma_{railmovable} := \alpha \cdot \sigma_{rail\_movable\_\Delta T} + \beta \cdot \sigma_{rail\_movable\_braking} + \gamma \cdot \sigma_{rail\_movable\_\theta H} = 73.9\ MPa$$

Total horizontal support reaction:

$$F_{support} := \alpha \cdot F_{support\_\Delta T} + \beta \cdot F_{support\_braking} + \gamma \cdot F_{support\_\theta H} = 1203.3\ kN$$

Total absolute displacement of the deck:

$$\delta_{deck\_fixed} := \delta_{deck\_fixed\_\Delta T} + \delta_{deck\_fixed\_braking} + \delta_{deck\_fixed\_\theta H} = 1.7\ mm$$

2.6 Summary of the hand calculation results for test case E1-3

The results from the hand calculation are summarized in table 1.

Table 1. Summary of the hand calculation results for test case E1-3

Hand calculation	Rail stress [MPa]	Absolute displacement [mm]	Support reaction [kN]
Temperature variation	-30,00	-1,17	700,00
Braking	-18,50	1,01	-603,33
Vertical bendning	-25,40	1,84	1106,67
Sum:	**-73,9**	**1,68**	**1203,33**

3 Hand calculation of test case F4-6 from Appendix D in UIC 774-3

The hand caclulation followed the same procedure as the hand calculation example "C-2 - Example 1a Simply-supported deck bridge with one elastic fixed support (deck slab bridge) / no expansion device" found in UIC Code 774-3R (2001, Appendix C).

Input data:

Simply-supported deck

One track

Deck length: $L := 60\ m$

Horizontal stiffness for the fixed support: $K_{fixed} := 120000\ \frac{kN}{m}$ $K_{fixed} = 120\ \frac{kN}{mm}$

$K_2 := 2 \cdot L$

No friction in the movable bearing

Deck bridge with a cross section according to figure 2 with the following parameters:

Young's modulus: $E := 210\ GPa$ $E = \left(2.1 \cdot 10^8\right)\ \frac{kN}{m^2}$

Moment of inertia: $I := 2.590\ m^4$

Area: $A := 0.74\ m^2$

Height: $H := 6\ m$

Center of gravity / neutral axis: $x_{cg} := 4.79\ m$

Distance from the upper surface of the slab to the decks neutral axis, (positive direction downwards): $\omega := H - x_{cg} = 1.21\ m$

ω/H value used in calibrating diagrams found in UIC Code 774-3R (2001, Appendix B): $\gamma := \frac{\omega}{H} = 0.2$

Displacement of the slab due to the rotation of the end section of the deck for deck bridges, load model 71 [LM71]: $\theta H := 8\ mm$

UIC 60 continuous welded rails ---> $A_{60} := 15.372 \cdot 10^{-3}\ m^2$ / track

Horizontal resistance k of the connection between the track and the structure/embankment:

- Resistance for the unloaded track: a displacement of 2 mm between the elastic zone and the plastc zone and a resistance of 20 kN/m in the plastic phase: $k_{rail\_unloaded} := 20\ \frac{kN}{m}$
- Resistance for the loaded track (vertical load 80 kN/m): a displacement of 2 mm between the elastic zone and the plastc zone and a resistance of 40 kN/m in the plastic phase: $k_{rail\_loaded} := 60\ \frac{kN}{m}$

Coefficient of thermal expansion: $\alpha := 1.0 \cdot 10^{-5}$

Thermal variation for the deck: $\Delta T_{deck} := -35\ °C$

$\Delta T_{deck} := 35\ °C$

Thermal variation for the rail: $\Delta T_{rail} := -50\ °C$

$\Delta T_{rail} := 50\ °C$

Horizontal braking force: $F_{braking} := 20\ \frac{kN}{m}$

Vertical load: $F_{vertical} := 80\ \frac{kN}{m}$

Direction of travel: From the movable support towards the fixed support (direction 2), see figure 1.

3.1 Effects due to temperature variation

In figure 12 and 13 are the diagrams for the stresses in the rail due to the temperature variation for the case without an expansion device shown.
In figure 14 is the support reaction due to the temperature variation for the case without an expansion device shown.

Temperature interaction effects parameters:

$\Delta T_{deck} = 35\ °C$

$L = 60\ m$

$K_{fixed} = 120\ \frac{kN}{mm}$ ---> $K_2 := 2 \cdot L$

Unloaded track: ---> $k_{20} := k_{rail\_unloaded} = 20\ \frac{kN}{m}$

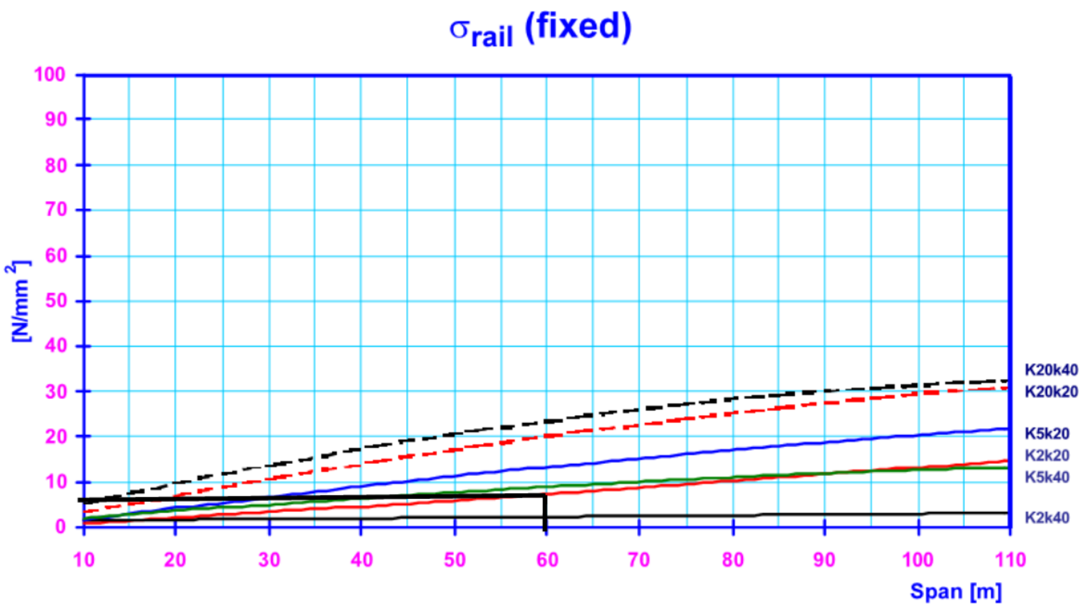


Figure 12. Temperature - variation load-case (ΔT_{deck}= 35 °C) (stresses in the fixed support), (UIC Code 774-3R, 2001).

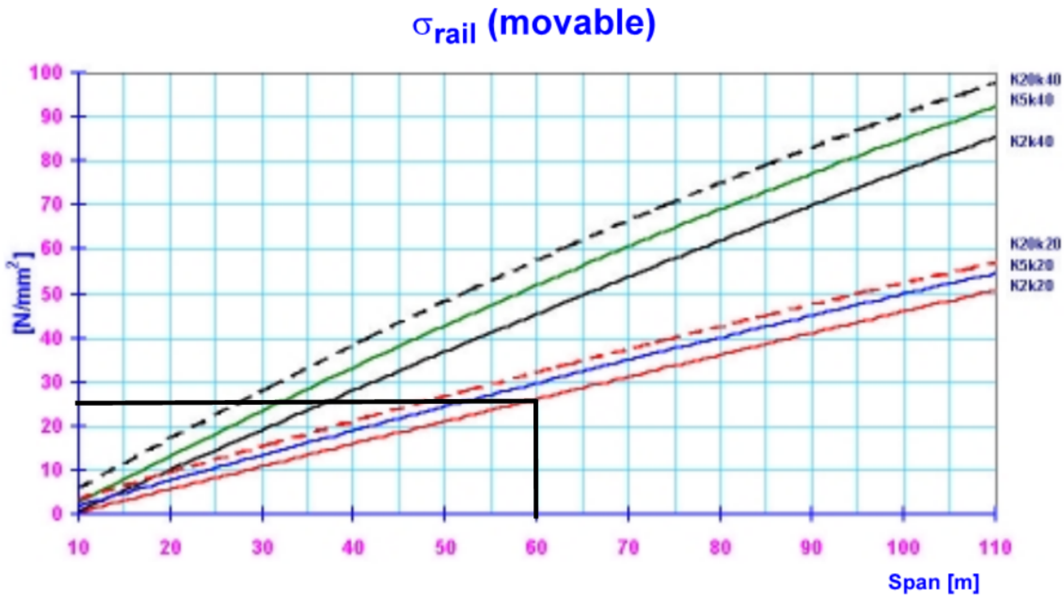


Figure 13. Temperature - variation load-case (ΔT_{deck} = 35 ℃) (stresses in the movable support), (UIC Code 774-3R, 2001).

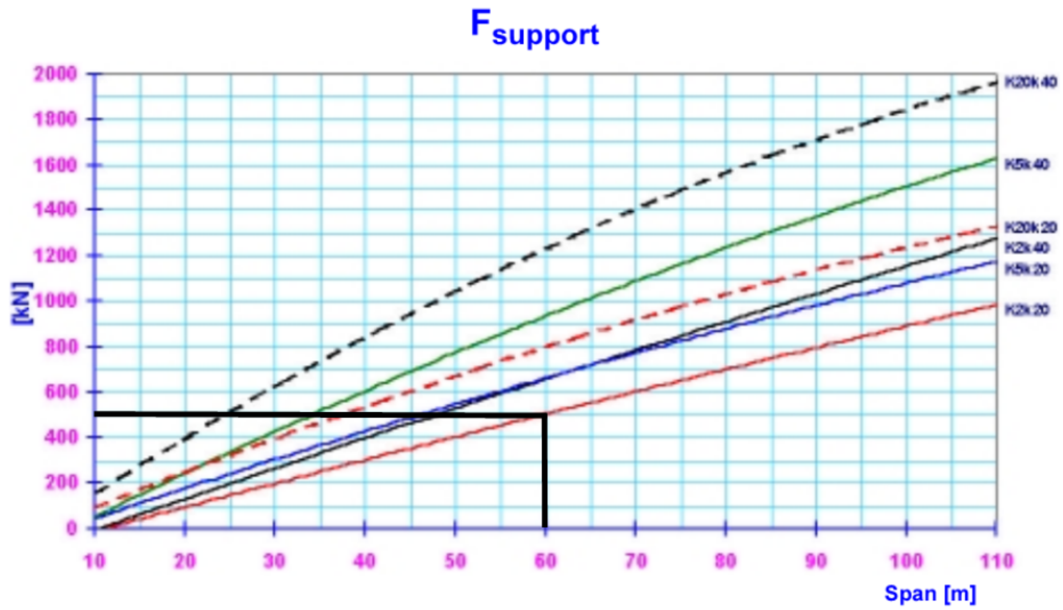


Figure 14. Temperature - variation load-case (ΔT_{deck} = 35 ℃) (support reaction), (UIC Code 774-3R, 2001).

$K_2\ k_{20}$ is used in figure 12, 13 and 14 to get the stresses in the rail and the support reaction.

Fixed support, stresses in the rail due to temperature variation according to figure 12:

Stresses in the rail at the fixed support: $\sigma_{rail\_fixed\_\Delta T} := 6\ \frac{N}{mm^2}$

Movable support, stresses in the rail due to temperature variation according to figure 13:

Stresses in the rail at the movable support: $\sigma_{rail\_movable\_\Delta T} := 25\ \frac{N}{mm^2}$

Support reaction due to temperature variation according to figure 14:

Support reaction: $F_{support\_\Delta T} := 490\ kN$

3.2 Effects due to braking

In figure 15 and 16 are the diagrams for the stresses in the rail due to braking for the case without an expansion device shown.
In figure 17 is the support reaction due to braking for the case without an expansion device shown.

Braking interaction effects parameters:

$L = 60\ m$

$K_{fixed} = 120\ \frac{kN}{mm}$ ---> $K_2 := 2 \cdot L$

Loaded track: ---> $k_{60} := k_{rail\_loaded} = 60\ \frac{kN}{m}$

$K_2\ k_{60}$ is used in figure 15, 16 and 17 to get the stresses in the rail and the support reaction.

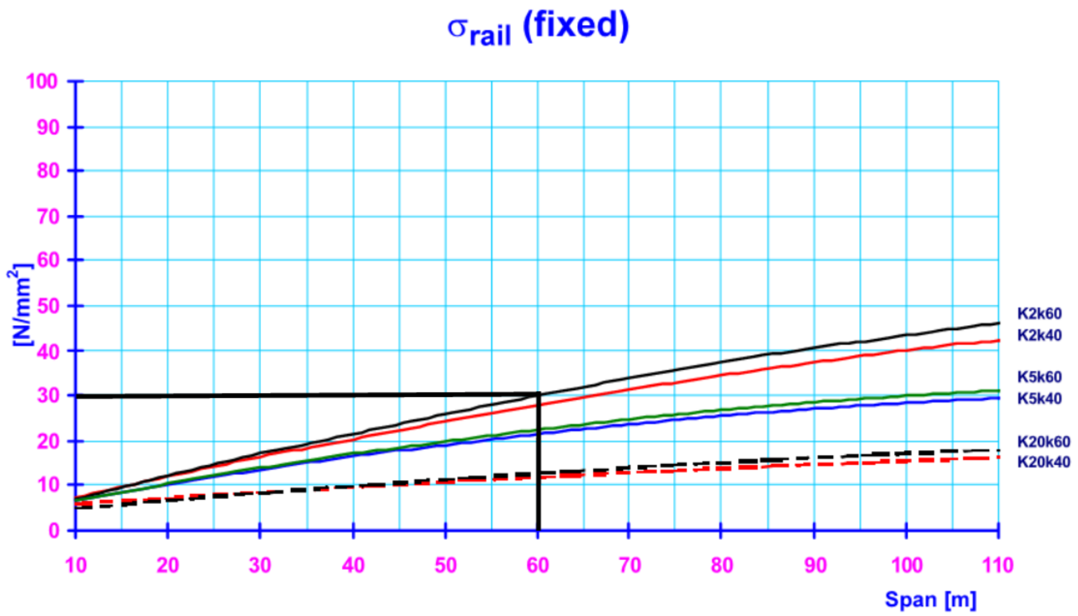


Figure 15. Braking load-case (fixed support) (20 kN/m), (UIC Code 774-3R, 2001).

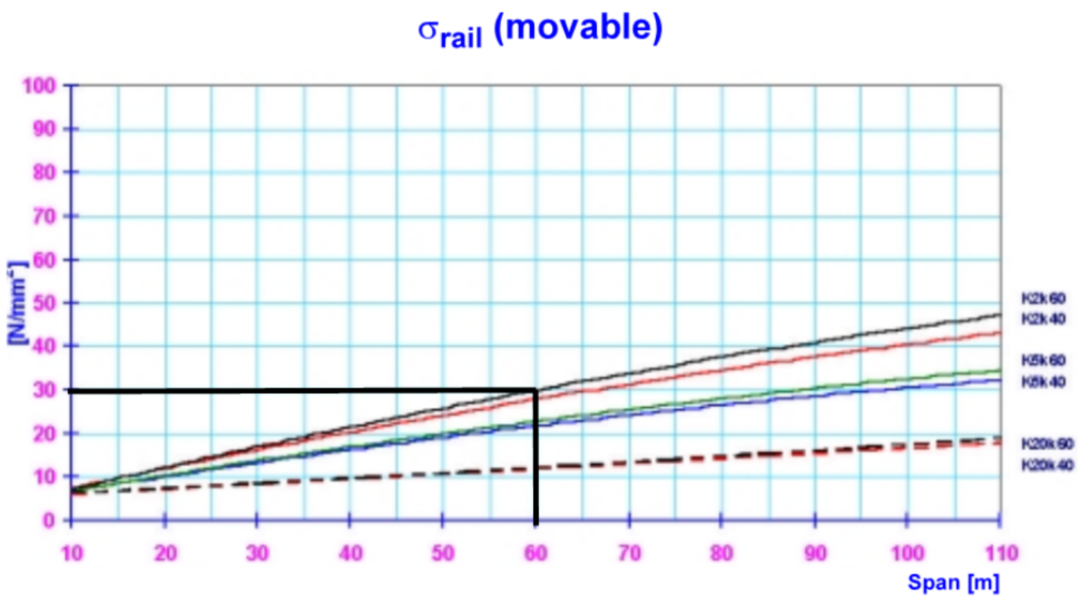


Figure 16. Braking load-case (movable support) (20kN/m), (UIC Code 774-3R, 2001).

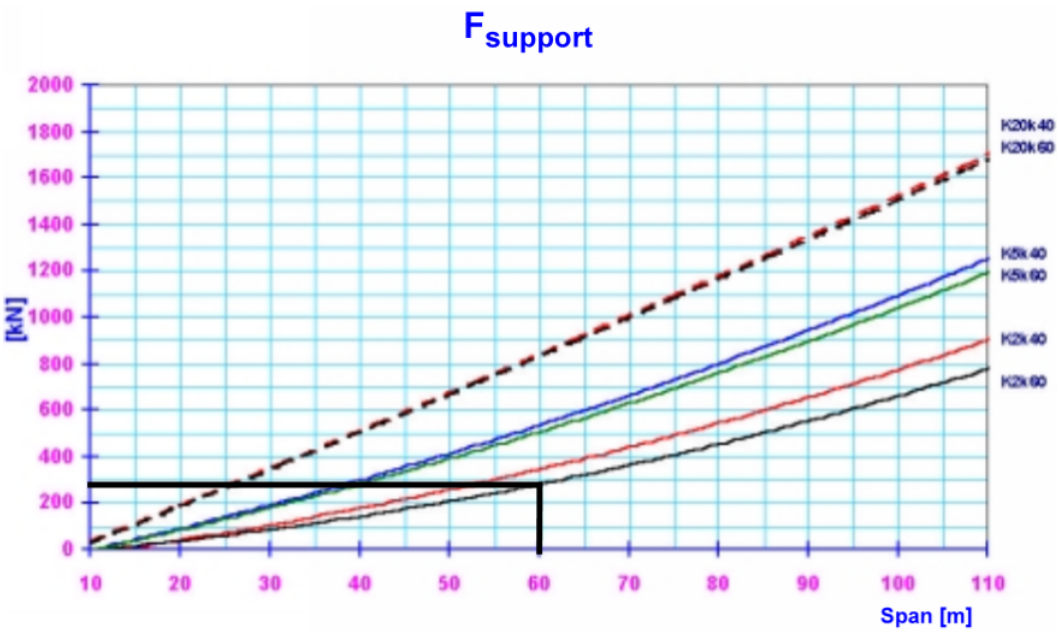


Figure 17. Braking - load-case (support reaction) (20kN/m), (UIC Code 774-3R, 2001).

Fixed support, stresses in the rail due to braking according to figure 15:

Stresses in the rail at the fixed support: $\sigma_{rail\_fixed\_braking} := 30 \ \frac{N}{mm^2}$

Movable support - stresses in the rail due to braking according to figure 16:

Stresses in the rail at the movable support: $\sigma_{rail\_movable\_braking} := 30 \ \frac{N}{mm^2}$

Support reaction due to braking according to figure 17:

Support reaction: $F_{support\_braking} := 280 \ kN$

The train moves in the direction from the movable support against the fixed support, see figure 1, therefore is the braking force that acts on the fixed support positive:

Support reaction: $F_{support\_braking} := F_{support\_braking} = 280 \ kN$

3.3 Effects due to vertical bending

In figure 18 and 19 are the diagrams for the stresses in the rail due to vertical bending for the case without an expansion device shown.
In figure 20 is the support reaction due to vertical bending for the case without an expansion device shown.

Vertical bending interaction effects parameters:

Deck bridge

$\theta H = 8\ mm$

$L = 60\ m$

$K_{fixed} = 120\ \frac{kN}{mm}$ ---> $K_{10} := 10 \cdot L$ $\gamma = 0.2$

UIC 60 --> A_{60}

An linear interpolation is performed to get the stresses in the rail and the support reaction for $\gamma = 0.2 / K_2$ from the diagrams in figure 18, 19 and 20.

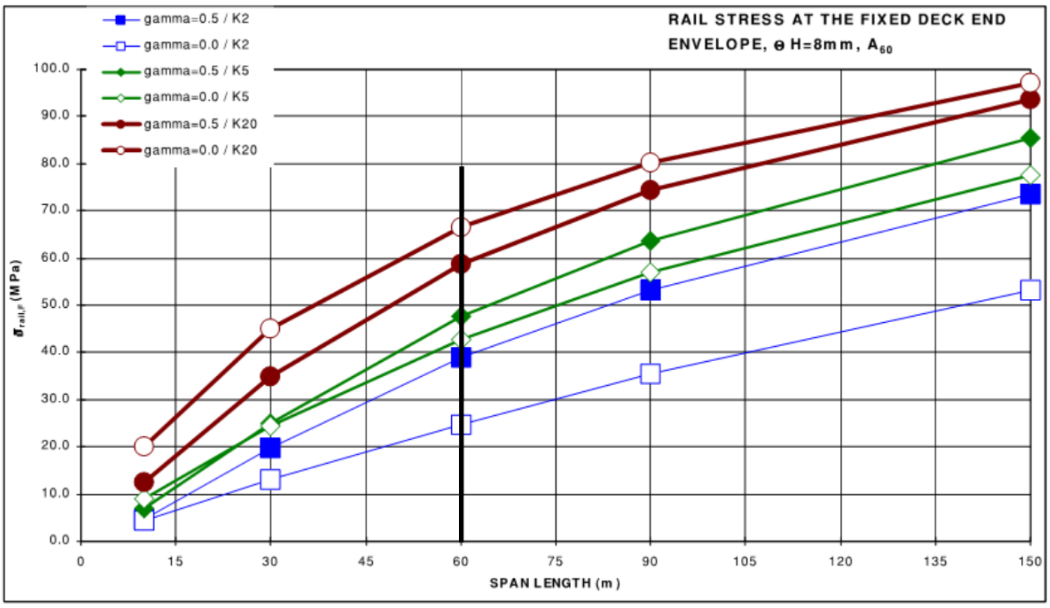


Figure 18. Vertical bending (fixed support), (UIC Code 774-3R, 2001).

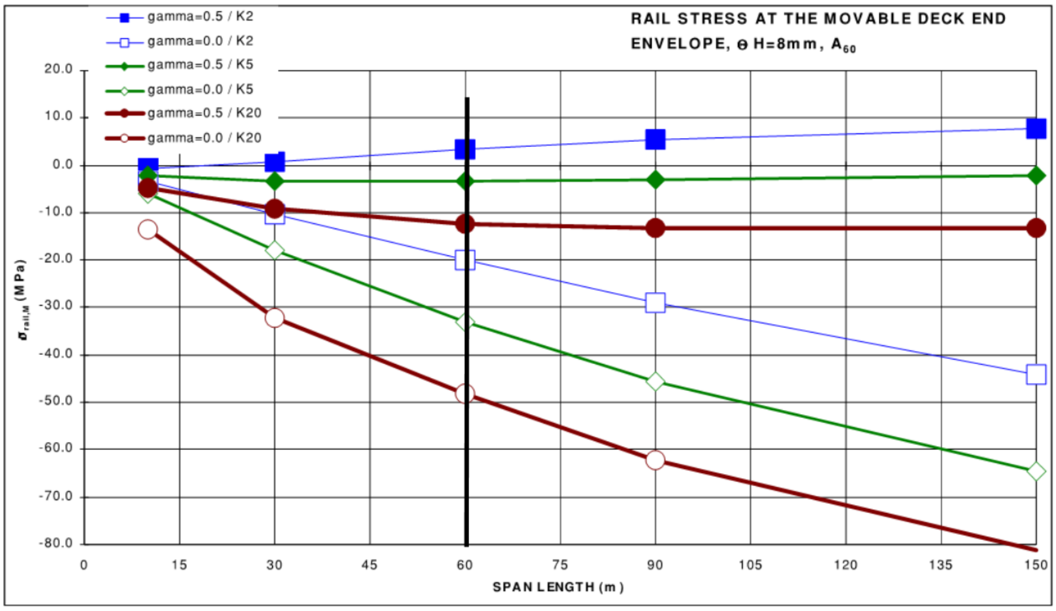


Figure 19. Vertical bending (movable support), (UIC Code 774-3R, 2001).

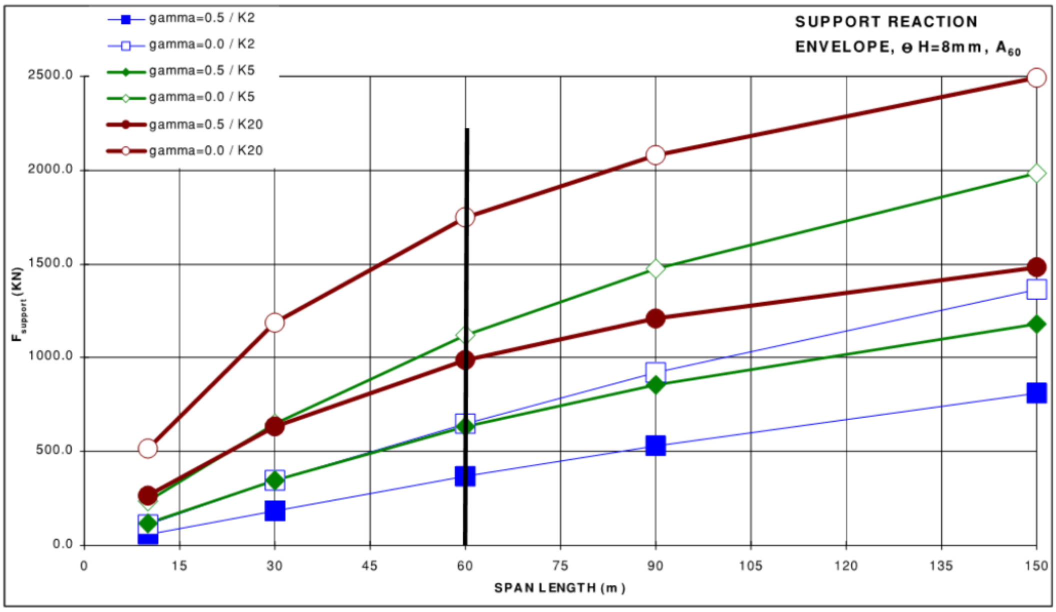


Figure 20. Vertical bending (support reaction), (UIC Code 774-3R, 2001).

Fixed deck end - stresses in the rail according figure 18:

Linear interpolation to get the stress in the rail for $\gamma = 0.2/K_2$*:*

$\gamma = 0.5/K_2$: $x_1 := 0.5$ $y_1 := 40 \frac{N}{mm^2}$

$\gamma = 0.0/K_2$: $x_2 := 0.0$ $y_2 := 25 \frac{N}{mm^2}$

$\gamma = 0.2/K_2$: $x := 0.2$

$$y := y_1 + \frac{(x - x_1) \cdot (y_2 - y_1)}{x_2 - x_1} \xrightarrow{explicit, ALL} 40 \frac{N}{mm^2} + \frac{(0.2 - 0.5) \cdot \left(25 \frac{N}{mm^2} - 40 \frac{N}{mm^2}\right)}{0.0 - 0.5} = 31 \frac{N}{mm^2}$$

$\gamma = 0.2/K_5$: $y_{0.2\_K2} := y = 31 \frac{N}{mm^2}$

Rail stress at the fixed deck end: $\sigma_{rail\_fixed\_\theta H} := y_{0.2\_K2} = 31 \frac{N}{mm^2}$ tension

According to UIC Code 774-3R (2001) should the stress due to rotation/vertical bending be taken as 0 when it has the opposite sign to the values of the stresses from the temperature variation and braking. In this case is the stress due to rotation a tensile stress, while the stresses from the temperature variation and braking is compressive stresses. Therefore should the stress from the vertical bending be taken equal to 0.

Representative value, additional compressive rail stress at the fixed deck end due to rotation: $\sigma_{rail\_fixed\_\theta H} := 0 \frac{N}{mm^2}$

Movable deck end - stresses in the rail according to figure 19:

Linear interpolation to get the stress in the rail for $\gamma = 0.2/K_2$*:*

$\gamma = 0.5/K_2$: $x_1 := 0.5$ $y_1 := 4 \frac{N}{mm^2}$

$\gamma = 0.0/K_2$: $x_2 := 0.0$ $y_2 := -19.5 \frac{N}{mm^2}$

$\gamma = 0.2/K_2$: $x := 0.2$

$$y := y_1 + \frac{(x - x_1) \cdot (y_2 - y_1)}{x_2 - x_1} \xrightarrow{explicit, ALL} 4\ \frac{N}{mm^2} + \frac{(0.2 - 0.5) \cdot \left(-19.5\ \frac{N}{mm^2} - 4\ \frac{N}{mm^2}\right)}{0.0 - 0.5} = -10.1\ \frac{N}{mm^2}$$

$\gamma = 0.2/K_2$: $y_{0.2\_K2} := y = -10.1\ \frac{N}{mm^2}$

Rail stress at the movable deck end: $\sigma_{rail\_movable\_\theta H} := y_{0.2\_K2} = -10.1\ \frac{N}{mm^2}$ ***compression***

Representative value, additional compressive rail stress at the fixed deck end due to rotation: $\sigma_{rail\_movable\_\theta H} := -\sigma_{rail\_movable\_\theta H} = 10.1\ \frac{N}{mm^2}$

Support reaction due to the vertical bending according to figure 20:

Linear interpolation to get the support reaction for $\gamma = 0.2/K_2$*:*

$\gamma = 0.5/K_2$: $x_1 := 0.5$ $y_1 := 370\ kN$

$\gamma = 0.0/K_2$: $x_2 := 0.0$ $y_2 := 640\ kN$

$\gamma = 0.2/K_2$: $x := 0.2$

$$y := y_1 + \frac{(x - x_1) \cdot (y_2 - y_1)}{x_2 - x_1} \xrightarrow{explicit, ALL} 370\ kN + \frac{(0.2 - 0.5) \cdot (640\ kN - 370\ kN)}{0.0 - 0.5} = 532\ kN$$

$\gamma = 0.2/K_2$: $y_{0.2\_K2} := y = 532\ kN$

Support reaction: $F_{support\_\theta H} := y_{0.2\_K2} = 532\ kN$

3.4 Absolute displacements

Absolute displacement of the deck due to braking:

$$\delta_{deck\_fixed\_braking} := \frac{-F_{support\_braking}}{K_{fixed}} = -2.33\ mm$$

If the following condition is fullfiled is also the ***relative displacement*** between the rail and the deck on the safe side, (UIC Code 774-3R, 2001):

$Verification :=$ if $\delta_{deck\_fixed\_braking} < 5\ mm$ | "OK!" | else | "Not OK!" $=$ "OK!"

Absolute displacement of the deck due to temperature variation:

$$\delta_{deck\_fixed\_\Delta T} := \frac{-F_{support\_\Delta T}}{K_{fixed}} = -4.08\ mm$$

Absolute displacement of the deck due to rotation / vertical bending:

$$\delta_{deck\_fixed\_\theta H} := \frac{F_{support\_\theta H}}{K_{fixed}} = 4.43\ mm$$

3.5 Combination of the load-case effects for test case E1-3

Interaction due to the temperature variation:	*Interaction due to braking:*	*Interaction due to vertical bendning:*
$\sigma_{rail\_fixed\_\Delta T} = 6\ MPa$	$\sigma_{rail\_fixed\_braking} = 30\ MPa$	$\sigma_{rail\_fixed\_\theta H} = 0\ MPa$
$\sigma_{rail\_movable\_\Delta T} = 25\ MPa$	$\sigma_{rail\_movable\_braking} = 30\ MPa$	$\sigma_{rail\_movable\_\theta H} = 10.1\ MPa$
$F_{support\_\Delta T} = 490\ kN$	$F_{support\_braking} = 280\ kN$	$F_{support\_\theta H} = 532\ kN$

According to UIC Code 774-3R (2001) should the values of the rail stresses and support reactions obtained from the graphs be taken with both the positive and negative signs in the combinations to find the worst case. The signs for the rail stresses and the support reactions from the vertical bending are given directly from the graphs, (UIC Code 774-3R, 2001).

Combination factors according to UIC Code 774-3R (2001):

$\alpha := 1.0$ $\beta := 1.0$ $\gamma := 1.0$

Total stress in the rail - fixed support:

$$\sigma_{railfixed} := \alpha \cdot \sigma_{rail\_fixed\_\Delta T} + \beta \cdot \sigma_{rail\_fixed\_braking} + \gamma \cdot \sigma_{rail\_fixed\_\theta H} = 36\ MPa$$

$$Verification := \text{if } \sigma_{railfixed} \le 72\ MPa \;\; \| \text{“OK!”} \;\; \text{else} \;\; \| \text{“Not OK!”} = \text{“OK!”}$$

Total stress in the rail - movable support:

$$\sigma_{railmovable} := \alpha \cdot \sigma_{rail\_movable\_\Delta T} + \beta \cdot \sigma_{rail\_movable\_braking} + \gamma \cdot \sigma_{rail\_movable\_\theta H} = 65.1\ MPa$$

Total horizontal support reaction:

$$F_{support} := \alpha \cdot F_{support\_\Delta T} + \beta \cdot F_{support\_braking} + \gamma \cdot F_{support\_\theta H} = 1302\ kN$$

Total absolute displacement:

$$\delta_{deck\_fixed} := \delta_{deck\_fixed\_\Delta T} + \delta_{deck\_fixed\_braking} + \delta_{deck\_fixed\_\theta H} = -2\ mm$$

3.6 Summary of the hand calculation results for test case F4-6

The results from the hand calculation are summarized in table 2.

Table 2. Summary of the hand calculation results for test case F4-6

Hand calculation	Rail stress [MPa]	Absolute displacement [mm]	Support reaction [kN]
Temperature variation	-25,00	-4,08	490,00
Braking	-30,00	-2,33	280,00
Vertical bendning	-10,10	4,43	532,00
Sum:	**-65,1**	**-1,98**	**1302,00**

4 References

UIC Code 774-3R, 2001. *Track/bridge Interaction: Recommendations for calculations,* Paris, France: International Union of Railways.

Appendix 2

Comparison between the results from the three test models

Table of Contents

1 Output data from the three test models for the two test cases

1.1 Test case E1-3

In the following sections are the normal force diagrams used in the linear superposition in Table 1.2 for test case E1-3 shown in Figure 1.2 - Figure 1.7. The largest combined compressing rail stress was found over the movable support.

1.1.1 Normal force diagram from the model with the center of gravity directly on the supports

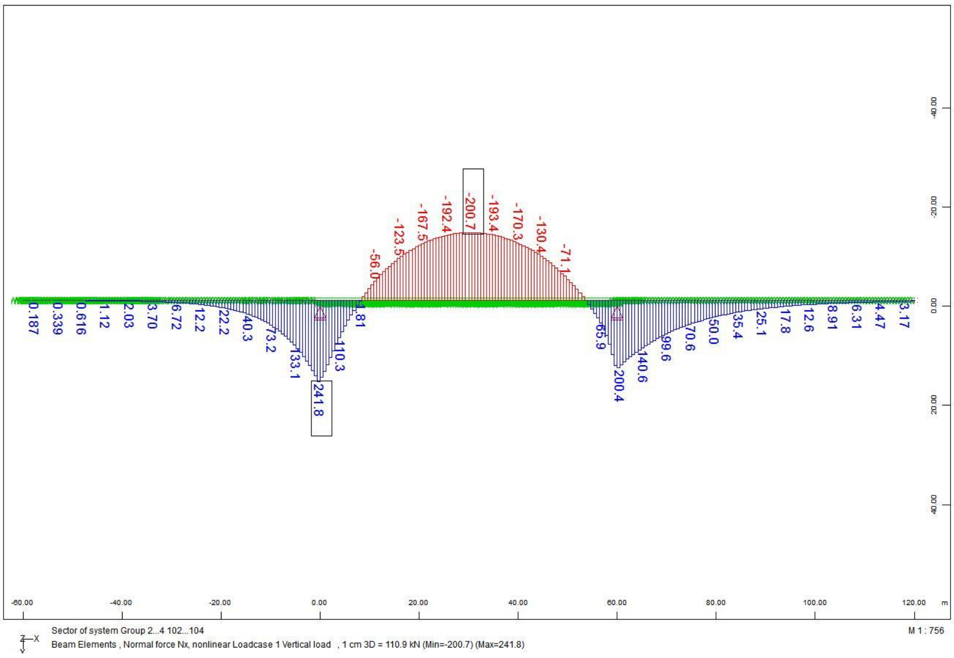


Figure 1.1 E1-3. Vertical load case - normal force diagram from the model with the center of gravity directly on the supports.

1.1.2 Normal force diagrams for each load case from the model with eccentric center of gravity

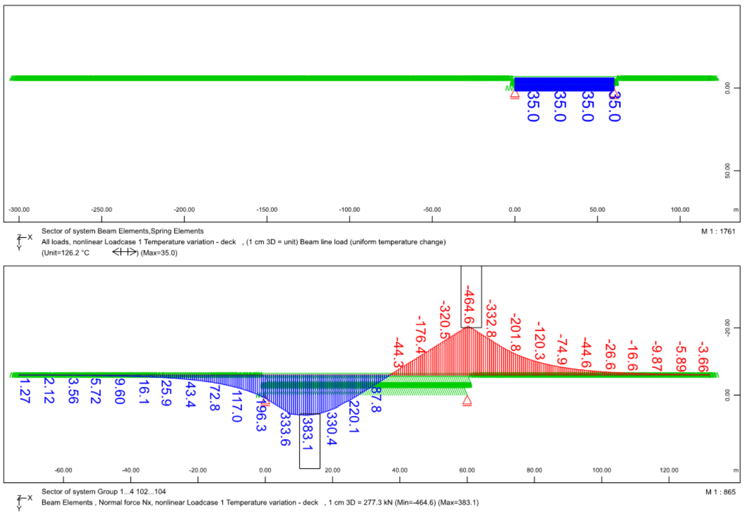


Figure 1.2 E1-3. Temperature variation for the deck - normal force diagram from the model with eccentric center of gravity.

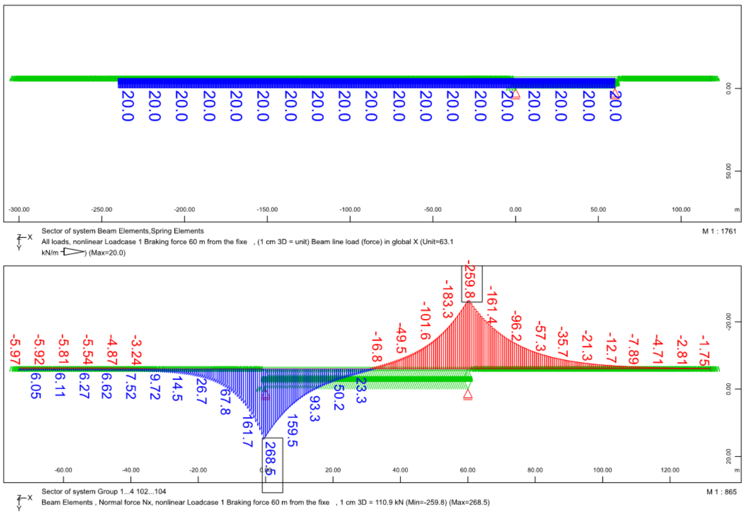


Figure 1.3 E1-3. Braking force load case - normal force diagram from the model with eccentric center of gravity.

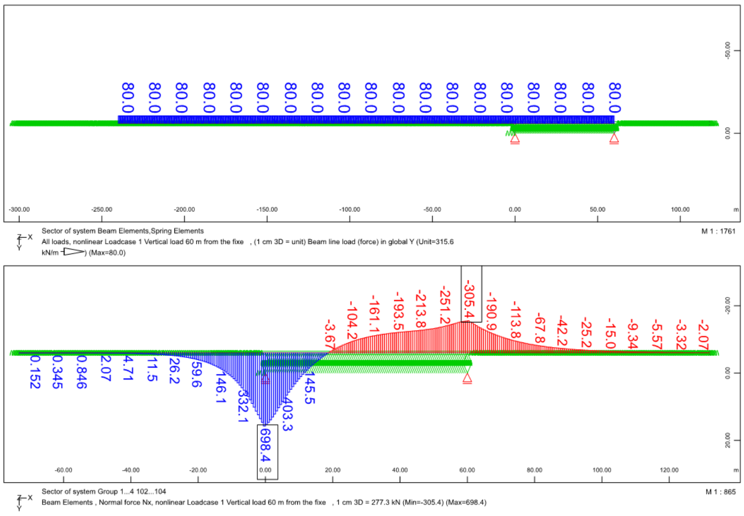


Figure 1.4 E1-3. Vertical load case - normal force diagram from the model with eccentric center of gravity.

1.1.3 Normal force diagrams for each load case from the model with coupled nodes

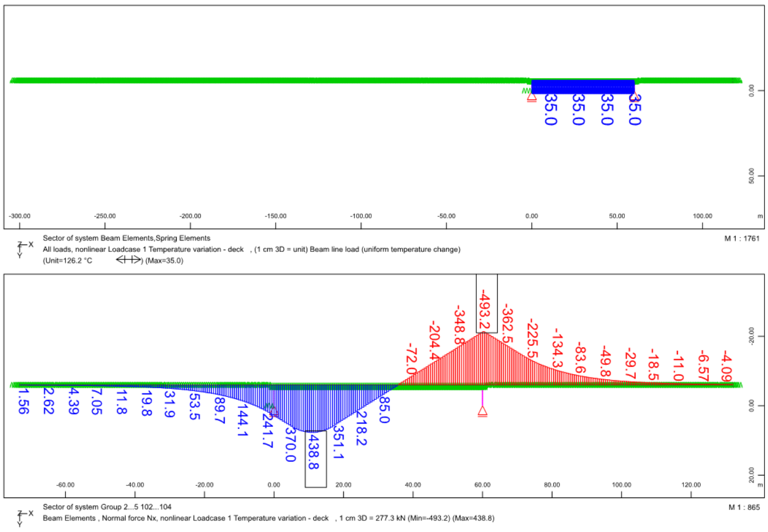


Figure 1.5 E1-3. Temperature variation for the deck - normal force diagram from the model with coupled nodes.

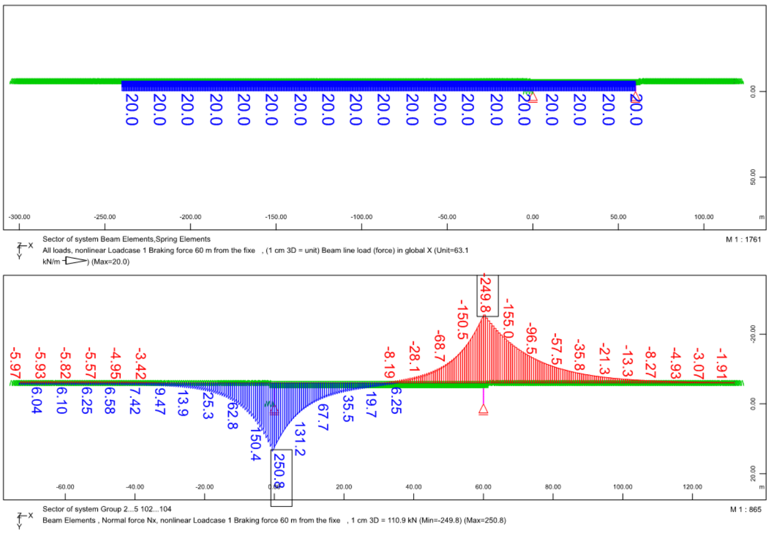


Figure 1.6 E1-3. Braking force load case - normal force diagram from the model with coupled nodes.

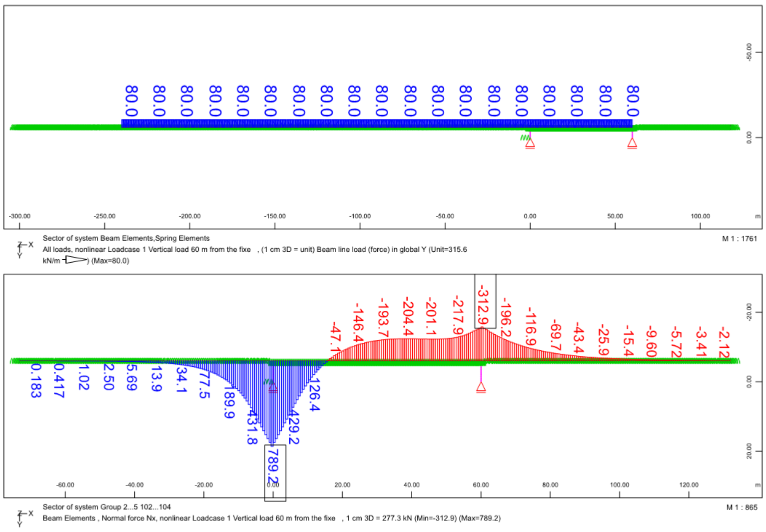


Figure 1.7 E1-3. Vertical load case - normal force diagram from the model with coupled nodes.

1.1.4 Summary of the results for test case E1-3

The results from the model with the center of gravity directly on the supports are not considered in the comparison between the models due to the strange behavior of the normal force for the vertical load case, see Figure 1.1. It is obviously an incorrect behavior if it is compared to the results from the two other models in Figure 1.4 and Figure 1.7 for the vertical load case.

In Table 1.1 are the results from the linear superposition for each load case summarized whereas the percentage error are summarized in Table 1.2.

Table 1.1 Summary of the results for test case E1-3.

Test case E1-3	Load case	Rail stress, σ_{rail} [MPa]	Top of the deck - abs.disp, δ_{deck} [mm]	Support reaction, $F_{support}$ [kN]
Hand calculation	Temperature variation - deck	-30,00	-1,17	700,00
	Braking	-18,50	1,01	-603,33
	Vertical bending - end rot	-25,40	1,84	1106,67
	Sum:	**-73,90**	**1,68**	**1203,34**
UIC Computer calculation	Temperature variation - deck	-30,67	-1,69	700,12
	Braking	-16,42	1,36	-813,22
	Vertical bending - end rot	-16,98	3,77	977,70
	Sum:	**-64,07**	**3,44**	**864,60**
Sofistik Eccentric center of gravity	Temperature variation - deck	-30,22	-2,23	678,50
	Braking	-16,90	1,14	-683,70
	Vertical bending - end rot	-19,87	5,11	1004,00
	Sum:	**-66,99**	**4,02**	**998,80**
Sofistik Coupled nodes	Temperature variation - deck	-32,08	-1,28	768,30
	Braking	-16,25	1,19	-711,40
	Vertical bending - end rot	-20,36	4,89	1102,00
	Sum:	**-68,69**	**4,80**	**1158,90**

Table 1.2 Comparison of the percentage error between the sums determined through each test model against the sums from the hand calculation and the computer calculation performed by UIC for test case E1-3.

Test case E1-3 - error against the sums from the hand calculation	Rail stress, σ_{rail} [%]	Top of the deck - abs.disp, δ_{deck} [%]	Support reaction, $F_{support}$ [%]
Sofistik Eccentric center of gravity	-9,3	139,3	-17,0
Sofistik Coupled nodes	-7,1	185,7	-3,7

Test case E1-3 - error against the sums from UIC's computer calculation	Rail stress, σ_{rail} [%]	Top of the deck - abs.disp, δ_{deck} [%]	Support reaction, $F_{support}$ [%]
Sofistik Eccentric center of gravity	4,6	16,9	10,3
Sofistik Coupled nodes	7,2	39,5	34,0

1.2 Test case F4-6

In the following sections are the normal force diagrams used in the linear superposition in Table 1.3 for test case F4-6 shown in Figure 1.9 - Figure 1.14. The largest combined compressing rail stress was found over the movable support.

1.2.1 Normal force diagram from the model with the center of gravity directly on the supports

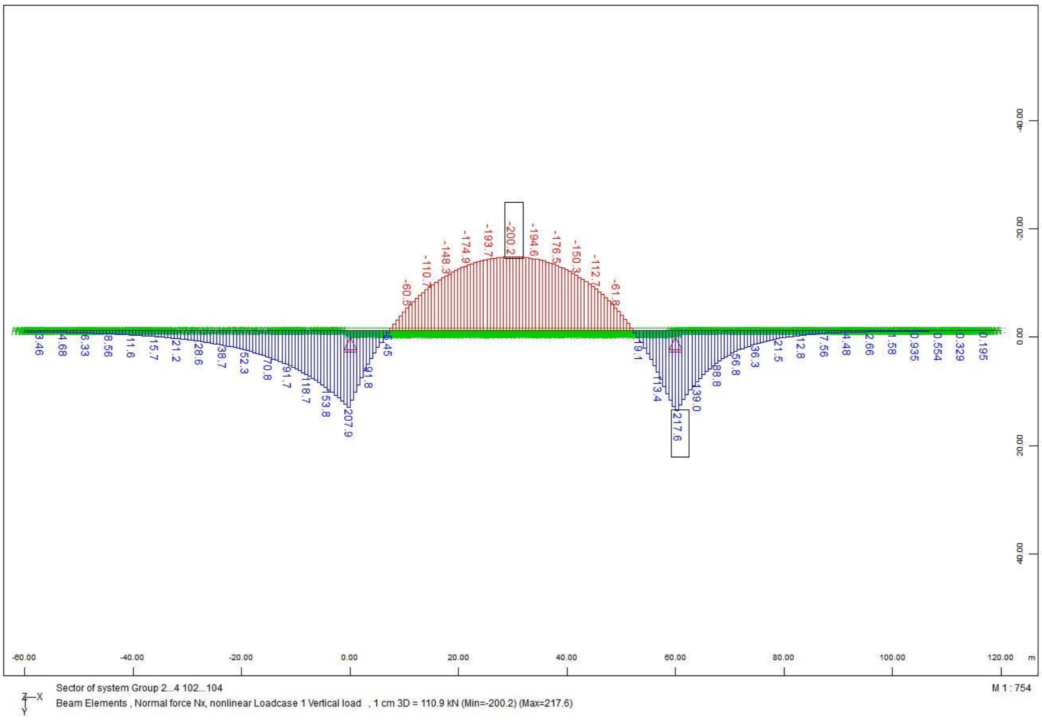


Figure 1.8 F4-6. Vertical load case - normal force diagram from the model with the center of gravity directly on the supports.

1.2.2 *Normal force diagrams for each load case from the model with eccentric center of gravity*

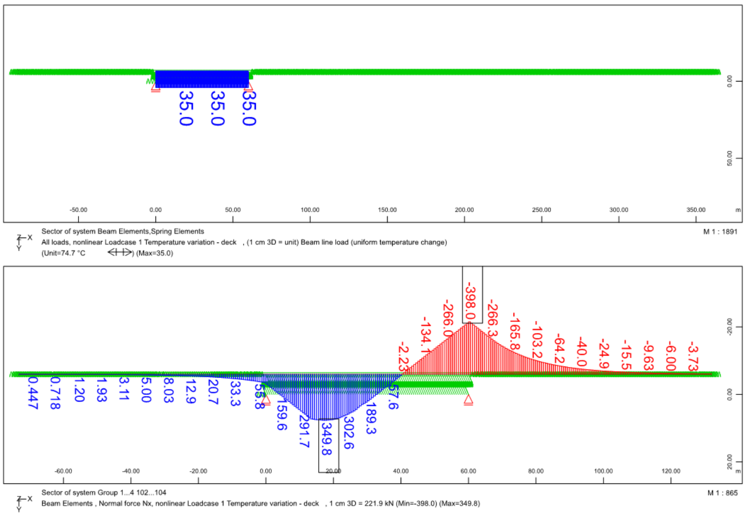


Figure 1.9 F4-6. Temperature variation for the deck - normal force diagram from the model with eccentric center of gravity.

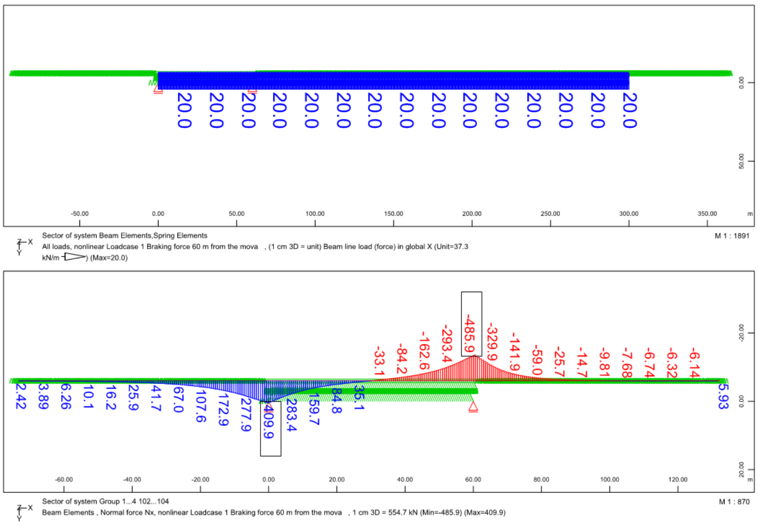


Figure 1.10 F4-6. Braking force load case - normal force diagram from the model with eccentric center of gravity.

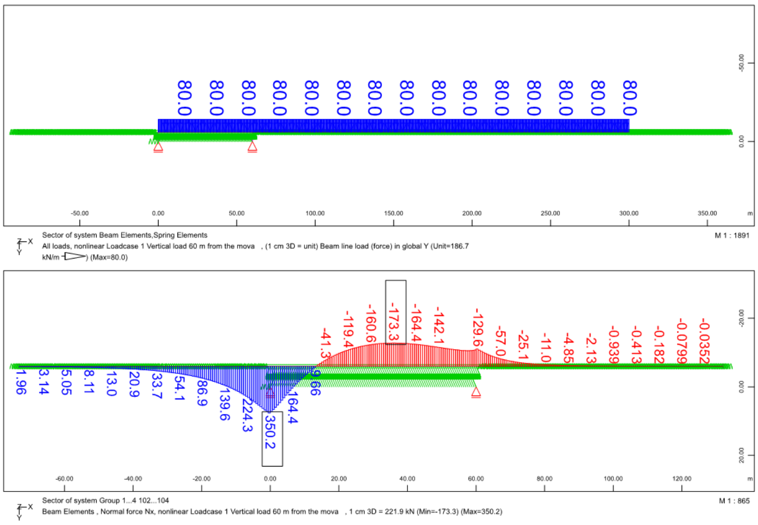


Figure 1.11 F4-6. Vertical load case - normal force diagram from the model with eccentric center of gravity.

1.2.3 *Normal force diagrams for each load case from the model with coupled nodes*

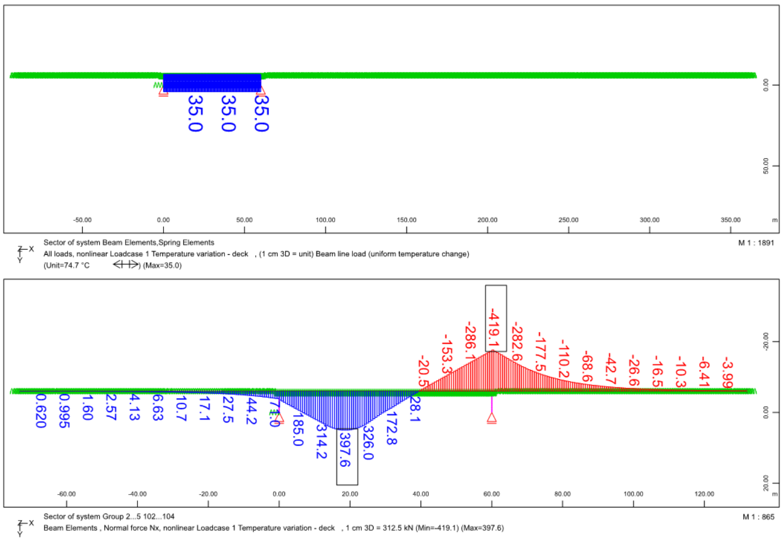


Figure 1.12 F4-6. Temperature variation for the deck - normal force diagram from the model with coupled nodes.

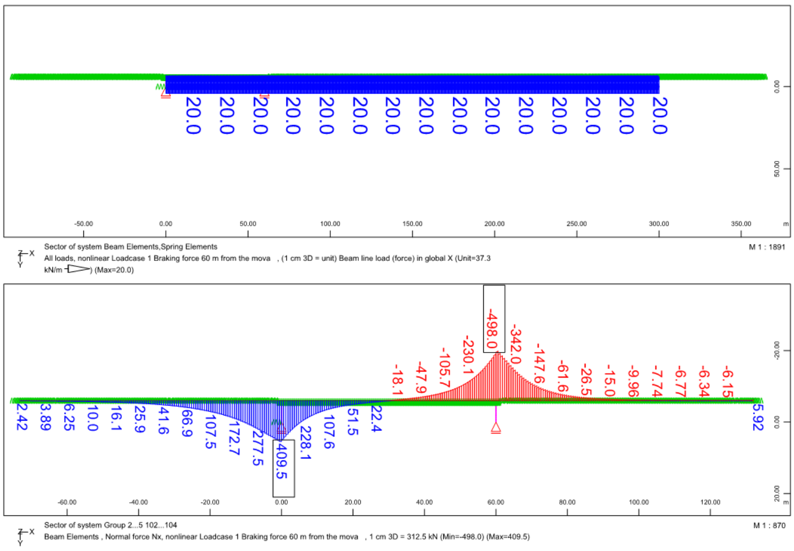


Figure 1.13 F4-6. Braking force load case - normal force diagram from the model with coupled nodes.

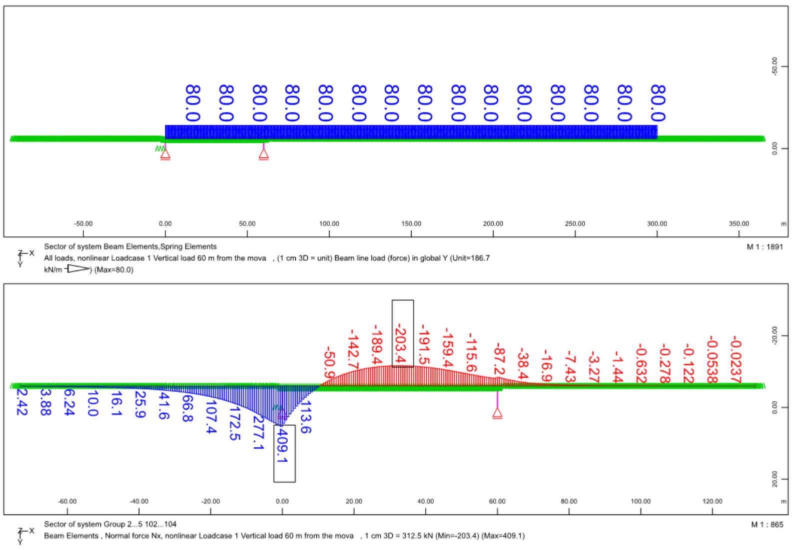


Figure 1.14 F4-6. Vertical load case - normal force diagram from the model with coupled nodes.

1.2.4 Summary of the results for test case F4-6

The results from the model with the center of gravity directly on the supports are not considered in the comparison between the models due to the strange behavior of the normal force for the vertical load case, see Figure 1.8. It is obviously an incorrect behavior if it is compared to the results from the two other models in Figure 1.11 and Figure 1.14 for the vertical load case.

In Table 1.3 are the results from the linear superposition for each load case summarized whereas the percentage error are summarized in Table 1.4.

Table 1.3 Summary of the results for test case F4-6.

Test case F4-6	Load case	Rail stress, σ_{rail} [MPa]	Top of the deck - abs.disp, δ_{deck} [mm]	Support reaction, $F_{support}$ [kN]
Hand calculation	Temperature variation - deck	-25,00	-4,08	490,00
	Braking	-30,00	-2,33	280,00
	Vertical bending - end rot	-10,10	4,43	532,00
	Sum:	**-65,10**	**-1,98**	**1302,00**
UIC Computer calculation	Temperature variation - deck	-25,97	-4,35	482,92
	Braking	-25,58	-3,19	383,07
	Vertical bending - end rot	-10,23	2,29	436,75
	Sum:	**-61,78**	**-5,25**	**1302,74**
Sofistik Eccentric center of gravity	Temperature variation - deck	-25,89	-4,78	461,60
	Braking	-31,61	-2,64	316,20
	Vertical bending - end rot	-8,43	3,36	479,80
	Sum:	**-65,93**	**-4,06**	**1257,60**
Sofistik Coupled nodes	Temperature variation - deck	-27,26	-4,66	496,60
	Braking	-32,40	-2,54	304,50
	Vertical bending - end rot	-5,67	3,17	496,40
	Sum:	**-65,33**	**-4,03**	**1297,50**

Table 1.4 Comparison of the percentage error between the sums determined through each test model against the sums from the hand calculation and the computer calculation performed by UIC for test case F4-6.

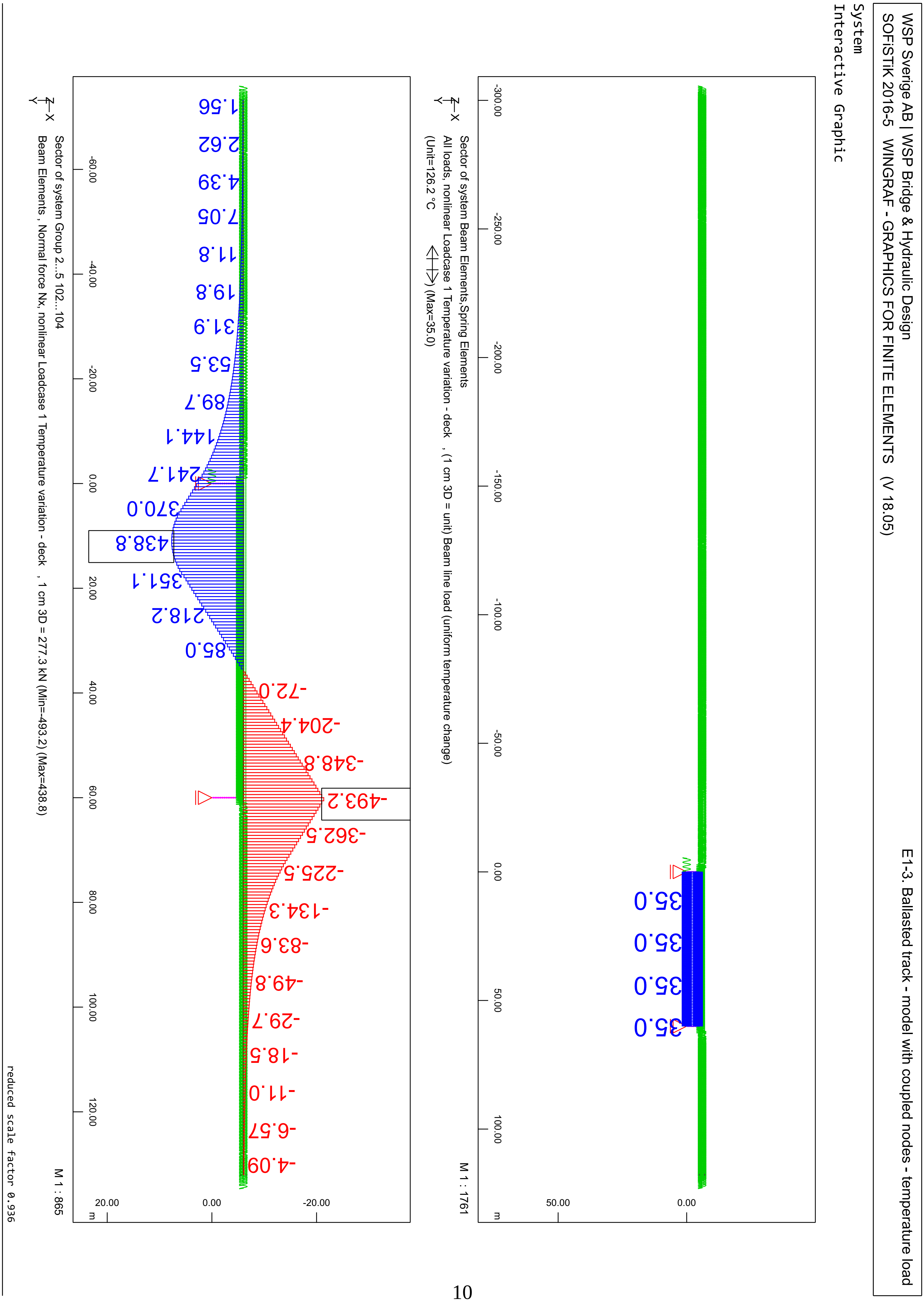
Test case F4-6 - error against the sums from the hand calculation	Rail stress, σ_{rail} [%]	Top of the deck - abs.disp, δ_{deck} [%]	Support reaction, $F_{support}$ [%]
Sofistik Eccentric center of gravity	1,3	105,1	-3,4
Sofistik Coupled nodes	0,4	103,5	-0,3

Test case F4-6 - error against the sums from UIC's computer calculation	Rail stress, σ_{rail} [%]	Top of the deck - abs.disp, δ_{deck} [%]	Support reaction, $F_{support}$ [%]
Sofistik Eccentric center of gravity	6,7	-22,7	-3,5
Sofistik Coupled nodes	5,8	-23,2	-0,4

2 Detailed results from Sofistik

In the following sections - section 2.1 and section 2.2 - are detailed output data from the model with coupled nodes shown for the two test cases, E1-3 respectively F4-6.

2.1 Detailed results from the model with coupled nodes for test case E1-3



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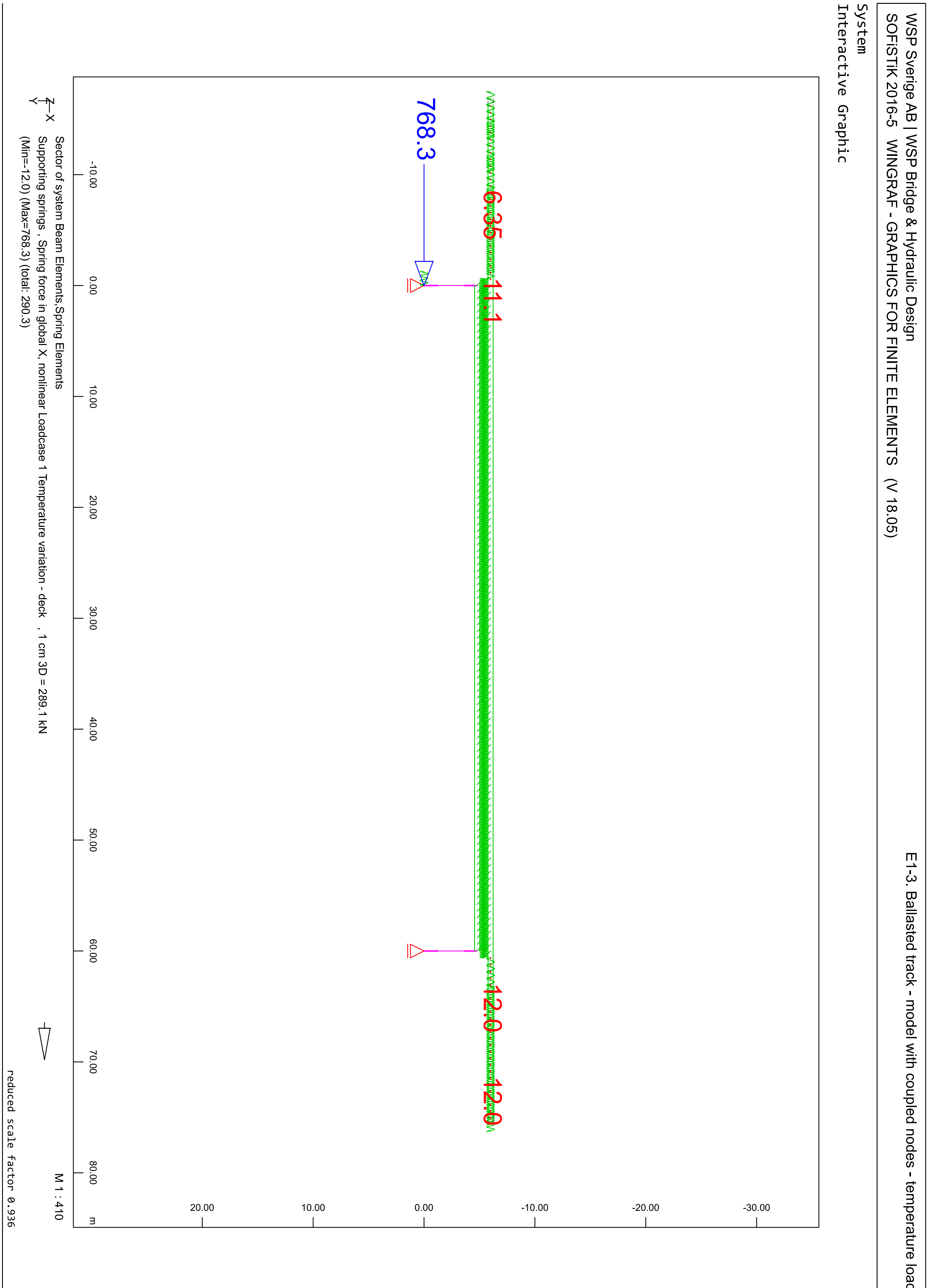

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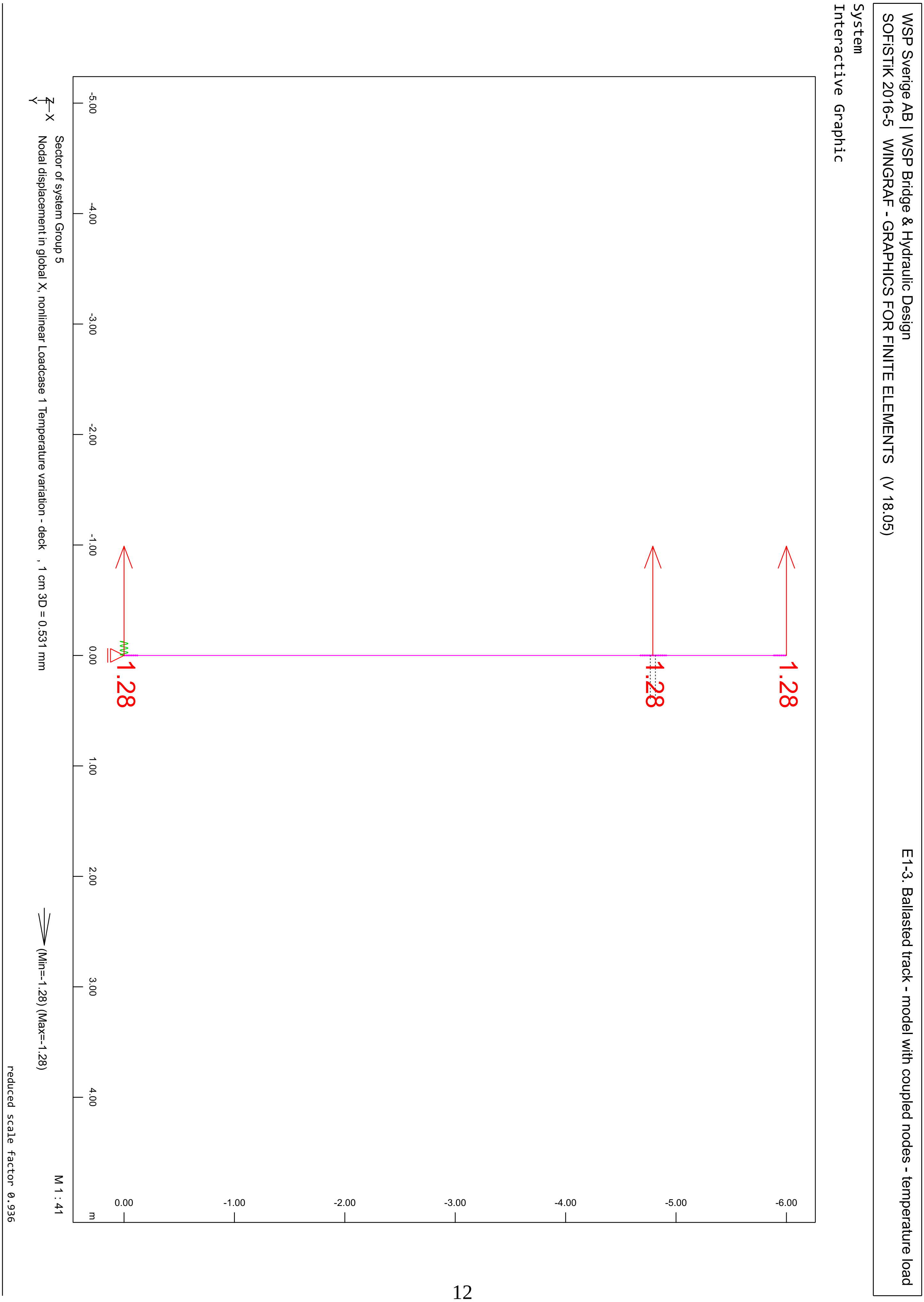

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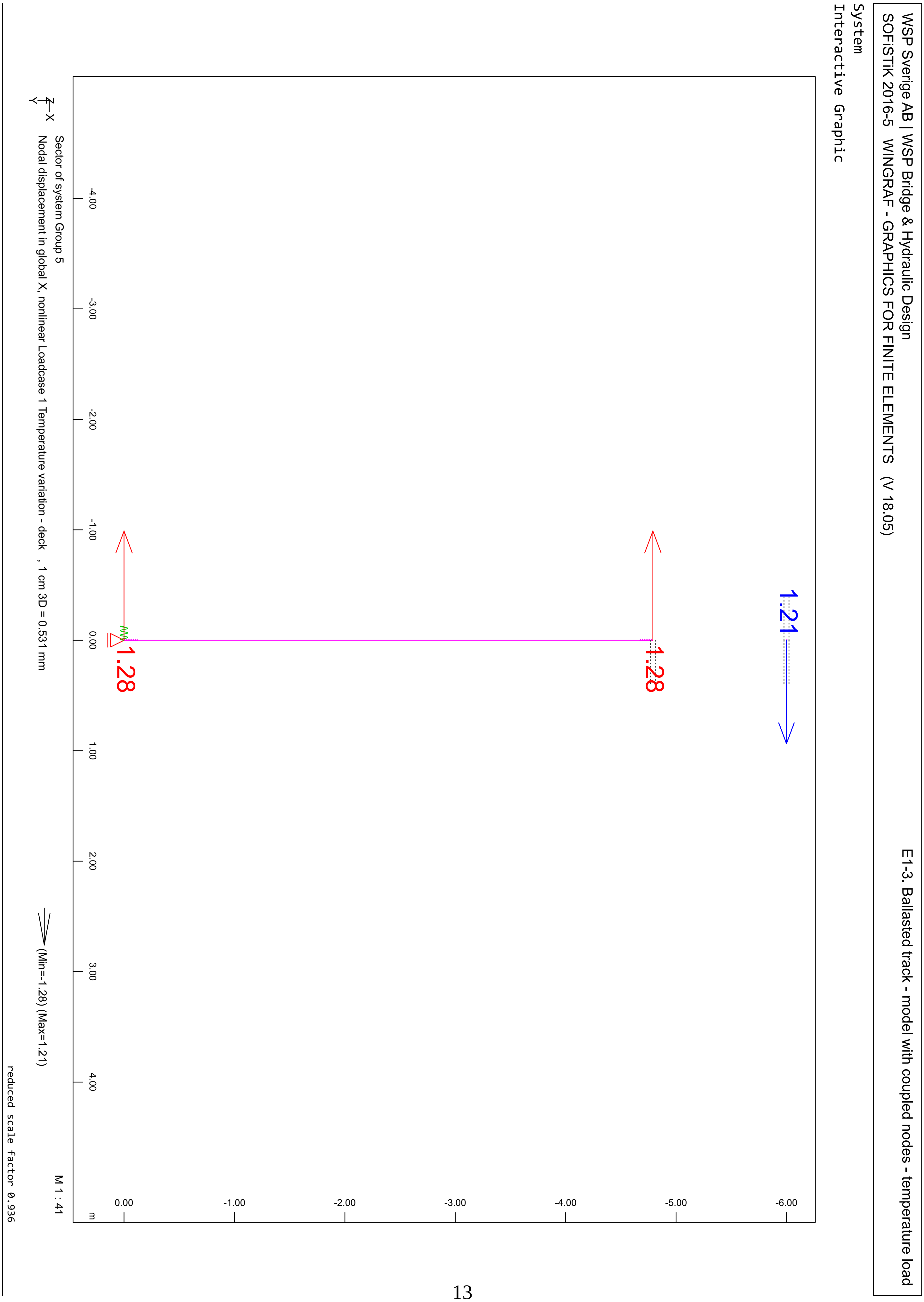

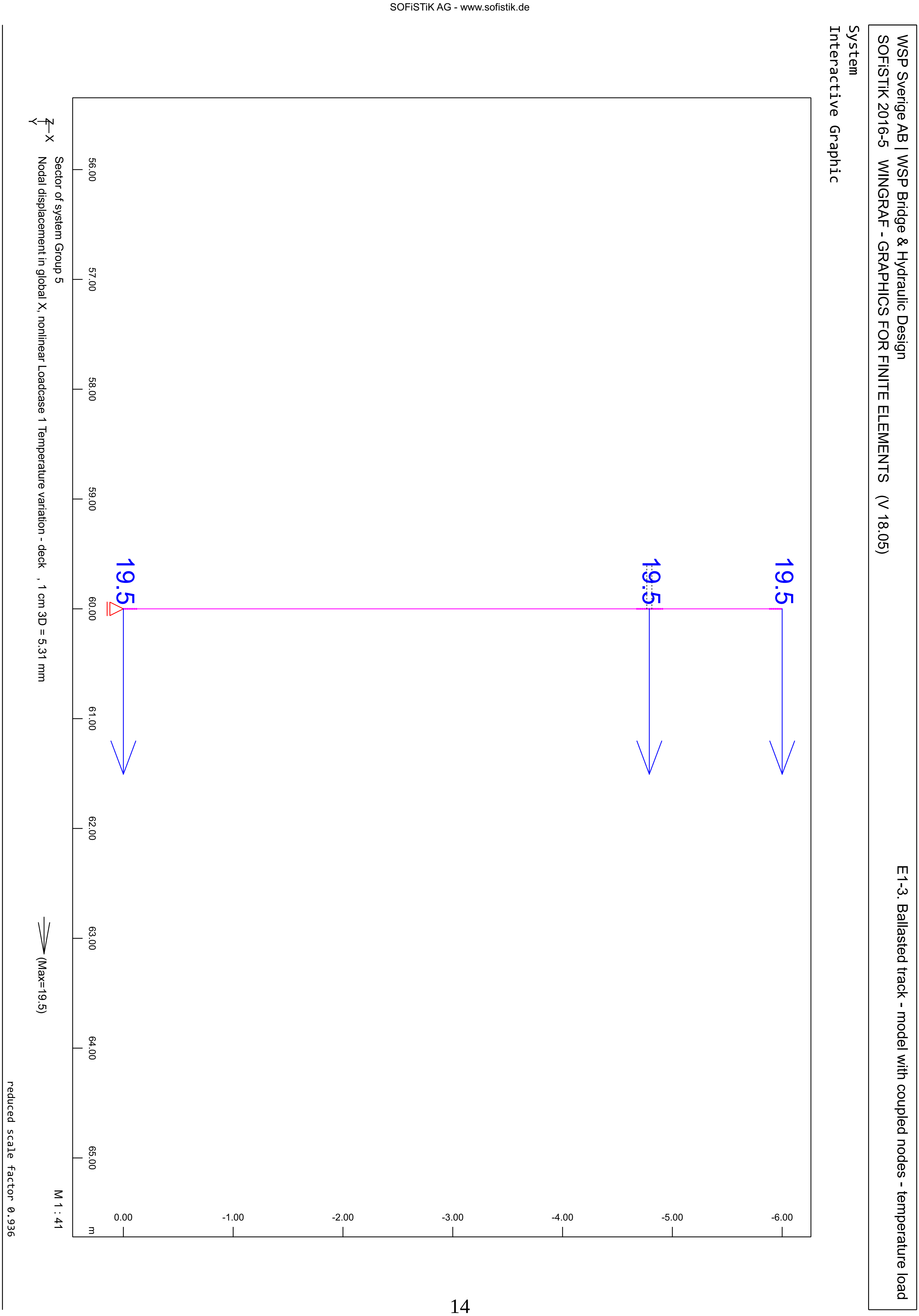
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WSP Sverige AB | WSP Bridge & Hydraulic Design
SOFiSTiK 2016-5 WINGRAF - GRAPHICS FOR FINITE ELEMENTS (V 18.05)
E1-3. Ballasted track - model with coupled nodes - temperature load
System
Interactive Graphic
19.5
19.5
19.5
56.00
57.00
58.00
59.00
60.00
61.00
62.00
63.00
64.00
65.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
m
M 1 : 41
Sector of system Group 5
Nodal displacement in global X, nonlinear Loadcase 1 Temperature variation - deck , 1 cm 3D = 5.31 mm
(Max=19.5)
reduced scale factor 0.936

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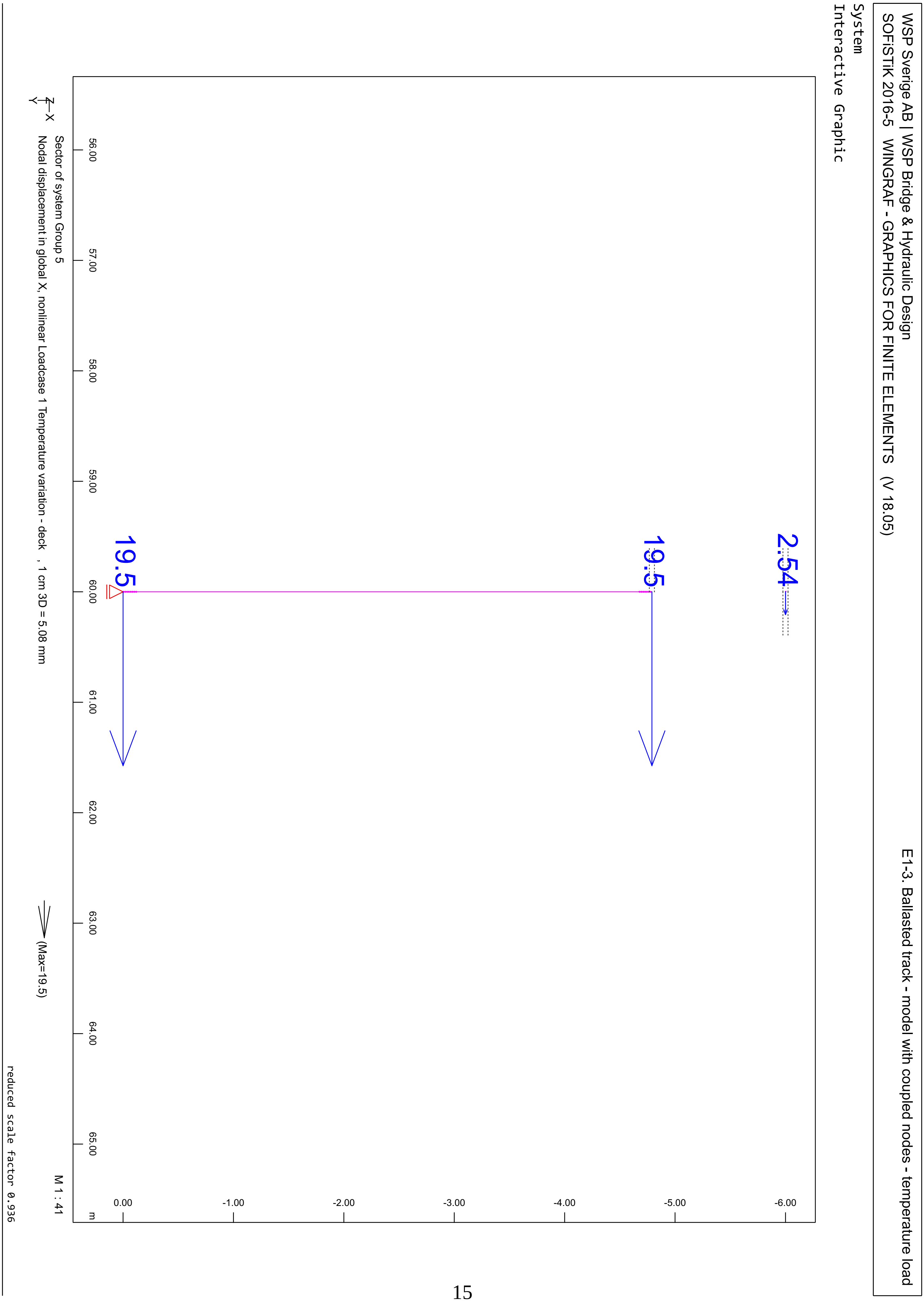

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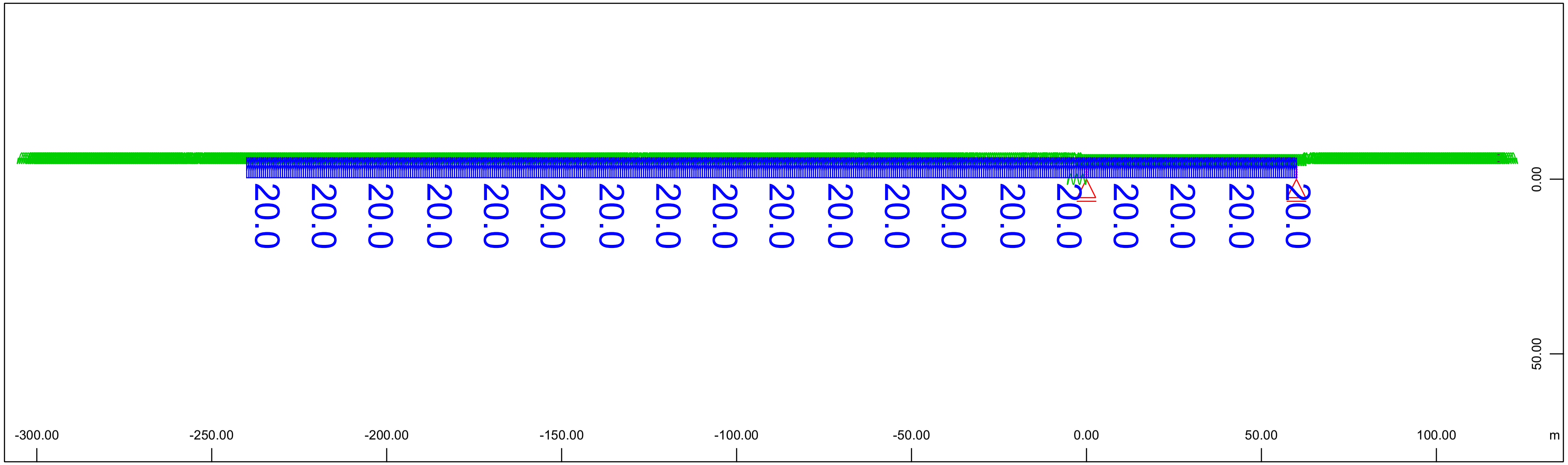
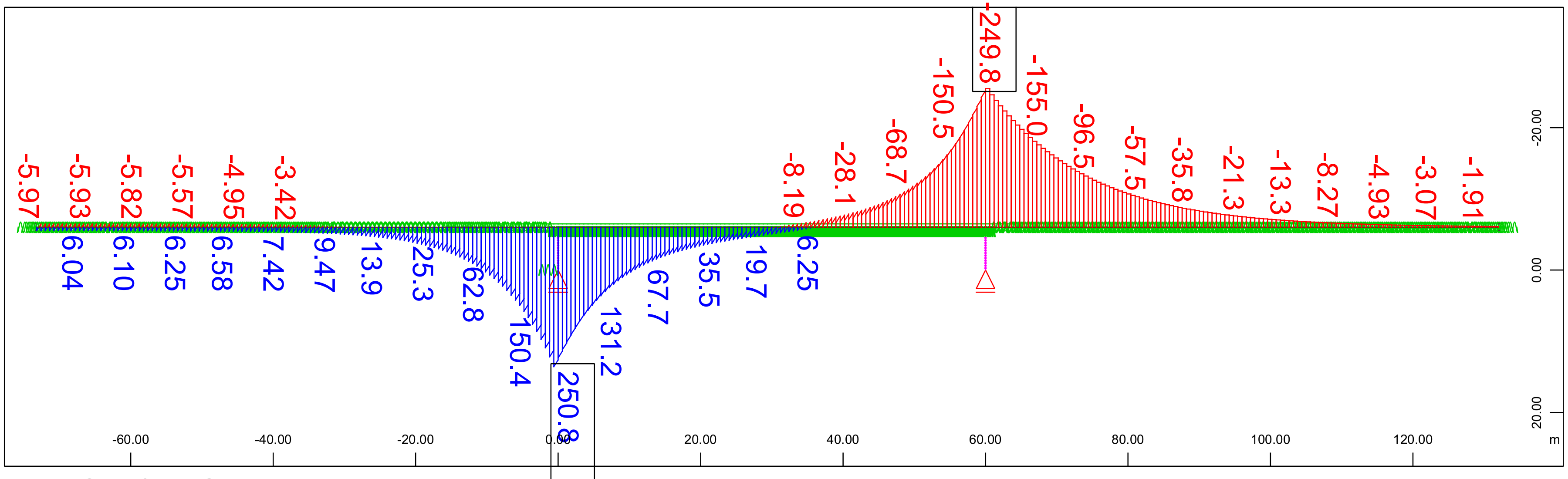
E1-3. Ballasted track - model with coupled nodes - braking force - z = 60 m

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Braking force 60 m from the fixe , (1 cm 3D = unit) Beam line load (force) in global X (Unit=63.1 kN/m) (Max=20.0)

M 1 : 1761



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Braking force 60 m from the fixe , 1 cm 3D = 110.9 kN (Min=-249.8) (Max=250.8)

M 1 : 865

reduced scale factor 0.936

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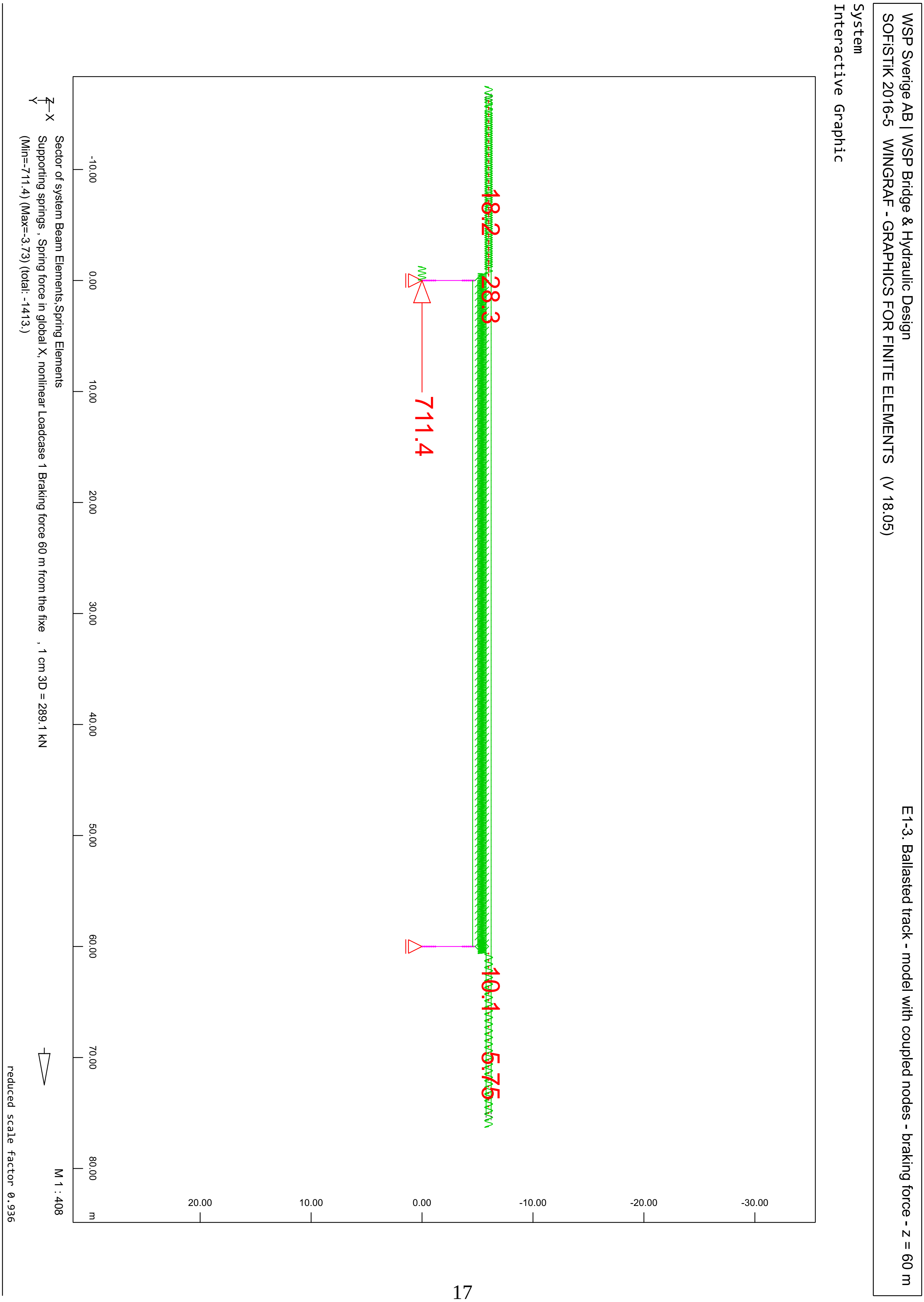

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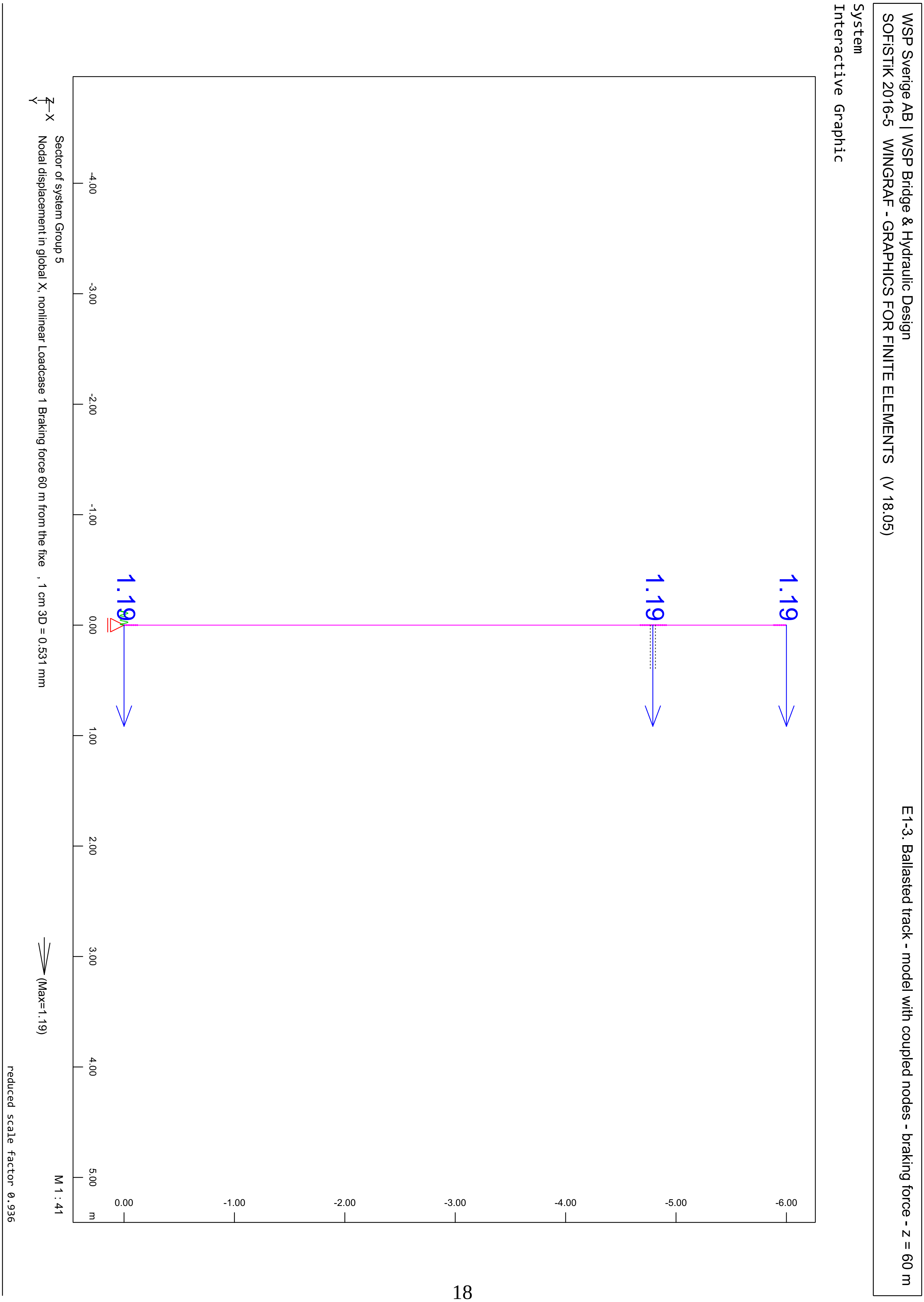

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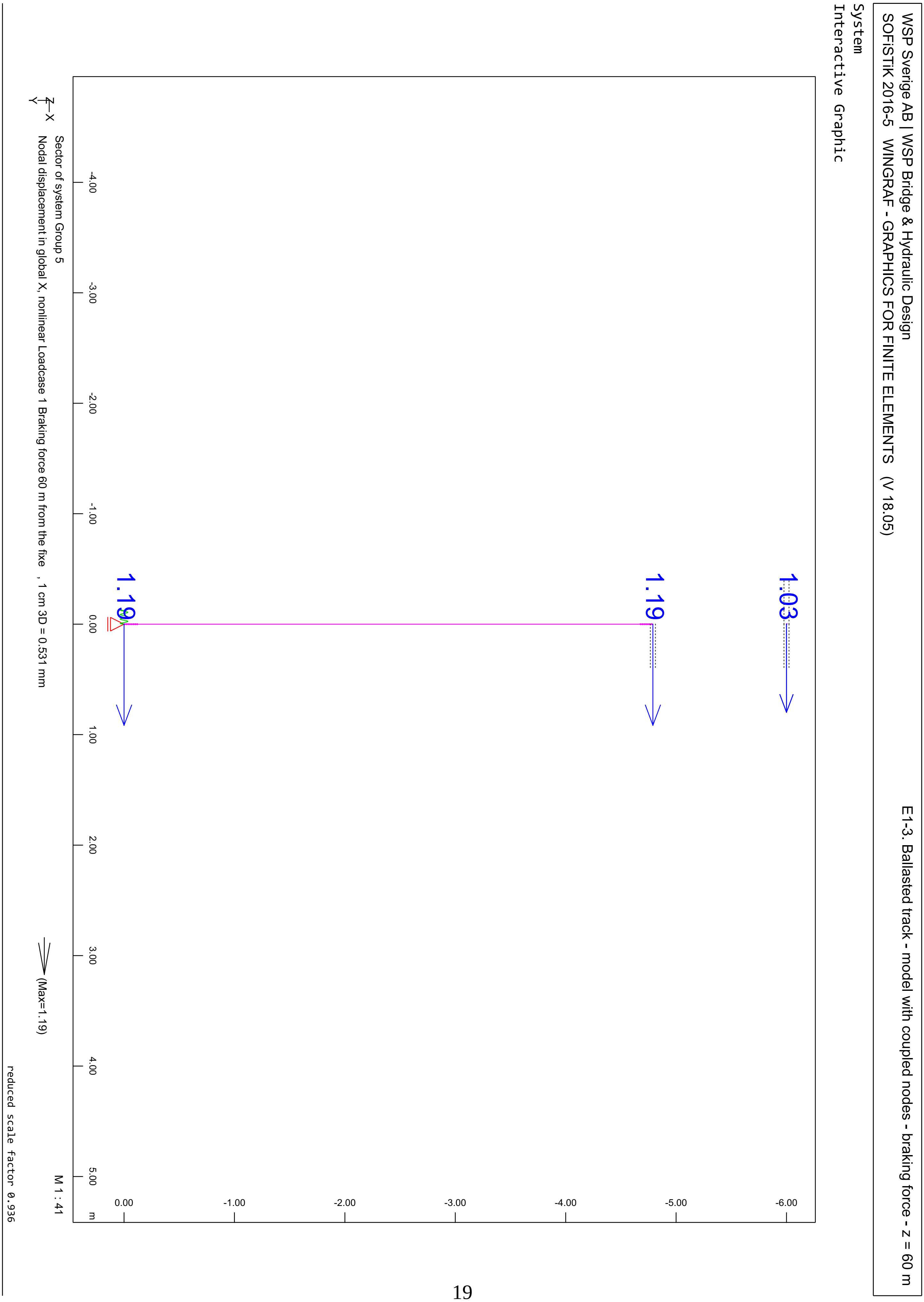

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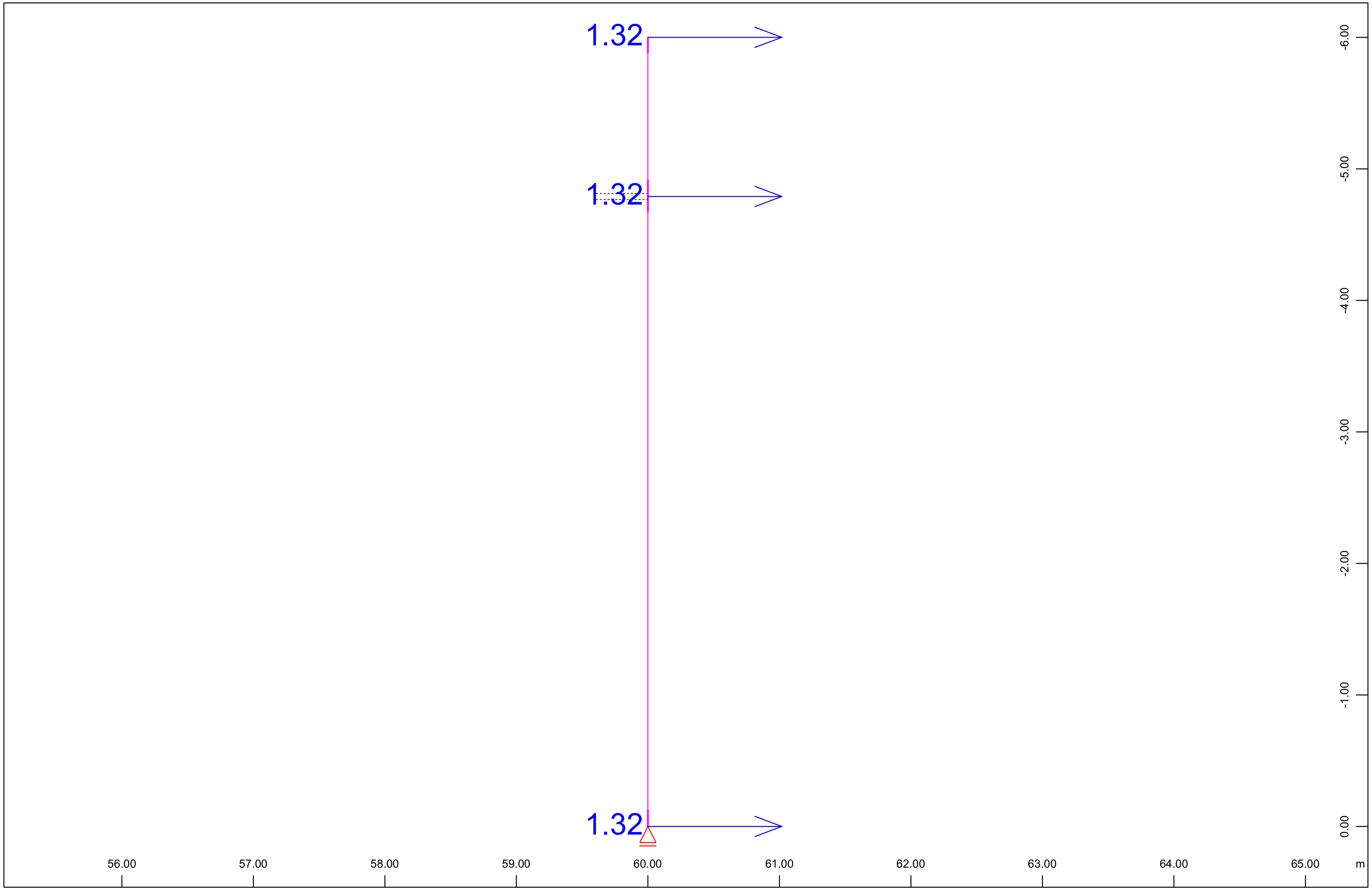
E1-3. Ballasted track - model with coupled nodes - braking force - z = 60 m

System
Interactive Graphic



Z—X
Y

Sector of system Group 5
Nodal displacement in global X, nonlinear Loadcase 1 Braking force 60 m from the fixe , 1 cm 3D = 0.531 mm
(Max=1.32)
M 1 : 41

reduced scale factor 0.936

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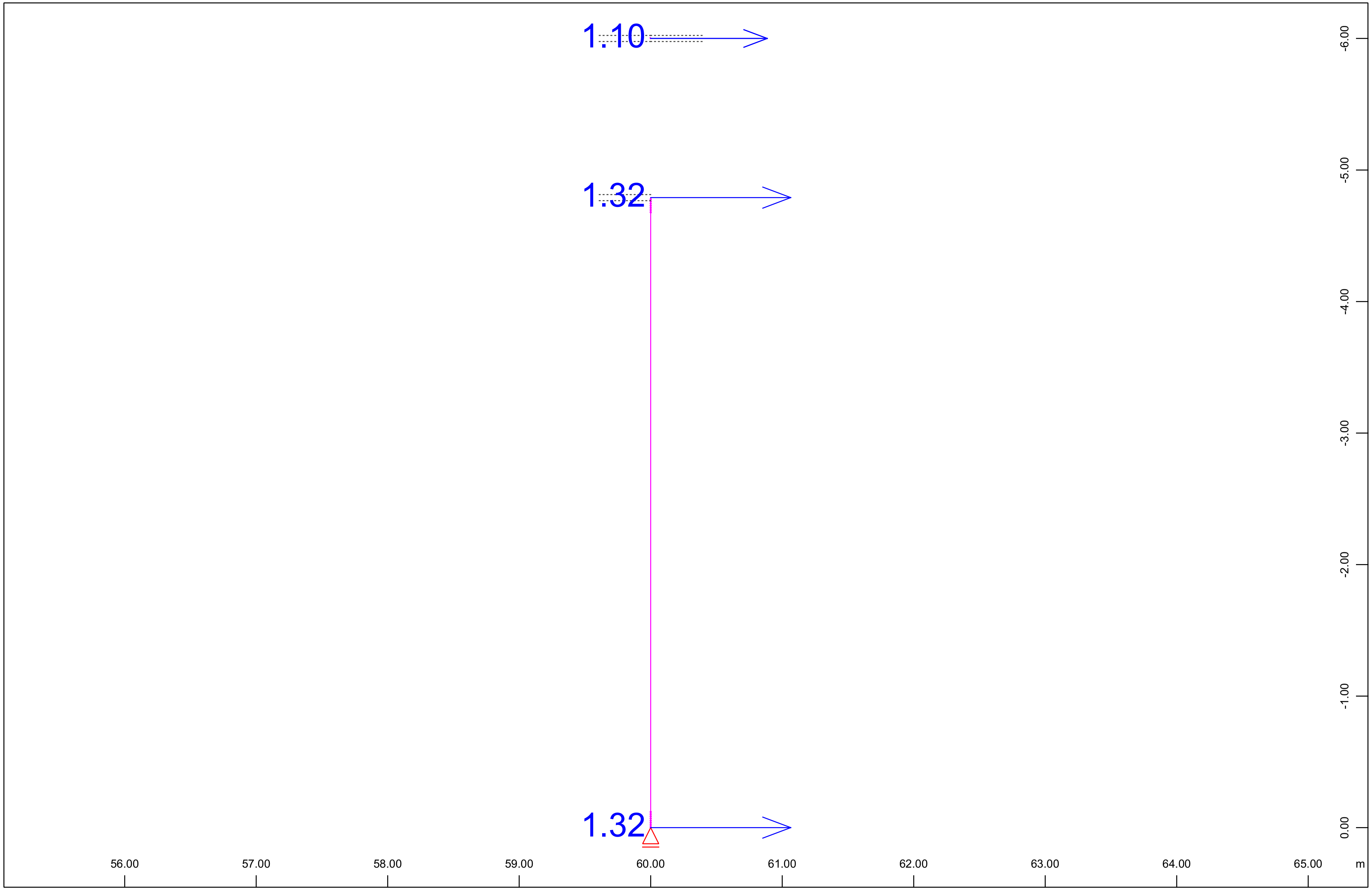
E1-3. Ballasted track - model with coupled nodes - braking force - z = 60 m

System
Interactive Graphic



Z—X
Y

Sector of system Group 5
Nodal displacement in global X, nonlinear Loadcase 1 Braking force 60 m from the fixe , 1 cm 3D = 0.508 mm

(Max=1.32)

M 1 : 41

reduced scale factor 0.936

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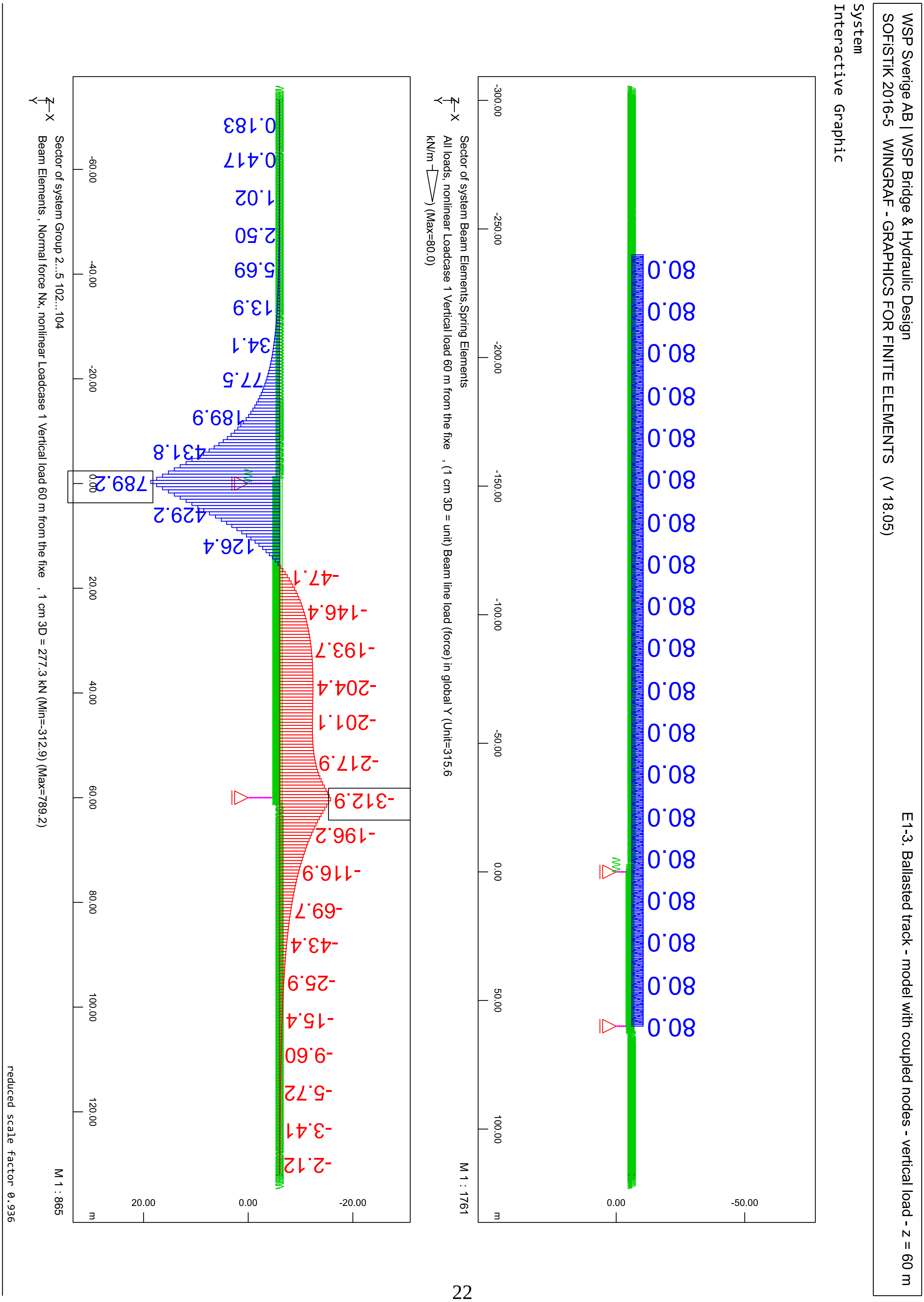

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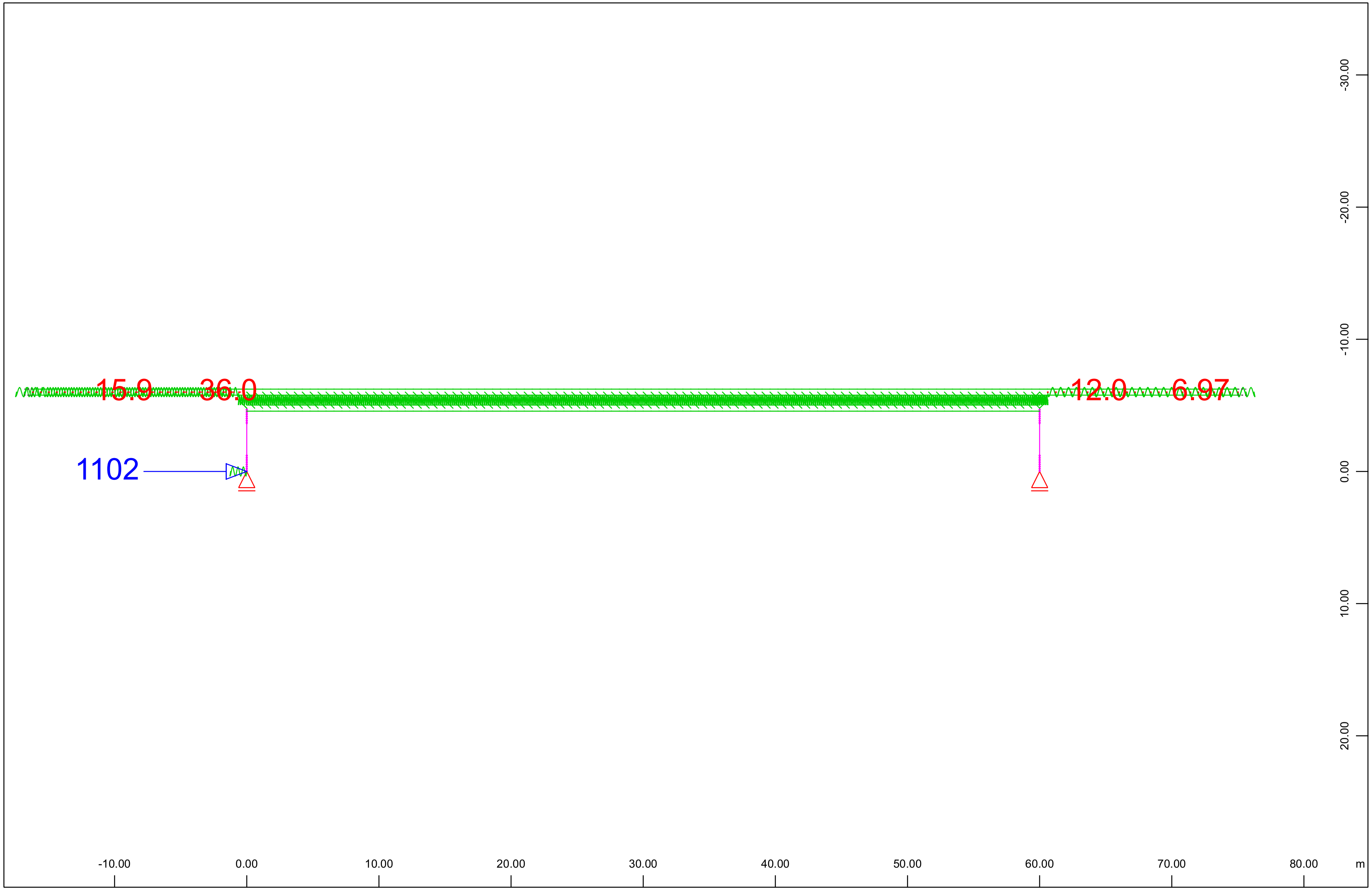
E1-3. Ballasted track - model with coupled nodes - vertical load - z = 60 m

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
Supporting springs , Spring force in global X, nonlinear Loadcase 1 Vertical load 60 m from the fixe , 1 cm 3D = 578.1 kN
(Min=-36.0) (Max=1102.) (total: 228.6)

reduced scale factor 0.936

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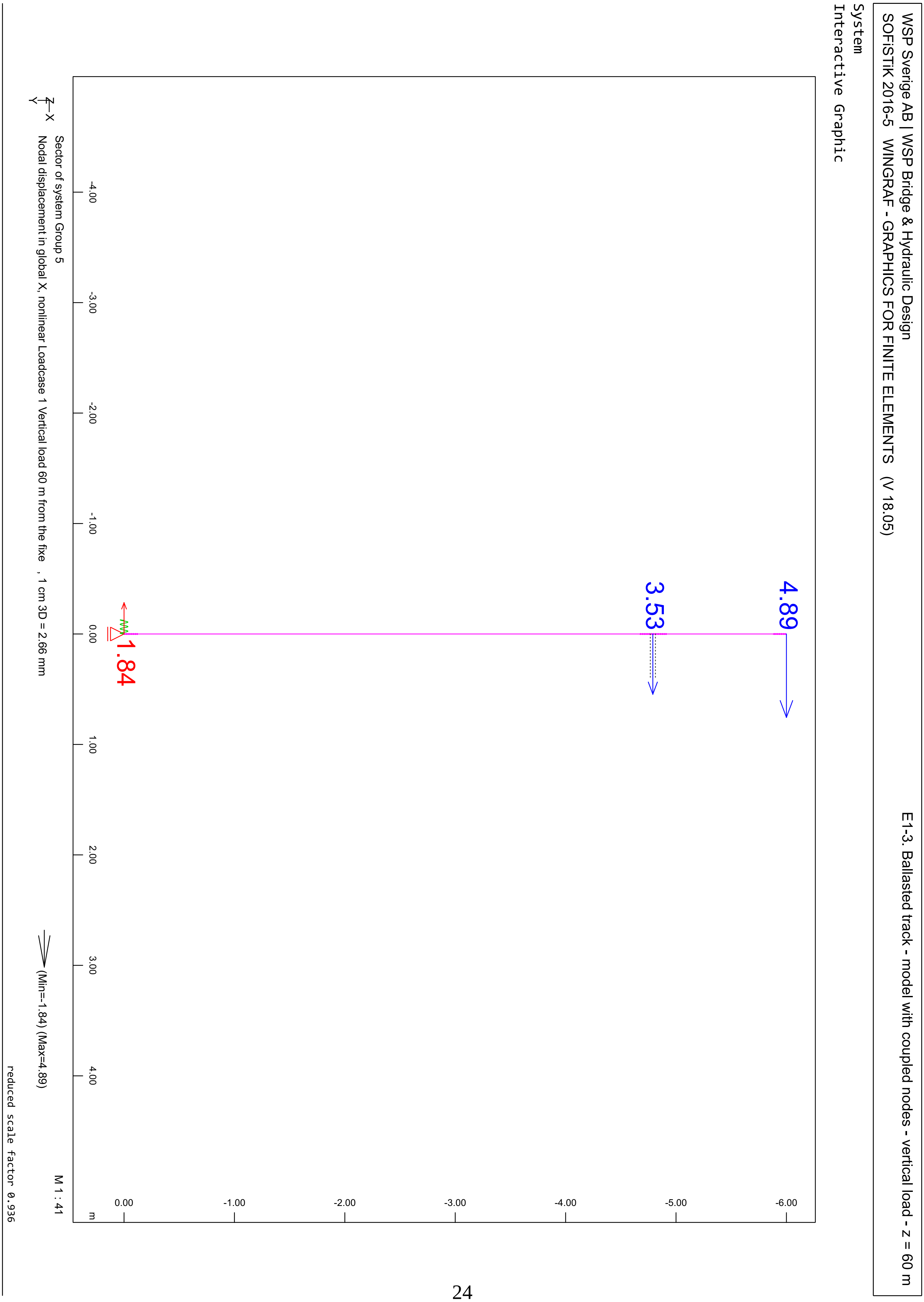

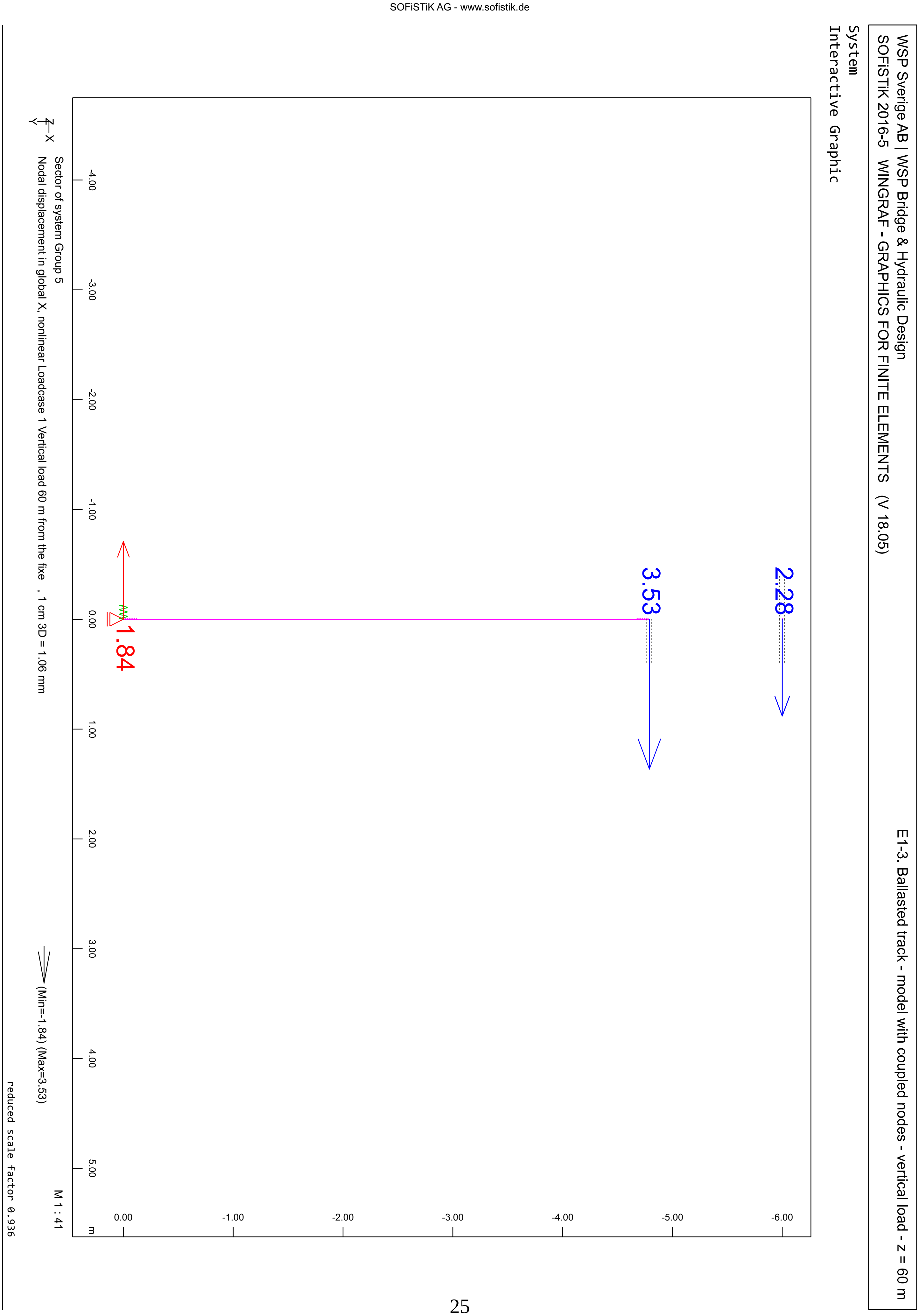
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SOFiSTiK 2016-5 WINGRAF - GRAPHICS FOR FINITE ELEMENTS (V 18.05)
E1-3. Ballasted track - model with coupled nodes - vertical load - z = 60 m
System
Interactive Graphic
2.28
3.53
1.84
Sector of system Group 5
Nodal displacement in global X, nonlinear Loadcase 1 Vertical load 60 m from the fixe , 1 cm 3D = 1.06 mm
(Min=-1.84) (Max=3.53)
M 1 : 41
reduced scale factor 0.936
-4.00
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
m
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00

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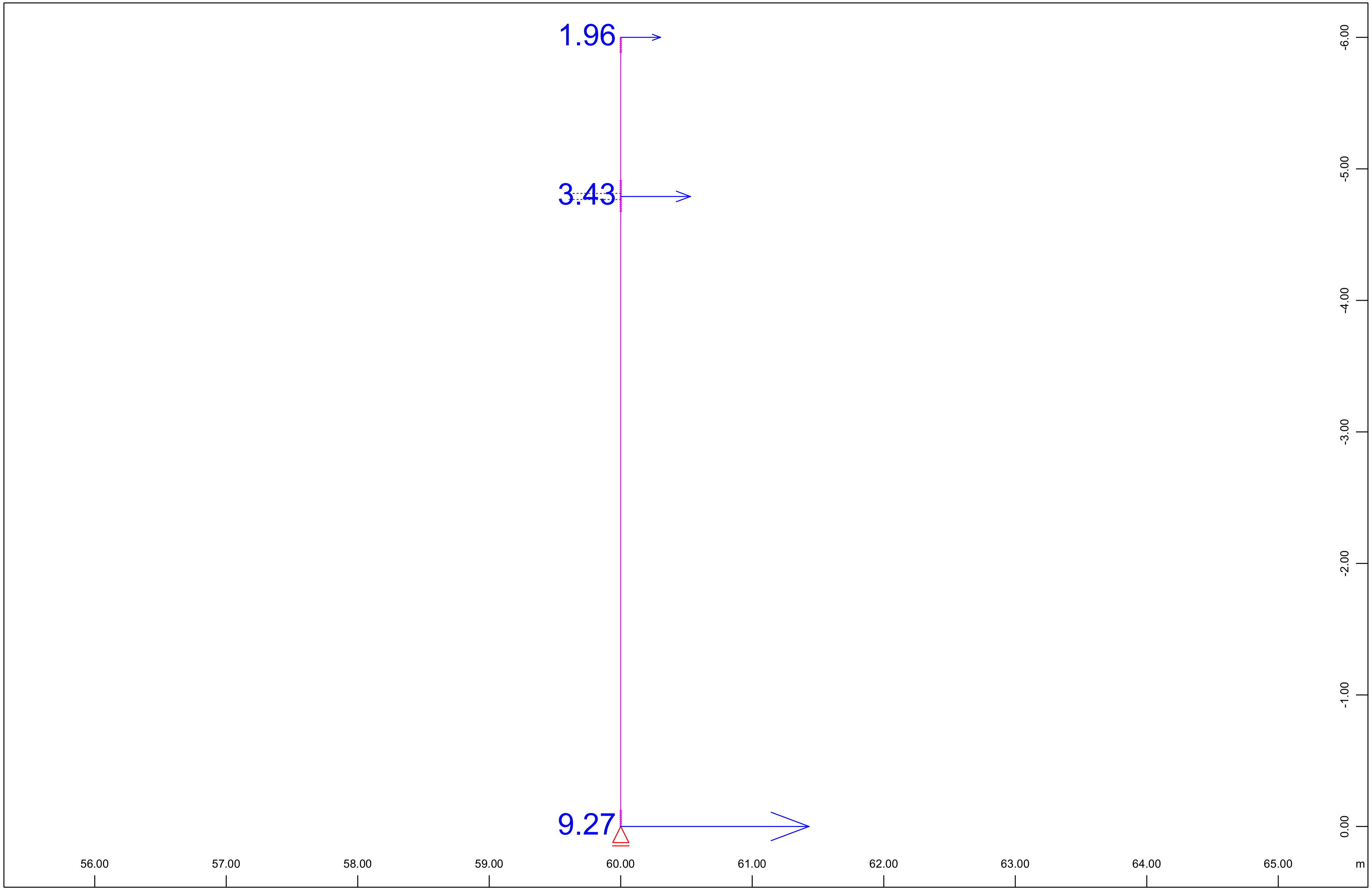
E1-3. Ballasted track - model with coupled nodes - vertical load - z = 60 m

System
Interactive Graphic



Sector of system Group 5
Nodal displacement in global X, nonlinear Loadcase 1 Vertical load 60 m from the fixe , 1 cm 3D = 2.66 mm
(Max=9.27)
M 1 : 41

reduced scale factor 0.936

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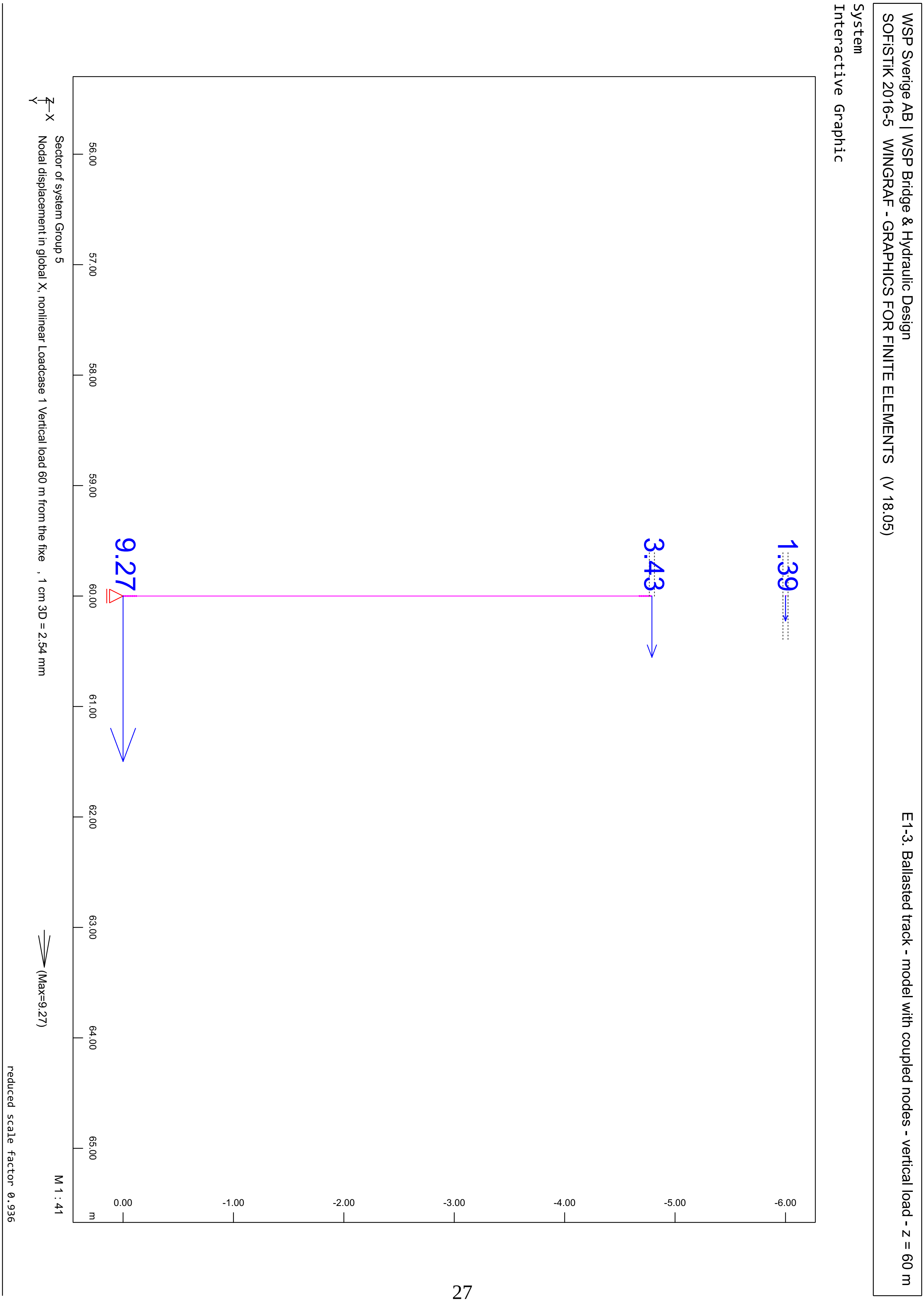
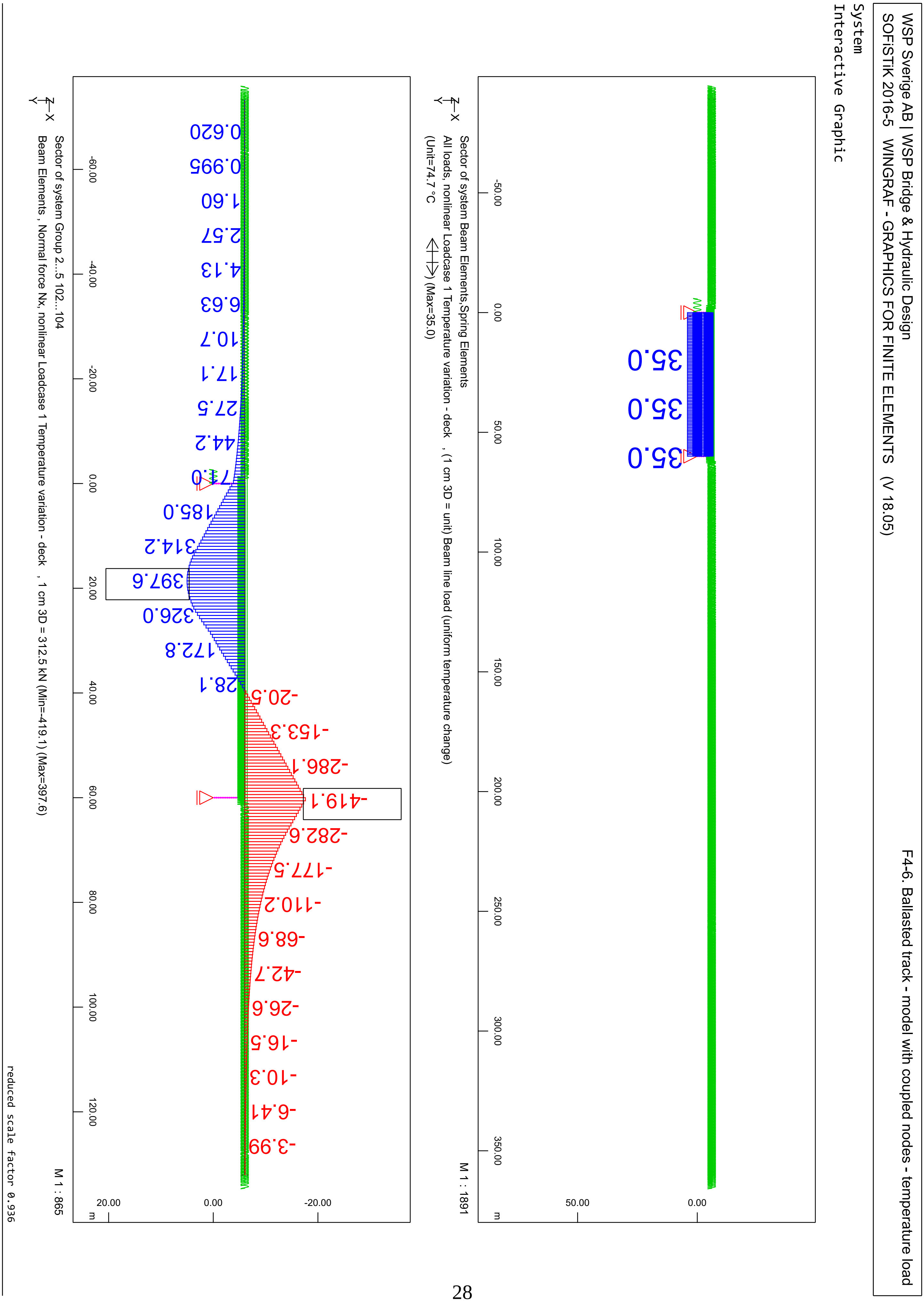
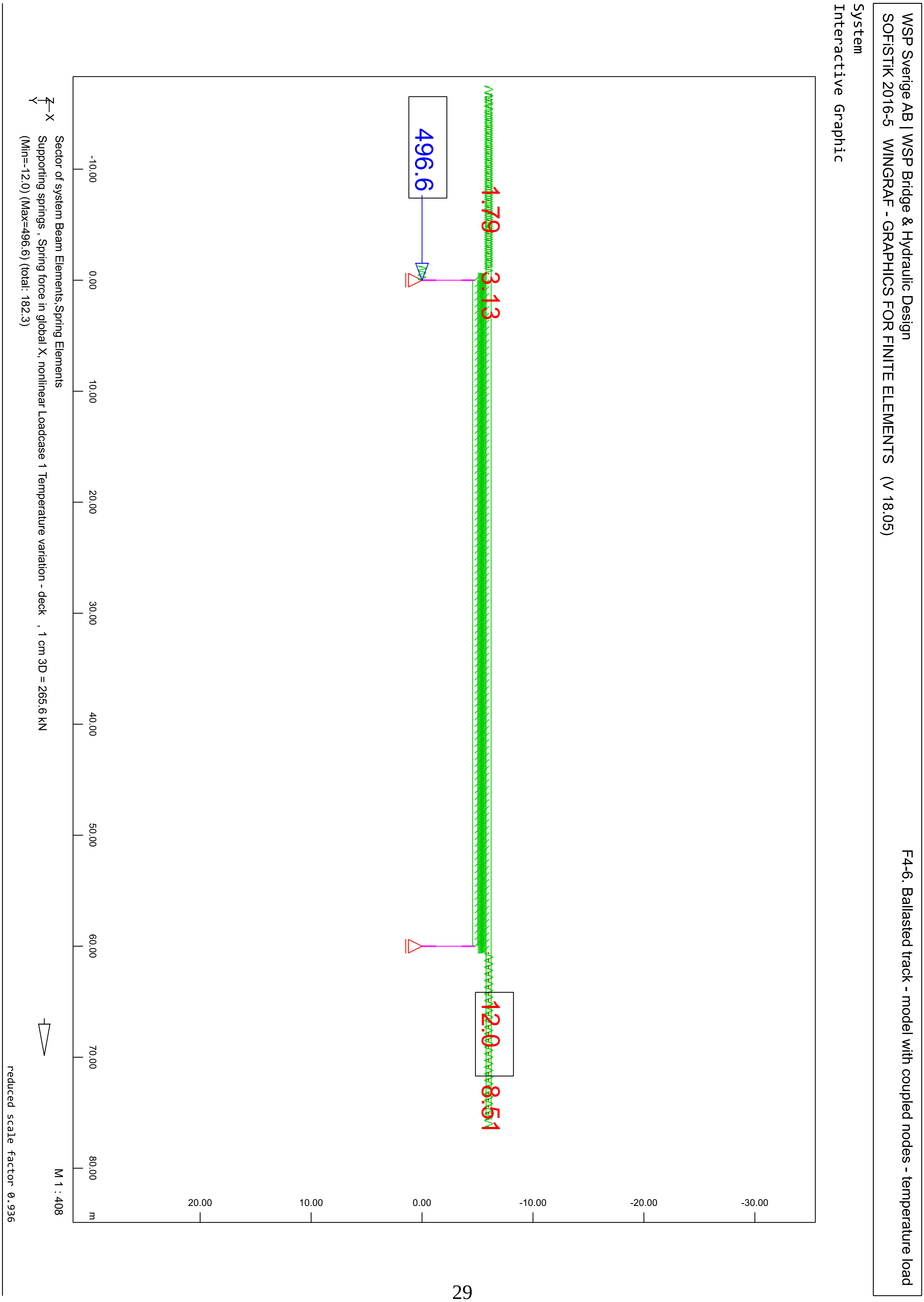


2.2 Detailed results from the model with coupled nodes for test case F4-6

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SOFiSTiK 2016-5 WINGRAF - GRAPHICS FOR FINITE ELEMENTS (V 18.05)
F4-6. Ballasted track - model with coupled nodes - temperature load
System
Interactive Graphic
496.6
1.79
3.13
12.0
8.51
-10.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
m
20.00
10.00
0.00
-10.00
-20.00
-30.00
Sector of system Beam Elements,Spring Elements
Supporting springs , Spring force in global X, nonlinear Loadcase 1 Temperature variation - deck , 1 cm 3D = 265.6 kN
(Min=-12.0) (Max=496.6) (total: 182.3)
M 1 : 408
reduced scale factor 0.936

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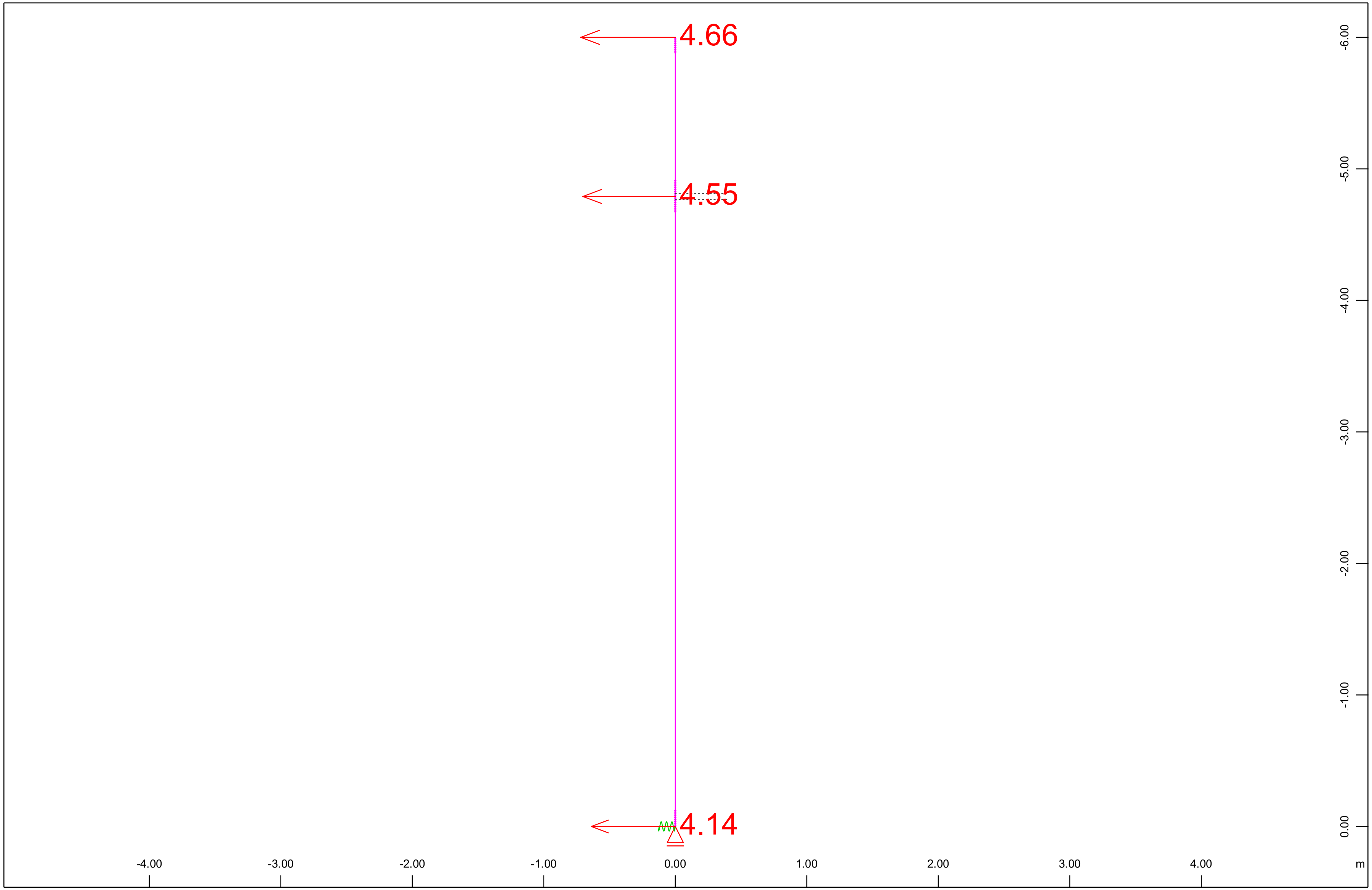
F4-6. Ballasted track - model with coupled nodes - temperature load

System
Interactive Graphic



Sector of system Group 5
Nodal displacement in global X, nonlinear Loadcase 1 Temperature variation - deck , 1 cm 3D = 2.66 mm
(Min=-4.66) (Max=-4.14)
M 1 : 41

reduced scale factor 0.936

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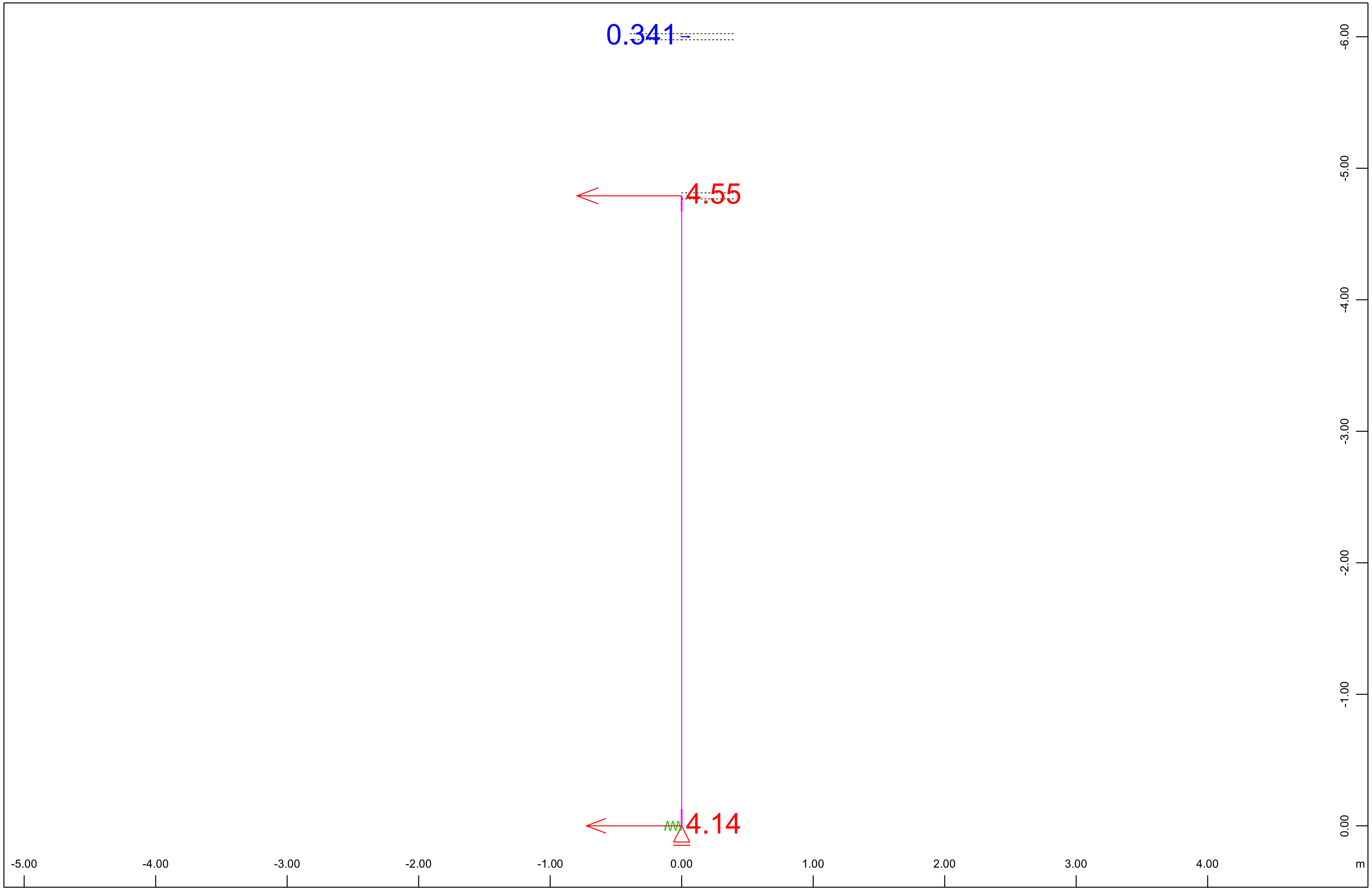
F4-6. Ballasted track - model with coupled nodes - temperature load

System
Interactive Graphic



Z—X
Y

Sector of system Group 5
Nodal displacement in global X, nonlinear Loadcase 1 Temperature variation - deck , 1 cm 3D = 2.34 mm

M 1 : 41

(Min=-4.55) (Max=0.341)

reduced scale factor 0.936

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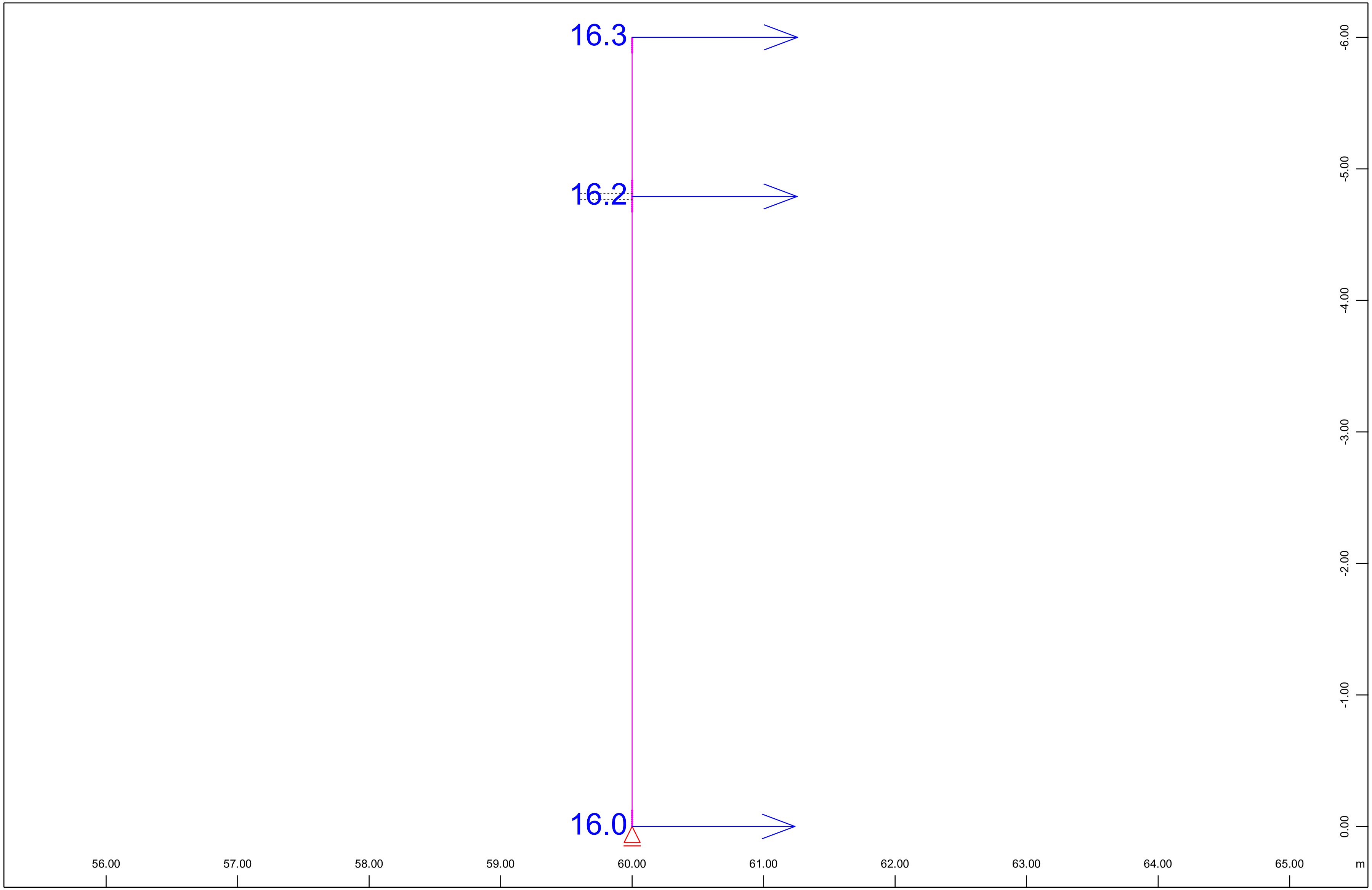
F4-6. Ballasted track - model with coupled nodes - temperature load

System
Interactive Graphic



Z X Y

Sector of system Group 5
Nodal displacement in global X, nonlinear Loadcase 1 Temperature variation - deck , 1 cm 3D = 5.31 mm

(Max=16.3)

M 1 : 41

reduced scale factor 0.936

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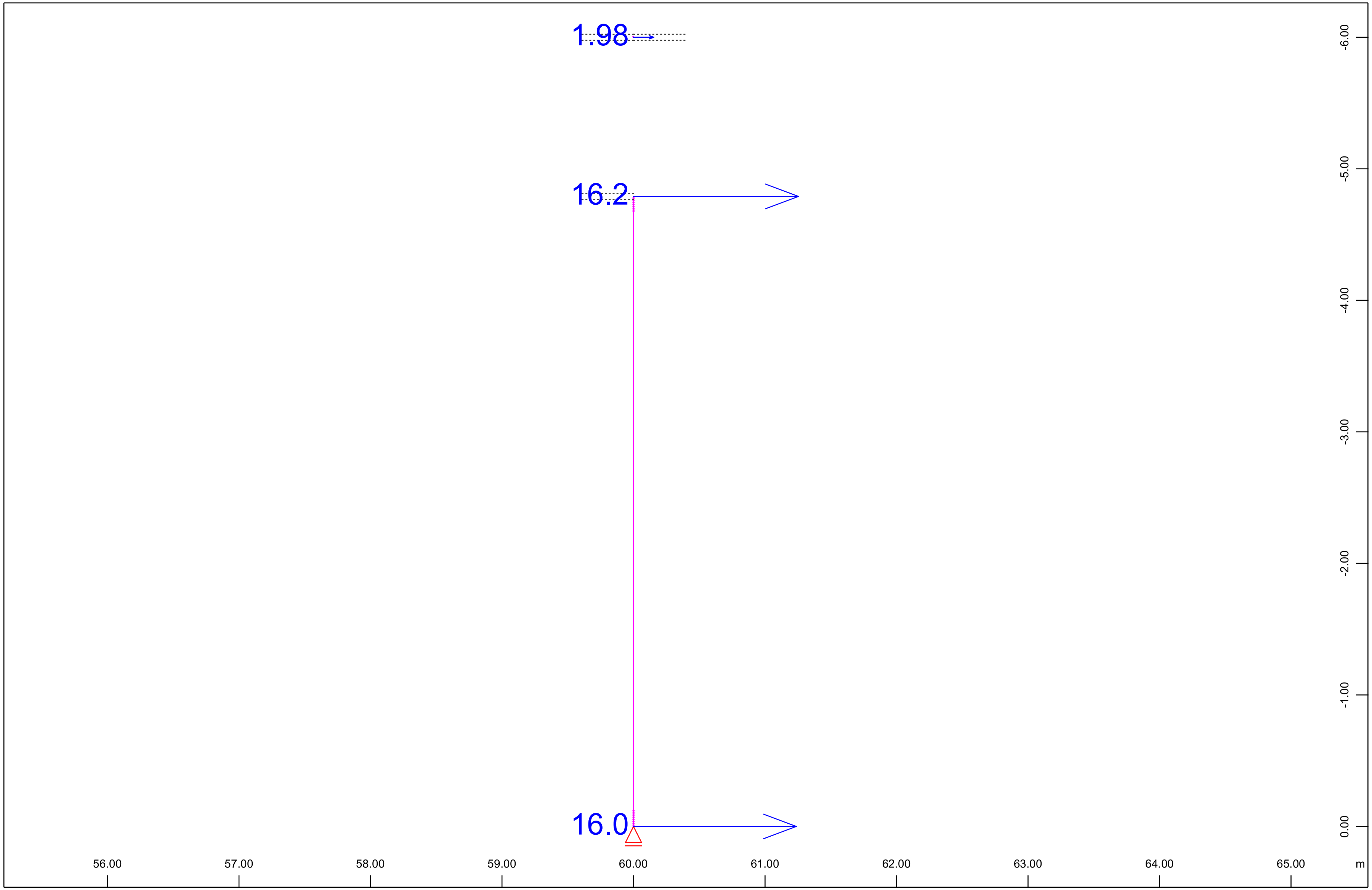
F4-6. Ballasted track - model with coupled nodes - temperature load

System
Interactive Graphic



Z X Y

Sector of system Group 5
Nodal displacement in global X, nonlinear Loadcase 1 Temperature variation - deck , 1 cm 3D = 5.31 mm

(Max=16.2)

M 1 : 41

reduced scale factor 0.936

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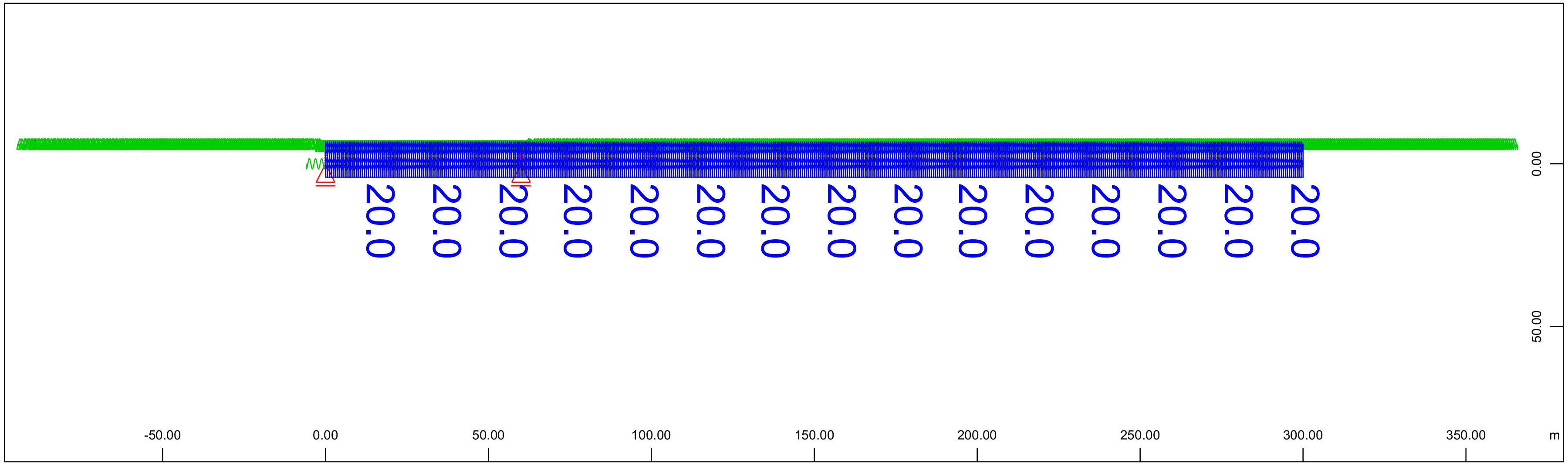
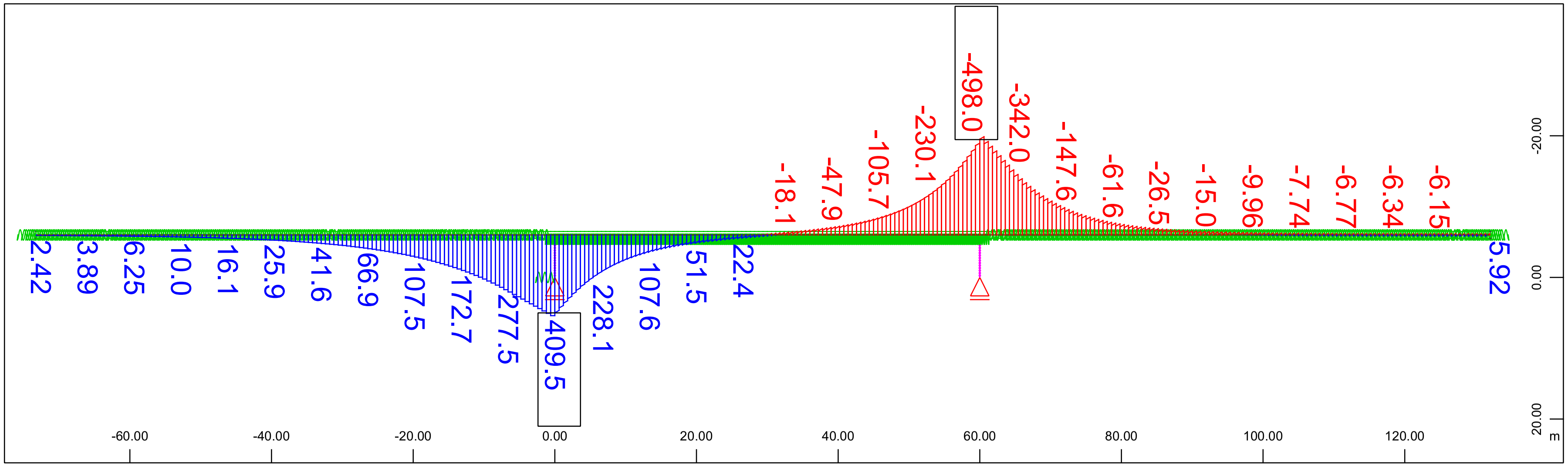
F4-6. Ballasted track - model with coupled nodes - braking force - z = 60 m

System
Interactive Graphic

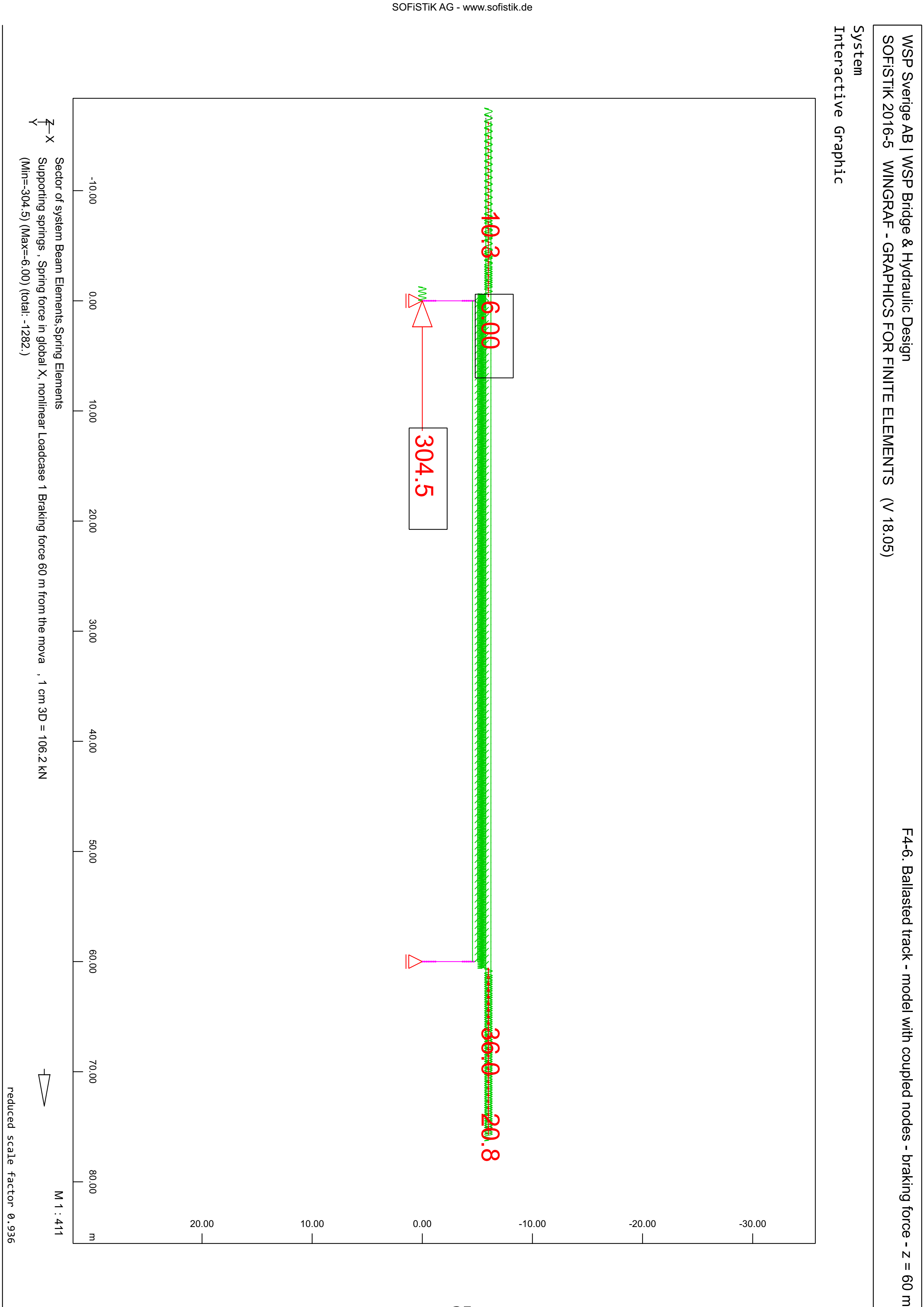


Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Braking force 60 m from the mova , (1 cm 3D = unit) Beam line load (force) in global X (Unit=37.3 kN/m) (Max=20.0)
M 1 : 1891



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Braking force 60 m from the mova , 1 cm 3D = 312.5 kN (Min=-498.0) (Max=409.5)
M 1 : 870

reduced scale factor 0.936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F4-6. Ballasted track - model with coupled nodes - braking force - z = 60 m
System
Interactive Graphic
10.3
6.00
304.5
36.0
20.8
-10.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
m
20.00
10.00
0.00
-10.00
-20.00
-30.00
Sector of system Beam Elements,Spring Elements
Supporting springs , Spring force in global X, nonlinear Loadcase 1 Braking force 60 m from the mova , 1 cm 3D = 106.2 kN
(Min=-304.5) (Max=-6.00) (total: -1282.)
M 1 : 411
reduced scale factor 0.936
X
Y
Z

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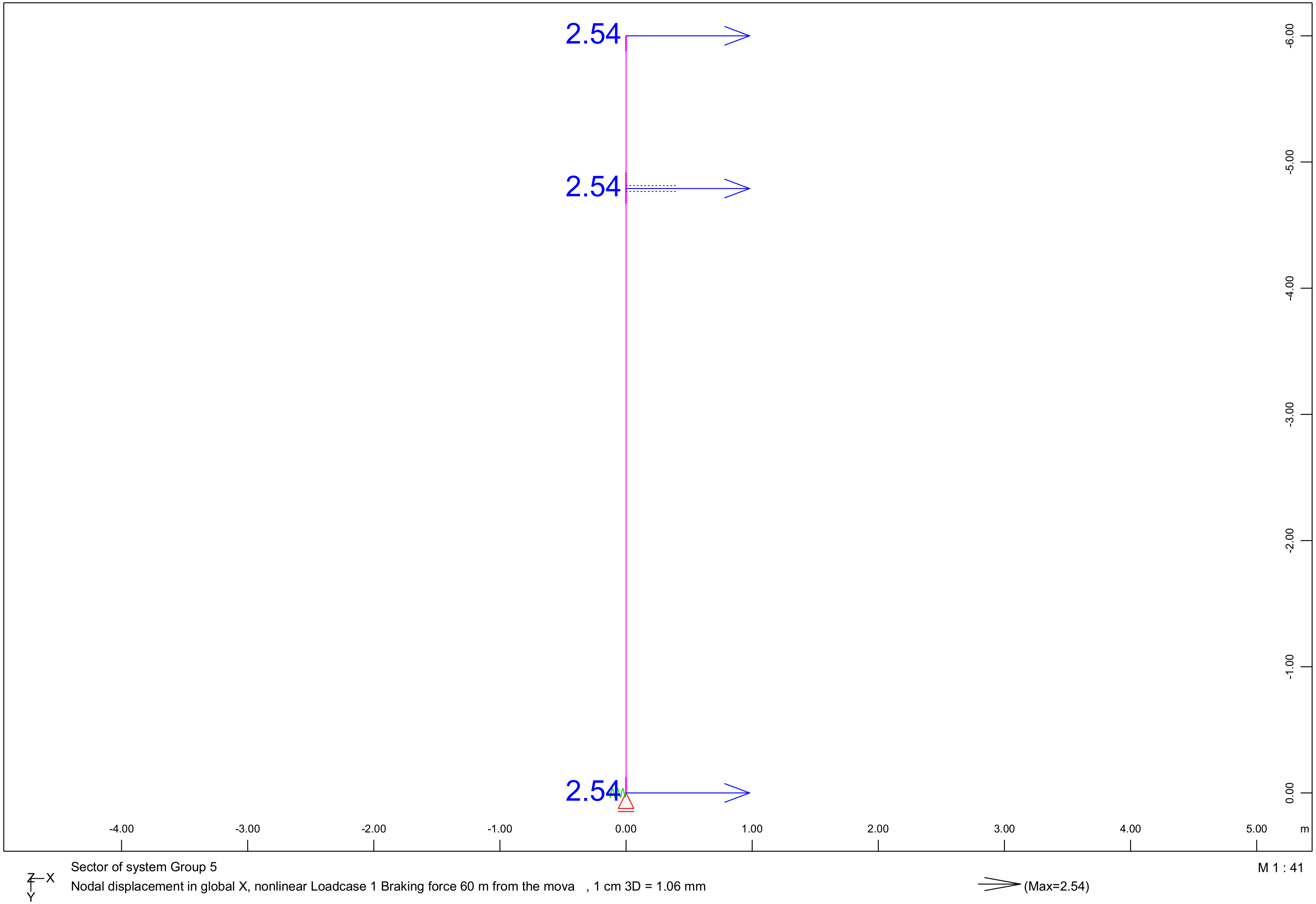
F4-6. Ballasted track - model with coupled nodes - braking force - z = 60 m

System
Interactive Graphic



Sector of system Group 5
Nodal displacement in global X, nonlinear Loadcase 1 Braking force 60 m from the mova , 1 cm 3D = 1.06 mm

M 1 : 41

reduced scale factor 0.936

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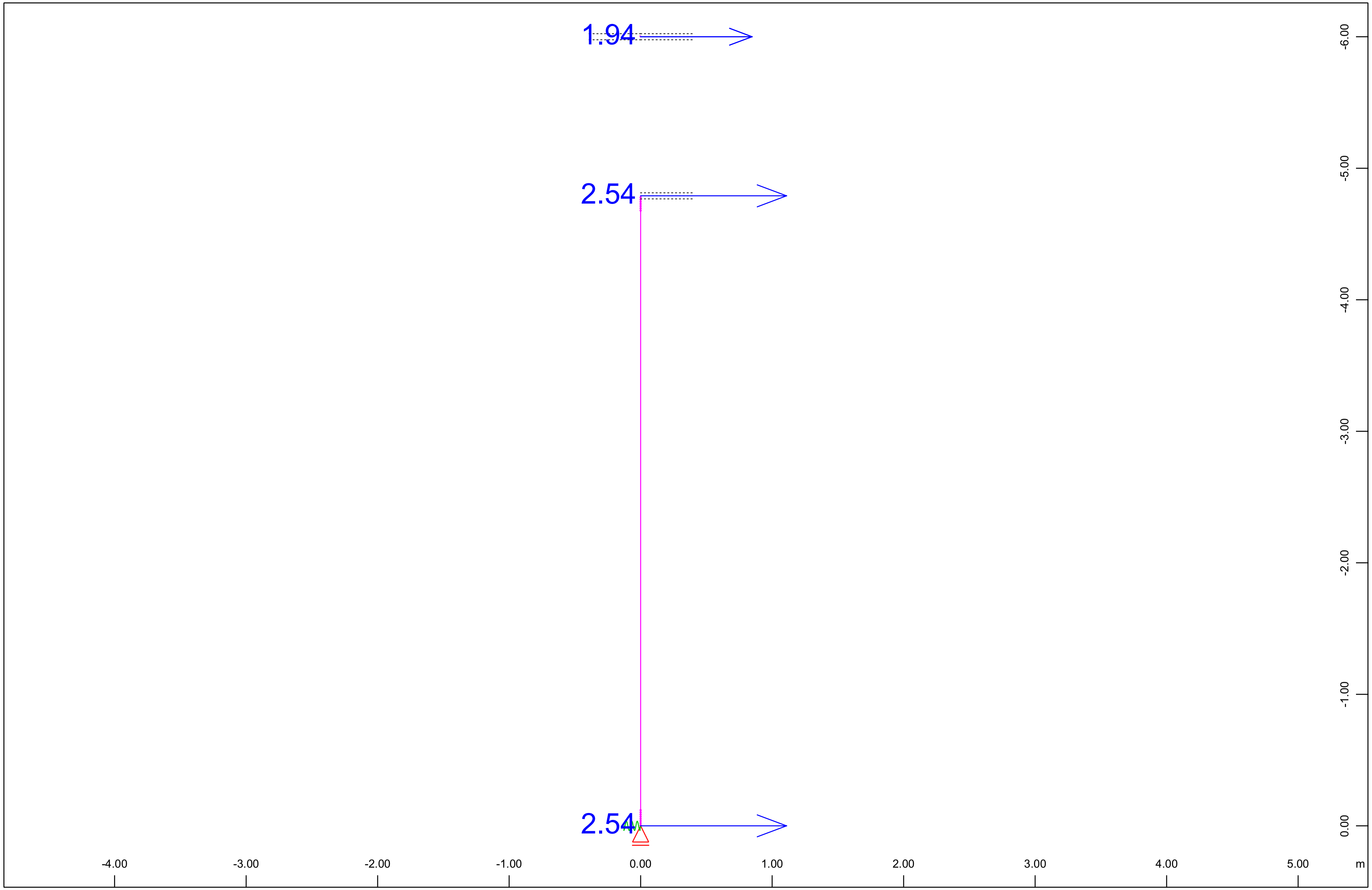
F4-6. Ballasted track - model with coupled nodes - braking force - z = 60 m

System
Interactive Graphic



Z–X
Y

Sector of system Group 5

Nodal displacement in global X, nonlinear Loadcase 1 Braking force 60 m from the mova , 1 cm 3D = 0.938 mm

(Max=2.54)

M 1 : 41

reduced scale factor 0.936

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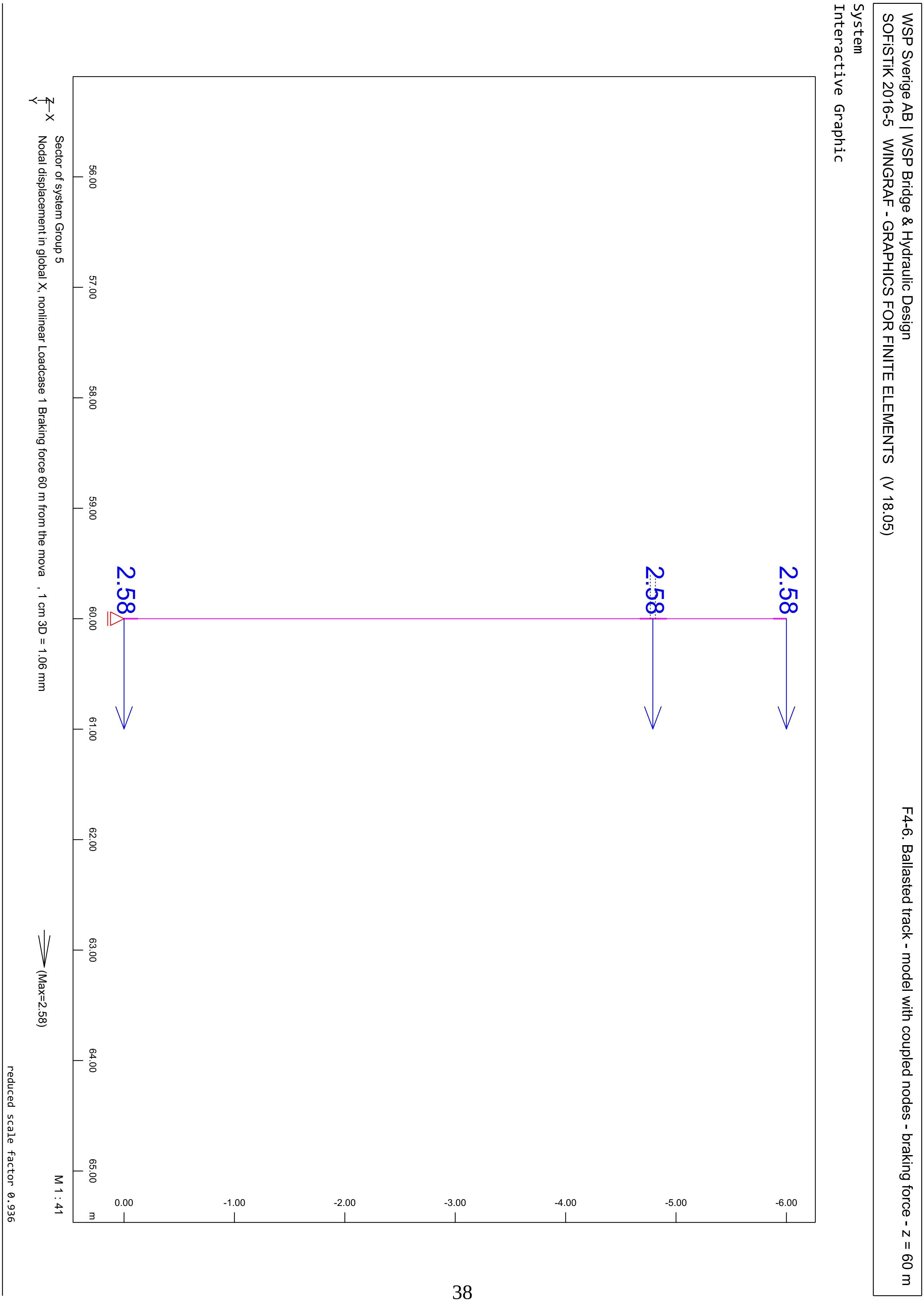

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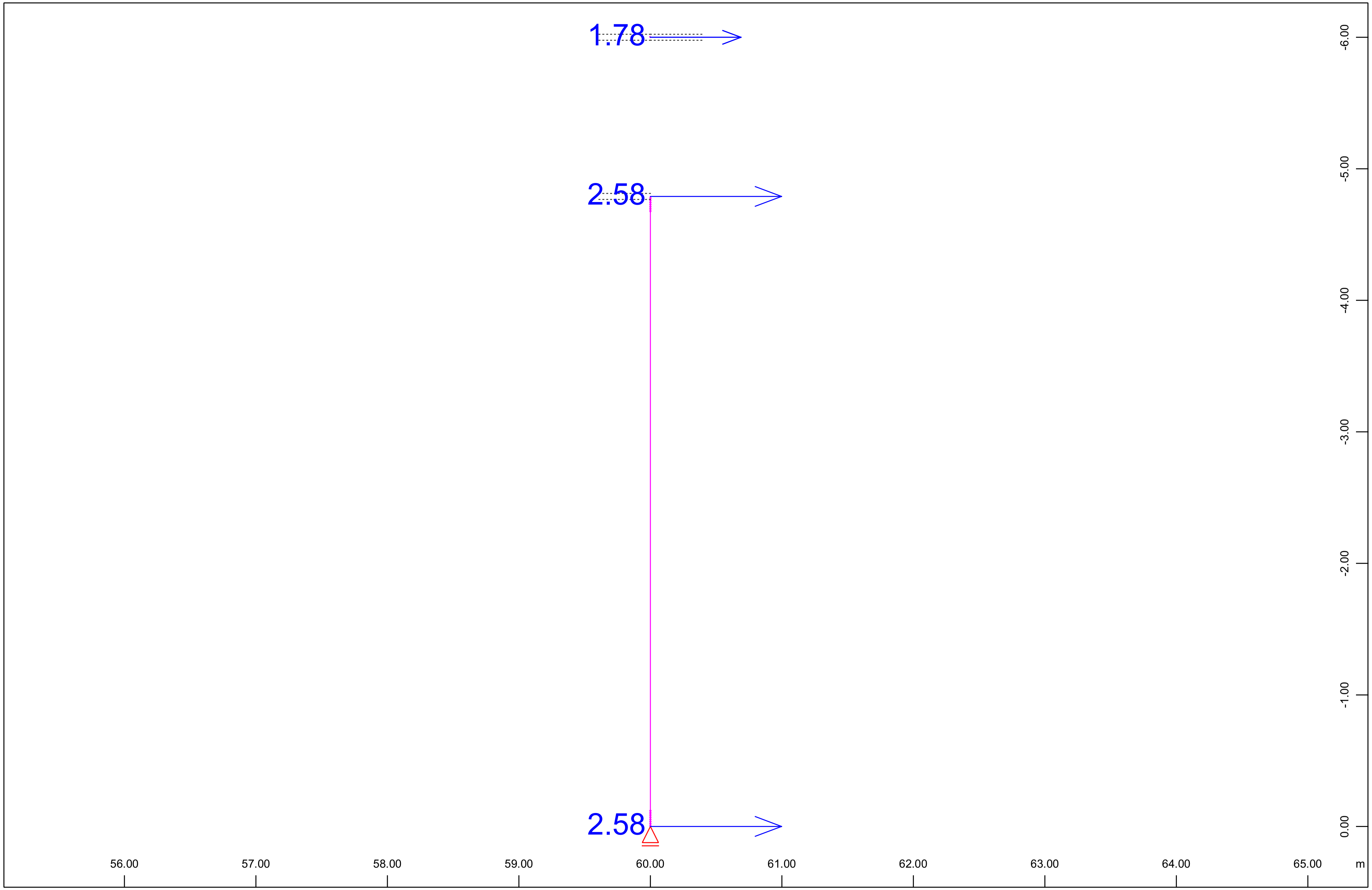
F4-6. Ballasted track - model with coupled nodes - braking force - z = 60 m

System
Interactive Graphic



Sector of system Group 5
Nodal displacement in global X, nonlinear Loadcase 1 Braking force 60 m from the mova , 1 cm 3D = 1.06 mm

(Max=2.58)

M 1 : 41

reduced scale factor 0.936

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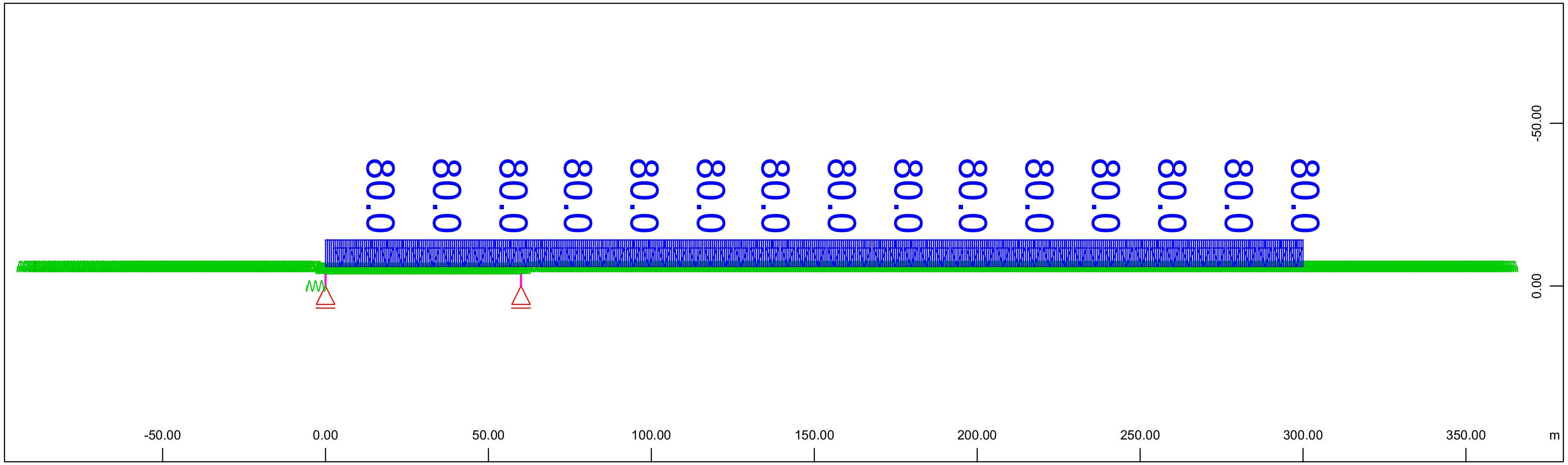
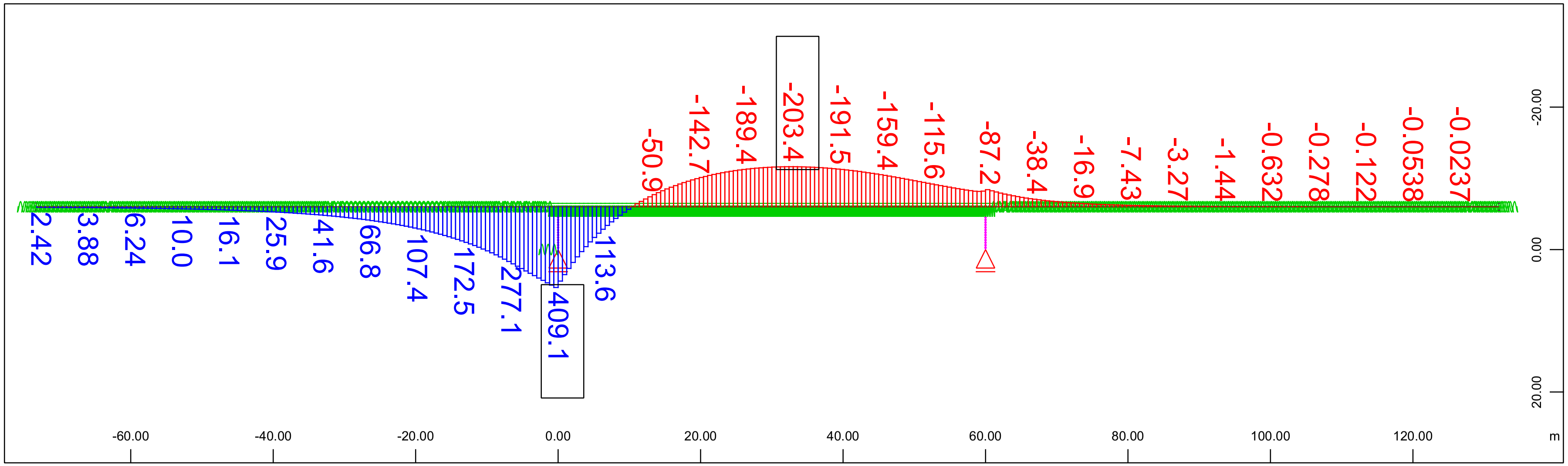
F4-6. Ballasted track - model with coupled nodes - vertical load - z = 60 m

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Vertical load 60 m from the mova , (1 cm 3D = unit) Beam line load (force) in global Y (Unit=186.7 kN/m) (Max=80.0)
M 1 : 1891



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Vertical load 60 m from the mova , 1 cm 3D = 312.5 kN (Min=-203.4) (Max=409.1)
M 1 : 865

reduced scale factor 0.936

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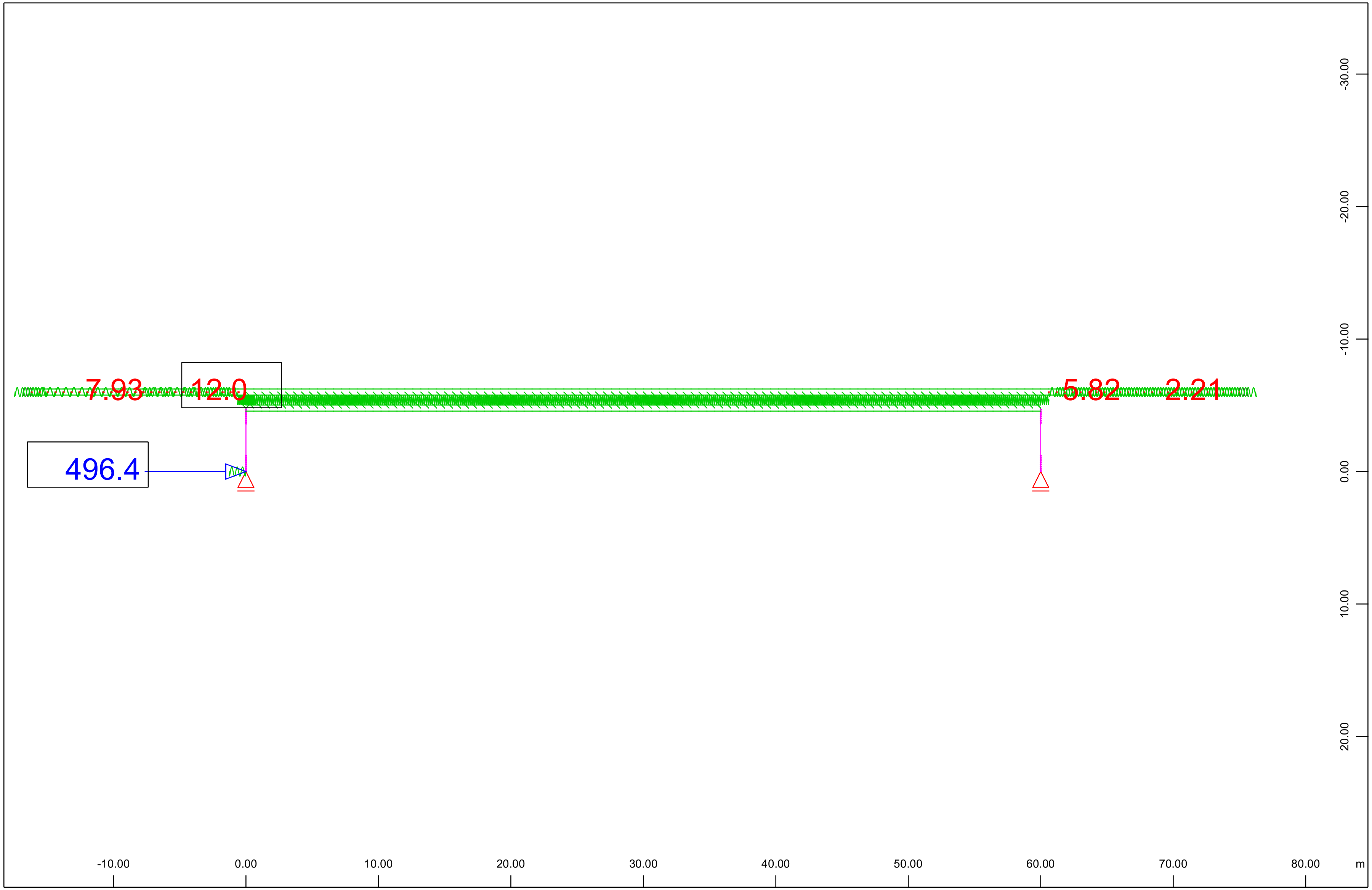
F4-6. Ballasted track - model with coupled nodes - vertical load - z = 60 m

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
Supporting springs , Spring force in global X, nonlinear Loadcase 1 Vertical load 60 m from the mova , 1 cm 3D = 265.6 kN
(Min=-12.0) (Max=496.4) (total: 152.5)

M 1 : 407

reduced scale factor 0.936

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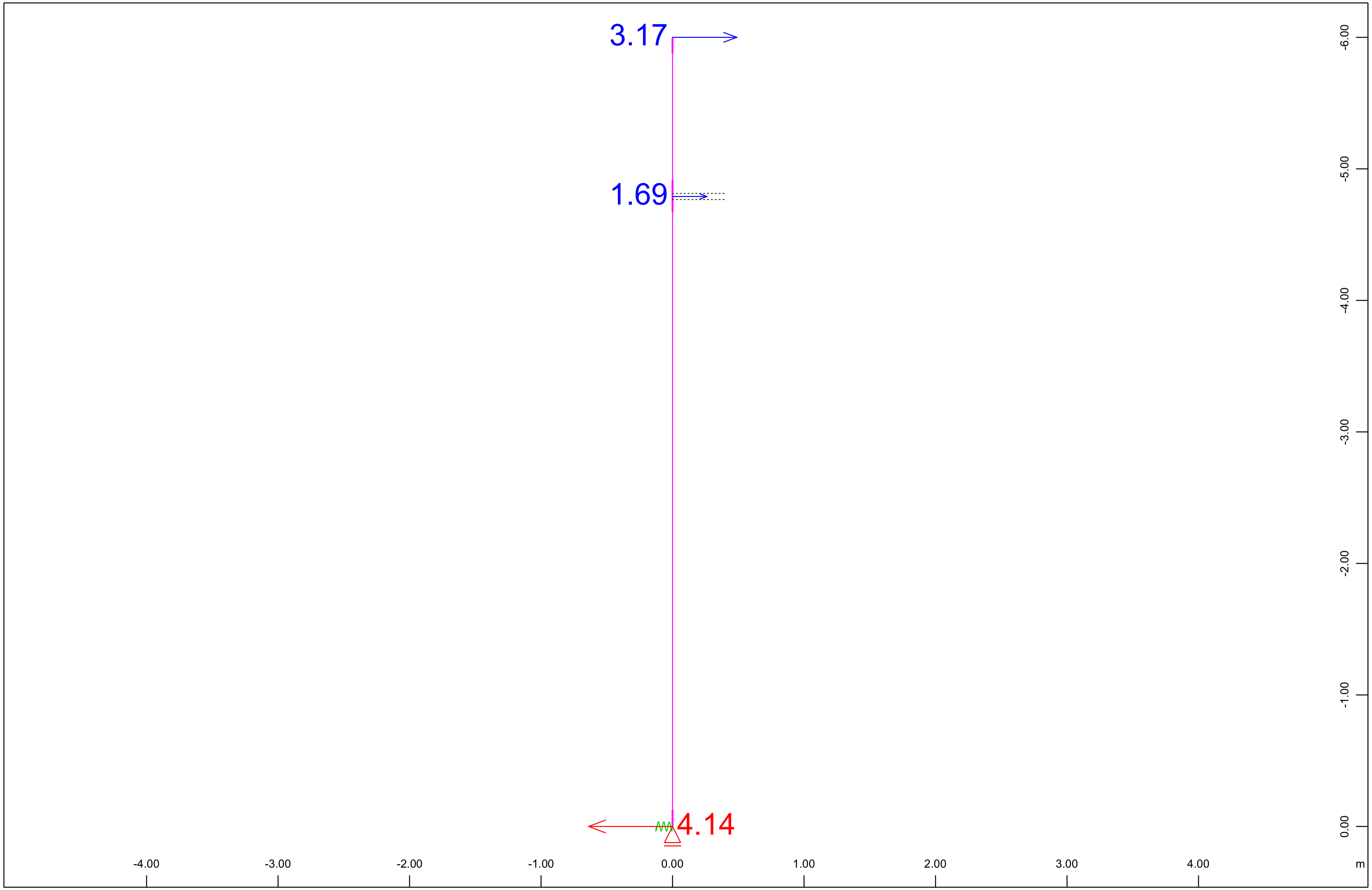
F4-6. Ballasted track - model with coupled nodes - vertical load - z = 60 m

System
Interactive Graphic



Sector of system Group 5
Nodal displacement in global X, nonlinear Loadcase 1 Vertical load 60 m from the mova , 1 cm 3D = 2.66 mm

M 1 : 41
(Min=-4.14) (Max=3.17)

reduced scale factor 0.936

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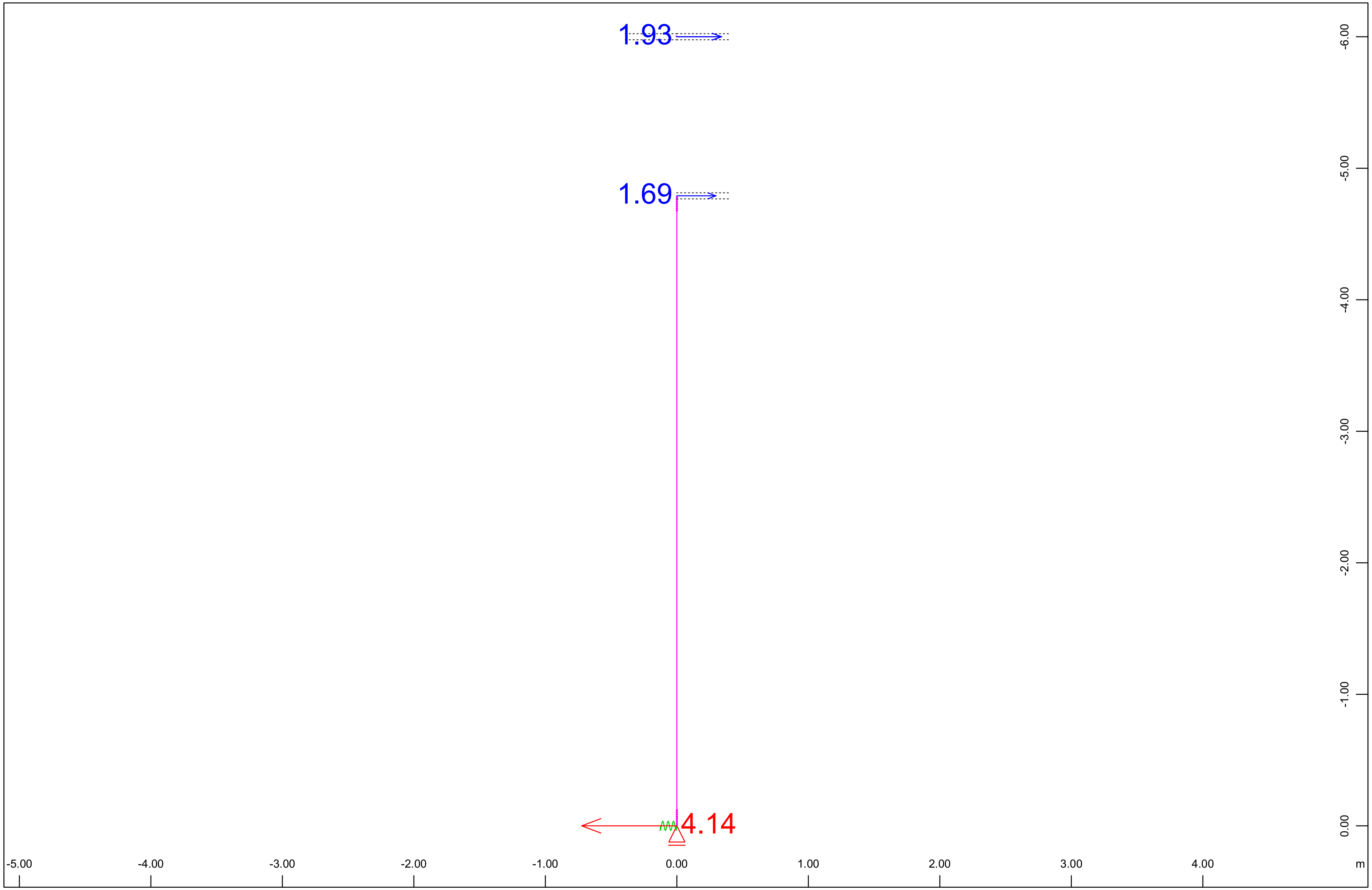
F4-6. Ballasted track - model with coupled nodes - vertical load - z = 60 m

System
Interactive Graphic



Z—X
Y

Sector of system Group 5
Nodal displacement in global X, nonlinear Loadcase 1 Vertical load 60 m from the mova , 1 cm 3D = 2.34 mm

M 1 : 41

(Min=-4.14) (Max=1.93)

reduced scale factor 0.936

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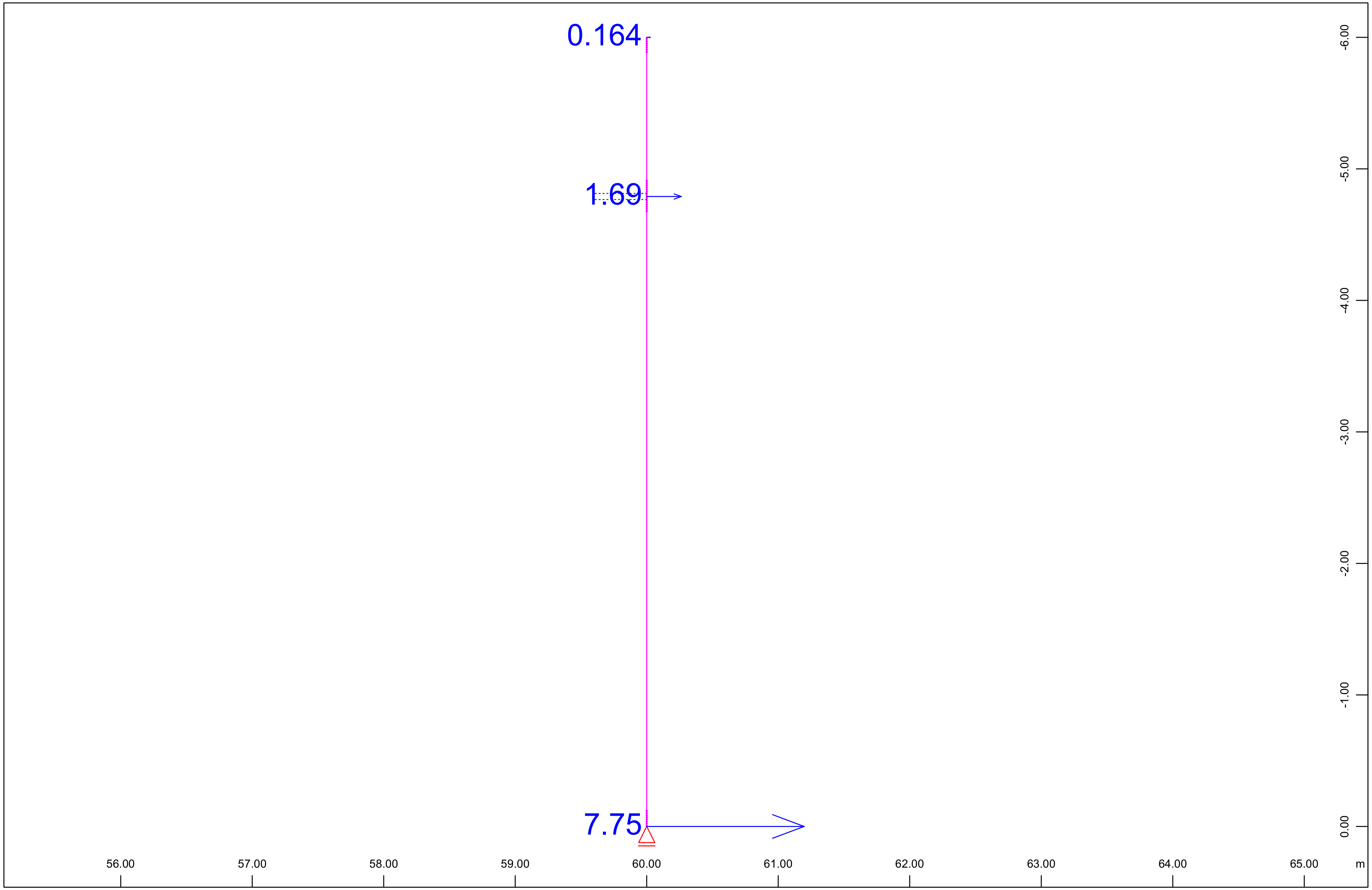
F4-6. Ballasted track - model with coupled nodes - vertical load - z = 60 m

System
Interactive Graphic



Sector of system Group 5
Nodal displacement in global X, nonlinear Loadcase 1 Vertical load 60 m from the mova , 1 cm 3D = 2.66 mm
(Max=7.75)
M 1 : 41
reduced scale factor 0.936

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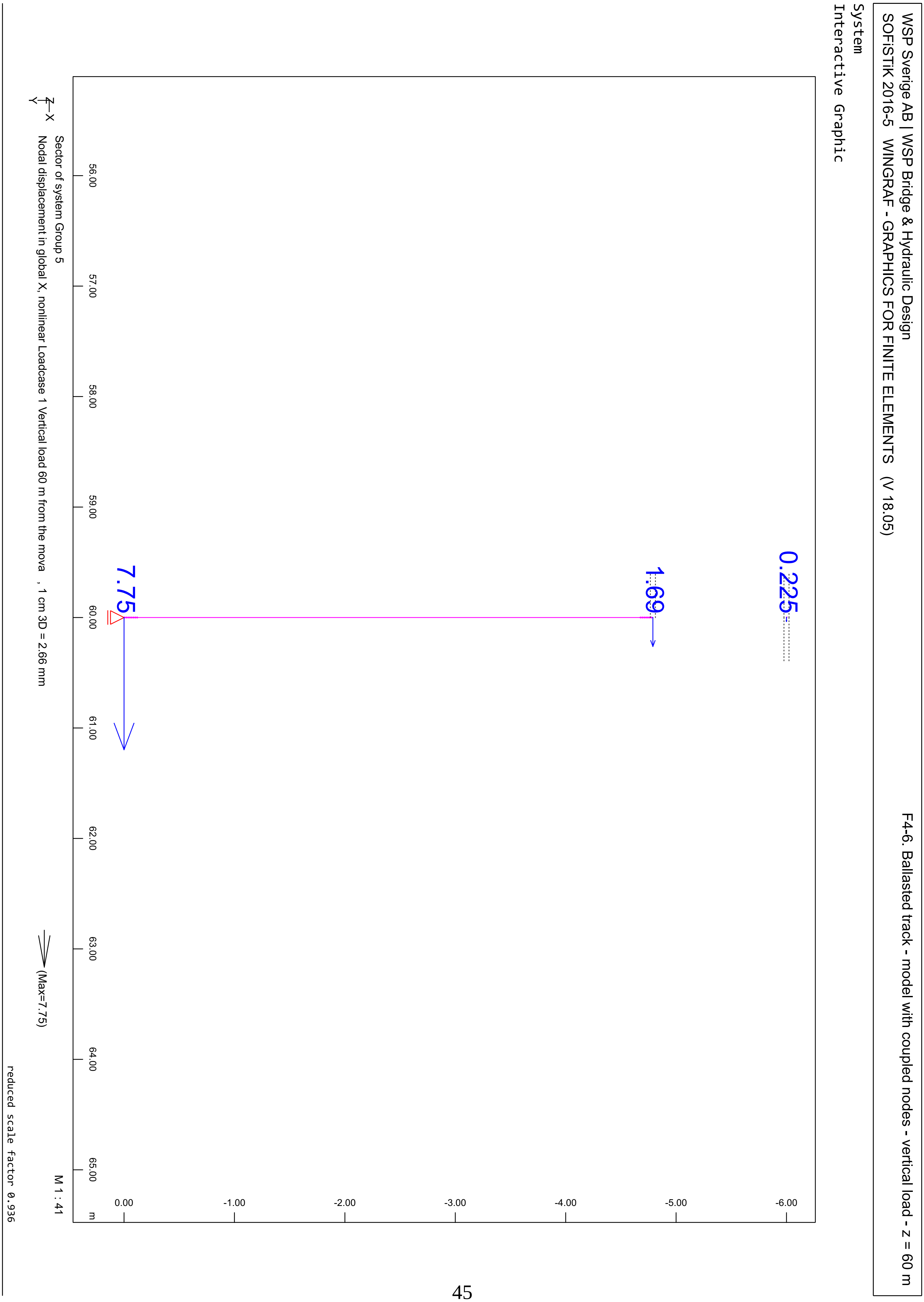

Appendix 3

Output data - determination of the largest compressive rail stresses and the worst train position

Table of Contents

1 E1-3 - Output data - determination of the worst position of the train on the bridge

In Figure 1.1 are the different train load positions illustrated.

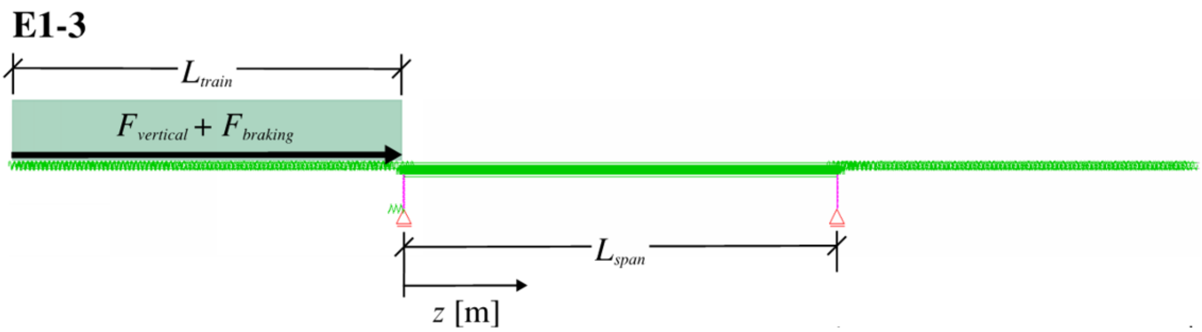

Figure 1.1 Load positions for the braking force and the vertical load.

1.1 E1-3 - Summary of the results

The compressive rail stresses at the movable support for different train load positions are shown in Table 1.1 and in Figure 1.2.

Table 1.1 E1-3 – Rail stress at the movable support - Braking force and vertical load.

Position *z* [m]	**Train loads**	**N_{rail} [kN]**	**Rail stress, σ_{rail} [MPa]**
0	Braking force	-8,78	-0,57
	Vertical load	-1,25	-0,08
	Sum:		**-0,65**
15	Braking force	-41	-2,67
	Vertical load	-55,2	-3,59
	Sum:		**-6,26**
30	Braking force	-84,9	-5,52
	Vertical load	-157,8	-10,27
	Sum:		**-15,79**
45	Braking force	-140,5	-9,14
	Vertical load	-252,3	-16,41
	Sum:		**-25,55**
60	Braking force	-249,8	-16,25
	Vertical load	-312,9	-20,36
	Sum:		**-36,61**

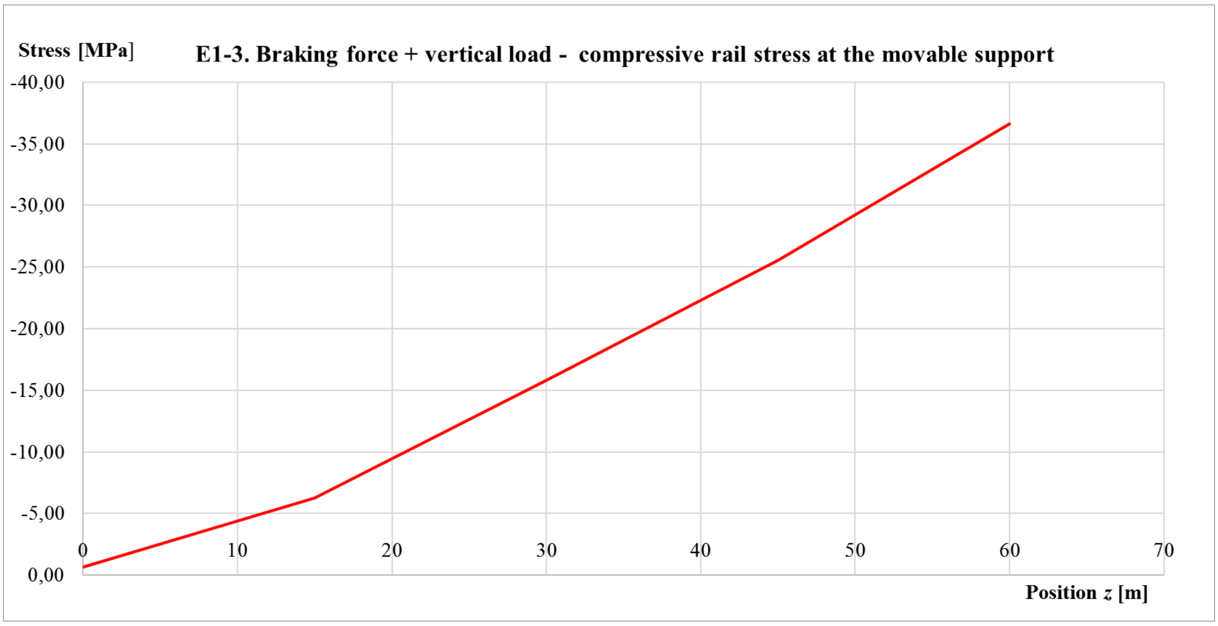

Figure 1.2 E1-3. Braking force + vertical load - compressive rail stress at the movable support for different train positions.

1.1.1 E1-3 - Largest compressive rail stress at the movable support (z = 60 m)

The largest total compressive rail stress at the movable support are shown in Table 1.2.

Table 1.2 E1-3. Total compressing rail stress at the movable support, train position z = 60 m from the fixed support.

Load case	N_{rail} **[kN]**	**Rail stress,** σ_{rail} **[MPa]**
Temperature variation - deck	-493,20	-32,08
Braking	-249,80	-16,25
Vertical bending - end rot	-312,90	-20,36
Sum:		**-68,69**

1.2 E1-3 - Normal force diagrams for every position

On the following pages are the normal force diagrams for the temperature variation load and every train load position in Table 1.1 and Table 1.2 shown.

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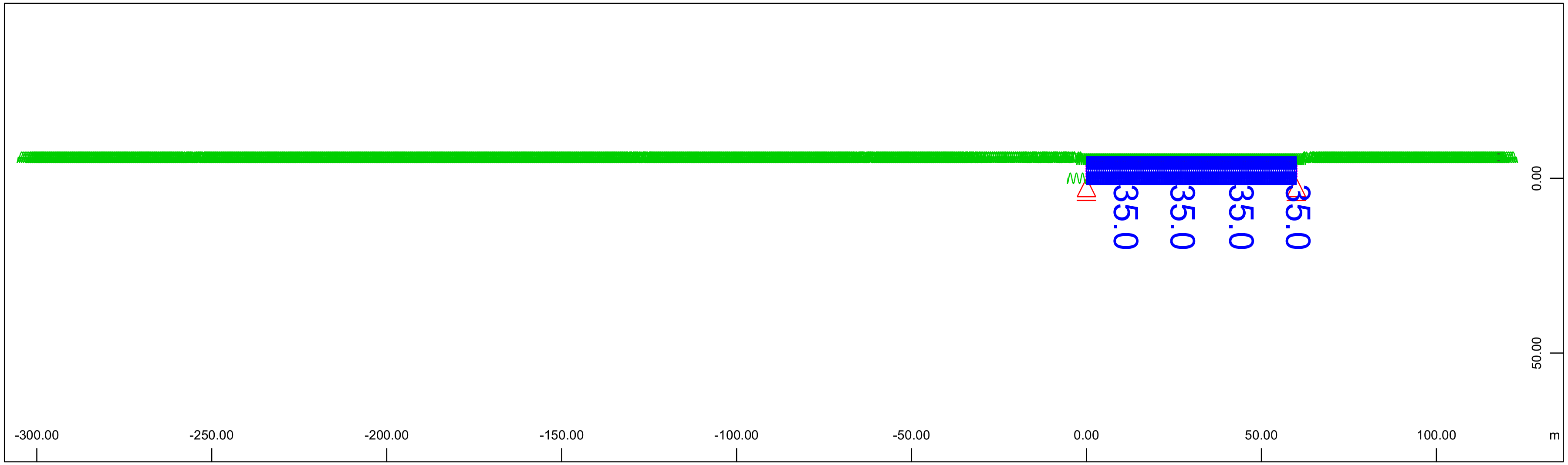
E1-3. Ballasted track - Temperature variation - deck

System

Interactive Graphic

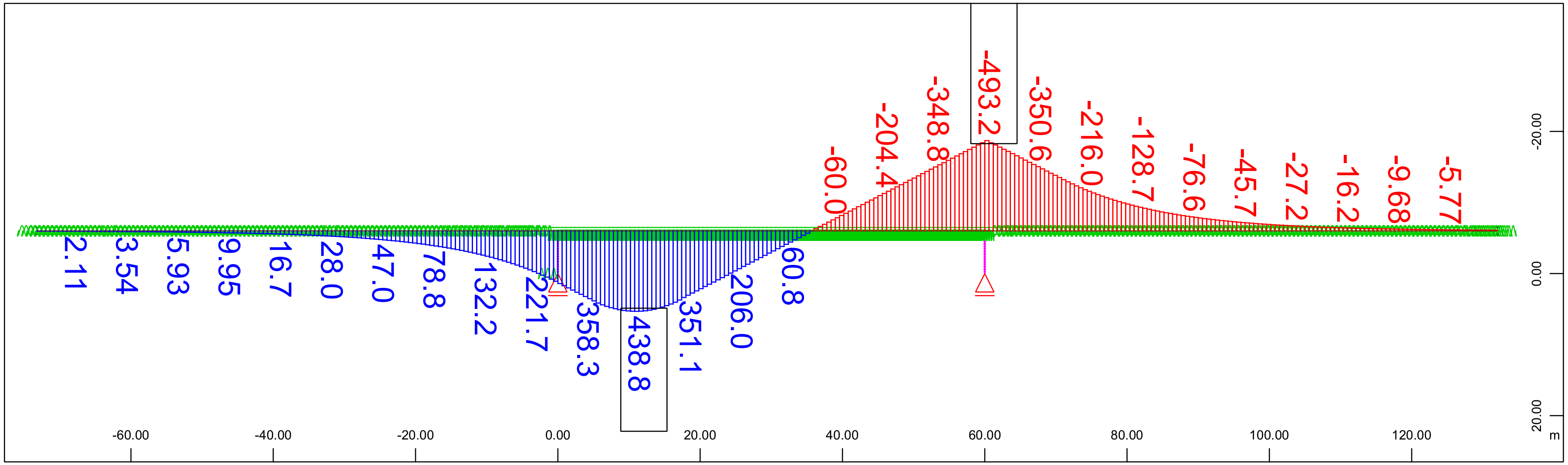


Sector of system Beam Elements,Spring Elements

All loads, nonlinear Loadcase 1 Temperature variation - deck , (1 cm 3D = unit) Beam line load (uniform temperature change)

(Unit=126.2 °C) (Max=35.0)

M 1 : 1761



Sector of system Group 2...5 102...104

Beam Elements , Normal force Nx, nonlinear Loadcase 1 Temperature variation - deck , 1 cm 3D = 335.9 kN (Min=-493.2) (Max=438.8)

M 1 : 866

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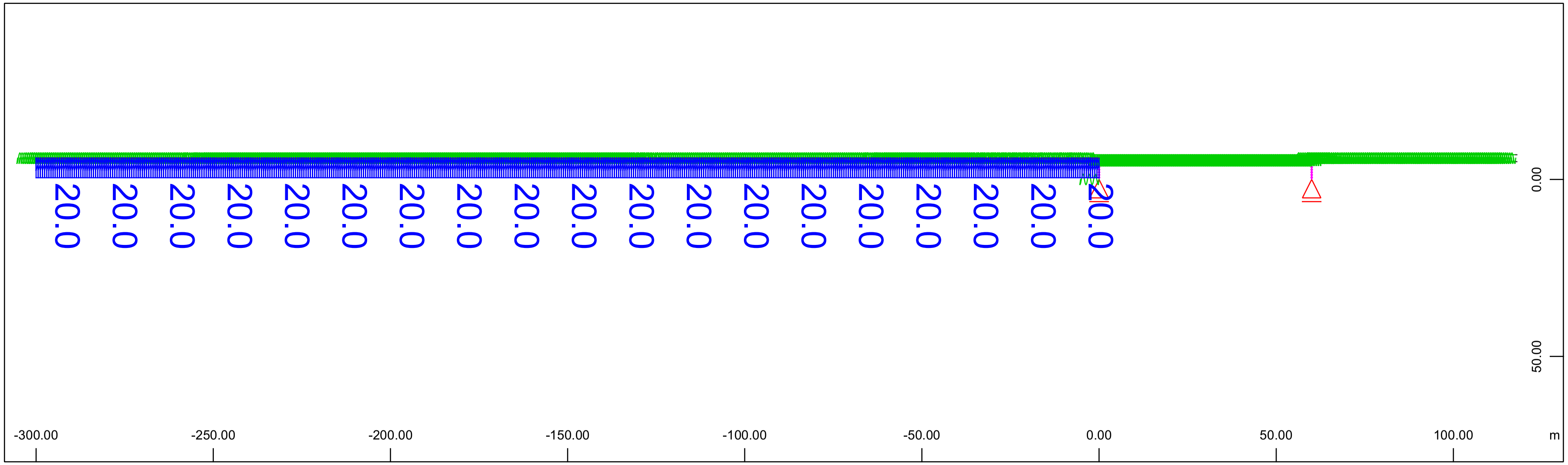
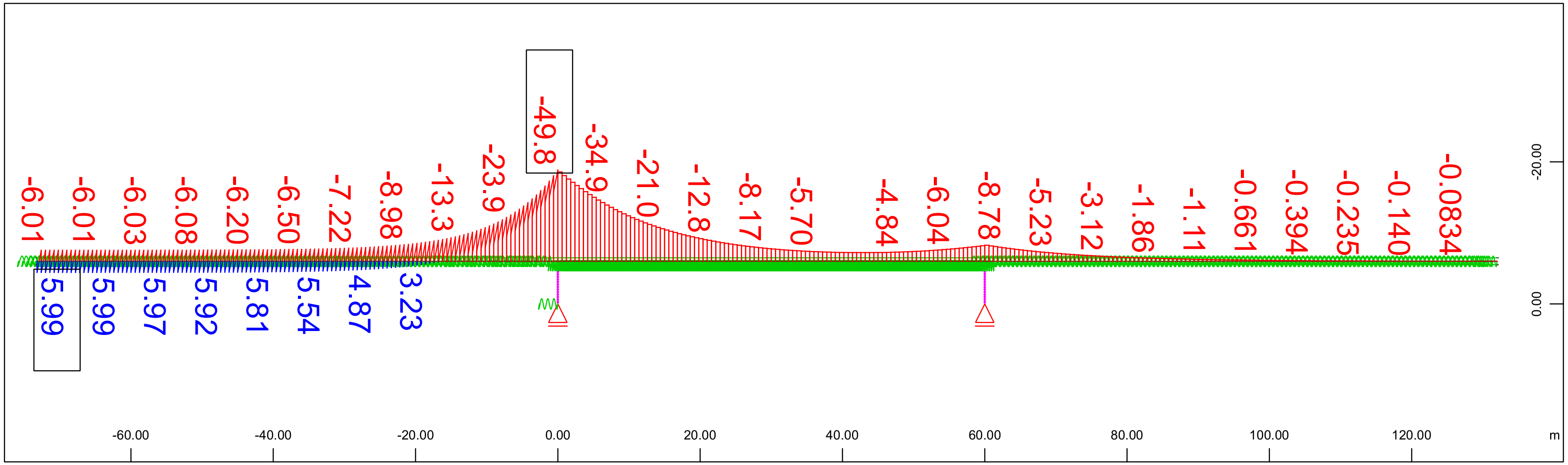
E1-3. Ballasted track - Braking force 0 m from the fixed support

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Braking force 0 m from the fixed , (1 cm 3D = unit) Beam line load (force) in global X (Unit=63.1 kN/m) (Max=20.0)
M 1 : 1739



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Braking force 0 m from the fixed , 1 cm 3D = 33.6 kN (Min=-49.8) (Max=5.99)
M 1 : 866

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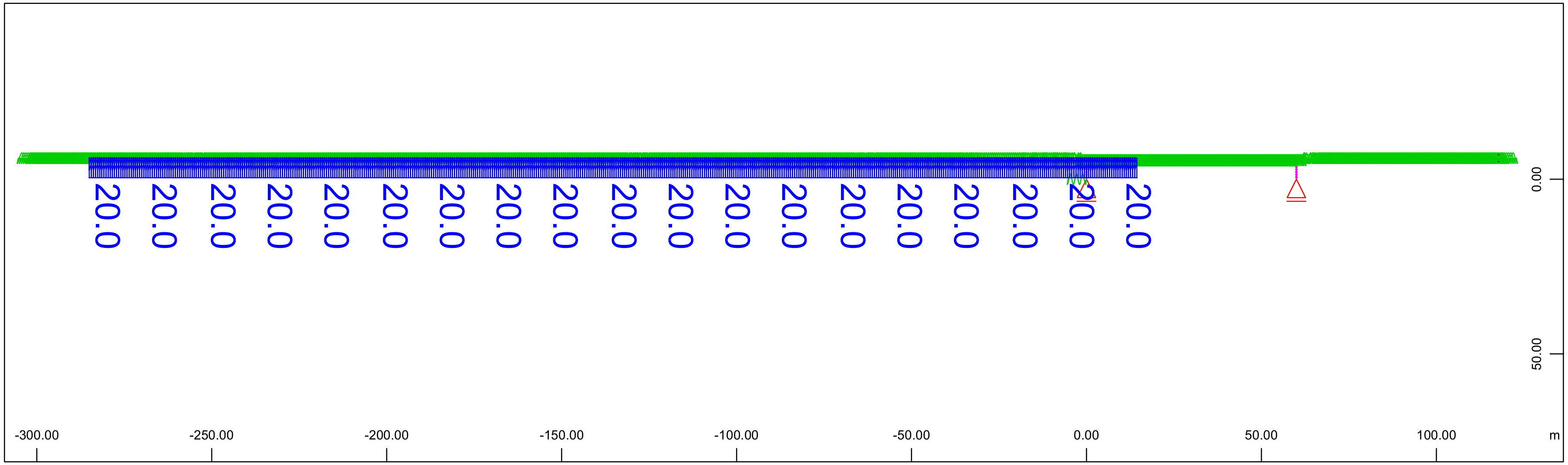
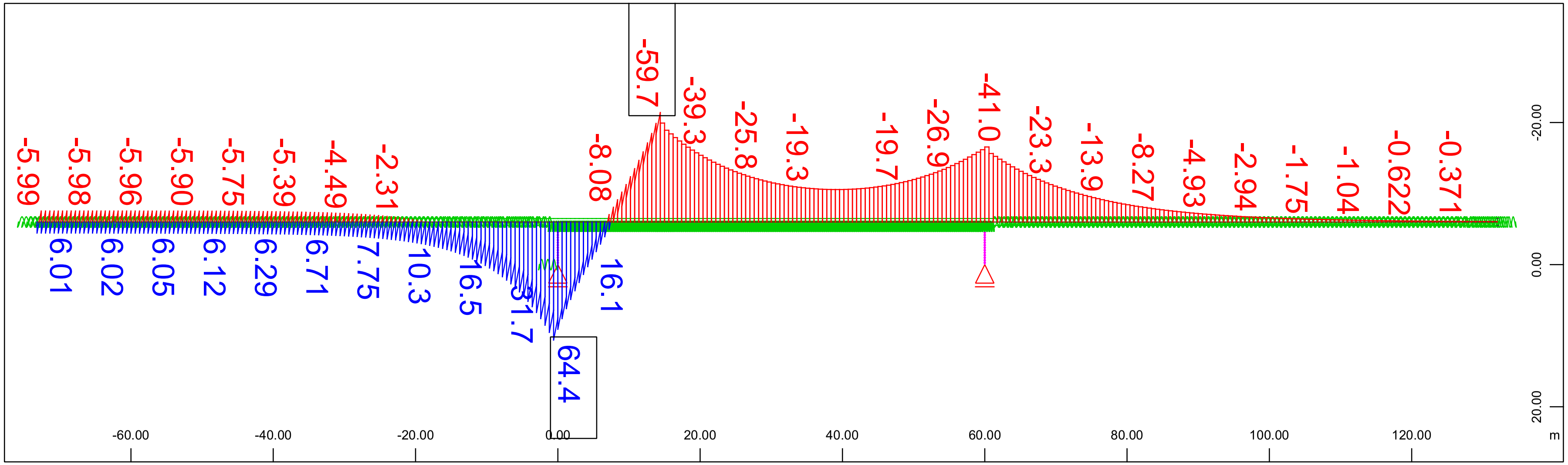
E1-3. Ballasted track - Braking force 15 m from the fixed support

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Braking force 15 m from the fixe , (1 cm 3D = unit) Beam line load (force) in global X (Unit=63.1 kN/m) (Max=20.0)

M 1 : 1761



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Braking force 15 m from the fixe , 1 cm 3D = 33.6 kN (Min=-59.7) (Max=64.4)

M 1 : 866

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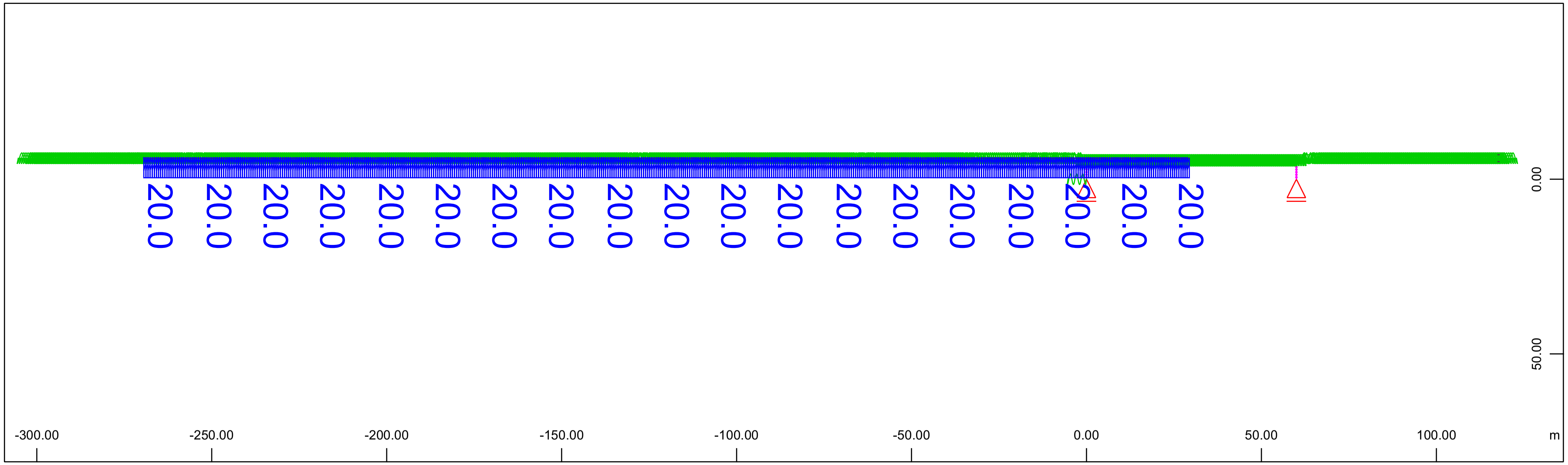
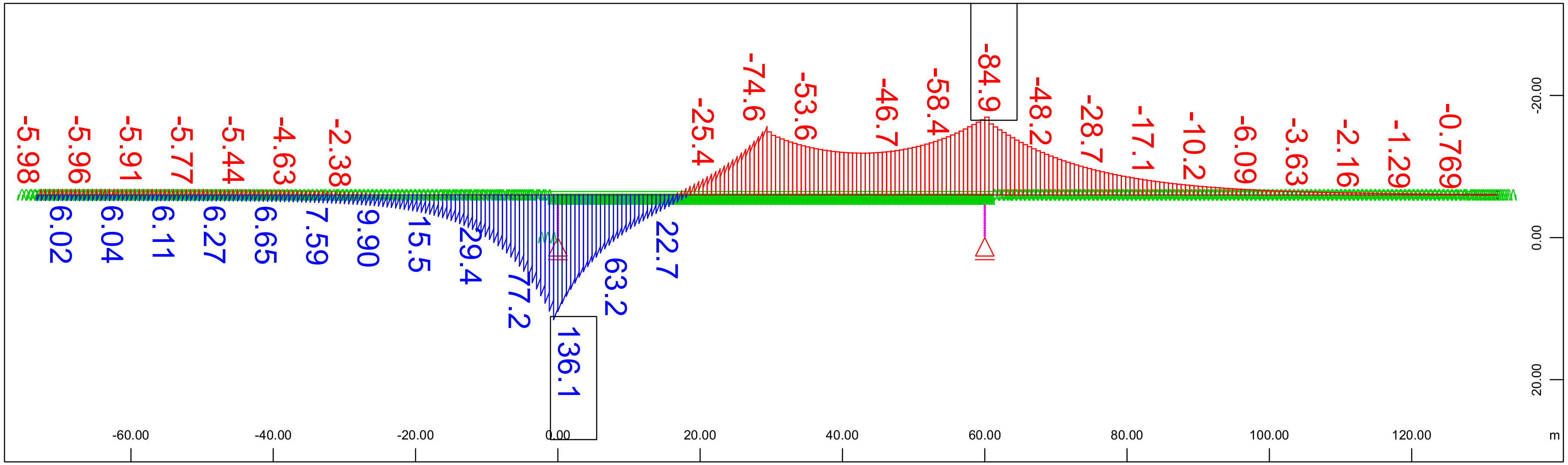
E1-3. Ballasted track - Braking force 30 m from the fixed support

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Braking force 30 m from the fixe , (1 cm 3D = unit) Beam line load (force) in global X (Unit=63.1 kN/m) (Max=20.0)

M 1 : 1761



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Braking force 30 m from the fixe , 1 cm 3D = 67.2 kN (Min=-84.9) (Max=136.1)

M 1 : 866

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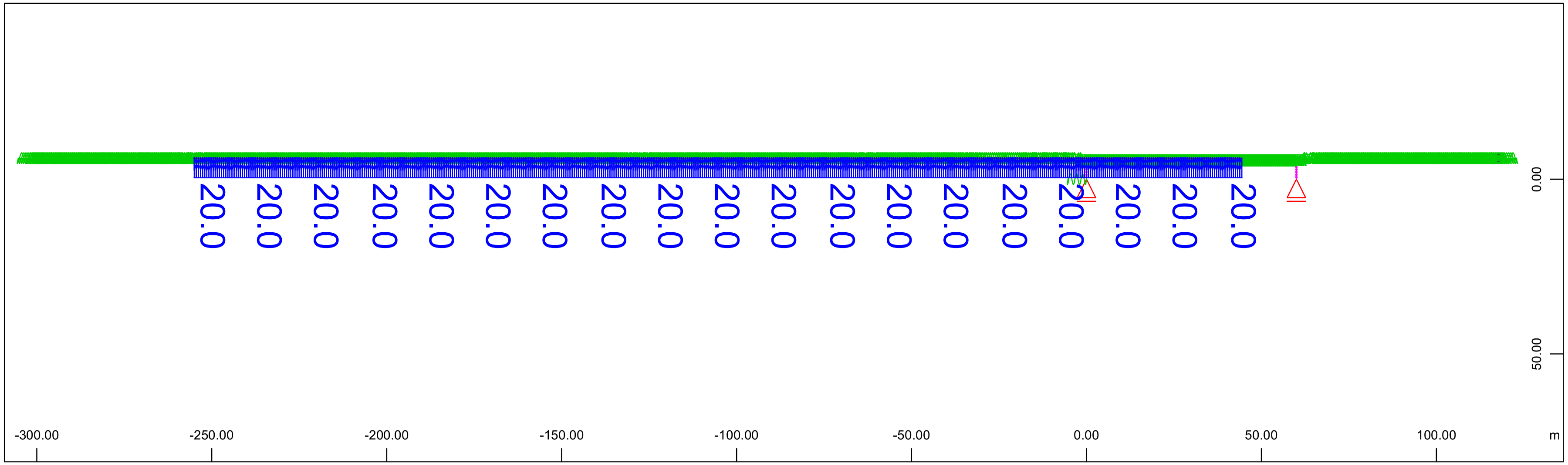
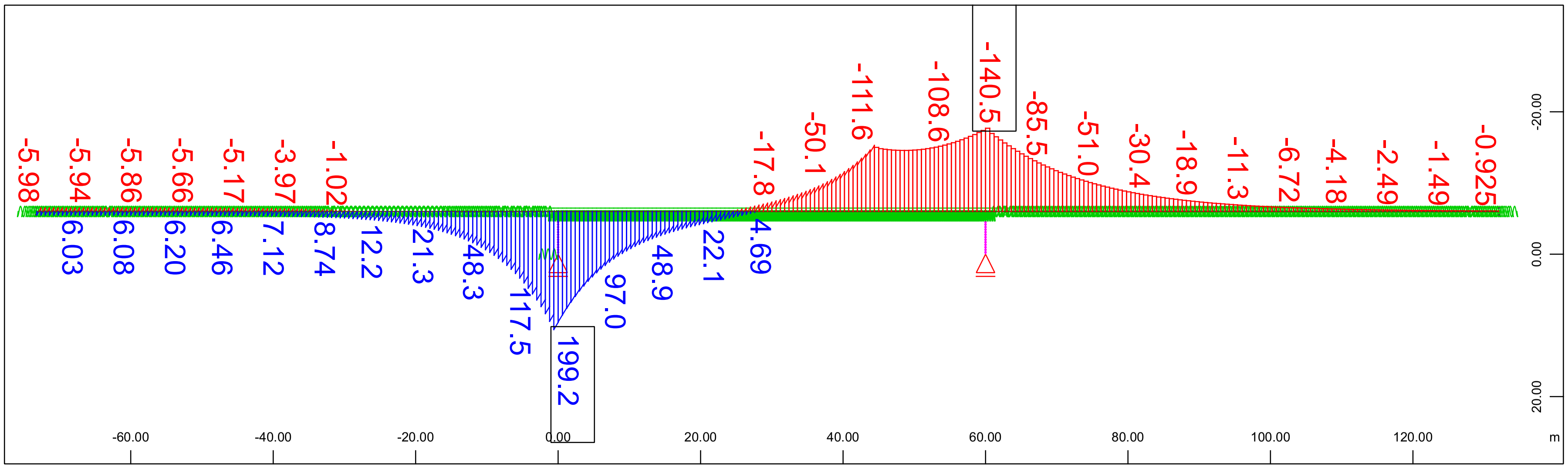
E1-3. Ballasted track - Braking force 45 m from the fixed support

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Braking force 45 m from the fixe , (1 cm 3D = unit) Beam line load (force) in global X (Unit=63.1 kN/m) (Max=20.0)

M 1 : 1761



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Braking force 45 m from the fixe , 1 cm 3D = 103.9 kN (Min=-140.5) (Max=199.2)

M 1 : 865

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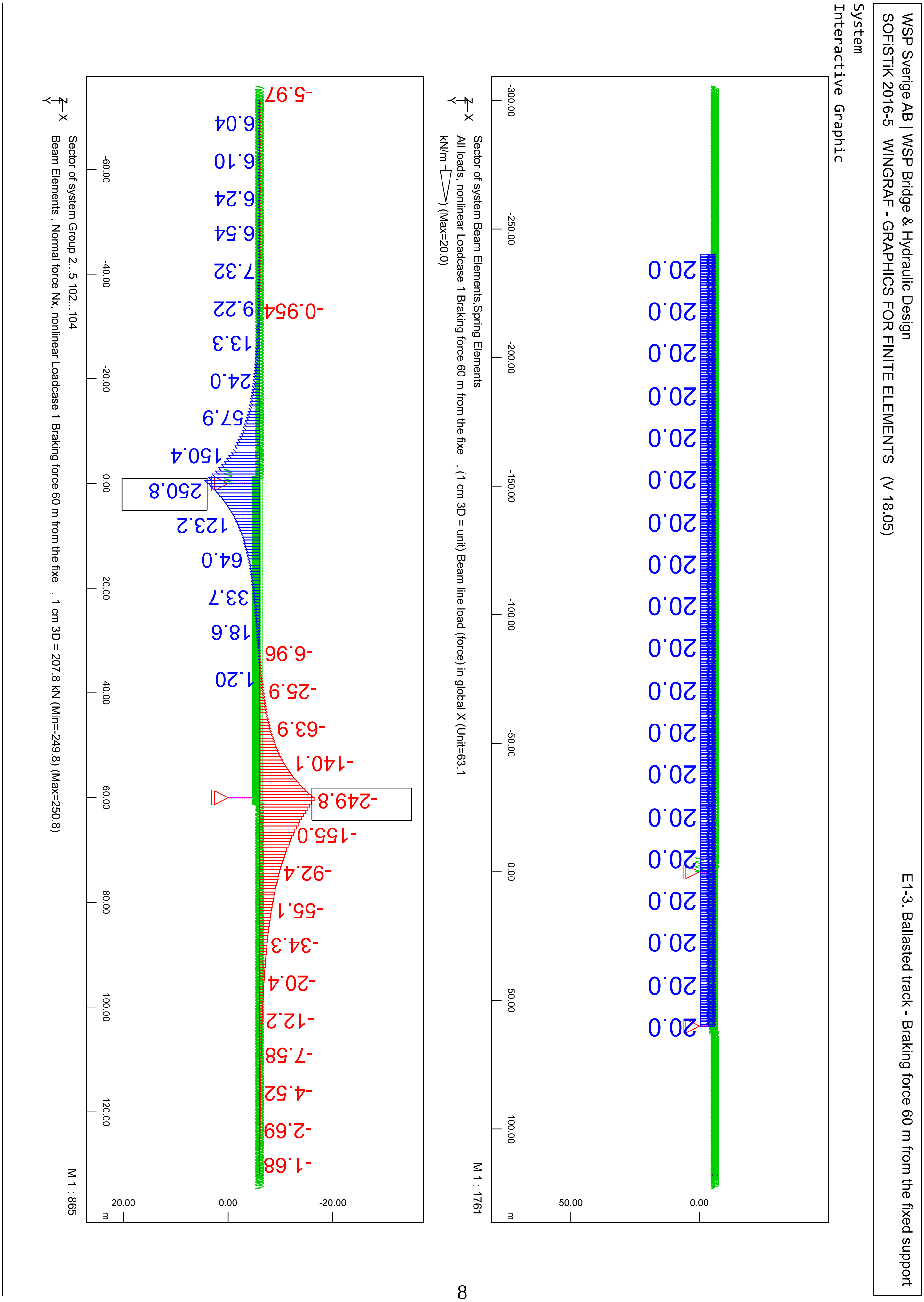
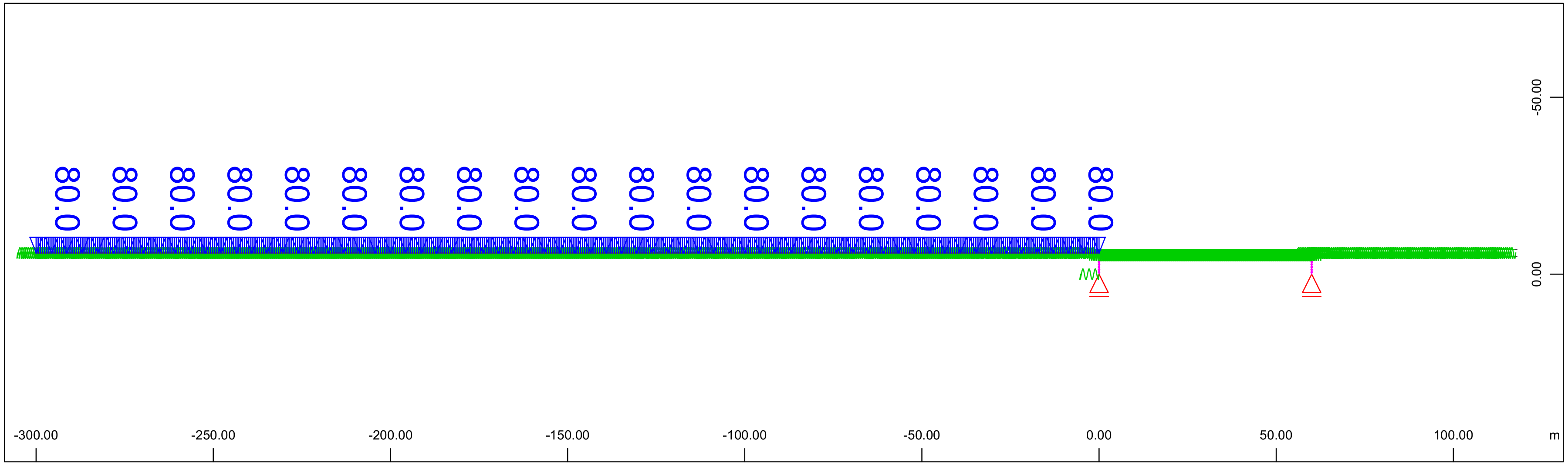
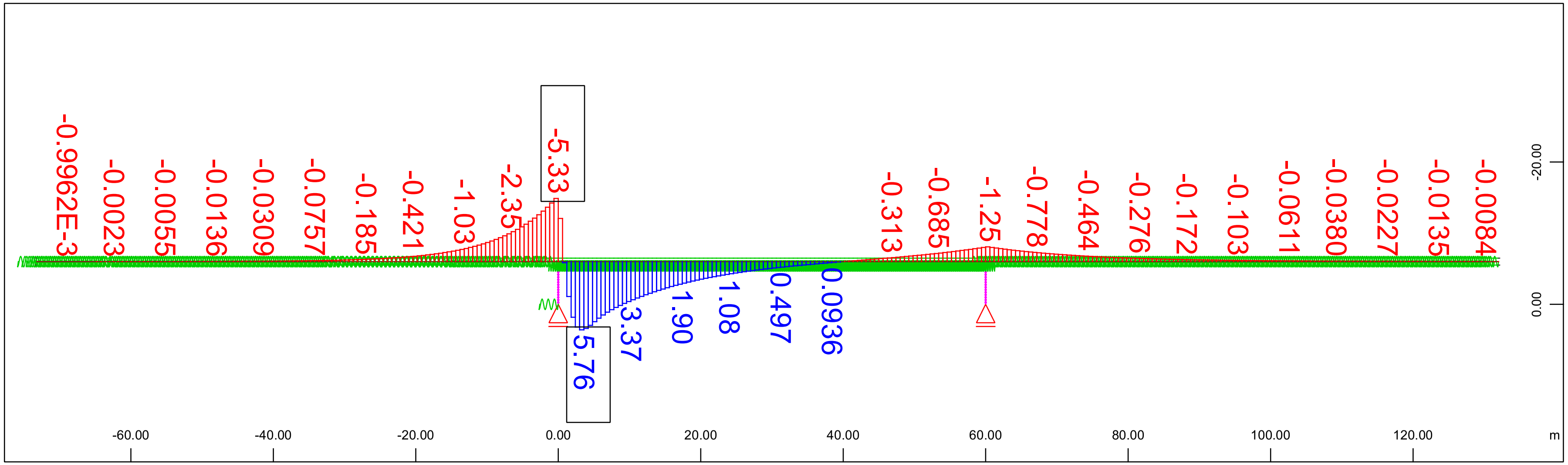


WSP Sverige AB | WSP Bridge & Hydraulic Design SOFiSTiK 2016-5 WINGRAF - GRAPHICS FOR FINITE ELEMENTS (V 18.05)	E1-3. Ballasted track - Vertical load 0 m from the fixed support

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Vertical load 0 m from the fixed , (1 cm 3D = unit) Beam line load (force) in global Y (Unit=315.6 kN/m) (Max=80.0)
M 1 : 1739



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Vertical load 0 m from the fixed , 1 cm 3D = 5.20 kN (Min=-5.33) (Max=5.76)
M 1 : 865

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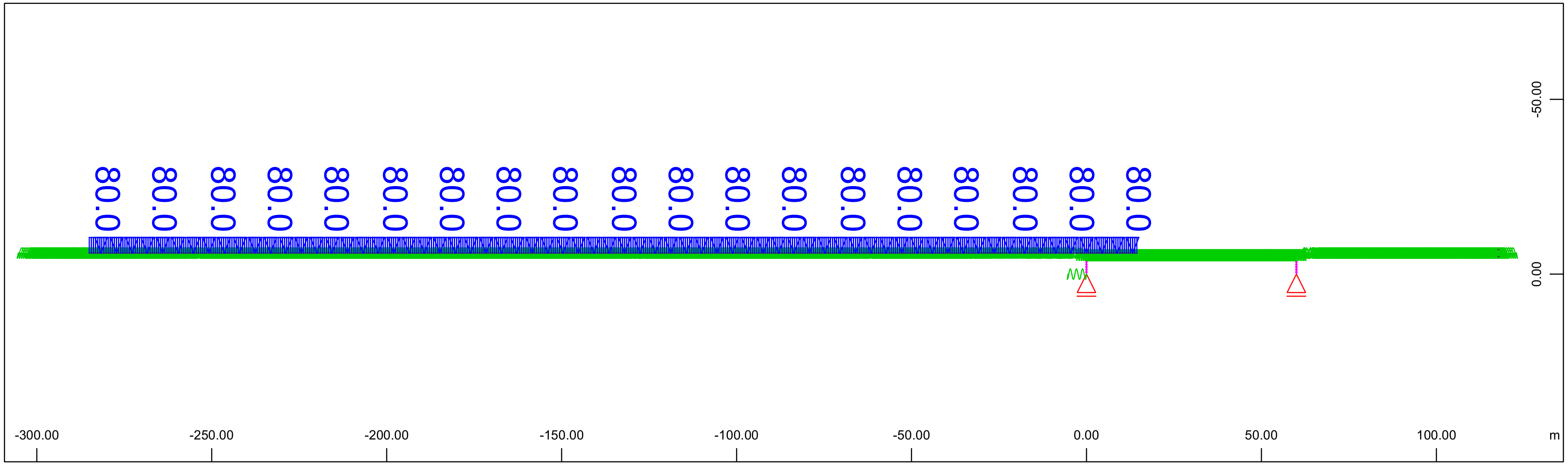
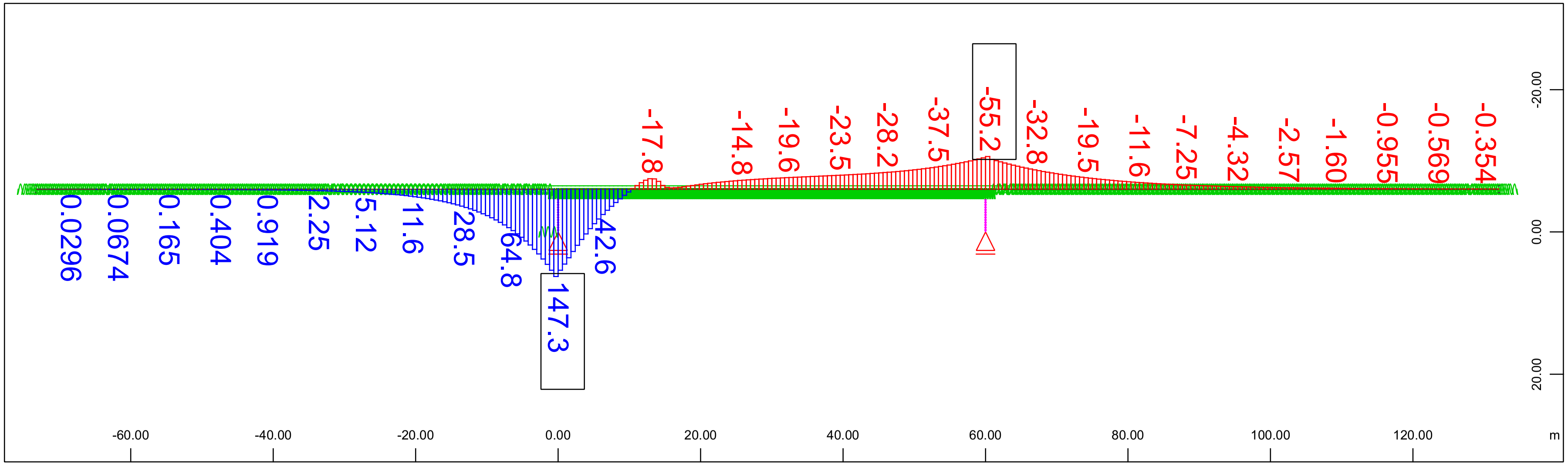
E1-3. Ballasted track - Vertical load 15 m from the fixed support

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Vertical load 15 m from the fixe , (1 cm 3D = unit) Beam line load (force) in global Y (Unit=315.6 kN/m) (Max=80.0)

M 1 : 1761



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Vertical load 15 m from the fixe , 1 cm 3D = 103.9 kN (Min=-55.2) (Max=147.3)

M 1 : 865

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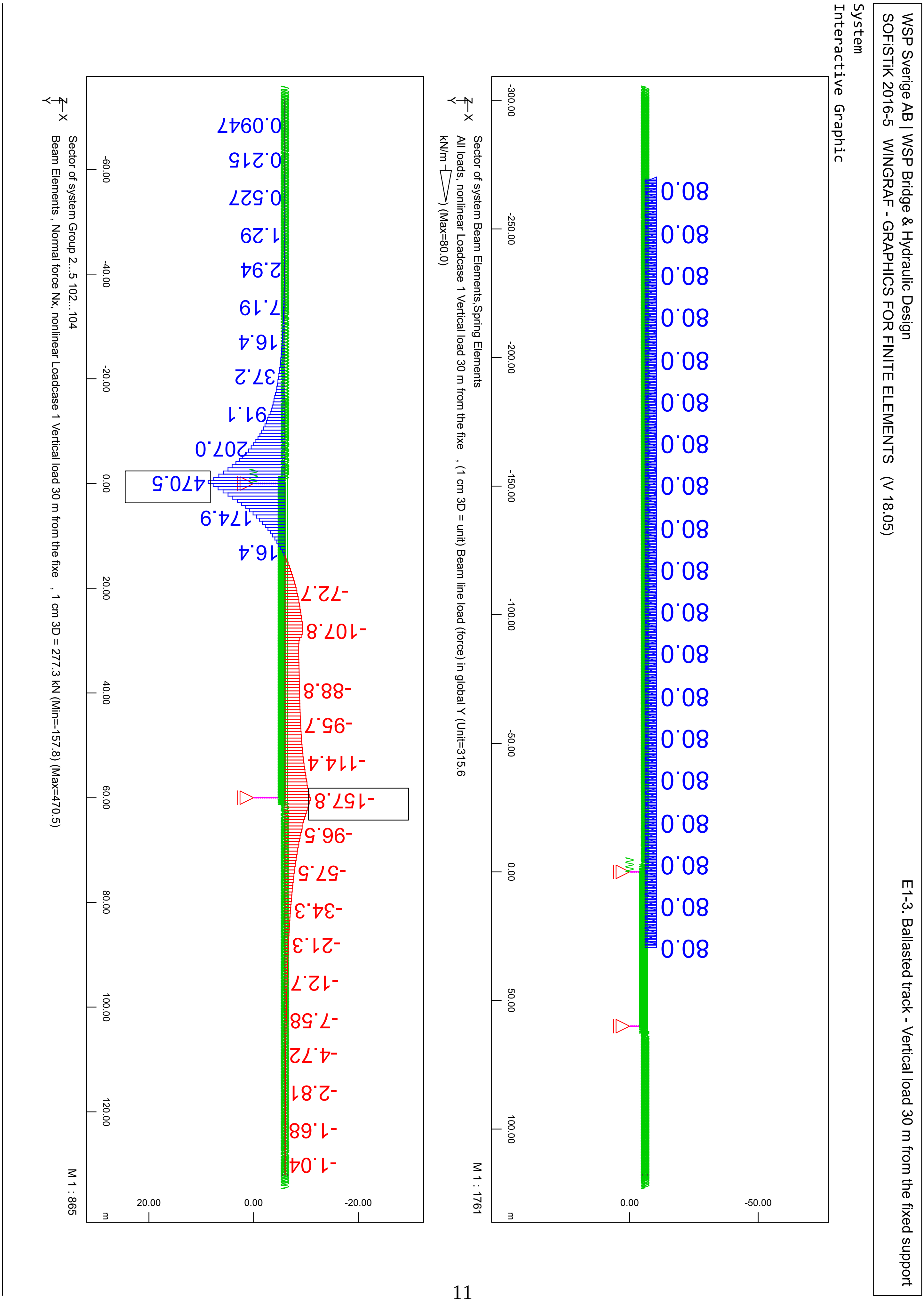

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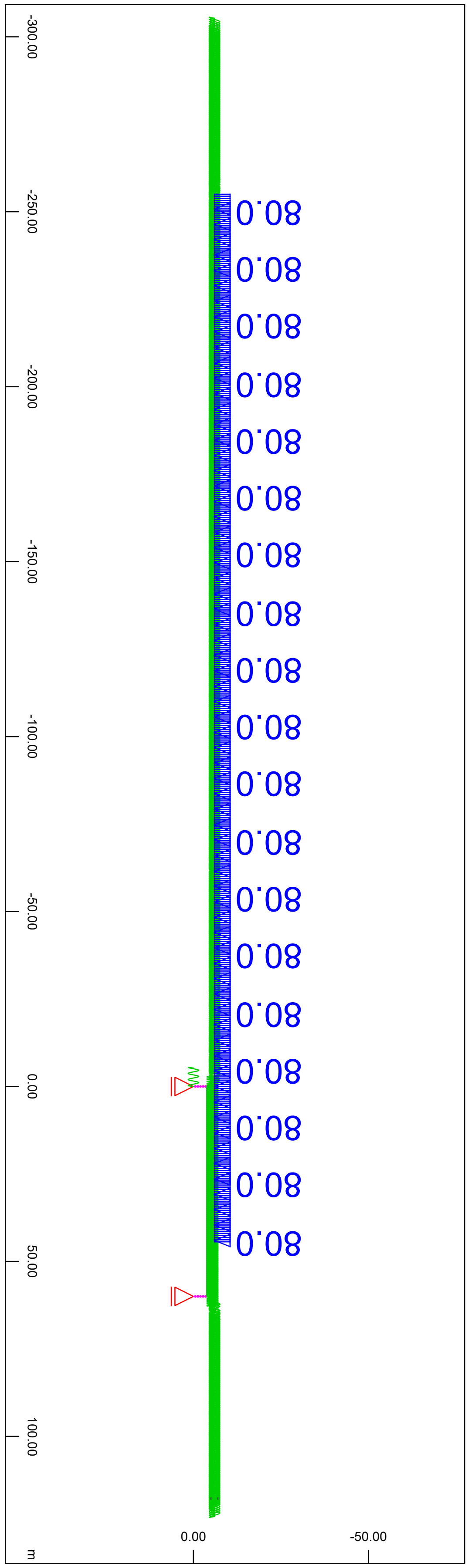
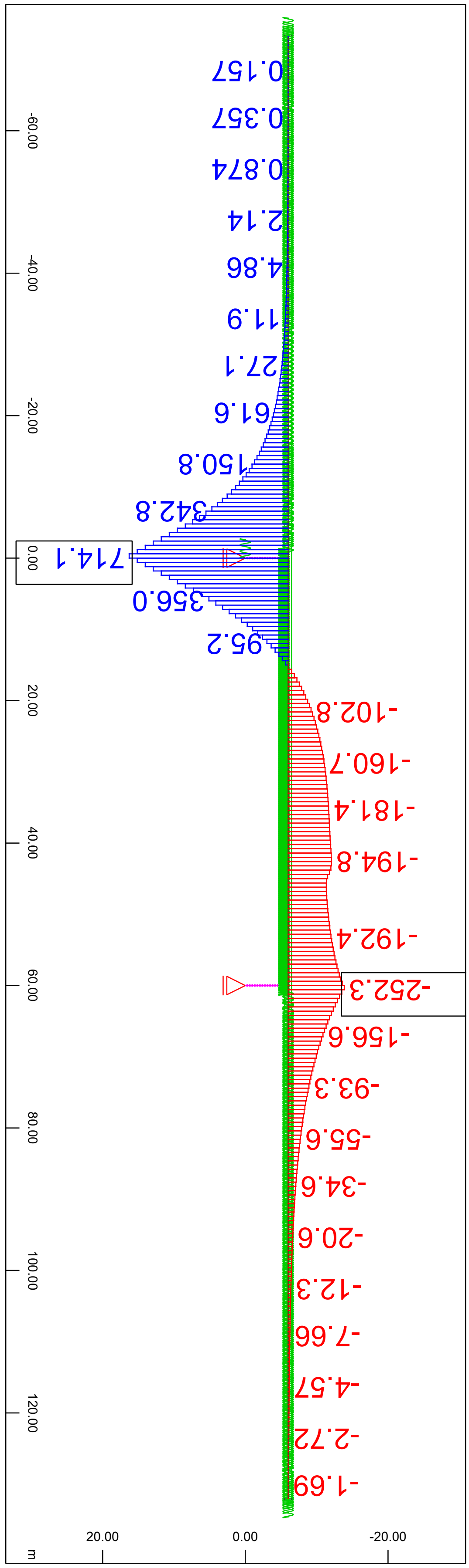
E1-3. Ballasted track - Vertical load 45 m from the fixed support

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Vertical load 45 m from the fixe , (1 cm 3D = unit) Beam line load (force) in global Y (Unit=315.6 kN/m) (Max=80.0)

M 1 : 1761



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Vertical load 45 m from the fixe , 1 cm 3D = 277.3 kN (Min=-252.3) (Max=714.1)

M 1 : 865

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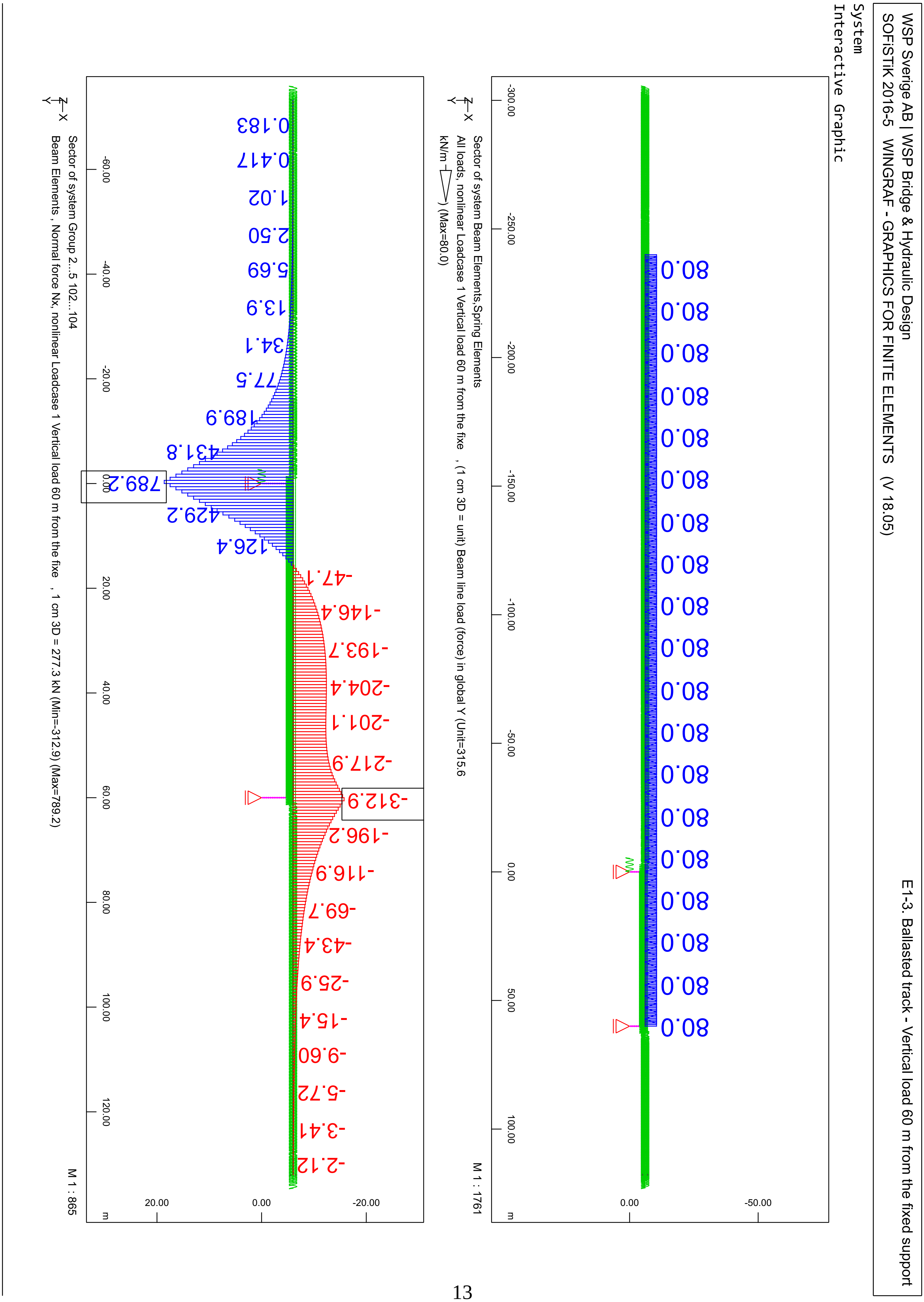

2 F4-6 - Output data - determination of the worst position of the train on the bridge

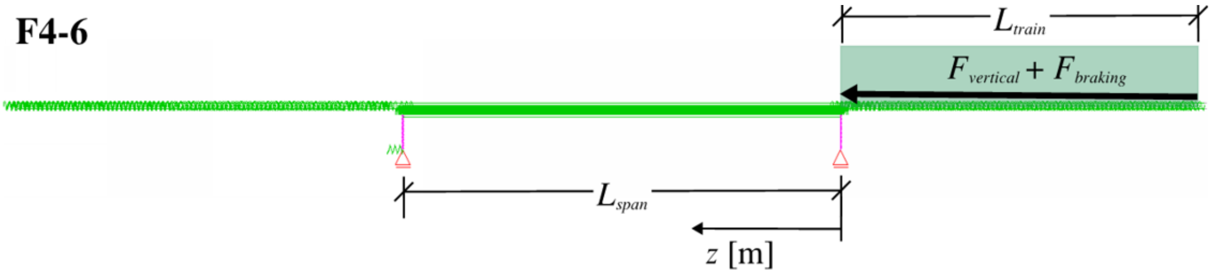

Figure 2.1 Load positions for the braking force and the vertical load.

In Figure 2.1 are the different train load positions illustrated.

2.1 F4-6 - Summary of the results

The compressive rail stresses at the movable support for different train load positions are shown in Figure 2.1 and in Figure 2.2.

Table 2.1 F4-6 - Braking force and vertical load.

Position z [m]	**Train loads**	N_{rail} **[kN]**	**Rail stress, σ_{rail} [MPa]**
0	Braking force	-43,5	-2,83
	Vertical load	-2,37	-0,15
	Sum:		**-2,98**
15	Braking force	-145	-9,43
	Vertical load	-9,79	-0,64
	Sum:		**-10,07**
30	Braking force	-285,8	-18,59
	Vertical load	-42,8	-2,78
	Sum:		**-21,38**
45	Braking force	-411	-26,74
	Vertical load	-74,6	-4,85
	Sum:		**-31,59**
60	Braking force	-498	-32,40
	Vertical load	-87,2	-5,67
	Sum:		**-38,07**

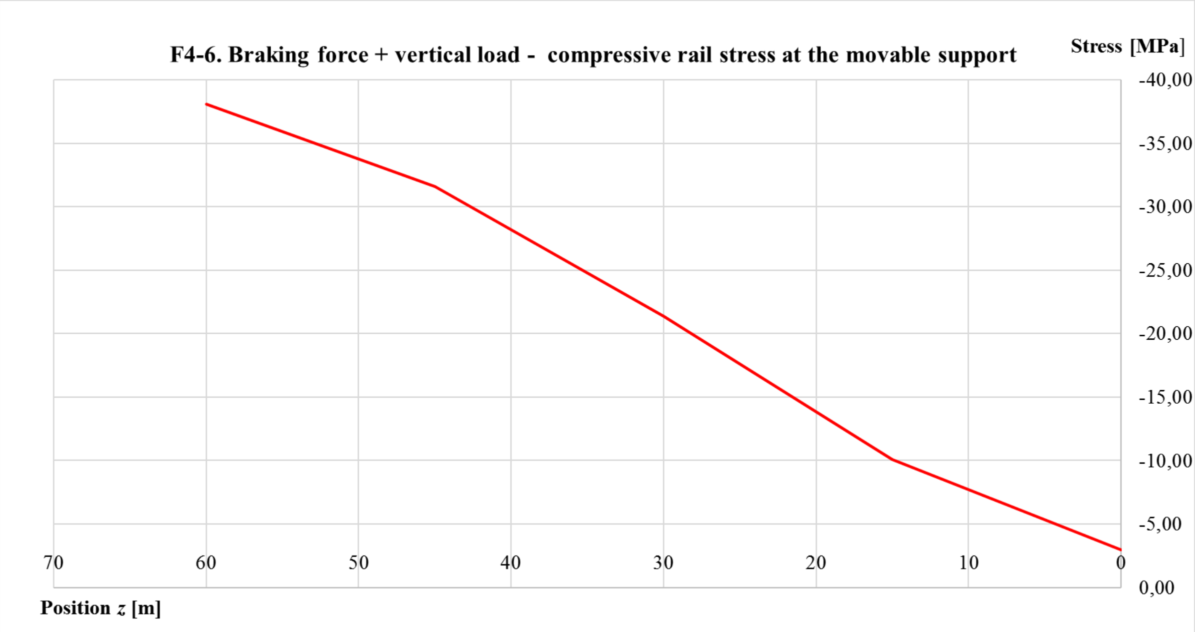

Figure 2.2 F4-6 Braking force + vertical load - compressive rail stress at the movable support for different train positions.

2.1.1 F4-6 - Largest compressive rail stress at the movable support (z = 60 m)

The largest total compressive rail stress at the movable support are shown in Table 2.2.

Table 2.2 F4-6. Total compressing rail stress at the movable support, train position z = 60 m from the movable support.

Load case	**N_{rail} [kN]**	**Rail stress, σ_{rail} [MPa]**
Temperature variation - deck	-419,10	-27,26
Braking	-498,00	-32,40
Vertical bending - end rot	-87,20	-5,67
Sum:		**-65,33**

2.2 F4-6 - Normal force diagrams for every position

On the following pages are the normal force diagrams for the temperature variation load and every train load position in Table 2.1 and Table 2.2 shown. To find the largest compressing rail stress at the movable support was the braking force tested in both directions. Diagrams for each braking direction are shown in this section. When the braking force are directed towards the movable support are the largest compressive rail stresses produced at the movable support

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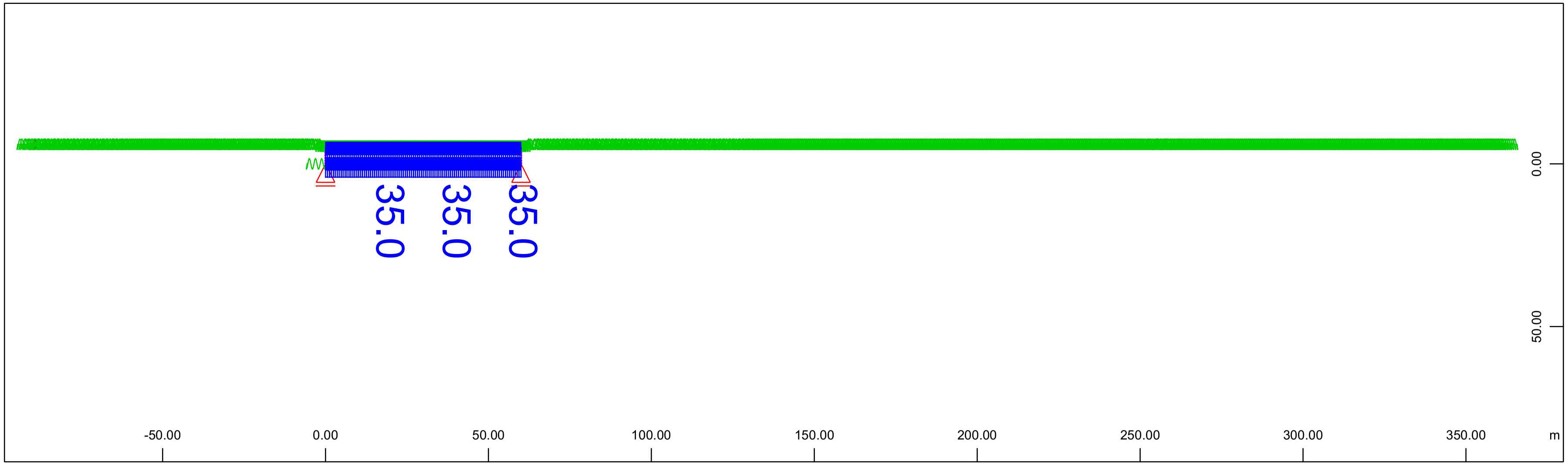
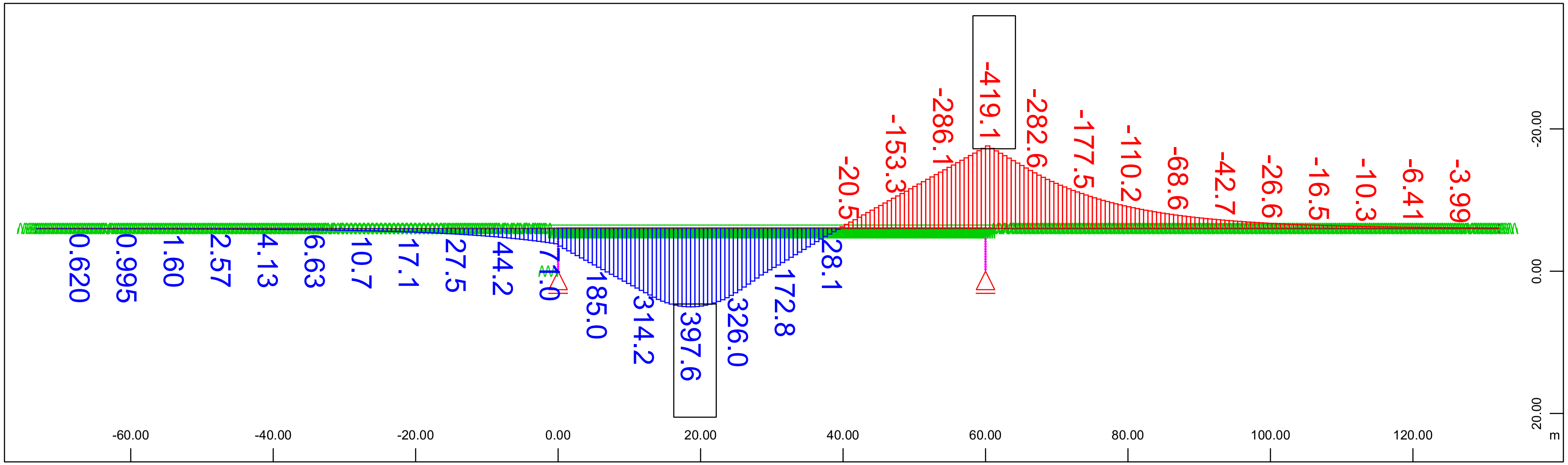
F4-6. Ballasted track - Temperature variation - deck

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Temperature variation - deck , (1 cm 3D = unit) Beam line load (uniform temperature change)
(Unit=74.7 °C) (Max=35.0)
M 1 : 1891



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Temperature variation - deck , 1 cm 3D = 312.5 kN (Min=-419.1) (Max=397.6)
M 1 : 865

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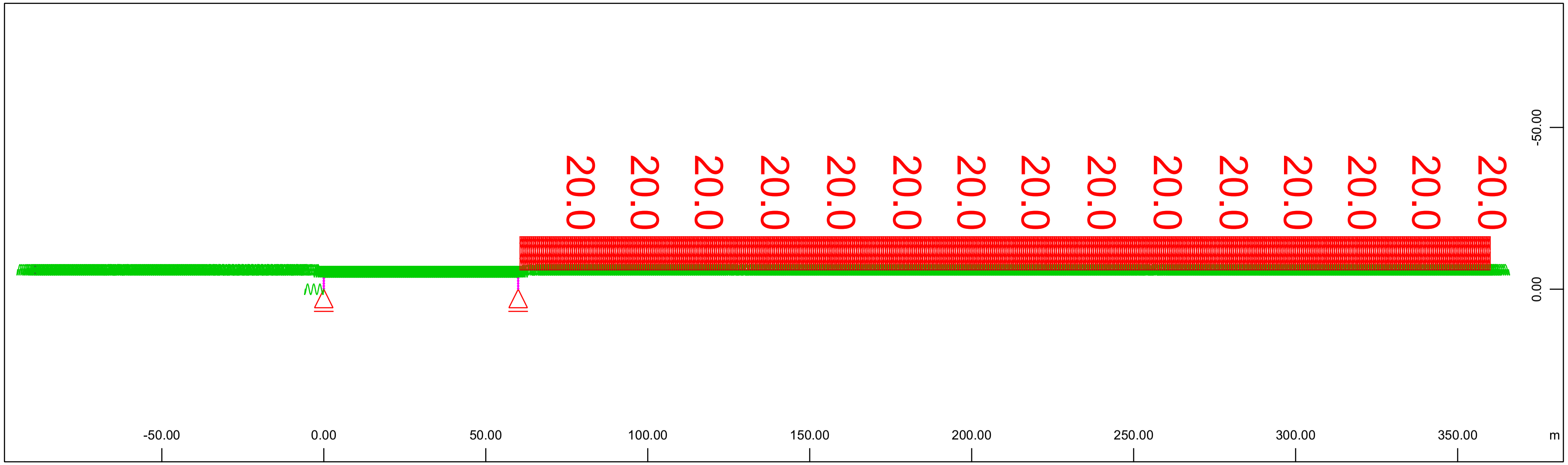
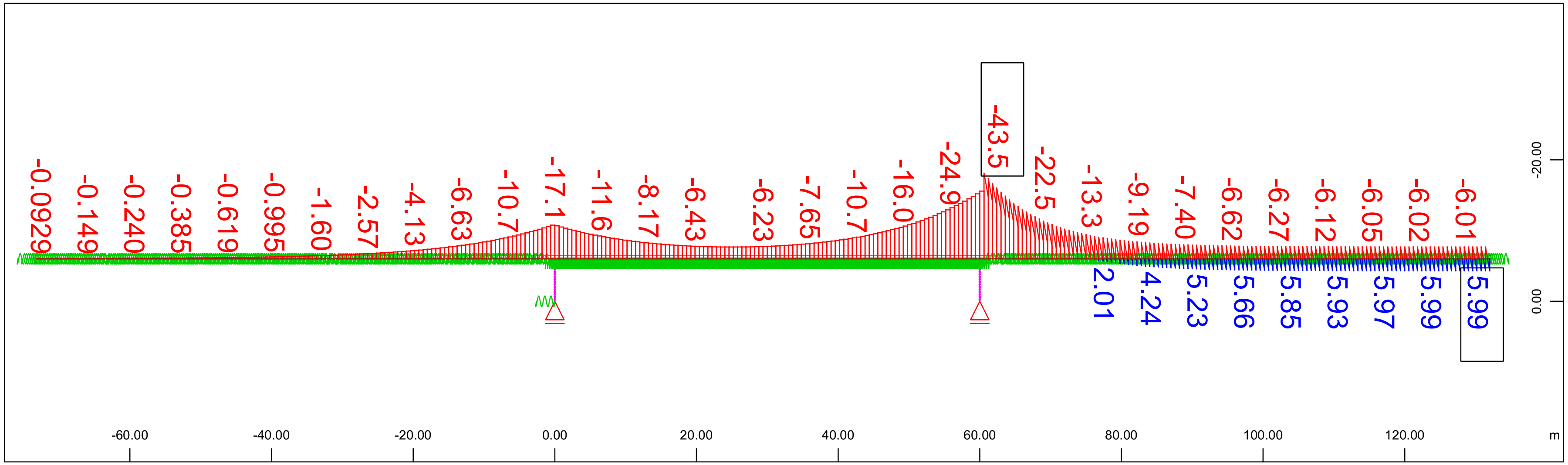
F4-6. Ballasted track - Braking force 0 m from the movable support - force direction towards the fixed support

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Braking force 0 m from the movab , (1 cm 3D = unit) Beam line load (force) in global X (Unit=37.3 kN/m) (Min=-20.0) (Max=-20.0)
M 1 : 1902



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Braking force 0 m from the movab , 1 cm 3D = 31.2 kN (Min=-43.5) (Max=5.99)
M 1 : 870

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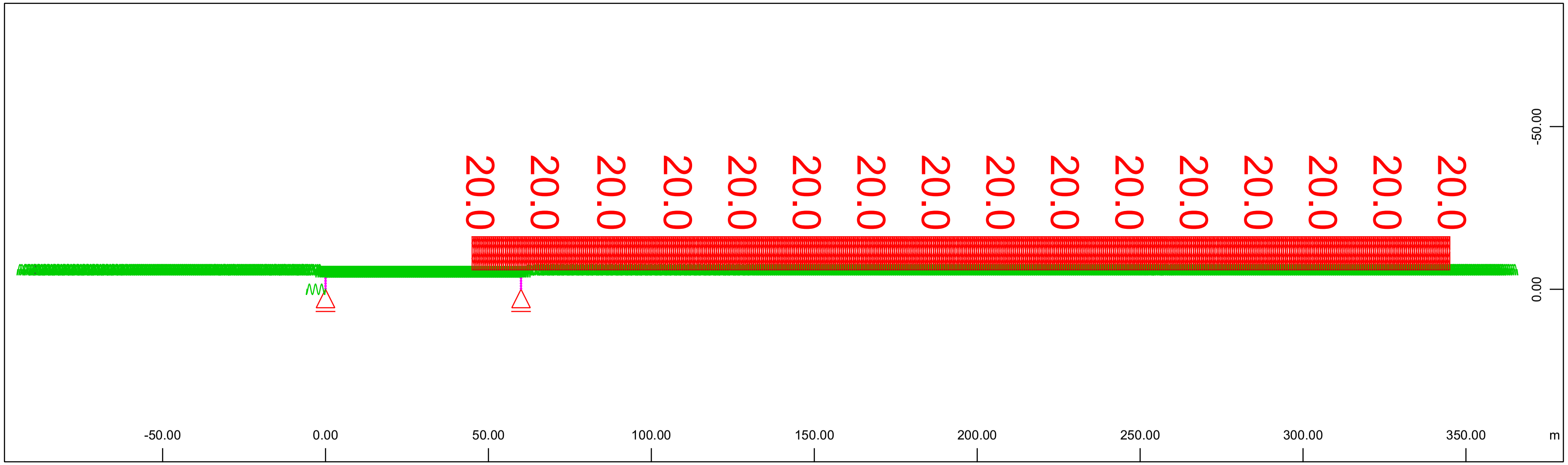
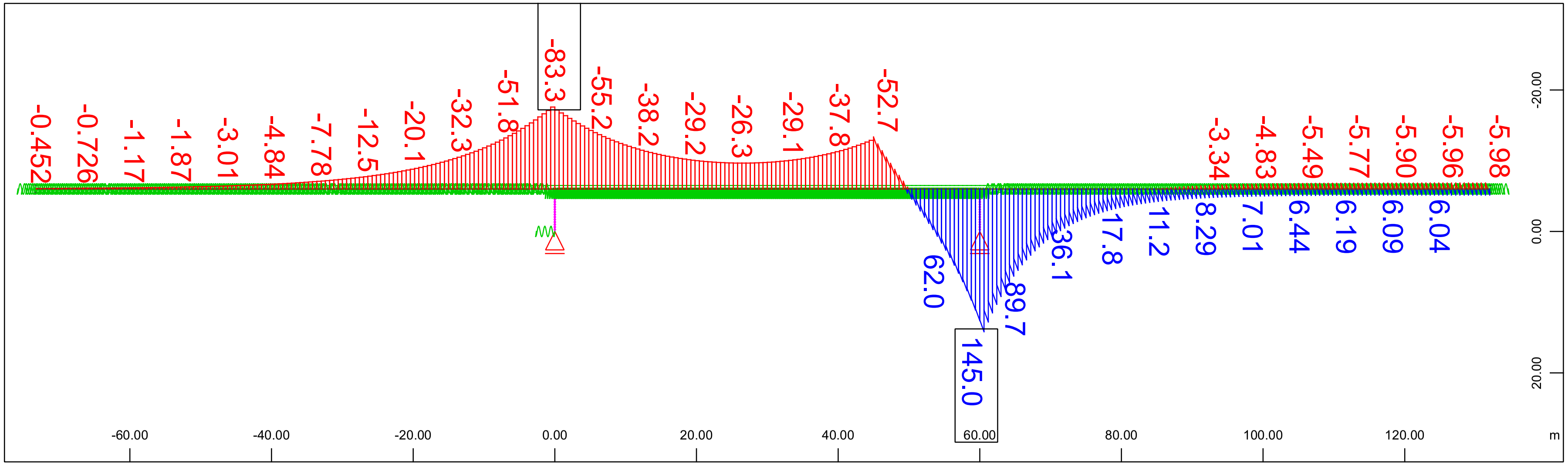
F4-6. Ballasted track - Braking force 15 m from the movable support - force direction towards the fixed support

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Braking force 15 m from the mova , (1 cm 3D = unit) Beam line load (force) in global X (Unit=37.3 kN/m) (Min=-20.0) (Max=-20.0)
M 1 : 1891



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Braking force 15 m from the mova , 1 cm 3D = 62.5 kN (Min=-83.3) (Max=145.0)
M 1 : 870

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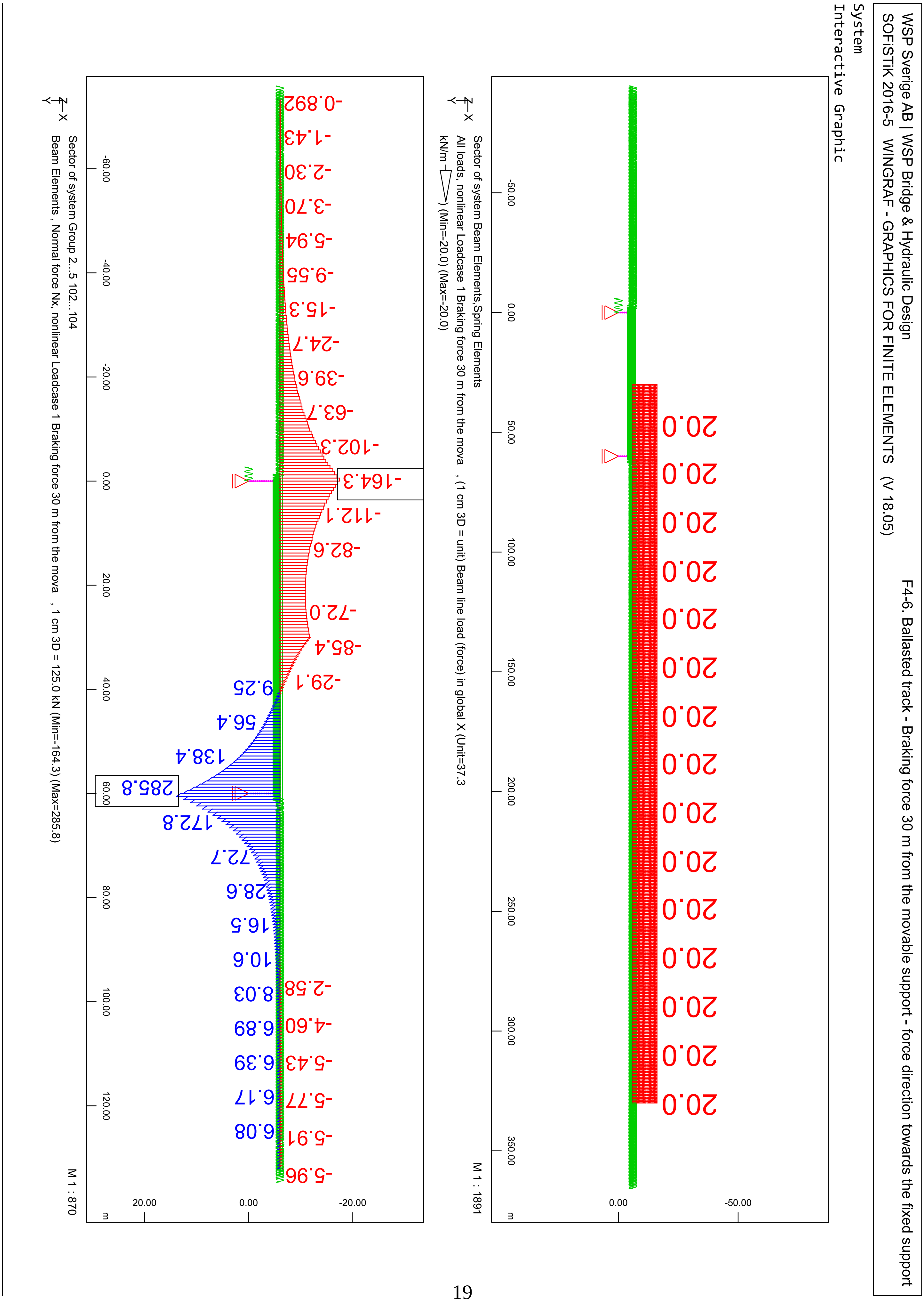

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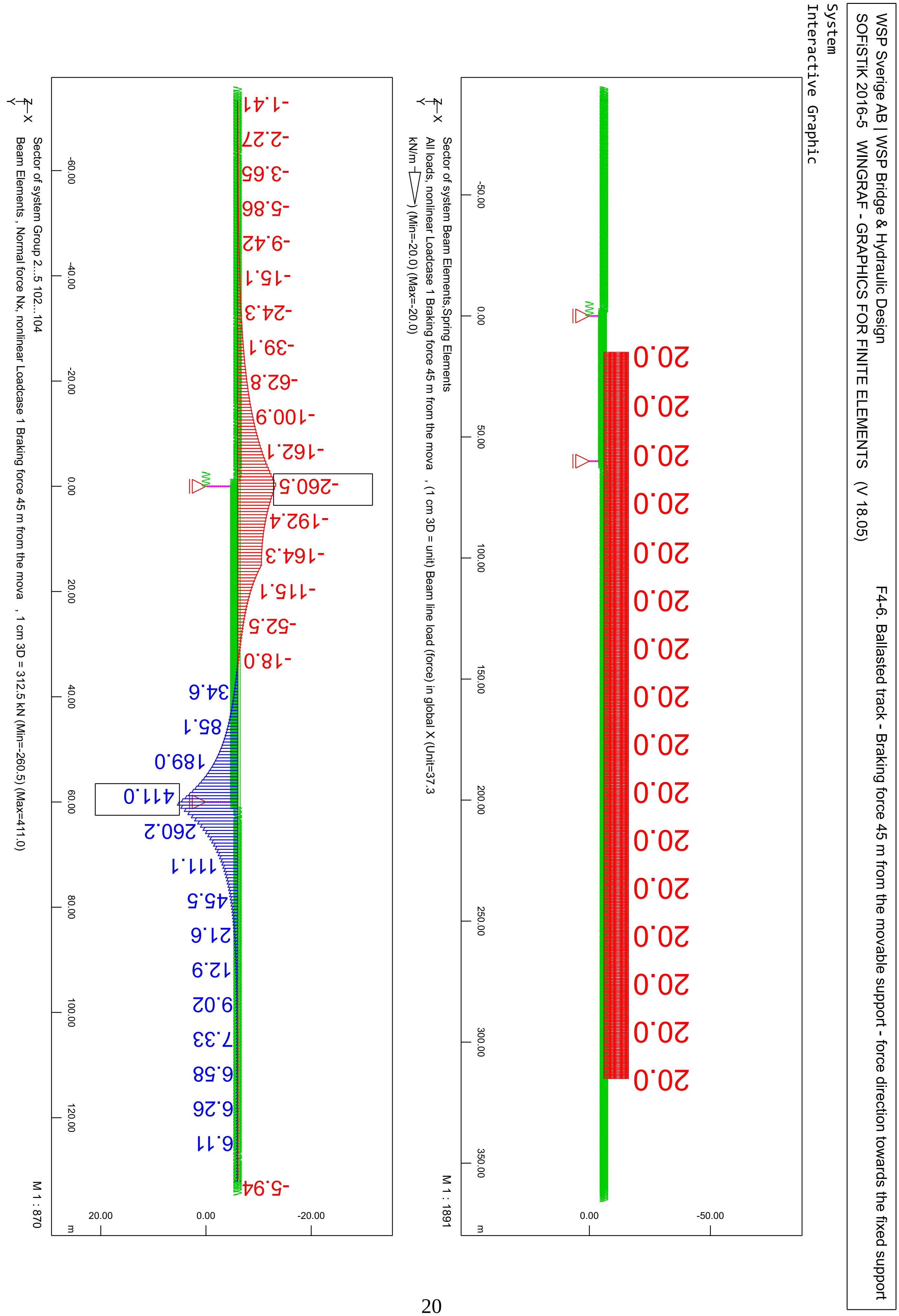

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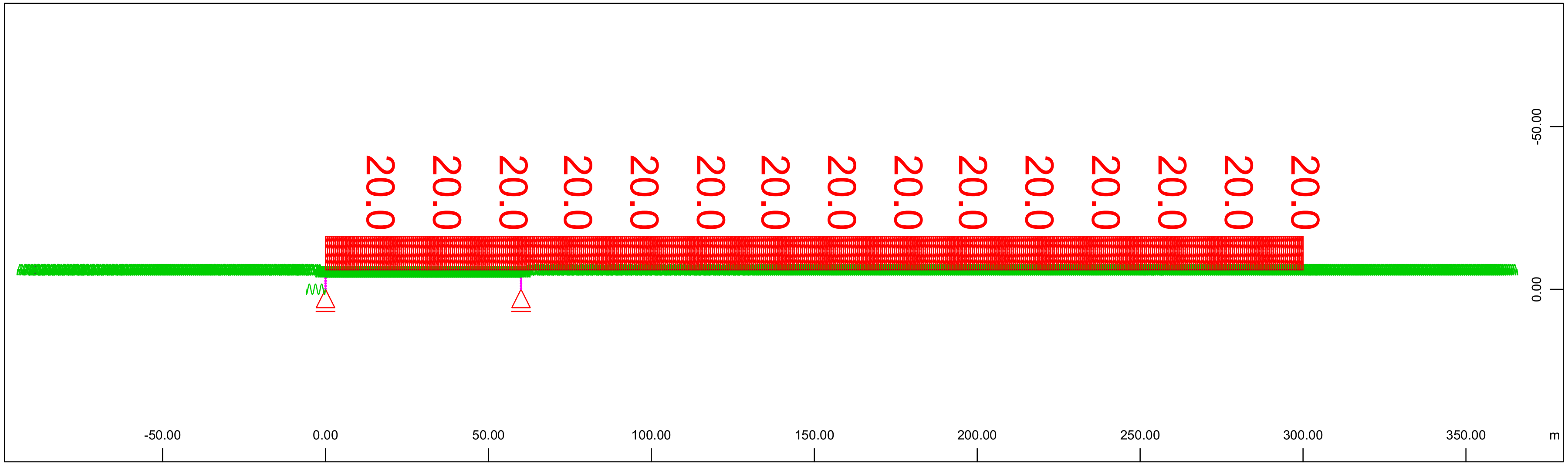
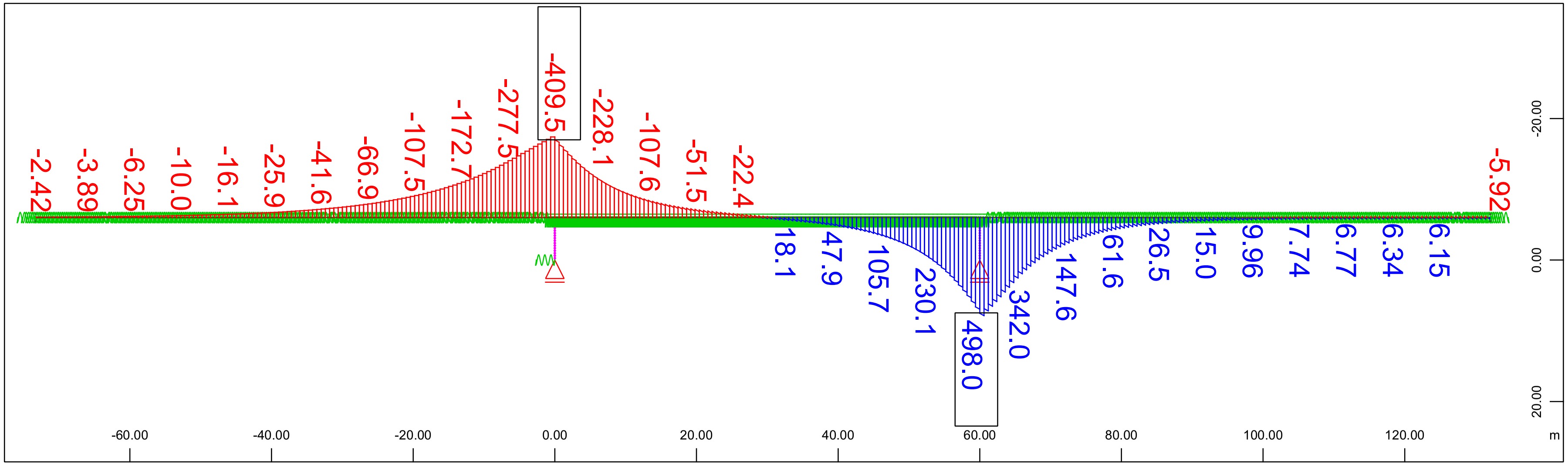
F4-6. Ballasted track - Braking force 60 m from the movable support - force direction towards the fixed support

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Braking force 60 m from the mova , (1 cm 3D = unit) Beam line load (force) in global X (Unit=37.3 kN/m) (Min=-20.0) (Max=-20.0)



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Braking force 60 m from the mova , 1 cm 3D = 312.5 kN (Min=-409.5) (Max=498.0)

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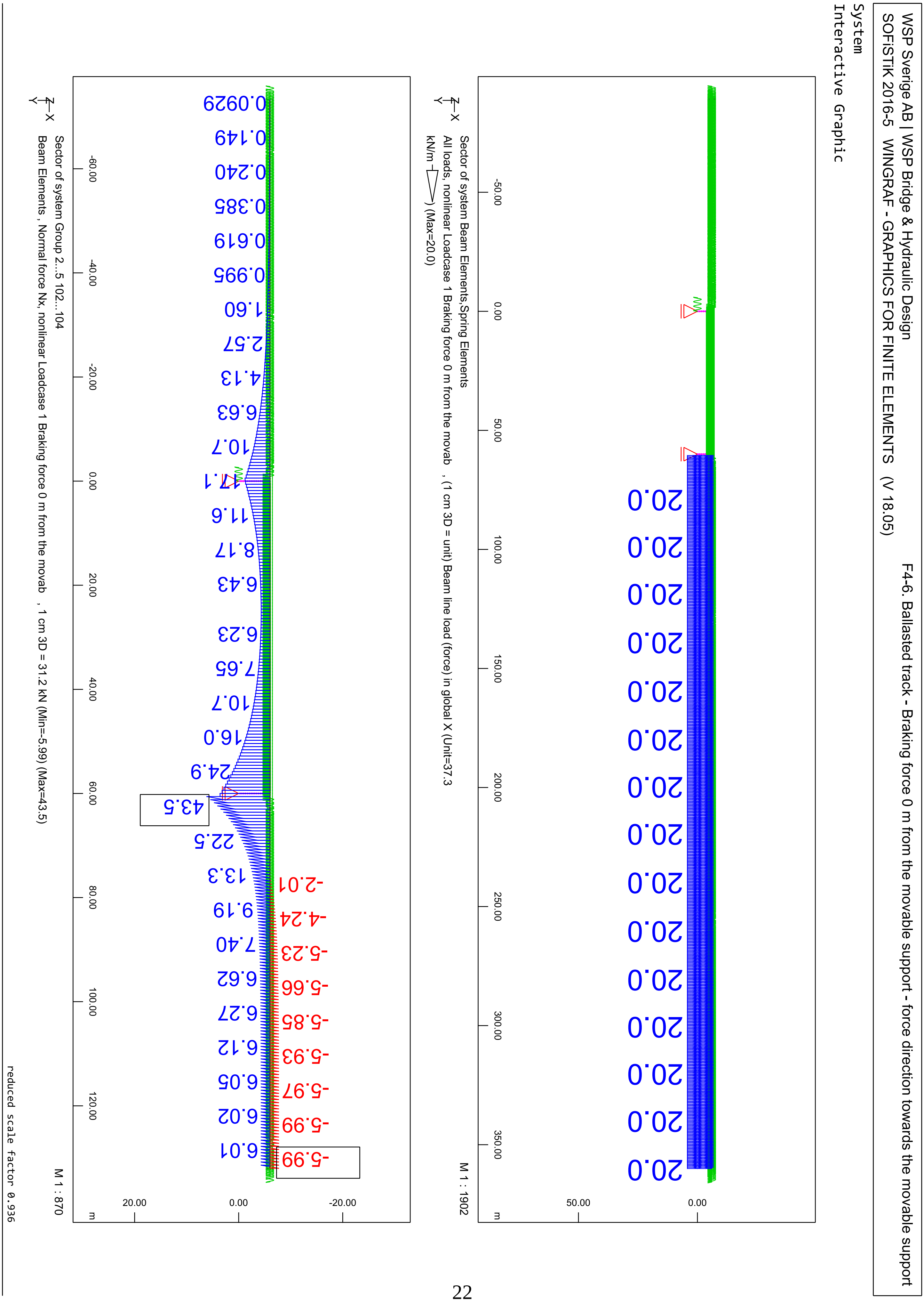

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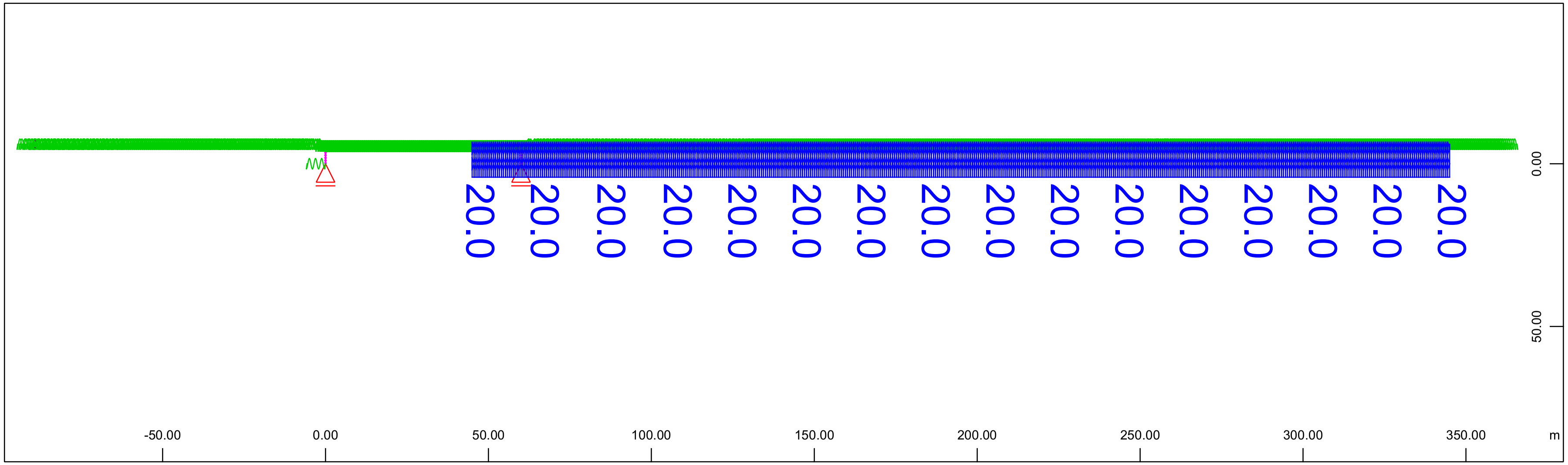
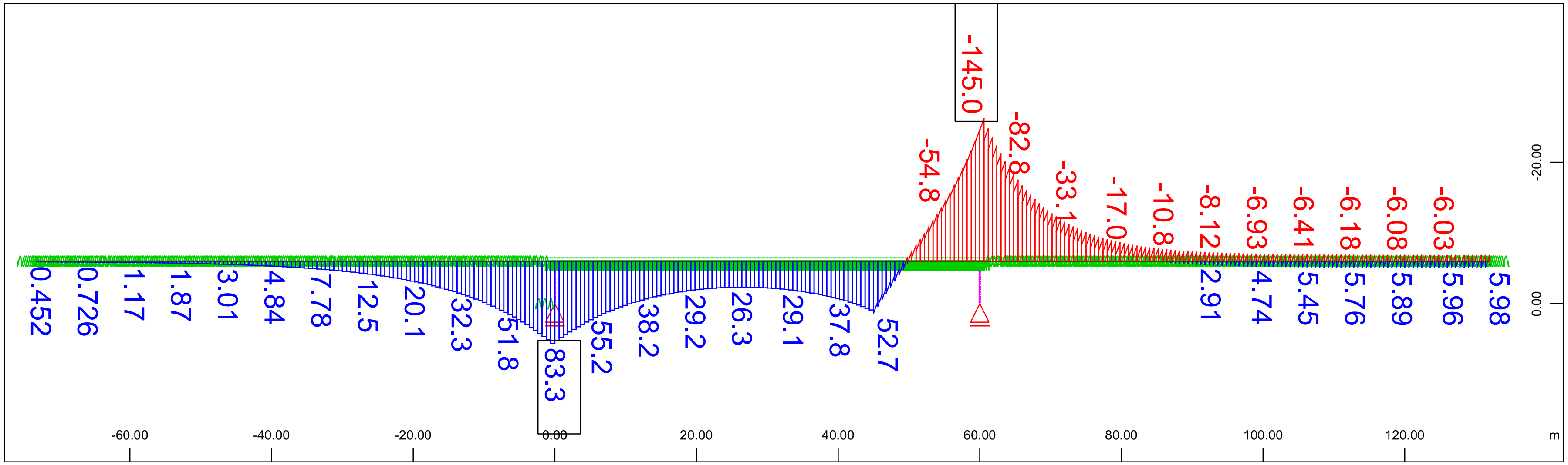
F4-6. Ballasted track - Braking force 15 m from the movable support - force direction towards the movable support

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Braking force 15 m from the mova , (1 cm 3D = unit) Beam line load (force) in global X (Unit=37.3 kN/m) (Max=20.0)
M 1 : 1891



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Braking force 15 m from the mova , 1 cm 3D = 62.5 kN (Min=-145.0) (Max=83.3)
M 1 : 870

reduced scale factor 0.936

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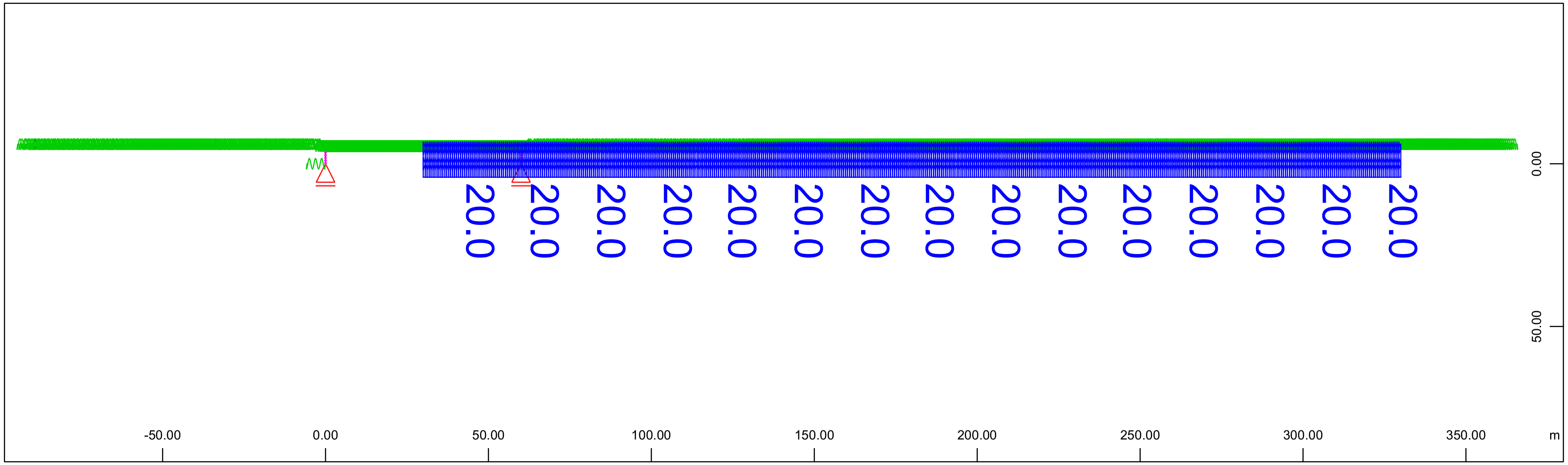
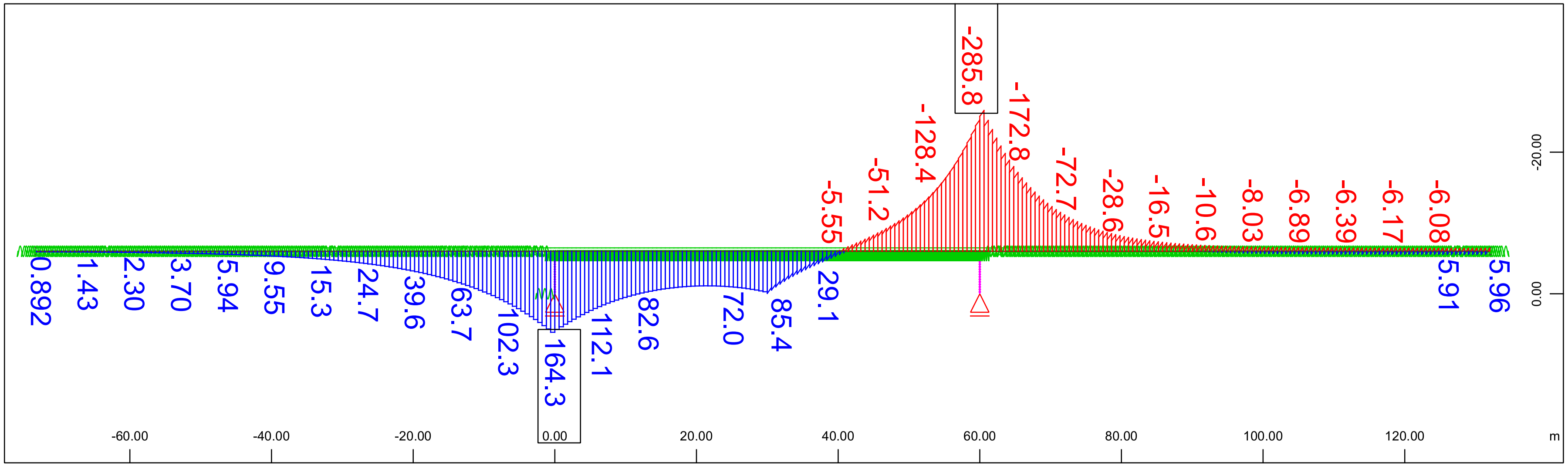
F4-6. Ballasted track - Braking force 30 m from the movable support - force direction towards the movable support

System
Interactive Graphic



M 1 : 1891

Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Braking force 30 m from the mova , (1 cm 3D = unit) Beam line load (force) in global X (Unit=37.3 kN/m) (Max=20.0)



M 1 : 870

Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Braking force 30 m from the mova , 1 cm 3D = 125.0 kN (Min=-285.8) (Max=164.3)

reduced scale factor 0.936

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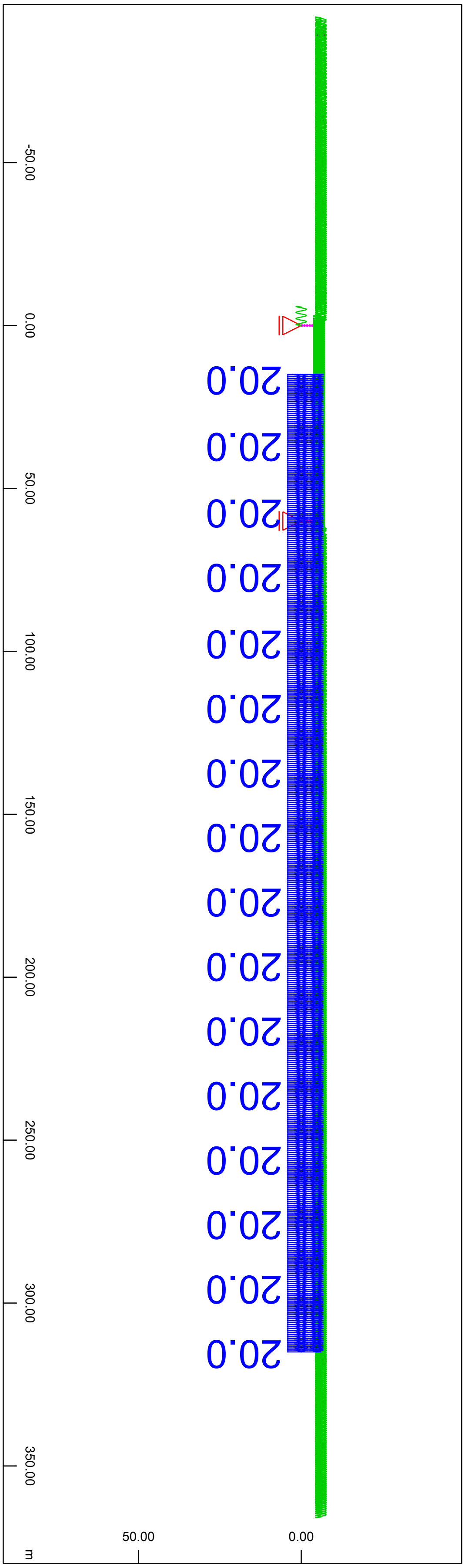
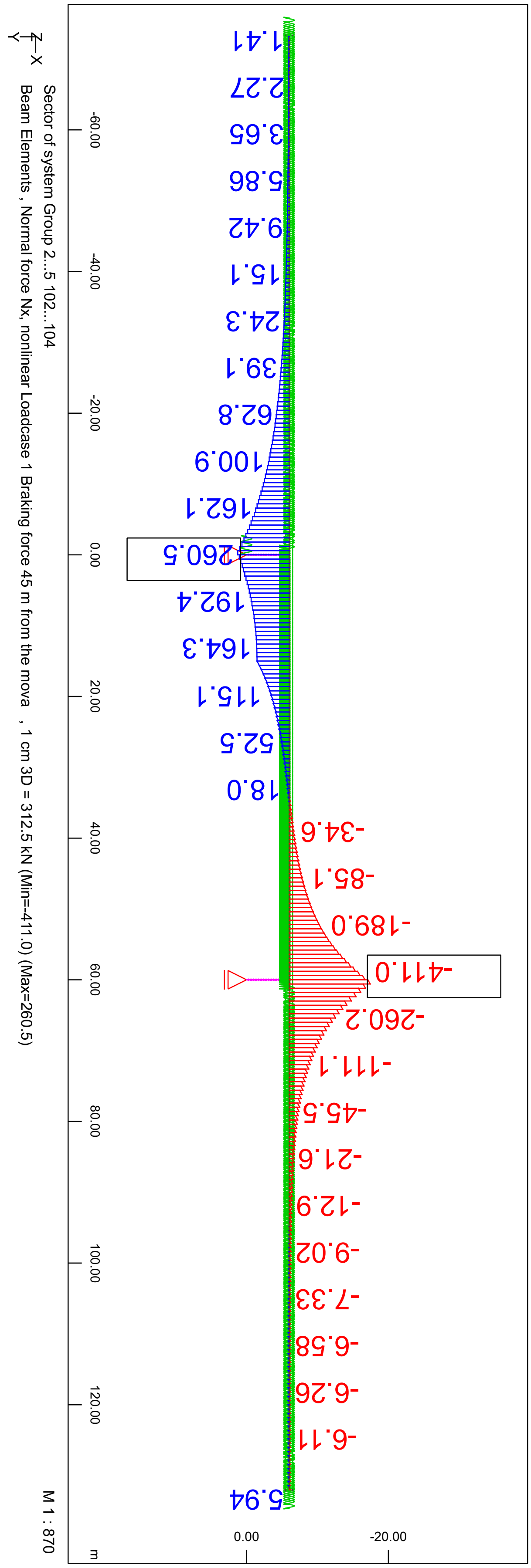
F4-6. Ballasted track - Braking force 45 m from the movable support - force direction towards the movable support

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Braking force 45 m from the mova , (1 cm 3D = unit) Beam line load (force) in global X (Unit=37.3 kN/m) (Max=20.0)
M 1 : 1891



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Braking force 45 m from the mova , 1 cm 3D = 312.5 kN (Min=-411.0) (Max=260.5)
M 1 : 870

reduced scale factor 0.936

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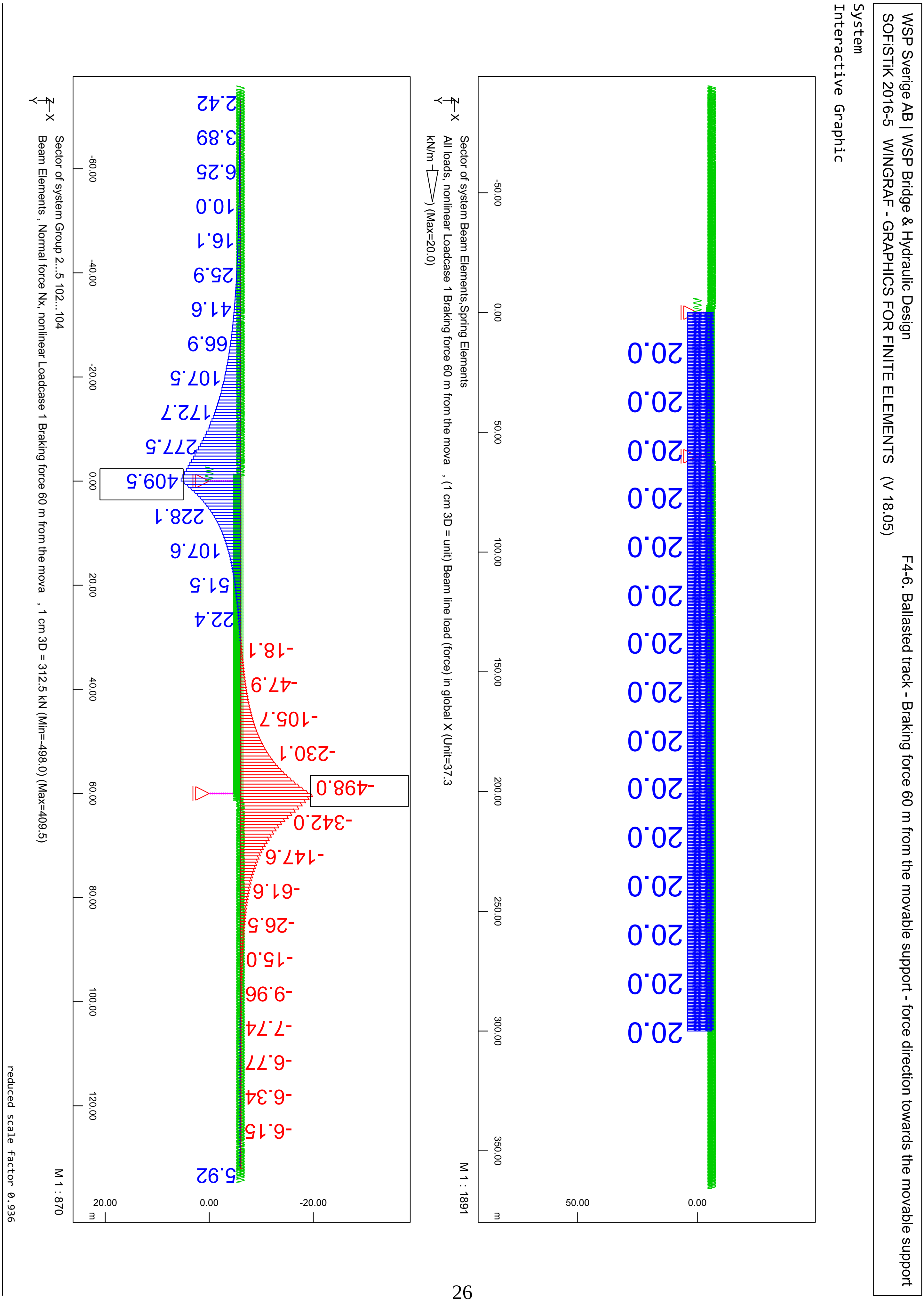

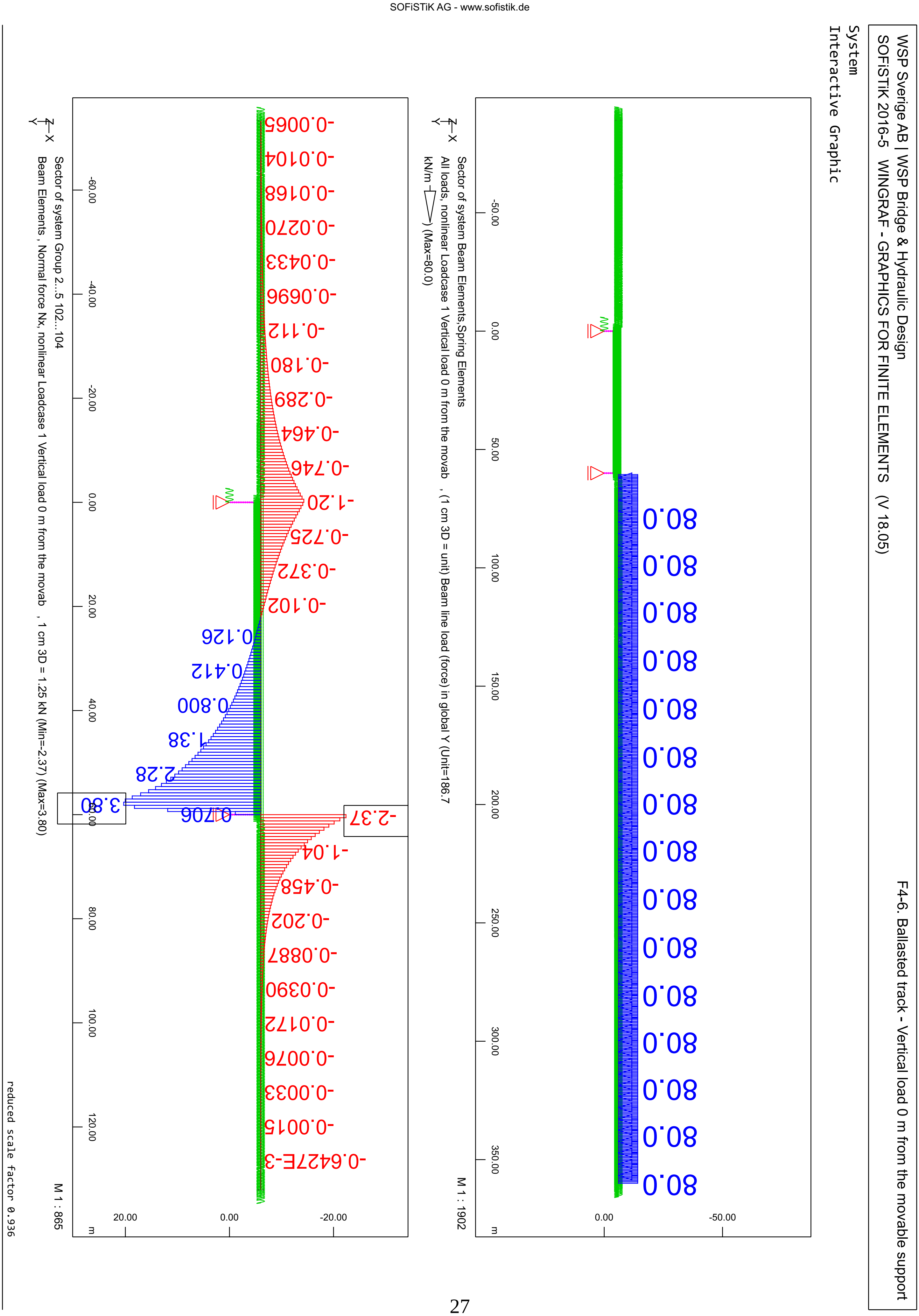
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F4-6. Ballasted track - Vertical load 0 m from the movable support
System
Interactive Graphic
Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Vertical load 0 m from the movab , (1 cm 3D = unit) Beam line load (force) in global Y (Unit=186.7 kN/m) (Max=80.0)
M 1 : 1902
80.0
Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Vertical load 0 m from the movab , 1 cm 3D = 1.25 kN (Min=-2.37) (Max=3.80)
M 1 : 865
-0.0065
-0.0104
-0.0168
-0.0270
-0.0433
-0.0696
-0.112
-0.180
-0.289
-0.464
-0.746
-1.20
-0.725
-0.372
-0.102
0.126
0.412
0.800
1.38
2.28
3.80
0.706
-2.37
-1.04
-0.458
-0.202
-0.0887
-0.0390
-0.0172
-0.0076
-0.0033
-0.0015
-0.6427E-3
reduced scale factor 0.936

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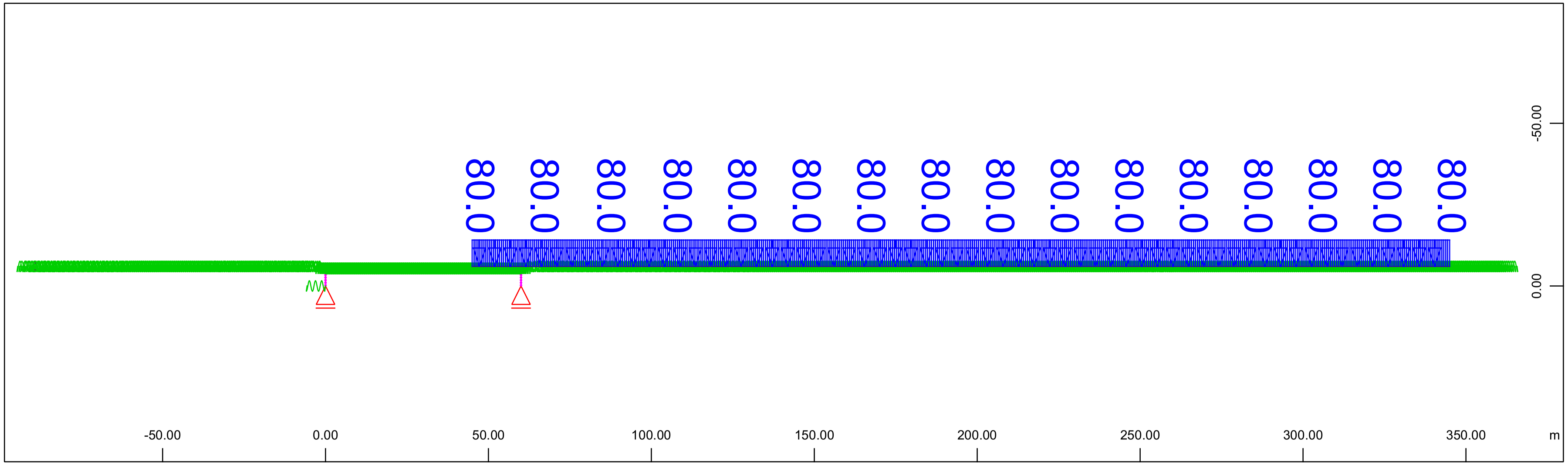
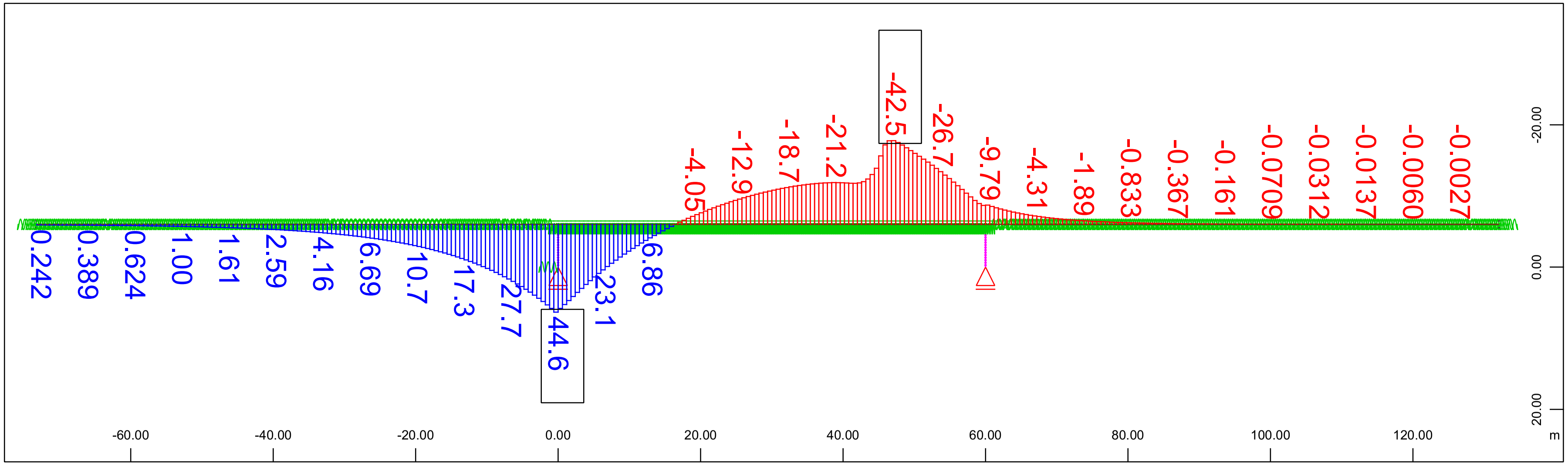
F4-6. Ballasted track - Vertical load 15 m from the movable support

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Vertical load 15 m from the mova , (1 cm 3D = unit) Beam line load (force) in global Y (Unit=186.7 kN/m) (Max=80.0)

M 1 : 1891



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Vertical load 15 m from the mova , 1 cm 3D = 31.2 kN (Min=-42.5) (Max=44.6)

M 1 : 865

reduced scale factor 0.936

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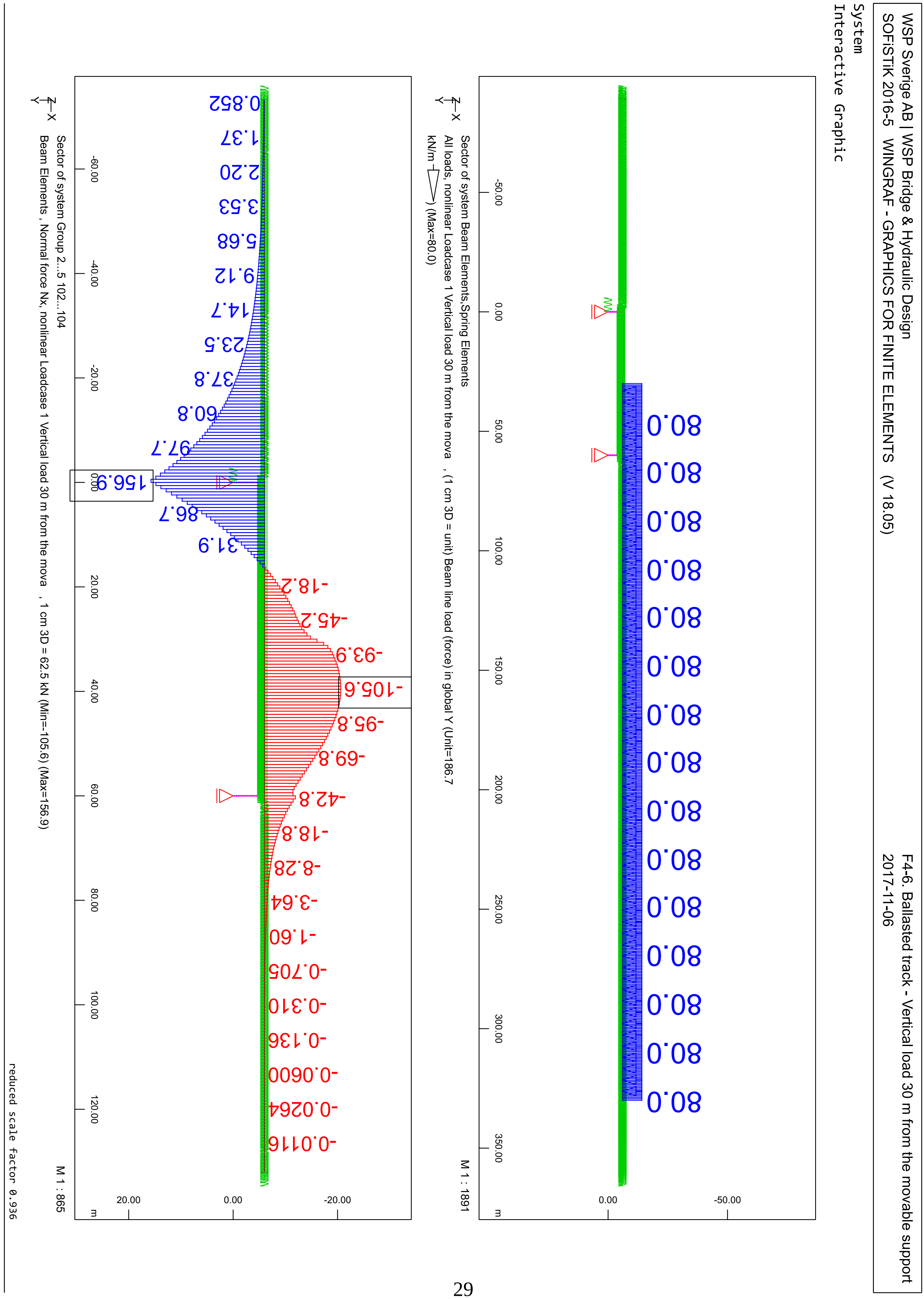

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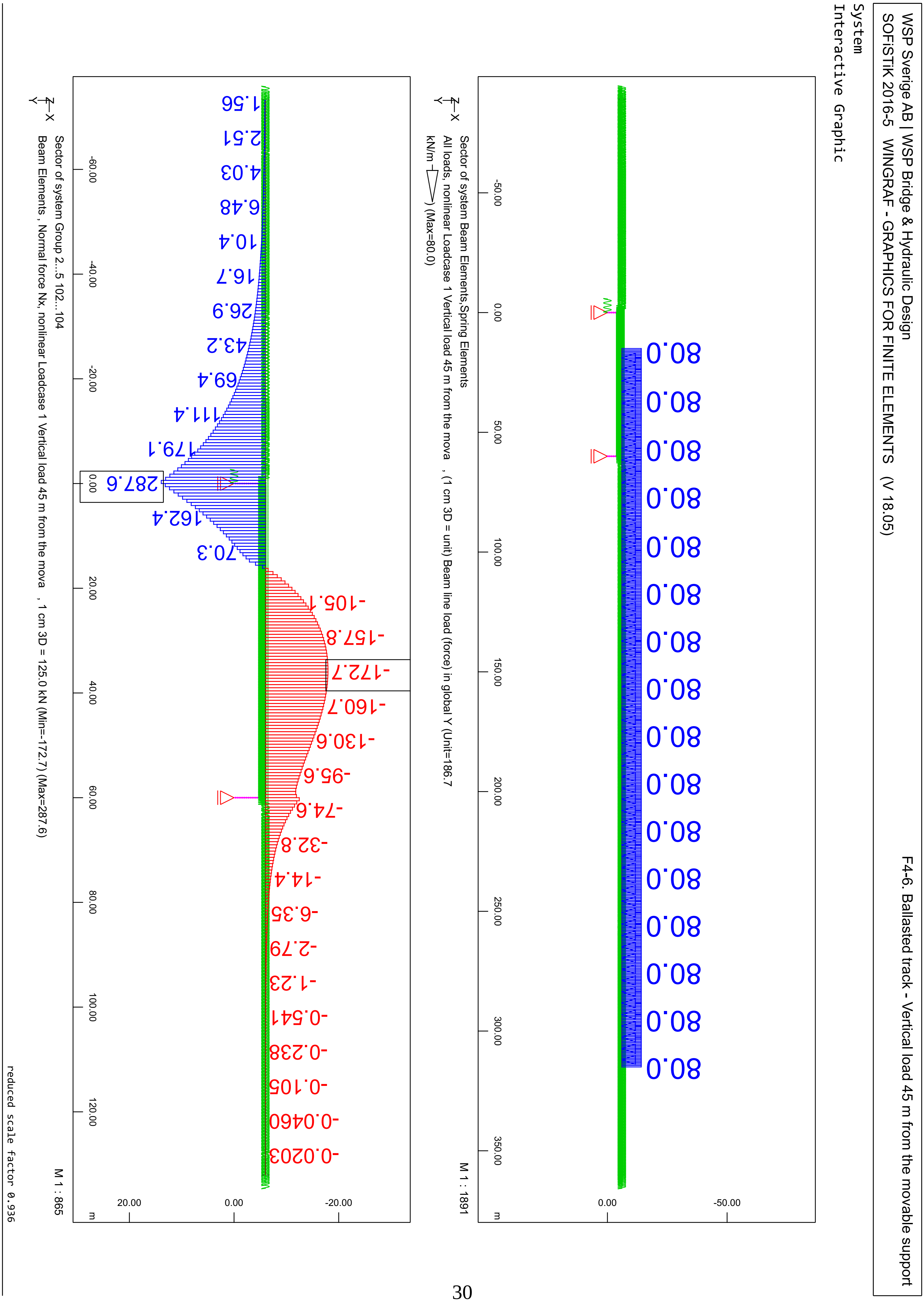

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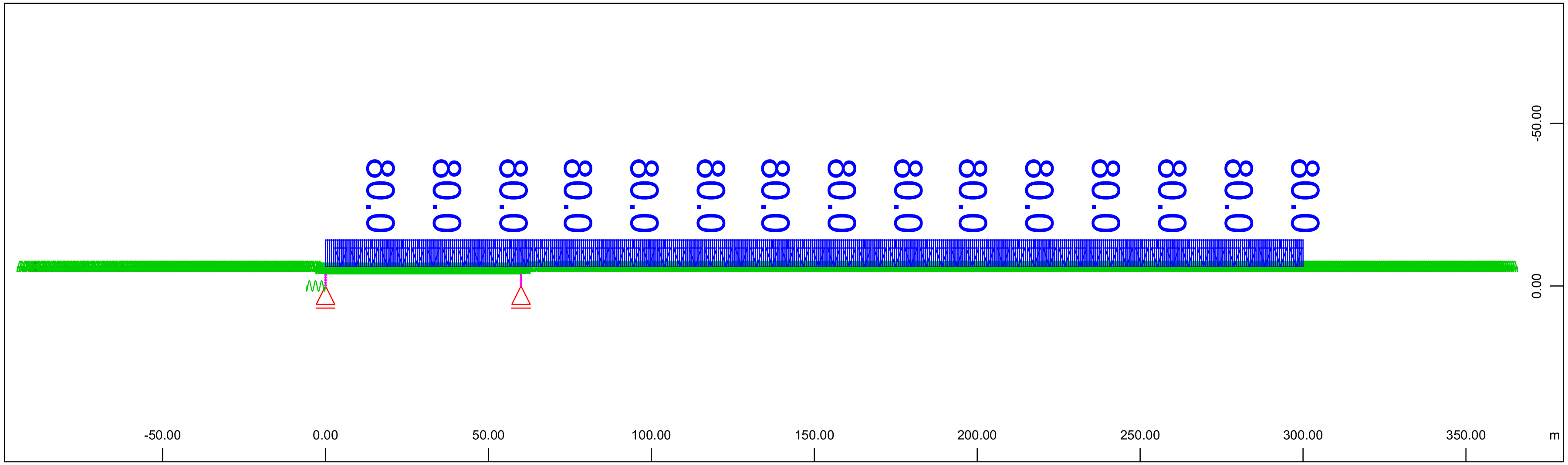
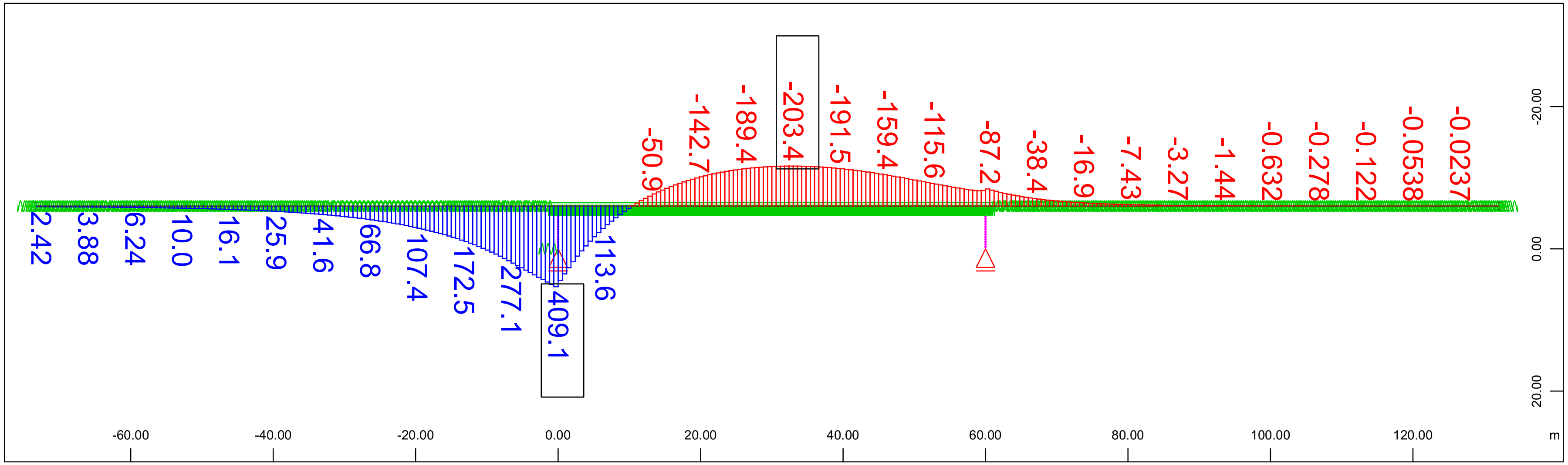
System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Vertical load 60 m from the mova , (1 cm 3D = unit) Beam line load (force) in global Y (Unit=186.7 kN/m) (Max=80.0)

M 1 : 1891



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Vertical load 60 m from the mova , 1 cm 3D = 312.5 kN (Min=-203.4) (Max=409.1)

M 1 : 865

reduced scale factor 0.936

Appendix 4

Results from the two slab track models – with and without a floating slab mat

Table of Contents

1 Model with a slab track without a floating slab mat

In section 1.3 and section 1.4 are detailed normal force diagrams presented for each test case.

1.1 E1-3 – results from the slab track model without a floating slab mat

In Table 1.1 are the rail stresses at the movable support from the slab track model without a floating slab mat summarized.

Table 1.1 E1-3. Train position z = 60 m in the slab track model without a floating slab mat. Linear superposition of the compressive rail stresses at the movable support.

Load case	N_{rail} **[kN]**	**Rail stress, σ_{rail} [MPa]**
Temperature variation - deck	-887,00	-57,70
Braking	-336,50	-21,89
Vertical bending - end rot	-409,20	-26,62
Sum:		**-106,2**

1.2 F4-6 – results from the slab track model without a floating slab mat

In Table 1.2 are the rail stresses at the movable support from the slab track model without a floating slab mat summarized.

Table 1.2 F4-6. Train position z = 60 m in the slab track model without a floating slab mat. Linear superposition of the compressive rail stresses at the movable support.

Load case	N_{rail} **[kN]**	**Rail stress, σ_{rail} [MPa]**
Temperature variation - deck	-661,00	-43,00
Braking	-504,20	-32,80
Vertical bending - end rot	60,00	3,90
Sum:		**-71,9**

1.3 E1-3. Detailed normal force diagrams from the model without a floating slab mat

On the following pages are detailed normal force diagrams for test case E1-3 without a floating slab mat presented.

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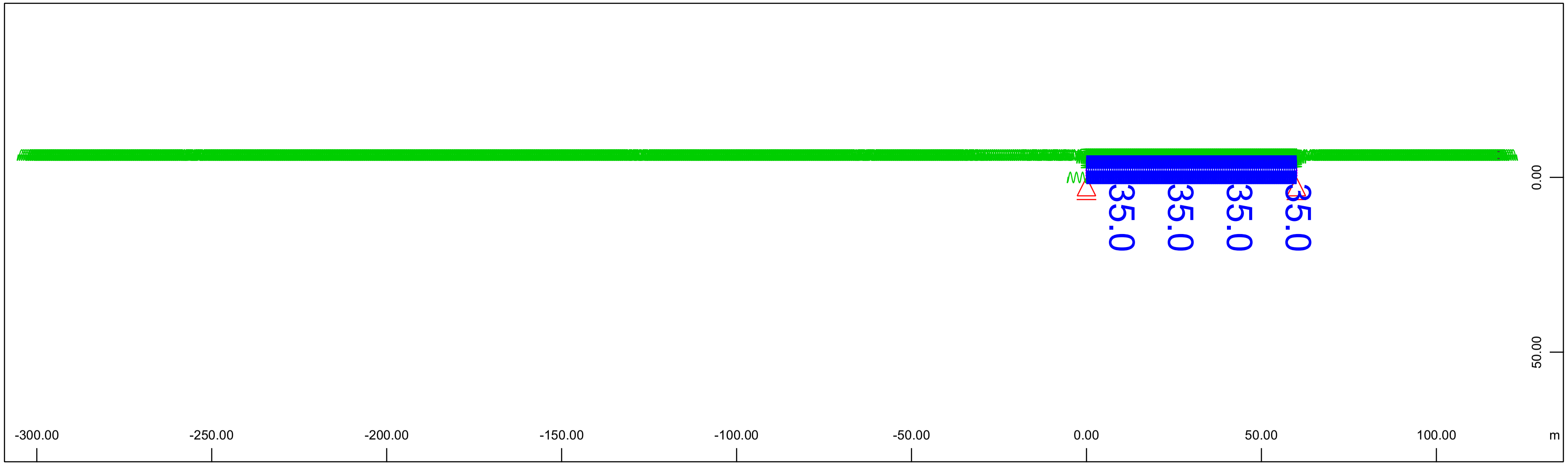
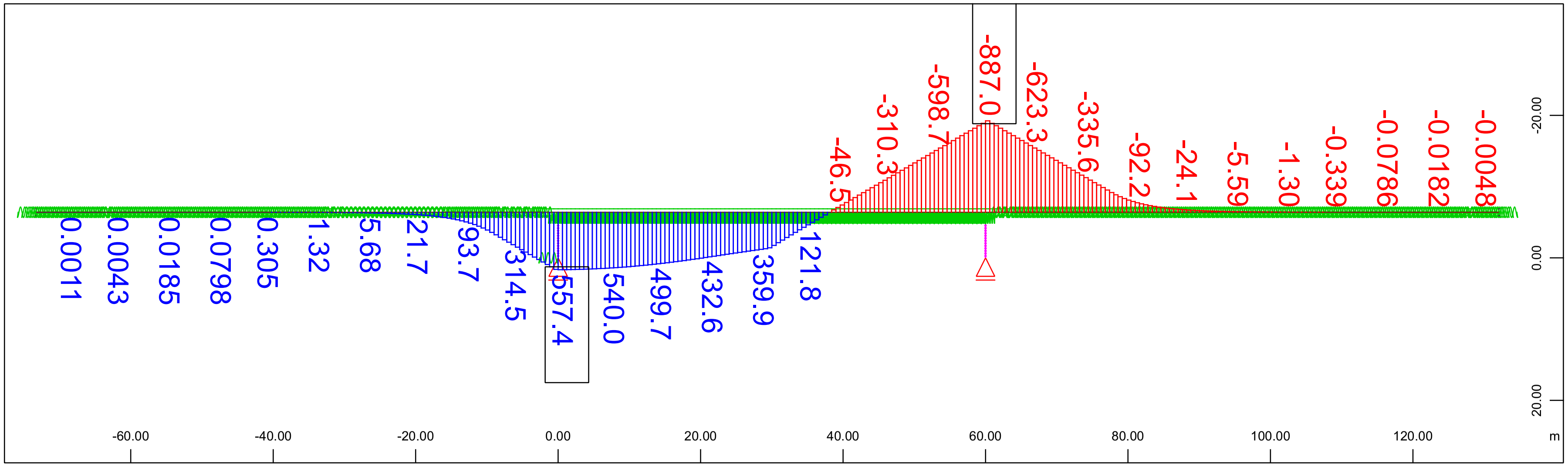
E1-3. Slab track - Temperature variation - deck

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Temperature variation - deck , (1 cm 3D = unit) Beam line load (uniform temperature change)
(Unit=126.2 °C) (Max=35.0)

M 1 : 1761



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Temperature variation - deck , 1 cm 3D = 597.7 kN (Min=-887.0) (Max=557.4)

M 1 : 865

reduced scale factor 0.936

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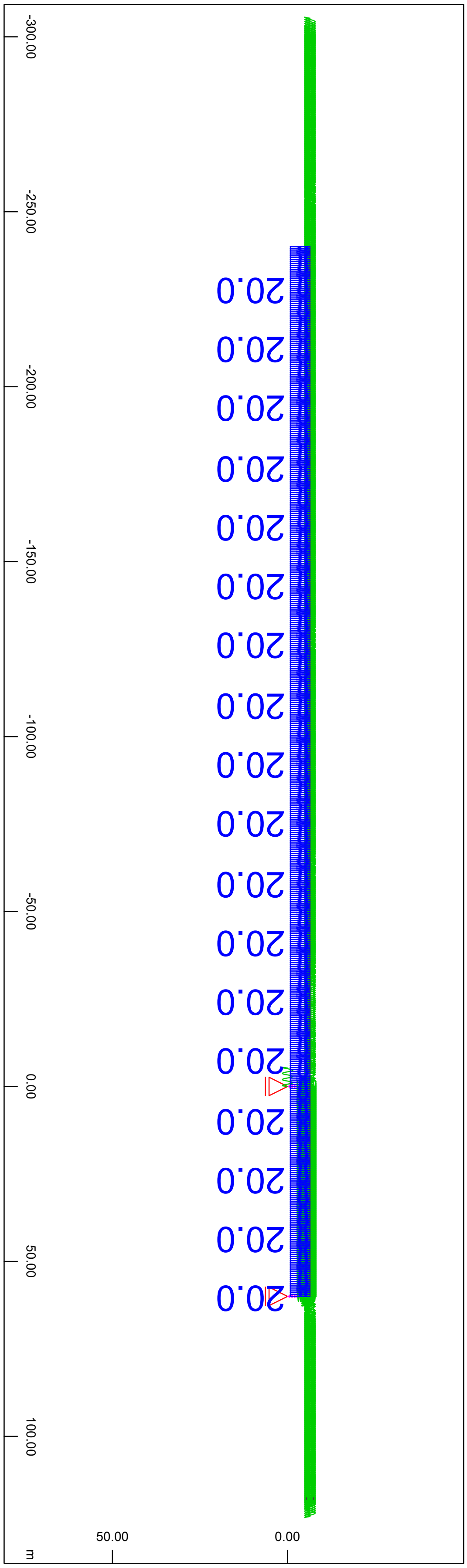
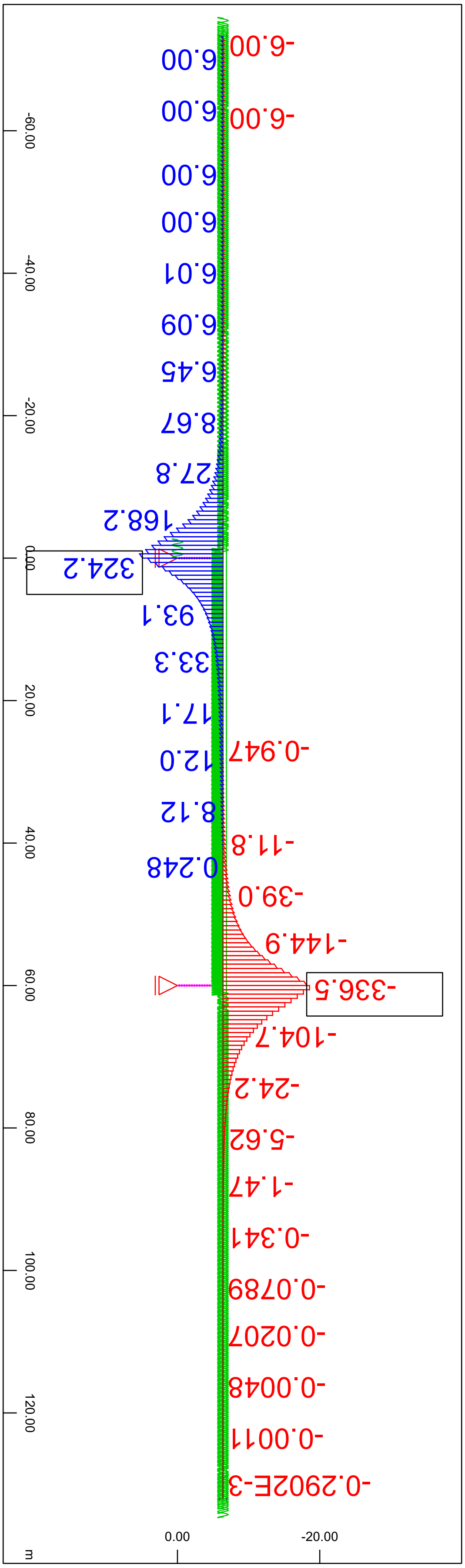
E1-3. Slab track - Braking force 60 m from the fixed support

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Braking force 60 m from the fixe , (1 cm 3D = unit) Beam line load (force) in global X (Unit=63.1 kN/m) (Max=20.0)

M 1 : 1761



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Braking force 60 m from the fixe , 1 cm 3D = 239.1 kN (Min=-336.5) (Max=324.2)

M 1 : 865

reduced scale factor 0.936

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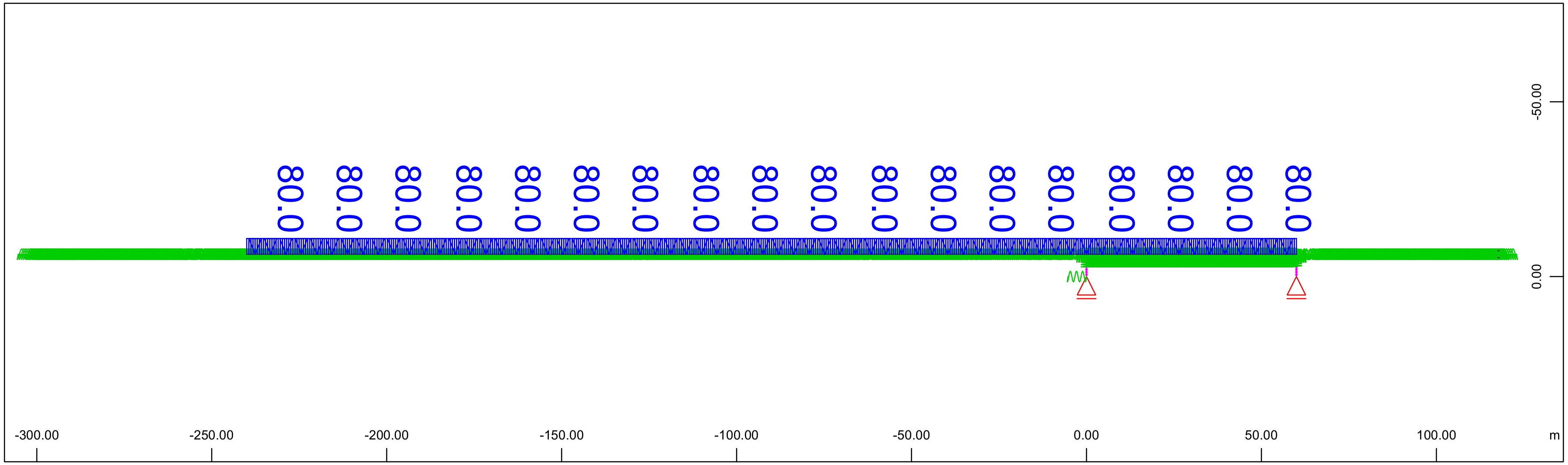
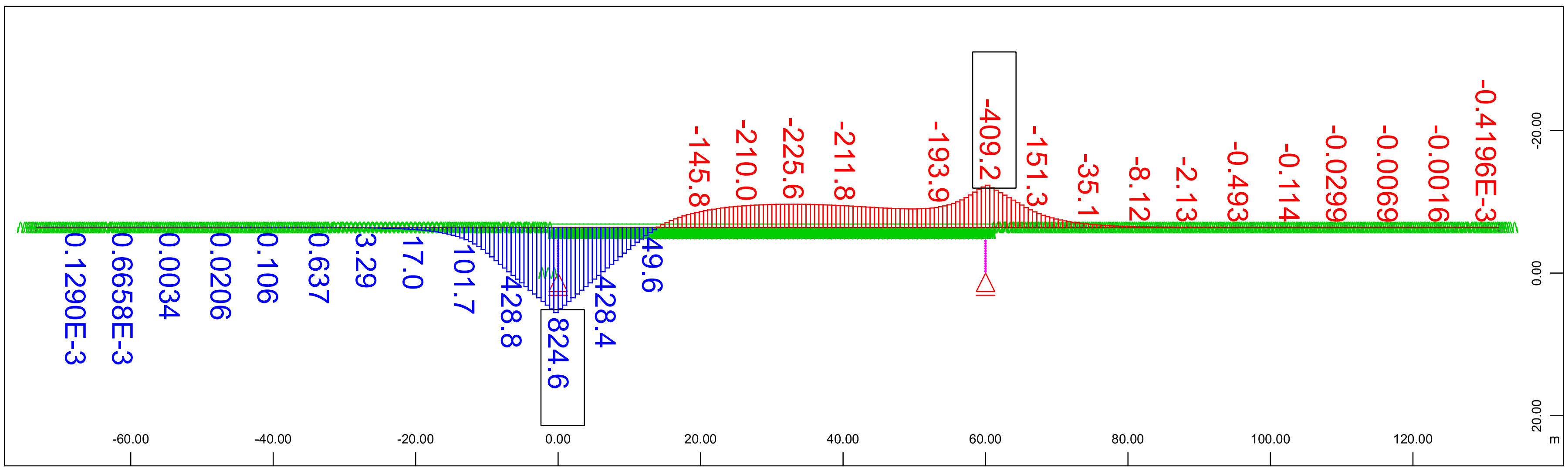
E1-3. Slab track - Vertical load 60 m from the fixed support

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Vertical load 60 m from the fixe , (1 cm 3D = unit) Beam line load (force) in global Y (Unit=315.6 kN/m) (Max=80.0)
M 1 : 1761



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Vertical load 60 m from the fixe , 1 cm 3D = 597.7 kN (Min=-409.2) (Max=824.6)
M 1 : 865

reduced scale factor 0.936

1.4 F4-6. Detailed normal force diagrams from the model without a floating slab mat

On the following pages are detailed normal force diagrams for test case F4-6 without a floating slab mat presented.

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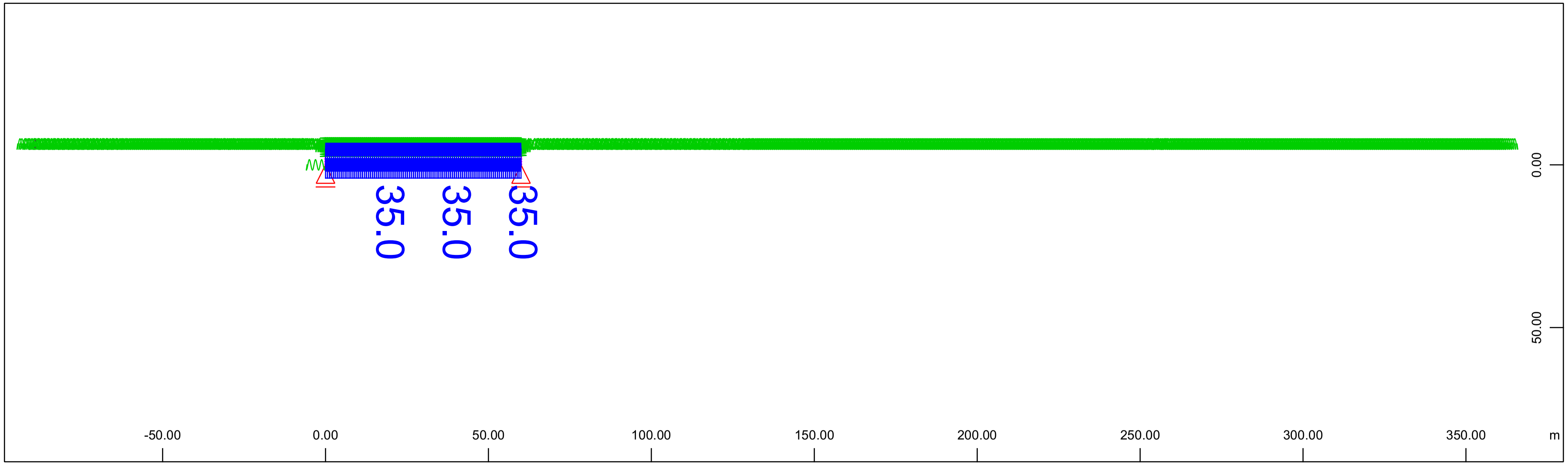
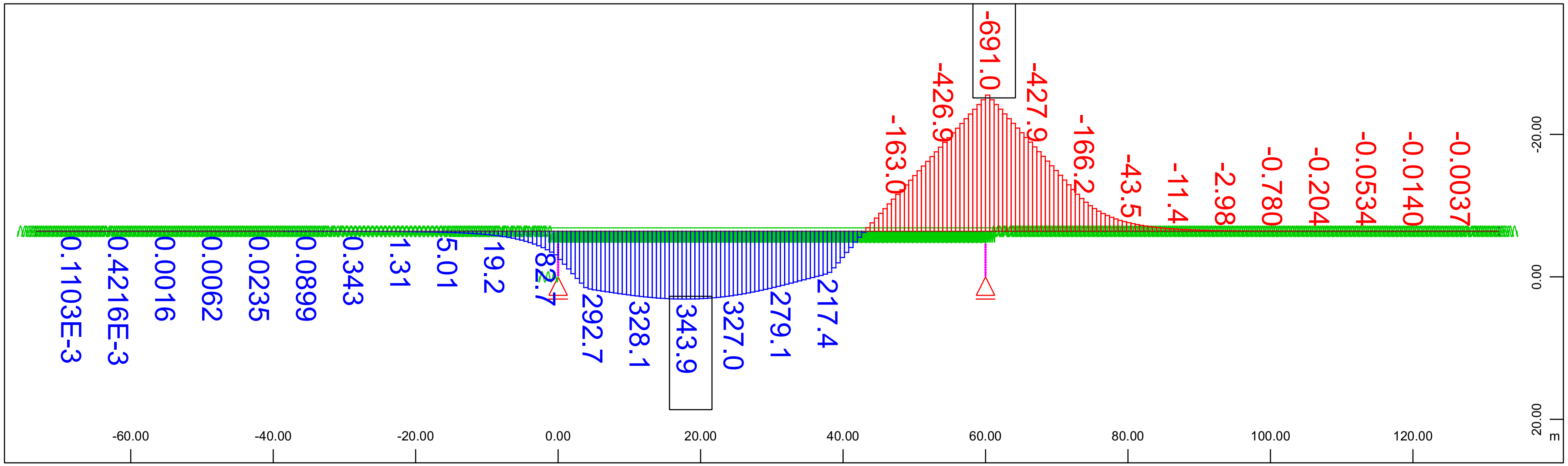
F4-6. Slab track - Temperature variation - deck

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Temperature variation - deck , (1 cm 3D = unit) Beam line load (uniform temperature change)
(Unit=74.7 °C) (Max=35.0)
M 1 : 1891



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Temperature variation - deck , 1 cm 3D = 312.5 kN (Min=-691.0) (Max=343.9)
M 1 : 865

reduced scale factor 0.936

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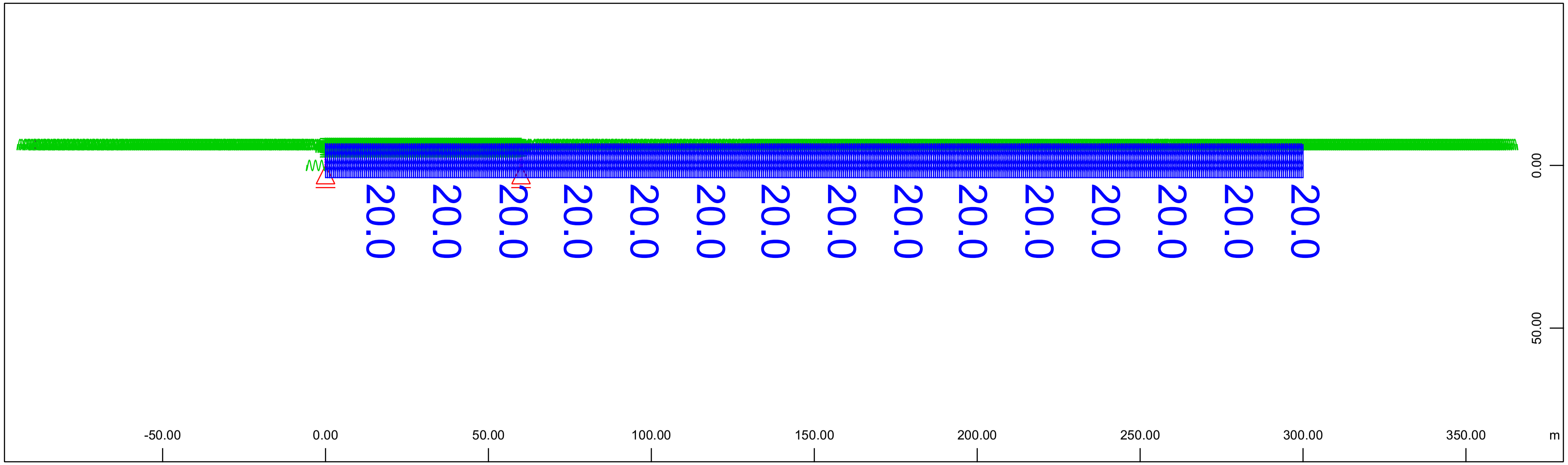
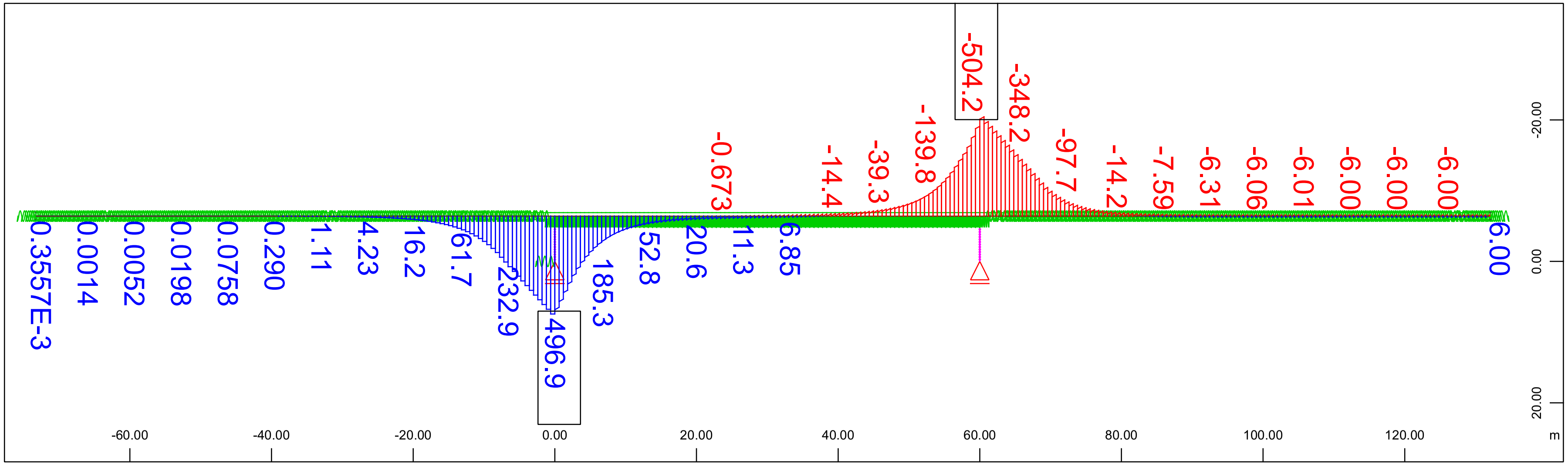
F4-6. Slab track - Braking force 60 m from the movable support

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Braking force 60 m from the mova , (1 cm 3D = unit) Beam line load (force) in global X (Unit=37.3 kN/m) (Max=20.0)
M 1 : 1891



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Braking force 60 m from the mova , 1 cm 3D = 312.5 kN (Min=-504.2) (Max=496.9)
M 1 : 870

reduced scale factor 0.936

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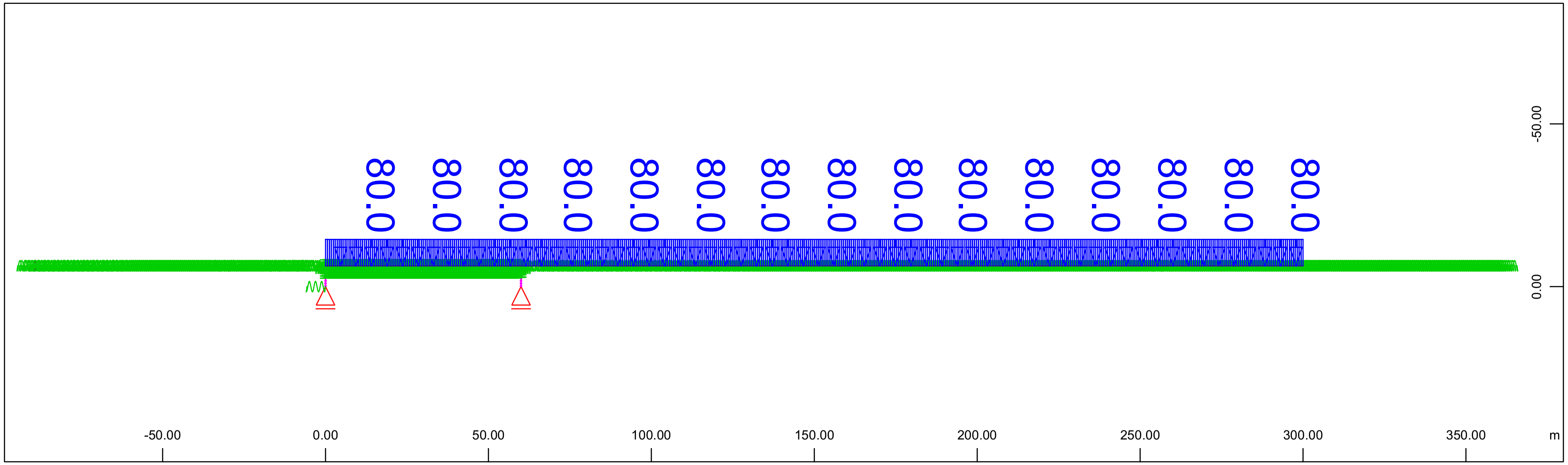
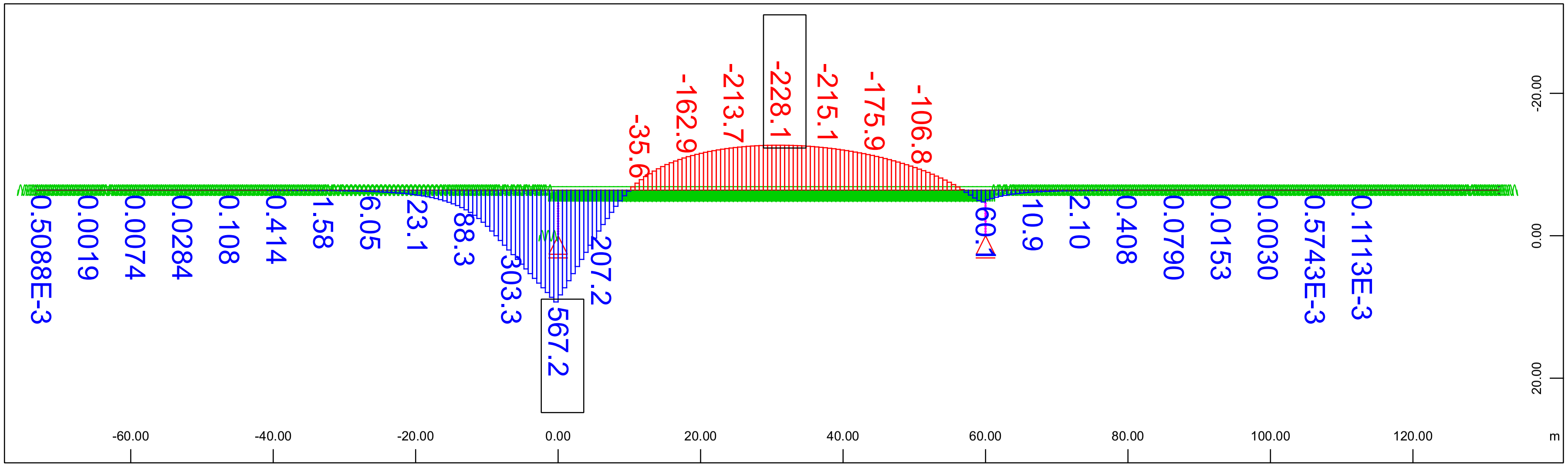
F4-6. Slab track - Vertical load 60 m from the fixed support

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Vertical load 60 m from the mova , (1 cm 3D = unit) Beam line load (force) in global Y (Unit=186.7 kN/m) (Max=80.0)
M 1 : 1891



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Vertical load 60 m from the mova , 1 cm 3D = 312.5 kN (Min=-228.1) (Max=567.2)
M 1 : 865

reduced scale factor 0.936

2 Model with a slab track and a floating slab mat

In Table 2.1 are the vertical and horizontal bedding modulus for the used floating slab mat presented.

Table 2.1 Static vertical and horizontal bedding modulus for edilon sedra TRACKELAST STM / RPU / Blue elastic mat (floating slab mat).

Thickness [mm]	Static vertical bedding modulus, $k_{bm,mat,v}$ [kN/m^3]	Static horizontal bedding modulus, $k_{bm,mat,h}$ [kN/m^3]
12,0	10000,0	3333,3
15,0	8000,0	2666,7
20,0	6000,0	2000,0
25,0	5000,0	1666,7
28,0	4000,0	1333,3
30,0	4000,0	1333,3
35,0	3000,0	1000,0

In section 2.3 – section 2.6 are detailed normal force diagrams presented for each test case.

2.1 E1-3 – Results from the slab track model with a floating slab mat

In Table 2.2 and in Figure 3.1 are the compressive rail stresses at the movable support for different mat thicknesses summarized. More detailed results are presented in section 2.1.1 and section 2.1.2 in Table 2.3 - Table 2.16. The train position is z = 60 m in the model.

Table 2.2 E1-3. Rail stress at the movable support from the slab track model with a floating slab mat. With and without the horizontal mat stiffness $k_{bm,mat,h}$.

Mat thickness [mm]	With $k_{bm,mat,h}$ Rail stress, σ_{rail} [MPa]	Without $k_{bm,mat,h}$ Rail stress, σ_{rail} [MPa]
12,0	-99,1	-98,5
15,0	-98,9	-98,6
20,0	-98,8	-98,6
25,0	-98,6	-98,2
28,0	-98,4	-98,2
30,0	-98,4	-98,1
35,0	-98,3	-98,3

2.1.1 E1-3 – floating slab mat without a horizontal stiffness

In section are 2.3 detailed normal force diagrams for each load case with different mat thicknesses presented.

Table 2.3 E1-3 – floating slab mat with a thickness of 12 mm without a horizontal stiffness – linear superposition of the rail stresses at the movable support.

Load case	***N*** ***rail*** **[kN]**	**Rail stress, σ_{rail} [MPa]**
Temperature variation - deck	-810,20	-52,71
Braking	-339,50	-22,09
Vertical bending - end rot	-363,70	-23,66
Sum:		**-98,5**

Table 2.4 E1-3 – floating slab mat with a thickness of 15 mm without a horizontal stiffness – linear superposition of the rail stresses at the movable support.

Load case	***N*** ***rail*** **[kN]**	**Rail stress, σ_{rail} [MPa]**
Temperature variation - deck	-813,80	-52,94
Braking	-339,50	-22,09
Vertical bending - end rot	-363,10	-23,62
Sum:		**-98,6**

Table 2.5 E1-3 – floating slab mat with a thickness of 20 mm without a horizontal stiffness – linear superposition of the rail stresses at the movable support.

Load case	***N*** ***rail*** **[kN]**	**Rail stress, σ_{rail} [MPa]**
Temperature variation - deck	-813,80	-52,94
Braking	-339,40	-22,08
Vertical bending - end rot	-362,10	-23,56
Sum:		**-98,6**

Table 2.6 E1-3 – floating slab mat with a thickness of 25 mm without a horizontal stiffness – linear superposition of the rail stresses at the movable support.

Load case	***N*** ***rail*** **[kN]**	**Rail stress, σ_{rail} [MPa]**
Temperature variation - deck	-809,10	-52,63
Braking	-339,40	-22,08
Vertical bending - end rot	-361,10	-23,49
Sum:		**-98,2**

Table 2.7 E1-3 – floating slab mat with a thickness of 28 mm without a horizontal stiffness – linear superposition of the rail stresses at the movable support.

Load case	***N rail*** **[kN]**	**Rail stress, σ_{rail} [MPa]**
Temperature variation - deck	-809,00	-52,63
Braking	-339,40	-22,08
Vertical bending - end rot	-360,50	-23,45
Sum:		**-98,2**

Table 2.8 E1-3 – floating slab mat with a thickness of 30 mm without a horizontal stiffness – linear superposition of the rail stresses at the movable support.

Load case	***N rail*** **[kN]**	**Rail stress, σ_{rail} [MPa]**
Temperature variation - deck	-809,00	-52,63
Braking	-339,40	-22,08
Vertical bending - end rot	-360,10	-23,43
Sum:		**-98,1**

Table 2.9 E1-3 – floating slab mat with a thickness of 35 mm without a horizontal stiffness – linear superposition of the rail stresses at the movable support.

Load case	***N rail*** **[kN]**	**Rail stress, σ_{rail} [MPa]**
Temperature variation - deck	-813,20	-52,90
Braking	-339,30	-22,07
Vertical bending - end rot	-359,10	-23,36
Sum:		**-98,3**

2.1.2 E1-3 – floating slab mat with a horizontal stiffness

In section are 2.4 detailed normal force diagrams for each load case with different mat thicknesses presented.

Table 2.10 E1-3 – floating slab mat with a thickness of 12 mm with a horizontal stiffness – linear superposition of the rail stresses at the movable support.

Load case	N_{rail} **[kN]**	**Rail stress,** σ_{rail} **[MPa]**
Temperature variation - deck	-816,20	-53,10
Braking	-339,30	-22,07
Vertical bending - end rot	-367,80	-23,93
Sum:		**-99,1**

Table 2.11 E1-3 – floating slab mat with a thickness of 15 mm with a horizontal stiffness – linear superposition of the rail stresses at the movable support.

Load case	N_{rail} **[kN]**	**Rail stress,** σ_{rail} **[MPa]**
Temperature variation - deck	-815,30	-53,04
Braking	-339,30	-22,07
Vertical bending - end rot	-366,40	-23,84
Sum:		**-98,9**

Table 2.12 E1-3 – floating slab mat with a thickness of 20 mm with a horizontal stiffness – linear superposition of the rail stresses at the movable support.

Load case	N_{rail} **[kN]**	**Rail stress,** σ_{rail} **[MPa]**
Temperature variation - deck	-817,70	-53,19
Braking	-339,30	-22,07
Vertical bending - end rot	-361,90	-23,54
Sum:		**-98,8**

Table 2.13 E1-3 – floating slab mat with a thickness of 25 mm with a horizontal stiffness – linear superposition of the rail stresses at the movable support.

Load case	N_{rail} **[kN]**	**Rail stress,** σ_{rail} **[MPa]**
Temperature variation - deck	-812,60	-52,86
Braking	-339,30	-22,07
Vertical bending - end rot	-363,30	-23,63
Sum:		**-98,6**

Table 2.14 E1-3 – floating slab mat with a thickness of 28 mm with a horizontal stiffness – linear superposition of the rail stresses at the movable support.

Load case	***N rail*** **[kN]**	**Rail stress, σ_{rail} [MPa]**
Temperature variation - deck	-811,70	-52,80
Braking	-339,30	-22,07
Vertical bending - end rot	-362,30	-23,57
Sum:		**-98,4**

Table 2.15 E1-3 – floating slab mat with a thickness of 30 mm with a horizontal stiffness – linear superposition of the rail stresses at the movable support.

Load case	***N rail*** **[kN]**	**Rail stress, σ_{rail} [MPa]**
Temperature variation - deck	-811,70	-52,80
Braking	-339,30	-22,07
Vertical bending - end rot	-361,90	-23,54
Sum:		**-98,4**

Table 2.16 E1-3 – floating slab mat with a thickness of 35 mm with a horizontal stiffness – linear superposition of the rail stresses at the movable support.

Load case	***N rail*** **[kN]**	**Rail stress, σ_{rail} [MPa]**
Temperature variation - deck	-813,20	-52,90
Braking	-339,30	-22,07
Vertical bending - end rot	-359,10	-23,36
Sum:		**-98,3**

2.2 F4-6 – Results from the slab track model with a floating slab mat

In Table 2.17 and in Figure 3.2 are the compressive rail stresses at the movable support for different mat thicknesses summarized. More detailed results are presented in the sections 2.1.1 and section 2.1.2 in Table 2.18 - Table 2.31. The train is positioned in z = 60 m in the model.

Table 2.17 F4-6. Rail stress at the movable support from the slab track model with a floating slab mat. With and without the horizontal mat stiffness $k_{bm,mat,h}$.

Mat thickness [mm]	**With $k_{bm,mat,h}$ Rail stress, σ_{rail} [MPa]**	**Without $k_{bm,mat,h}$ Rail stress, σ_{rail} [MPa]**
12,0	-69,5	-69,0
15,0	-69,4	-68,8
20,0	-69,2	-68,8
25,0	-68,8	-68,7
28,0	-68,8	-68,6
30,0	-68,9	-68,6
35,0	-68,6	-68,6

2.2.1 F4-6 – floating slab mat without a horizontal stiffness

In section are 2.5 detailed normal force diagrams for each load case with different mat thicknesses presented.

Table 2.18 F4-6 – floating slab mat with a thickness of 12 mm without a horizontal stiffness –linear superposition of the rail stresses at the movable support.

Load case	**N_{rail} [kN]**	**Rail stress, σ_{rail} [MPa]**
Temperature variation - deck	-684,30	-44,52
Braking	-505,00	-32,85
Vertical bending - end rot	129,40	8,42
Sum:		**-69,0**

Table 2.19 F4-6 – floating slab mat with a thickness of 15 mm without a horizontal stiffness – linear superposition of the rail stresses at the movable support.

Load case	**N_{rail} [kN]**	**Rail stress, σ_{rail} [MPa]**
Temperature variation - deck	-681,60	-44,34
Braking	-505,00	-32,85
Vertical bending - end rot	129,40	8,42
Sum:		**-68,8**

Table 2.20 F4-6 – floating slab mat with a thickness of 20 mm without a horizontal stiffness – linear superposition of the rail stresses at the movable support.

Load case	***N*** ***rail*** **[kN]**	**Rail stress, σ_{rail} [MPa]**
Temperature variation - deck	-683,20	-44,44
Braking	-505,00	-32,85
Vertical bending - end rot	130,30	8,48
Sum:		**-68,8**

Table 2.21 F4-6 – floating slab mat with a thickness of 25 mm without a horizontal stiffness – linear superposition of the rail stresses at the movable support.

Load case	***N*** ***rail*** **[kN]**	**Rail stress, σ_{rail} [MPa]**
Temperature variation - deck	-683,20	-44,44
Braking	-504,70	-32,83
Vertical bending - end rot	131,10	8,53
Sum:		**-68,7**

Table 2.22 F4-6 – floating slab mat with a thickness of 28 mm without a horizontal stiffness – linear superposition of the rail stresses at the movable support.

Load case	***N*** ***rail*** **[kN]**	**Rail stress, σ_{rail} [MPa]**
Temperature variation - deck	-681,60	-44,34
Braking	-504,70	-32,83
Vertical bending - end rot	131,60	8,56
Sum:		**-68,6**

Table 2.23 F4-6 – floating slab mat with a thickness of 30 mm without a horizontal stiffness – linear superposition of the rail stresses at the movable support.

Load case	***N*** ***rail*** **[kN]**	**Rail stress, σ_{rail} [MPa]**
Temperature variation - deck	-674,80	-43,90
Braking	-504,70	-32,83
Vertical bending - end rot	131,90	8,58
Sum:		**-68,1**

Table 2.24 F4-6 – floating slab mat with a thickness of 35 mm without a horizontal stiffness – linear superposition of the rail stresses at the movable support.

Load case	***N*** ***rail*** **[kN]**	**Rail stress, σ_{rail} [MPa]**
Temperature variation - deck	-682,40	-44,39
Braking	-504,70	-32,83
Vertical bending - end rot	132,80	8,64
Sum:		**-68,6**

2.2.2 *F4-6 – floating slab mat with a horizontal stiffness*

In section are 2.6 detailed normal force diagrams for each load case with different mat thicknesses presented.

Table 2.25 F4-6 – floating slab mat with a thickness of 12 mm with a horizontal stiffness – linear superposition of the rail stresses at the movable support.

Load case	***N* $_{rail}$ [kN]**	**Rail stress, σ_{rail} [MPa]**
Temperature variation - deck	-681,30	-44,32
Braking	-505,00	-32,85
Vertical bending - end rot	117,40	7,64
Sum:		**-69,5**

Table 2.26 F4-6 – floating slab mat with a thickness of 15 mm with a horizontal stiffness – linear superposition of the rail stresses at the movable support.

Load case	***N* $_{rail}$ [kN]**	**Rail stress, σ_{rail} [MPa]**
Temperature variation - deck	-682,30	-44,39
Braking	-505,00	-32,85
Vertical bending - end rot	121,00	7,87
Sum:		**-69,4**

Table 2.27 F4-6 – floating slab mat with a thickness of 20 mm with a horizontal stiffness – linear superposition of the rail stresses at the movable support.

Load case	***N* $_{rail}$ [kN]**	**Rail stress, σ_{rail} [MPa]**
Temperature variation - deck	-681,60	-44,34
Braking	-505,00	-32,85
Vertical bending - end rot	123,00	8,00
Sum:		**-69,2**

Table 2.28 F4-6 – floating slab mat with a thickness of 25 mm with a horizontal stiffness – linear superposition of the rail stresses at the movable support.

Load case	***N* $_{rail}$ [kN]**	**Rail stress, σ_{rail} [MPa]**
Temperature variation - deck	-681,50	-44,33
Braking	-504,70	-32,83
Vertical bending - end rot	128,80	8,38
Sum:		**-68,8**

Table 2.29 F4-6 – floating slab mat with a thickness of 28 mm with a horizontal stiffness linear superposition of the rail stresses at the movable support.

Load case	N_{rail} [kN]	Rail stress, σ_{rail} [MPa]
Temperature variation - deck	-683,00	-44,43
Braking	-504,70	-32,83
Vertical bending - end rot	129,90	8,45
Sum:		**-68,8**

Table 2.30 F4-6 – floating slab mat with a thickness of 30 mm with a horizontal stiffness – linear superposition linear superposition of the rail stresses at the movable support.

Load case	N_{rail} [kN]	Rail stress, σ_{rail} [MPa]
Temperature variation - deck	-681,70	-44,35
Braking	-507,70	-33,03
Vertical bending - end rot	129,70	8,44
Sum:		**-68,9**

Table 2.31 F4-6 – floating slab mat with a thickness of 35 mm with a horizontal stiffness – linear superposition linear superposition of the rail stresses at the movable support.

Load case	N_{rail} [kN]	Rail stress, σ_{rail} [MPa]
Temperature variation - deck	-681,30	-44,32
Braking	-504,70	-32,83
Vertical bending - end rot	131,10	8,53
Sum:		**-68,6**

2.3 E1-3 - Detailed normal force diagrams from the model with a floating slab mat without a horizontal stiffness

On the following pages are detailed normal force diagrams for test case E1-3 with a floating slab mat without a horizontal stiffness presented.

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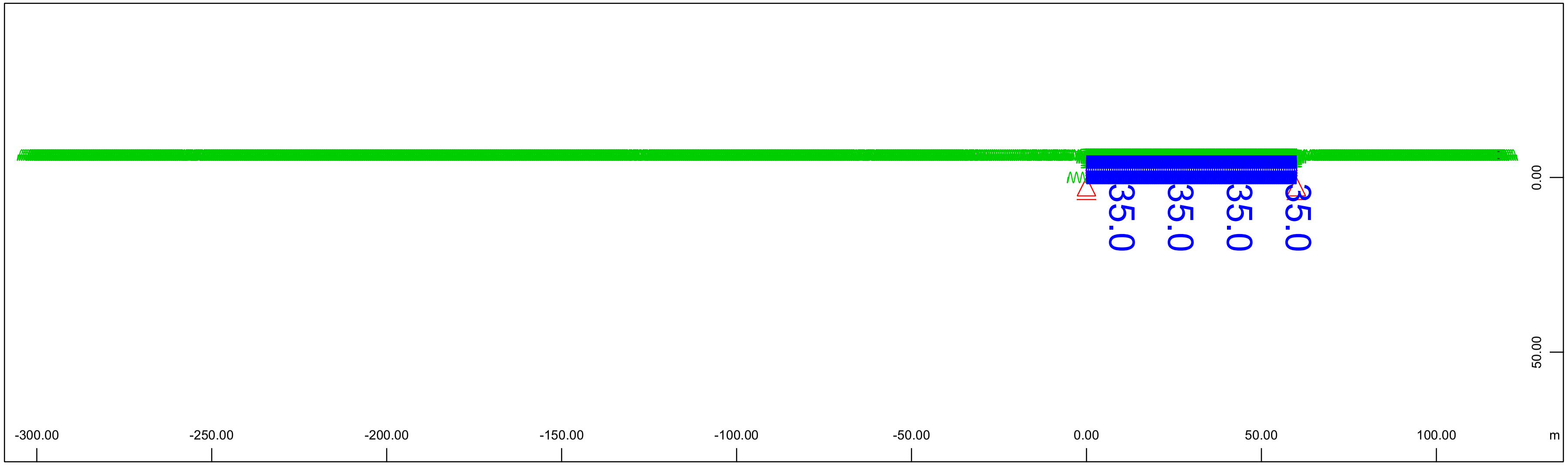
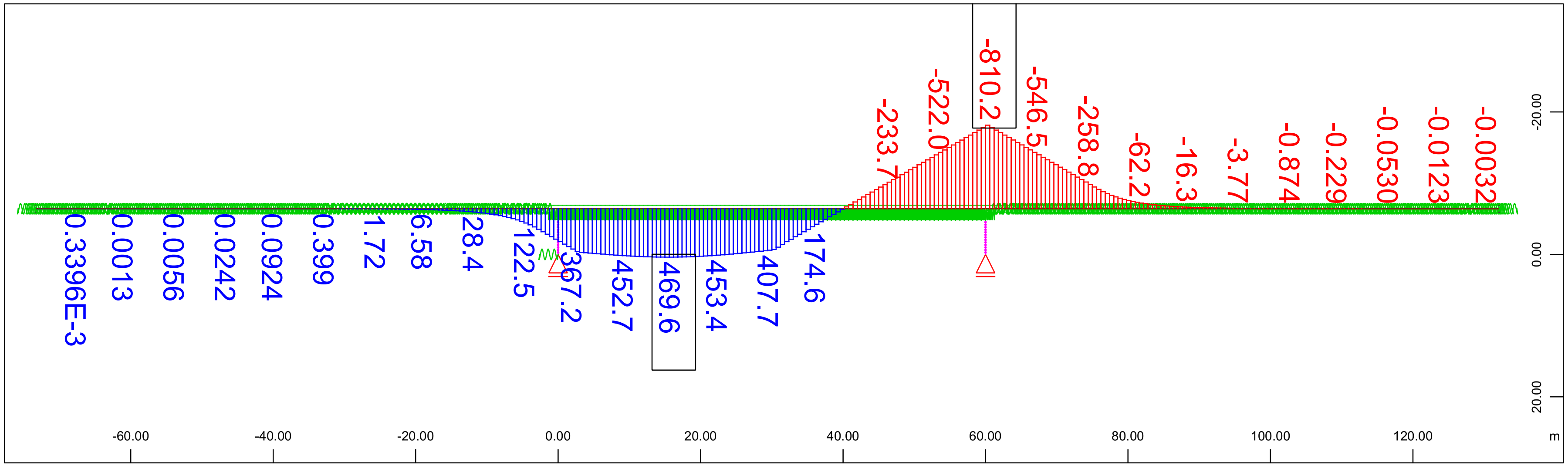
E1.3. Track slab + a floating slab mat with a thickness of 12 mm without a horizontal stiffness - Temperature variation - deck

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Temperature variation - deck , (1 cm 3D = unit) Beam line load (uniform temperature change)
(Unit=126.2 °C) (Max=35.0)
M 1 : 1761



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Temperature variation - deck , 1 cm 3D = 597.7 kN (Min=-810.2) (Max=469.6)
M 1 : 865

reduced scale factor 0.936

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WSP Sverige AB | WSP Bridge & Hydraulic Design	E1.3. Track slab + a floating slab mat with a thickness of 12 mm without a horizontal stiffness - Braking force
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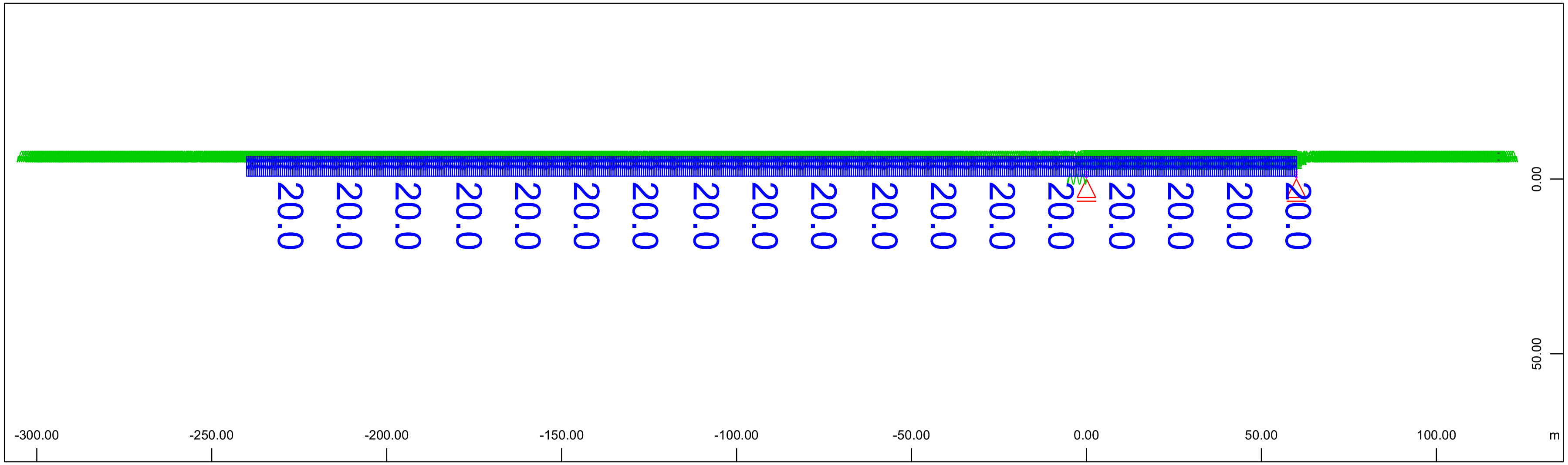
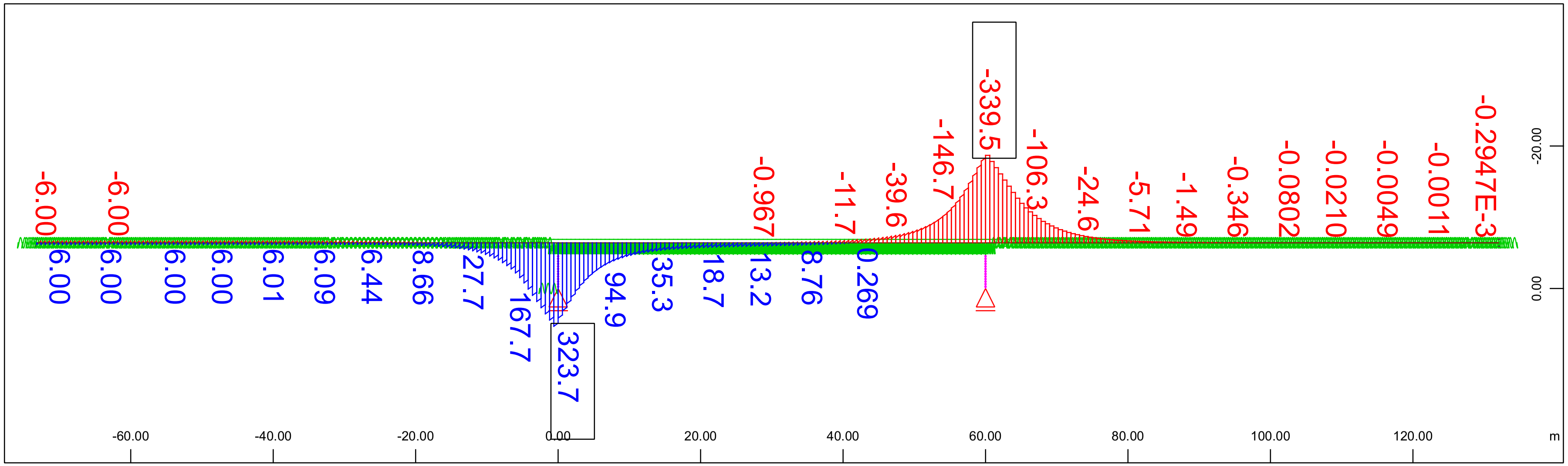
System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Braking force 60 m from the fixe , (1 cm 3D = unit) Beam line load (force) in global X (Unit=63.1 kN/m) (Max=20.0)

M 1 : 1761



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Braking force 60 m from the fixe , 1 cm 3D = 239.1 kN (Min=-339.5) (Max=323.7)

M 1 : 865

reduced scale factor 0.936

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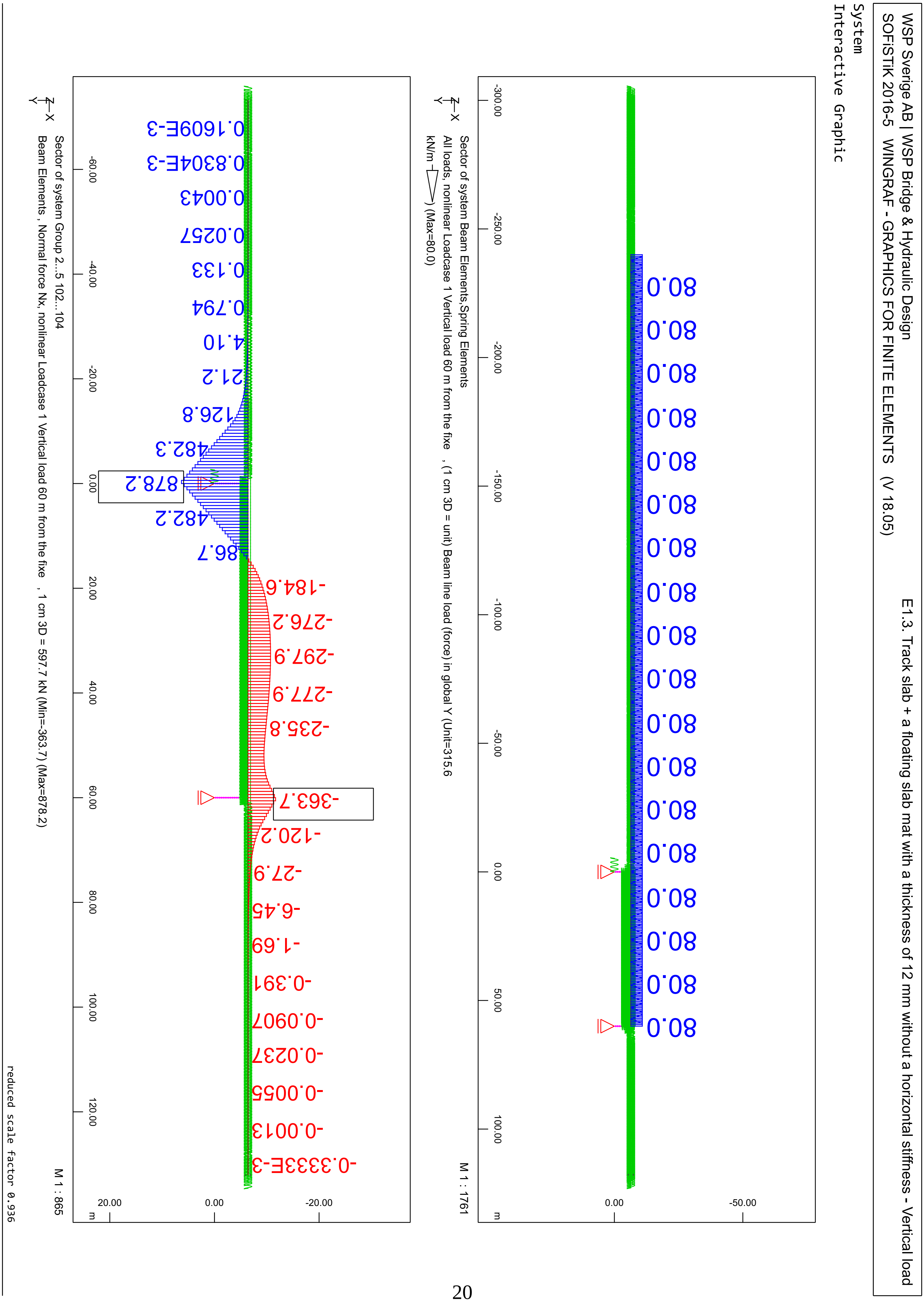

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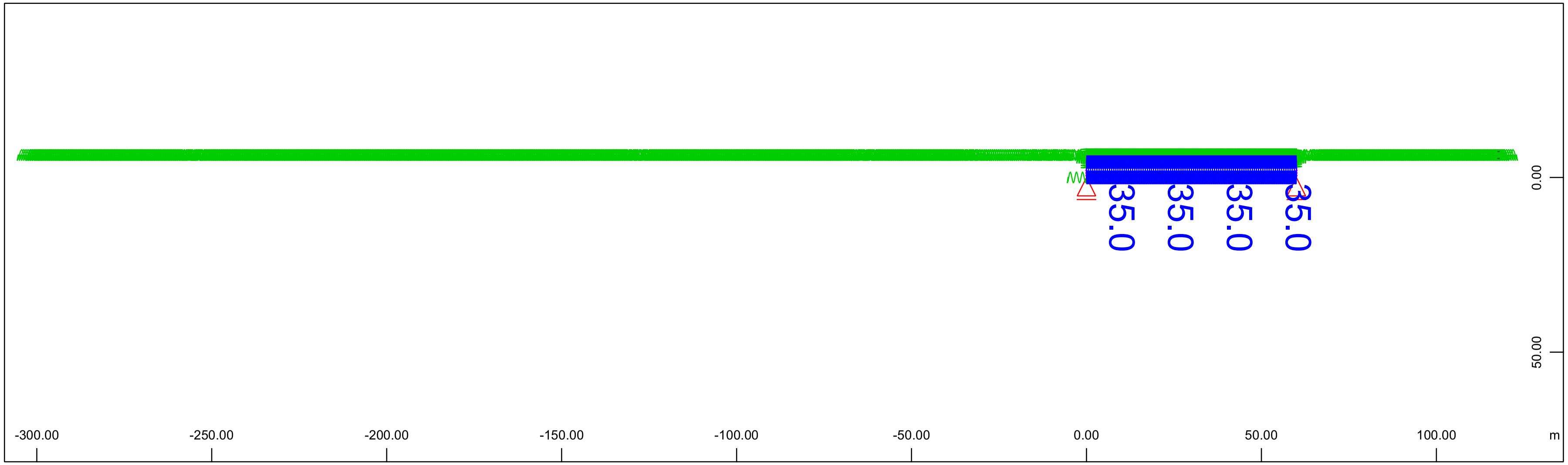
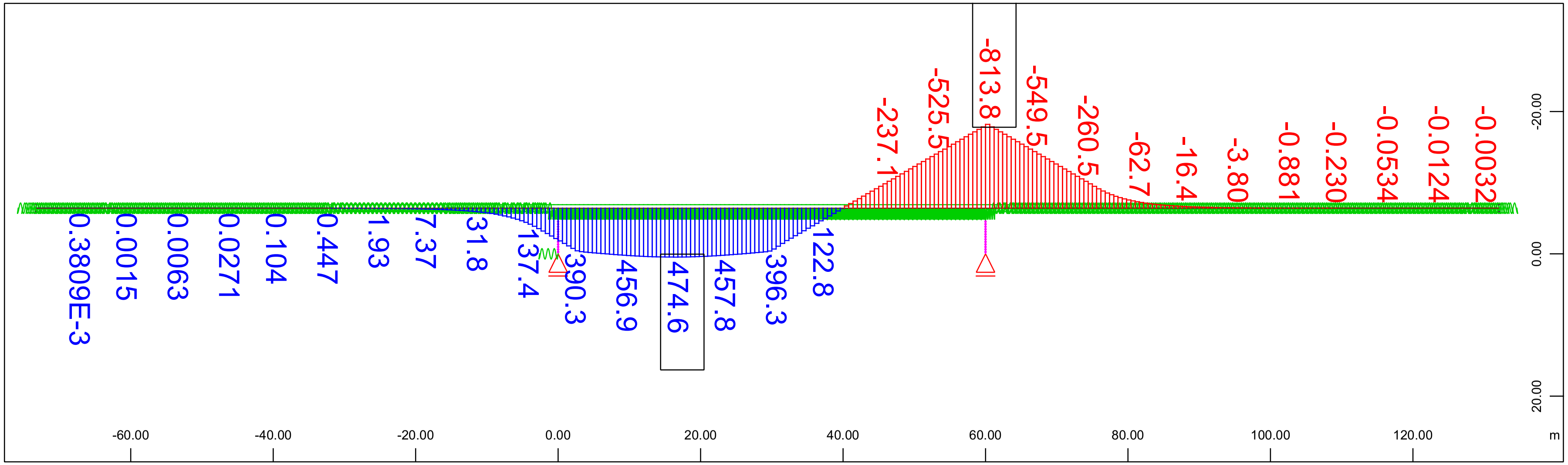
E1.3. Track slab + a floating slab mat with a thickness of 15 mm without a horizontal stiffness - Temperature variation - deck

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Temperature variation - deck , (1 cm 3D = unit) Beam line load (uniform temperature change)
(Unit=126.2 °C) (Max=35.0)
M 1 : 1761



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Temperature variation - deck , 1 cm 3D = 597.7 kN (Min=-813.8) (Max=474.6)
M 1 : 865

reduced scale factor 0.936

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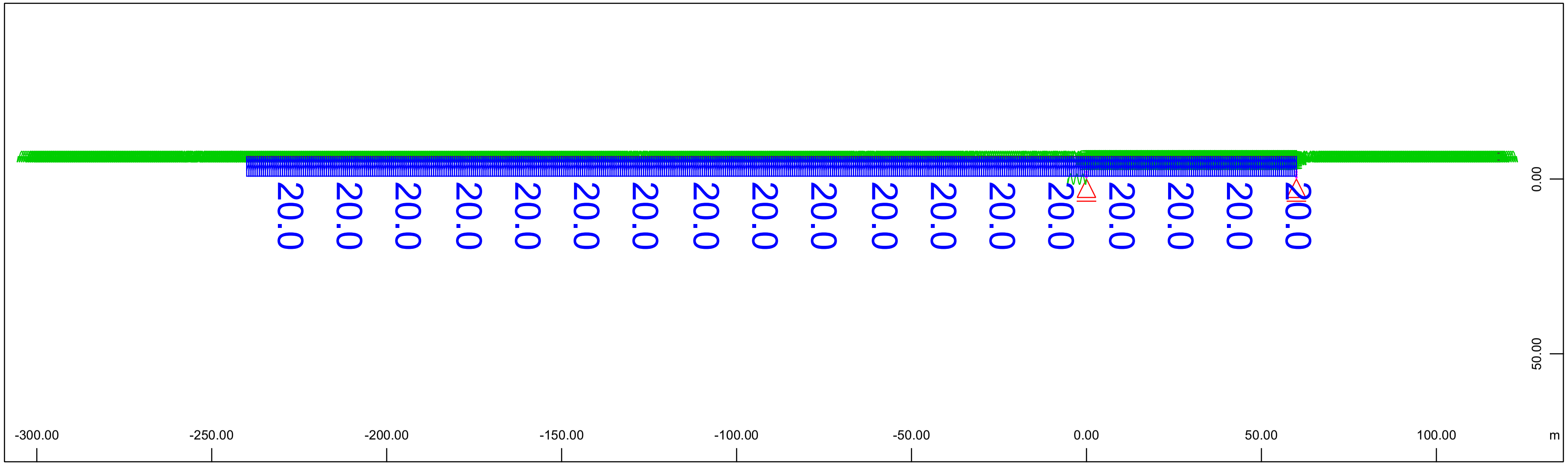
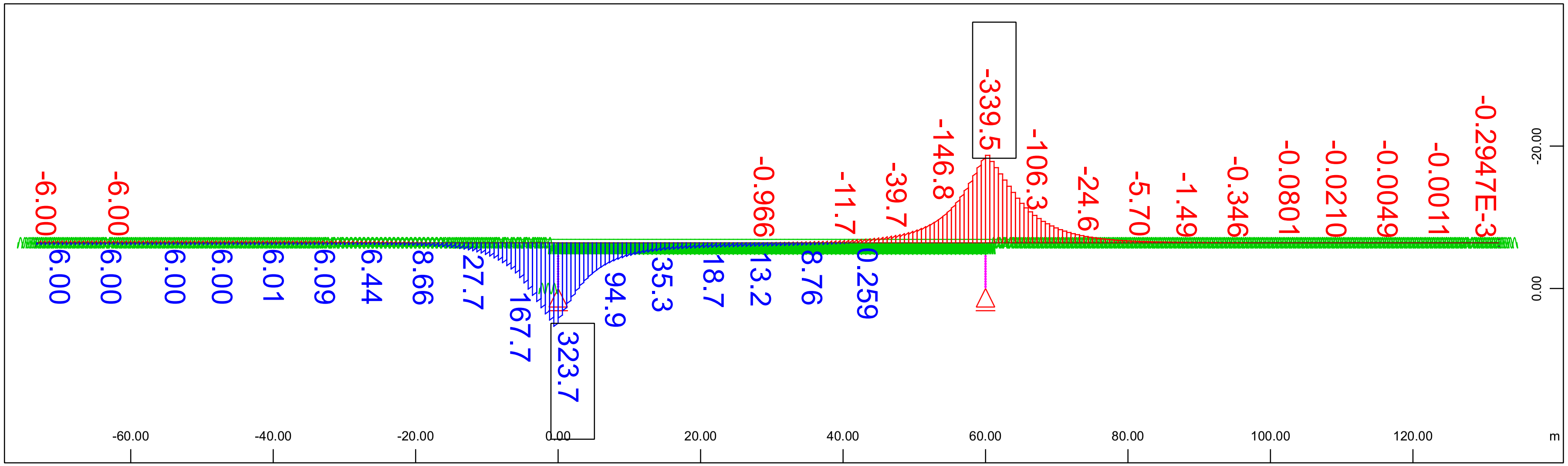
E1.3. Track slab + a floating slab mat with a thickness of 15 mm without a horizontal stiffness - Braking force

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Braking force 60 m from the fixe , (1 cm 3D = unit) Beam line load (force) in global X (Unit=63.1 kN/m) (Max=20.0)

M 1 : 1761



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Braking force 60 m from the fixe , 1 cm 3D = 239.1 kN (Min=-339.5) (Max=323.7)

M 1 : 865

reduced scale factor 0.936

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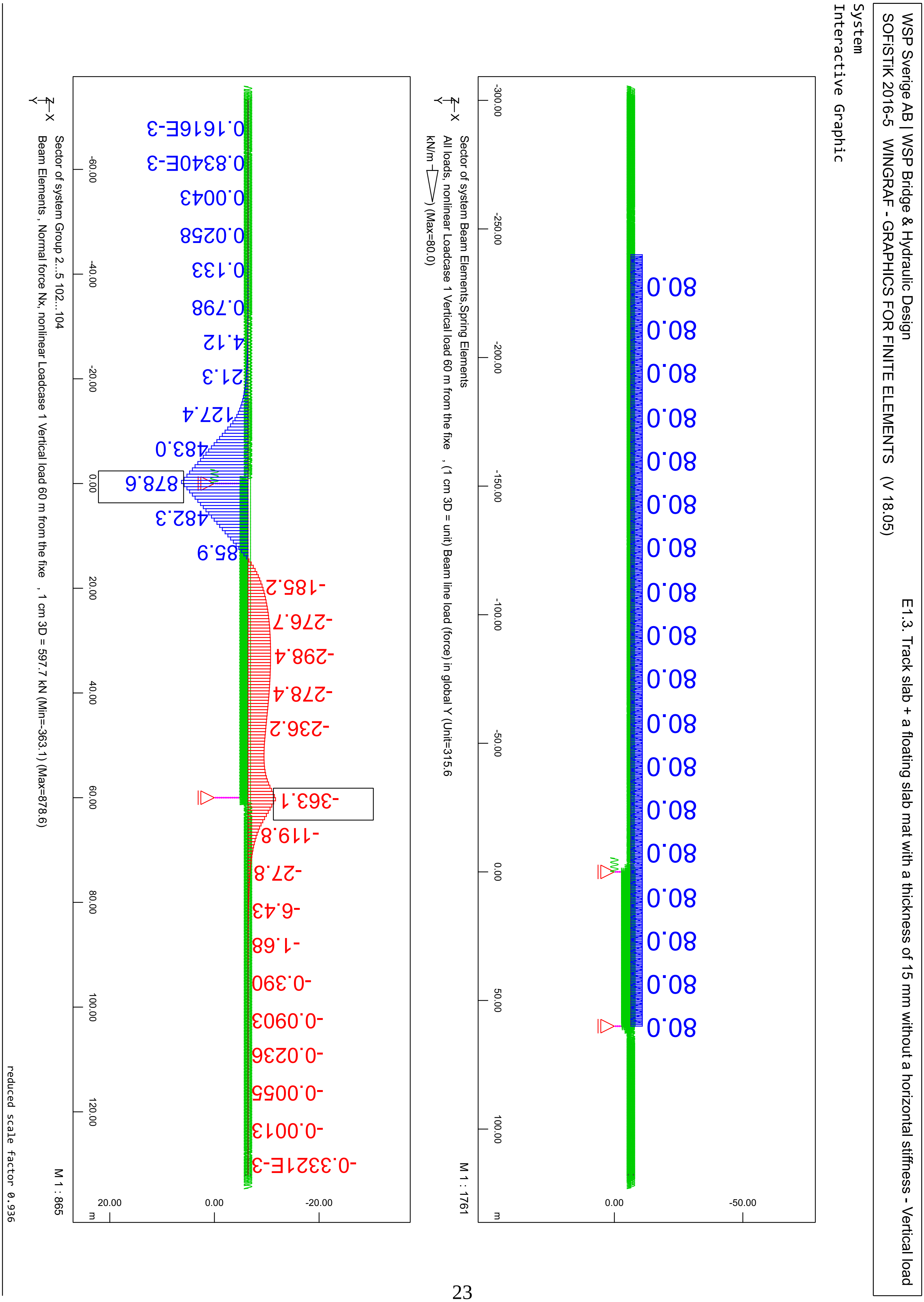
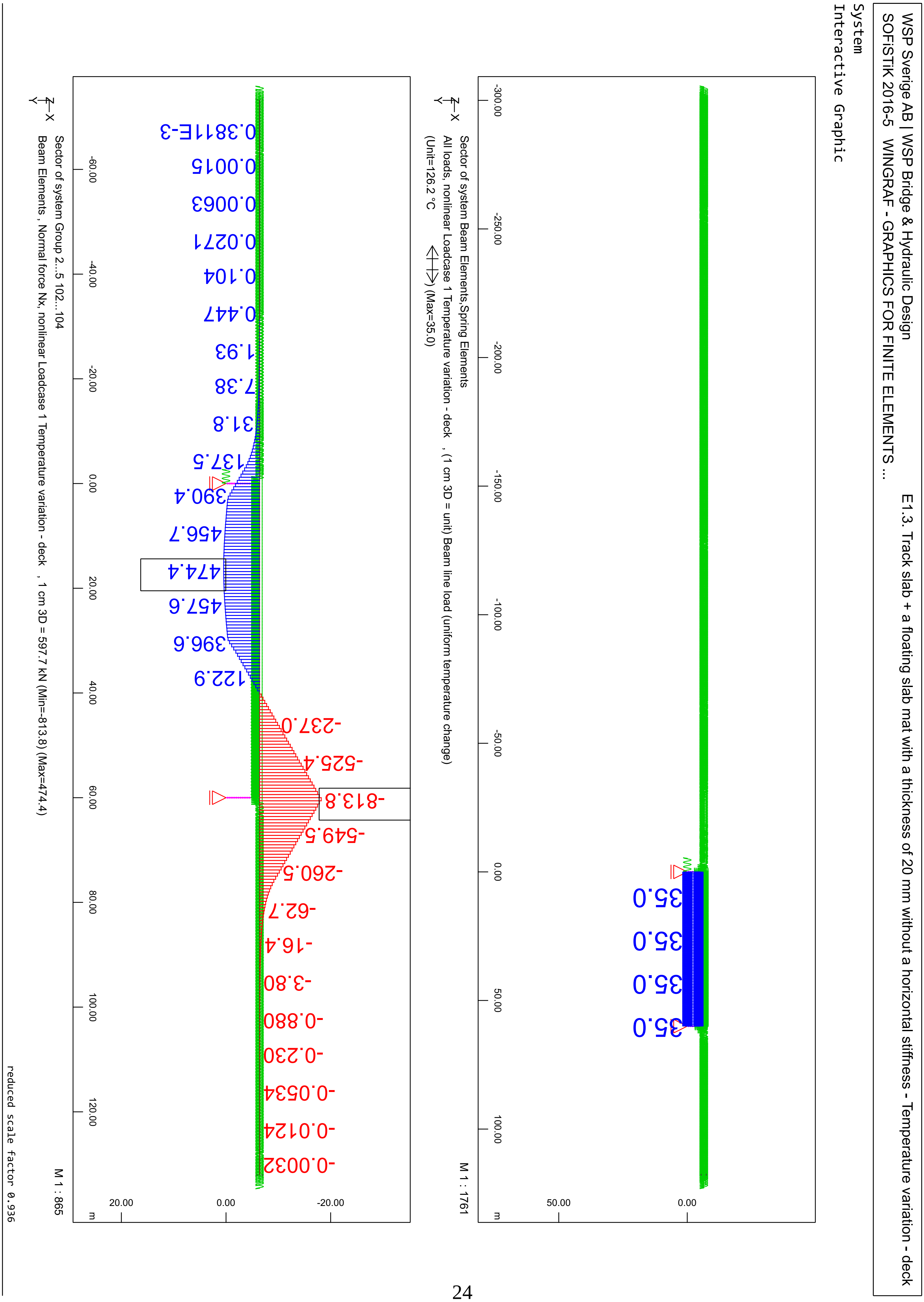


SOFiSTiK AG - www.sofistik.de



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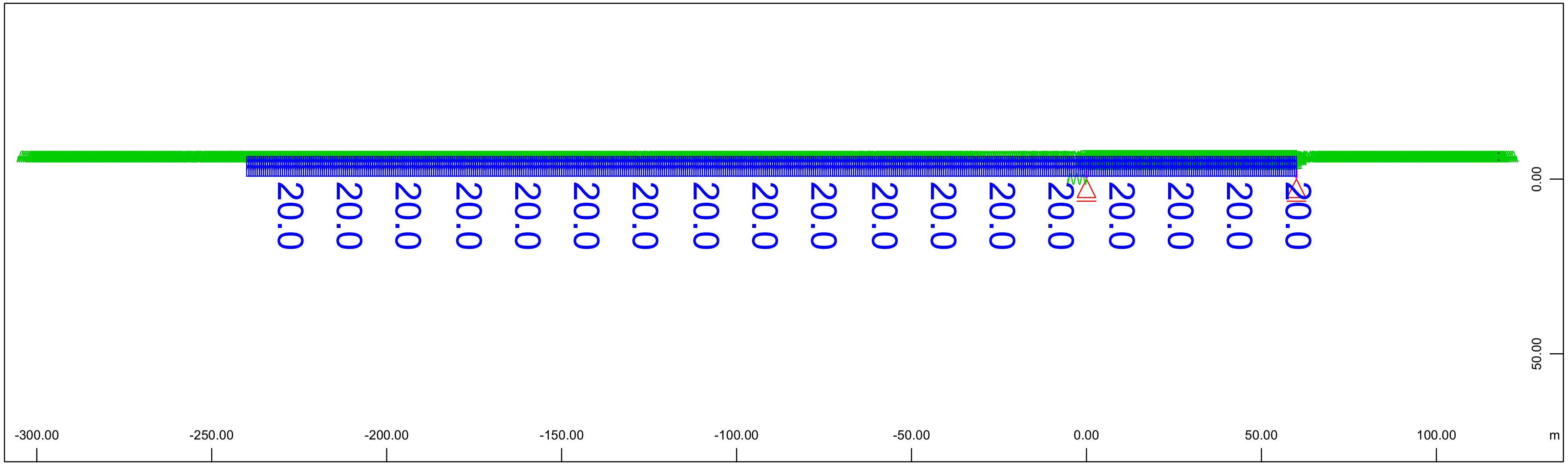
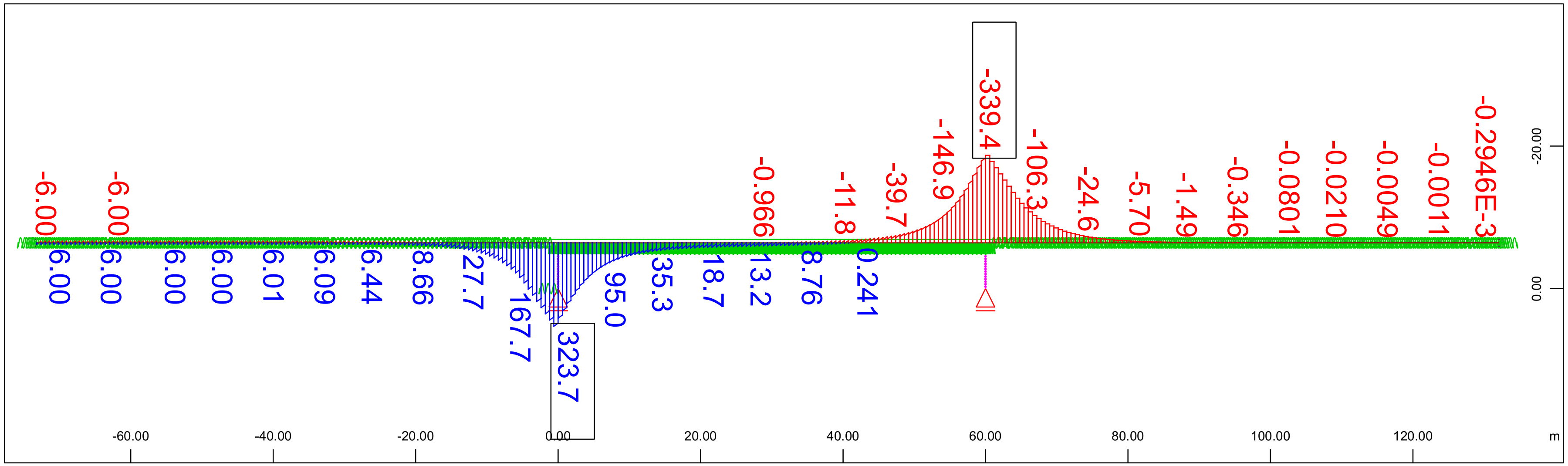
E1.3. Track slab + a floating slab mat with a thickness of 20 mm without a horizontal stiffness - Braking force

System
Interactive Graphic



M 1 : 1761

Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Braking force 60 m from the fixe , (1 cm 3D = unit) Beam line load (force) in global X (Unit=63.1 kN/m) (Max=20.0)



M 1 : 865

Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Braking force 60 m from the fixe , 1 cm 3D = 239.1 kN (Min=-339.4) (Max=323.7)

reduced scale factor 0.936

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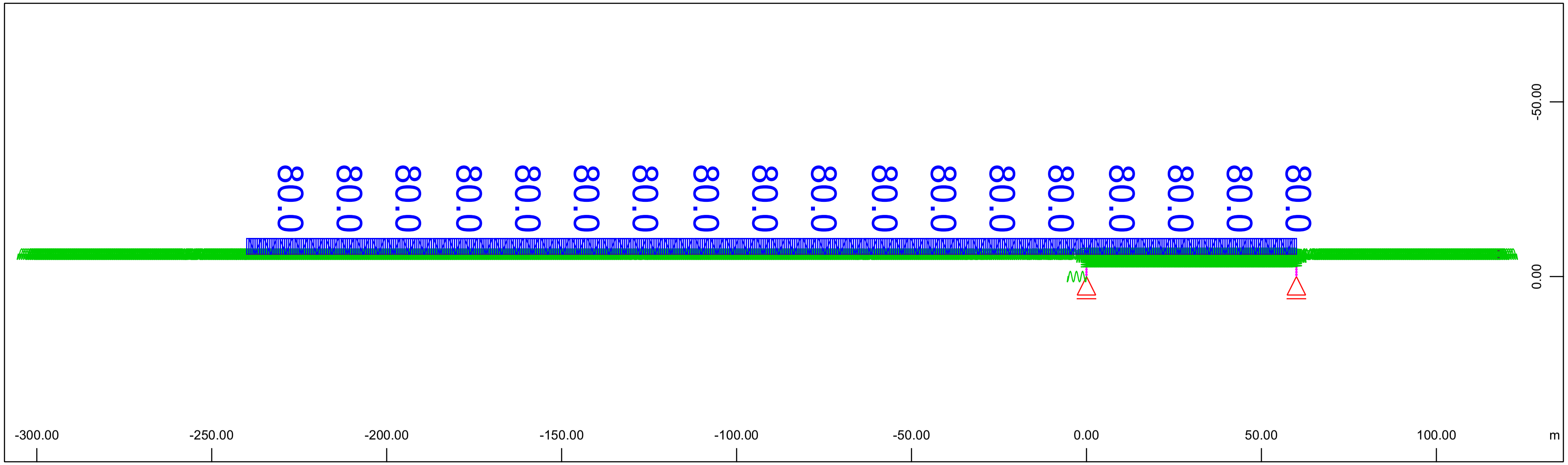
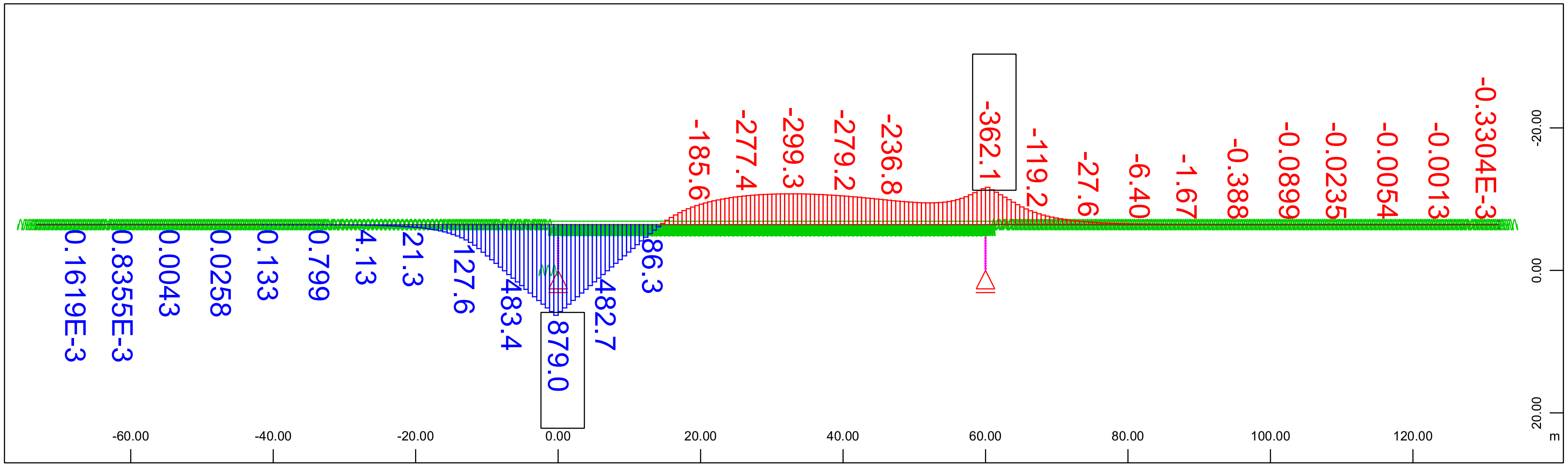
E1.3. Track slab + a floating slab mat with a thickness of 20 mm without a horizontal stiffness - Vertical load

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Vertical load 60 m from the fixe , (1 cm 3D = unit) Beam line load (force) in global Y (Unit=315.6 kN/m) (Max=80.0)
M 1 : 1761



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Vertical load 60 m from the fixe , 1 cm 3D = 597.7 kN (Min=-362.1) (Max=879.0)
M 1 : 865

reduced scale factor 0.936

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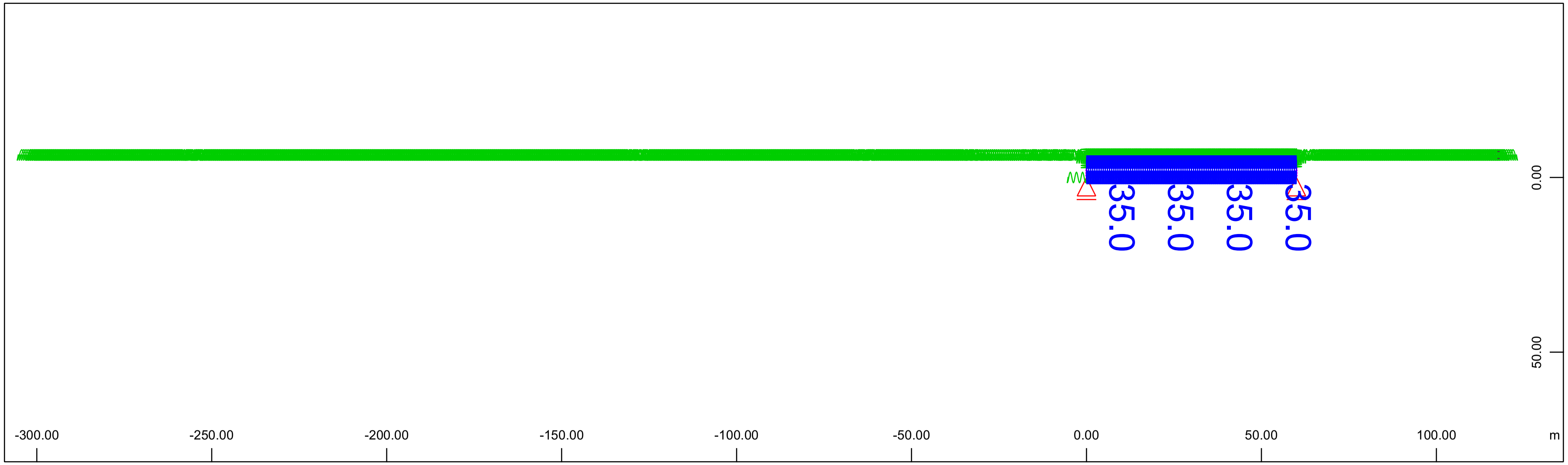
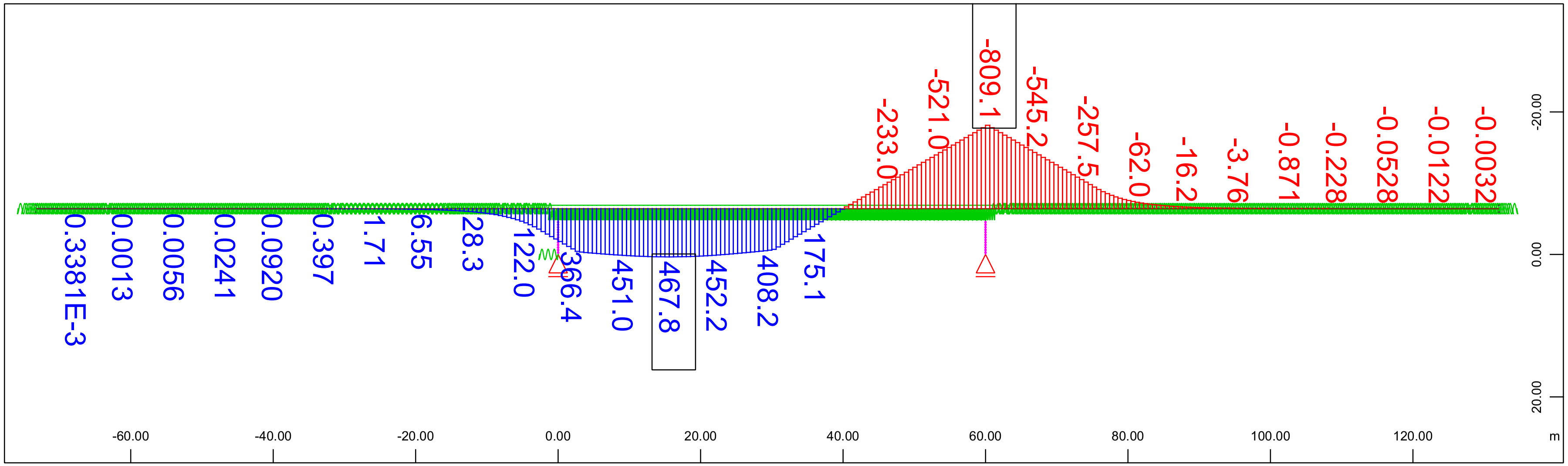
E1.3. Track slab + a floating slab mat with a thickness of 25 mm without a horizontal stiffness - Temperature variation - deck

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Temperature variation - deck , (1 cm 3D = unit) Beam line load (uniform temperature change)
(Unit=126.2 °C) (Max=35.0)
M 1 : 1761



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Temperature variation - deck , 1 cm 3D = 597.7 kN (Min=-809.1) (Max=467.8)
M 1 : 865

reduced scale factor 0.936

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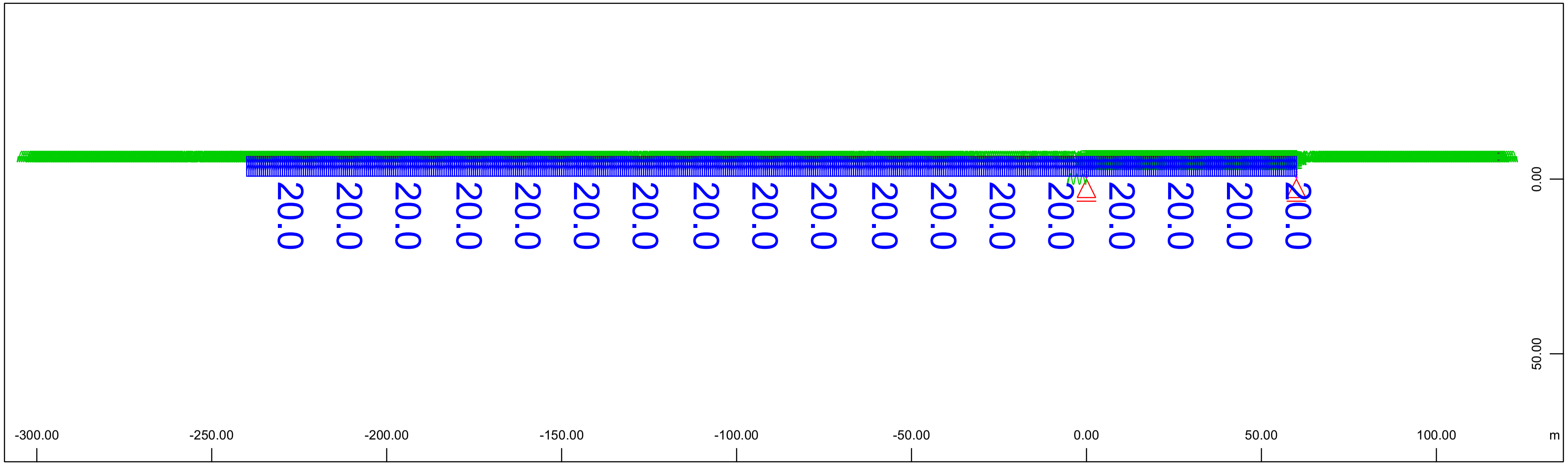
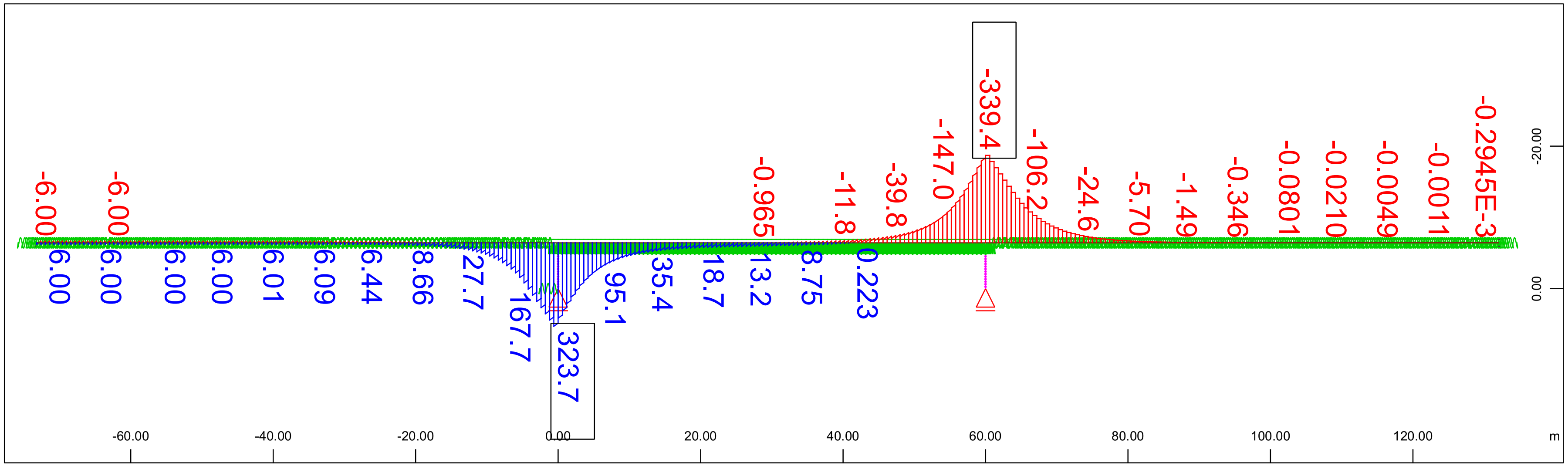
E1.3. Track slab + a floating slab mat with a thickness of 25 mm without a horizontal stiffness - Braking force

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Braking force 60 m from the fixe , (1 cm 3D = unit) Beam line load (force) in global X (Unit=63.1 kN/m) (Max=20.0)

M 1 : 1761



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Braking force 60 m from the fixe , 1 cm 3D = 239.1 kN (Min=-339.4) (Max=323.7)

M 1 : 865

reduced scale factor 0.936

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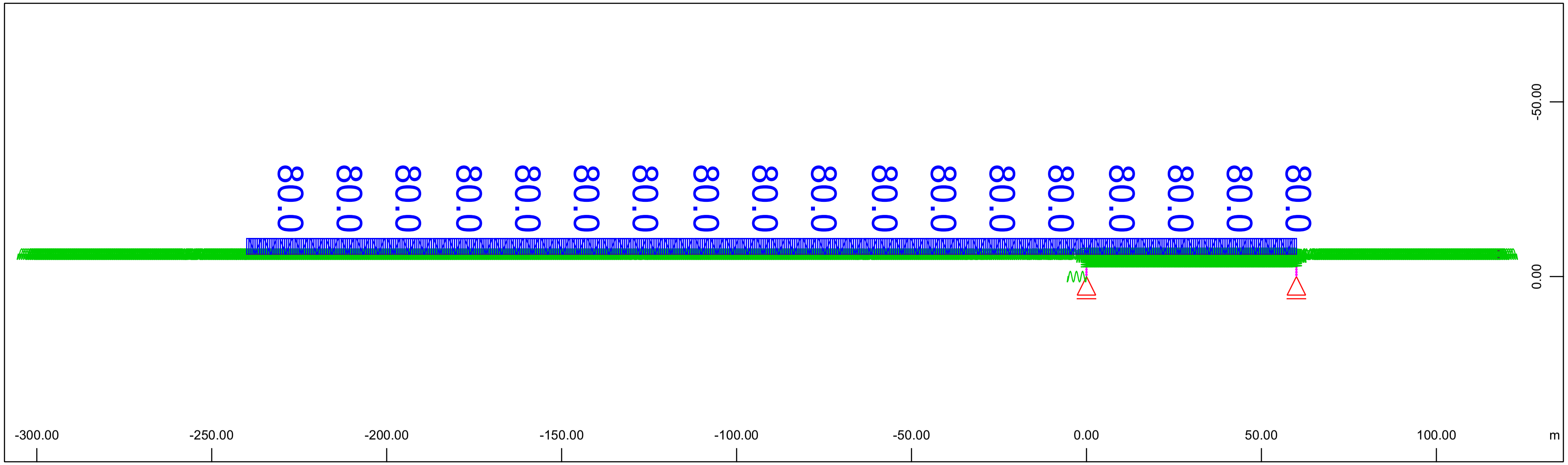
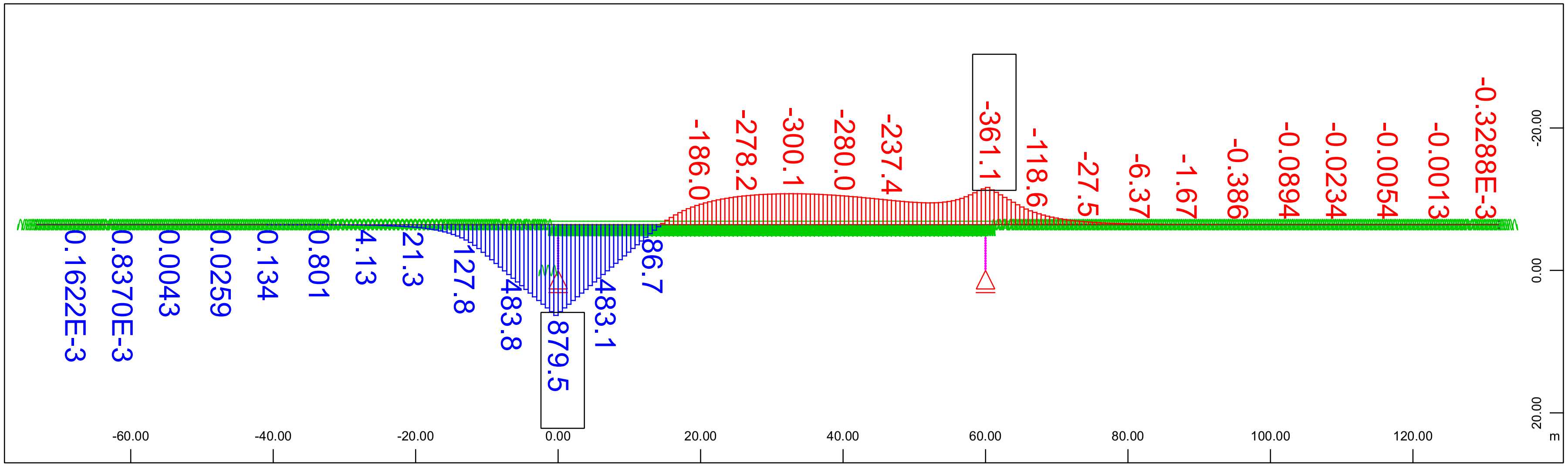
E1.3. Track slab + a floating slab mat with a thickness of 25 mm without a horizontal stiffness - Vertical load

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Vertical load 60 m from the fixe , (1 cm 3D = unit) Beam line load (force) in global Y (Unit=315.6 kN/m) (Max=80.0)

M 1 : 1761



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Vertical load 60 m from the fixe , 1 cm 3D = 597.7 kN (Min=-361.1) (Max=879.5)

M 1 : 865

reduced scale factor 0.936

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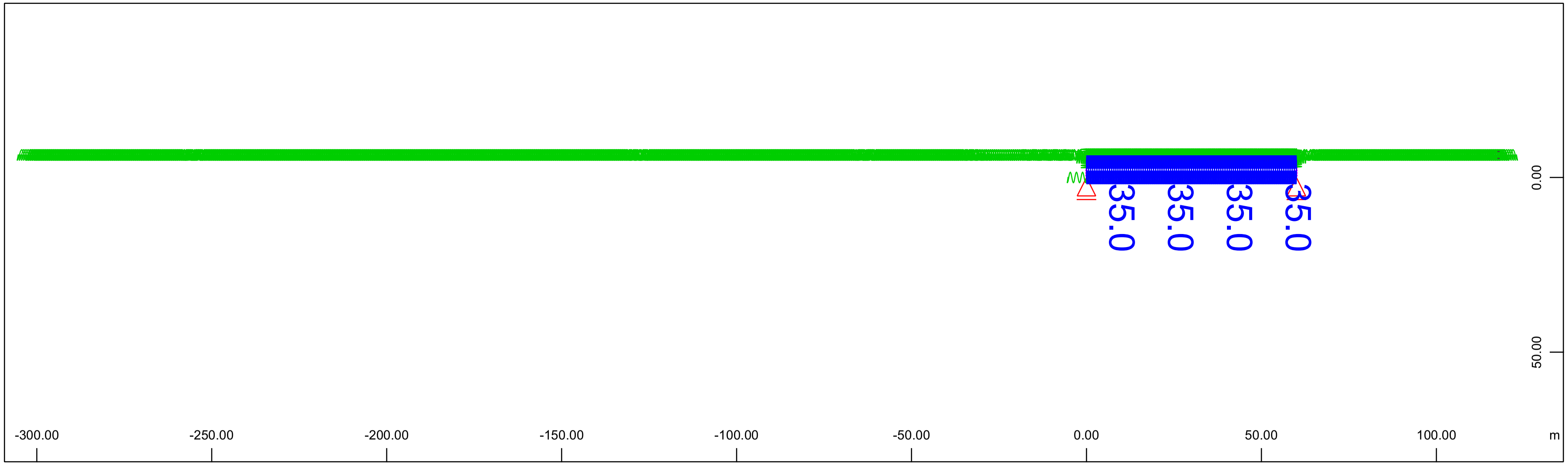
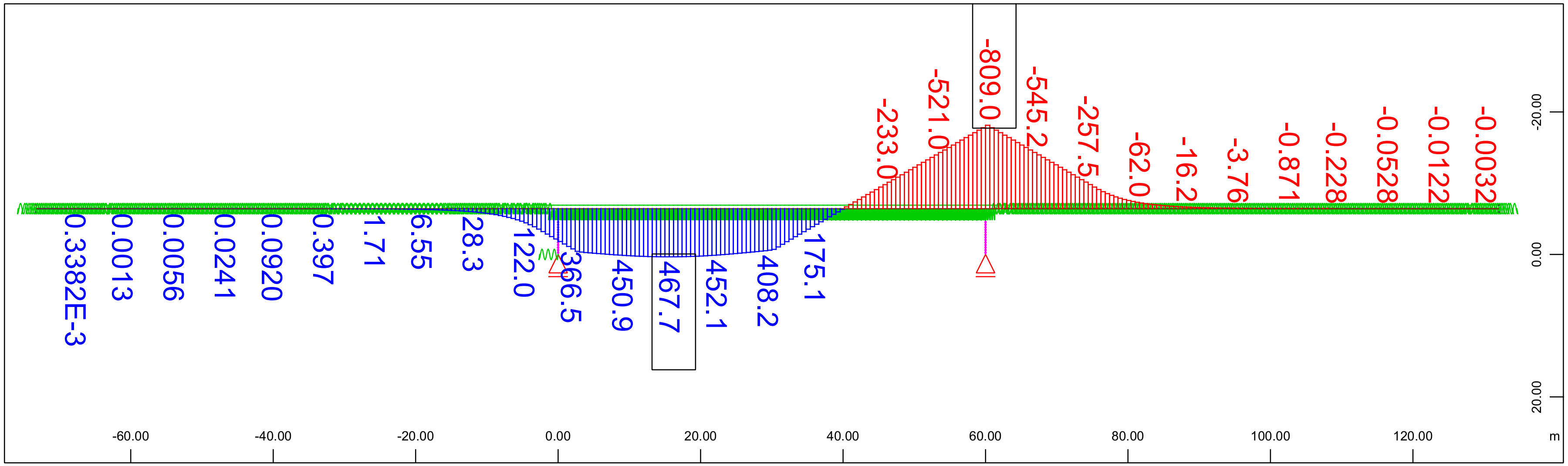
E1.3. Track slab + a floating slab mat with a thickness of 28 mm without a horizontal stiffness - Temperature variation - deck

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Temperature variation - deck , (1 cm 3D = unit) Beam line load (uniform temperature change)
(Unit=126.2 °C) (Max=35.0)

M 1 : 1761



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Temperature variation - deck , 1 cm 3D = 597.7 kN (Min=-809.0) (Max=467.7)

M 1 : 865

reduced scale factor 0.936

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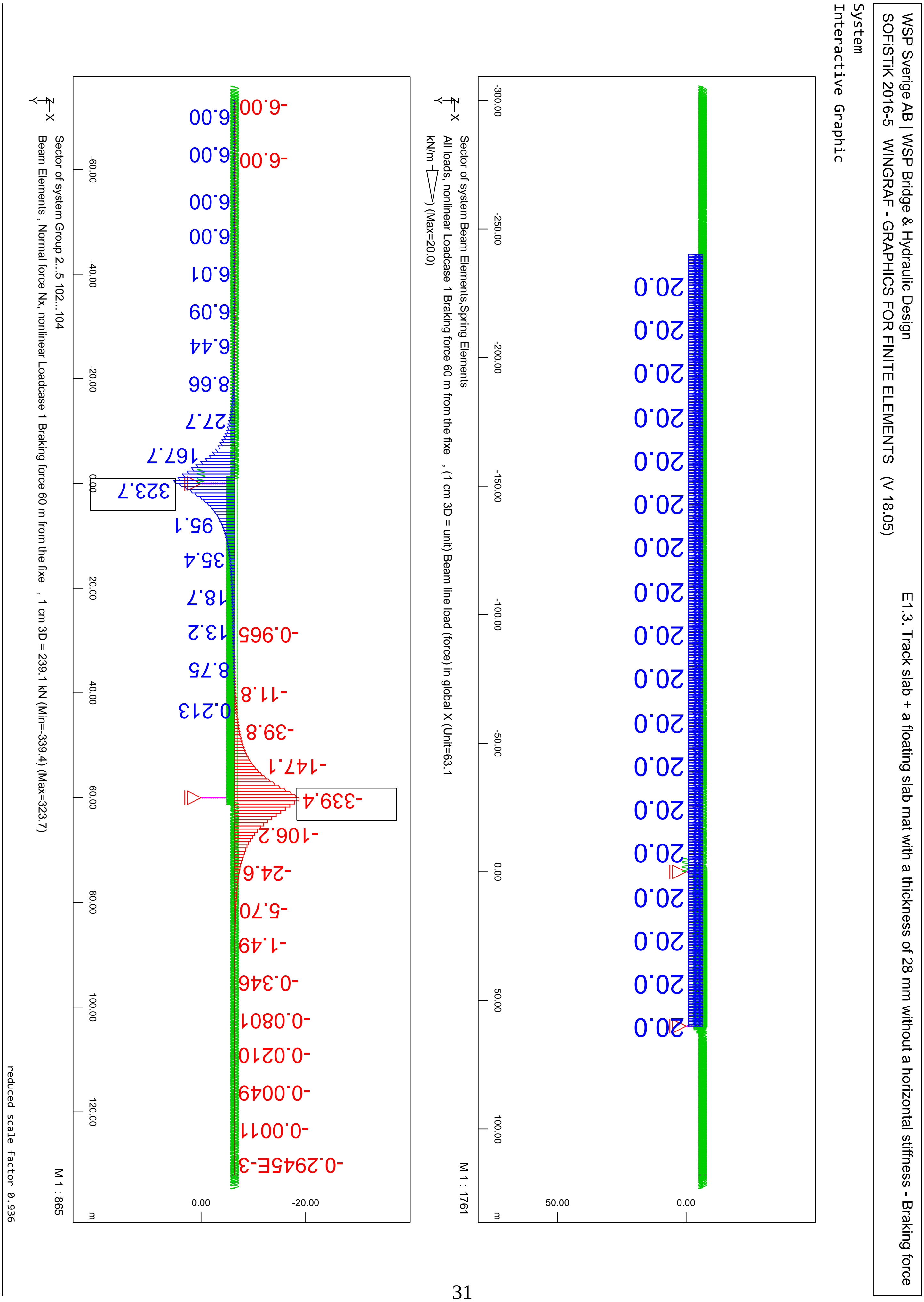

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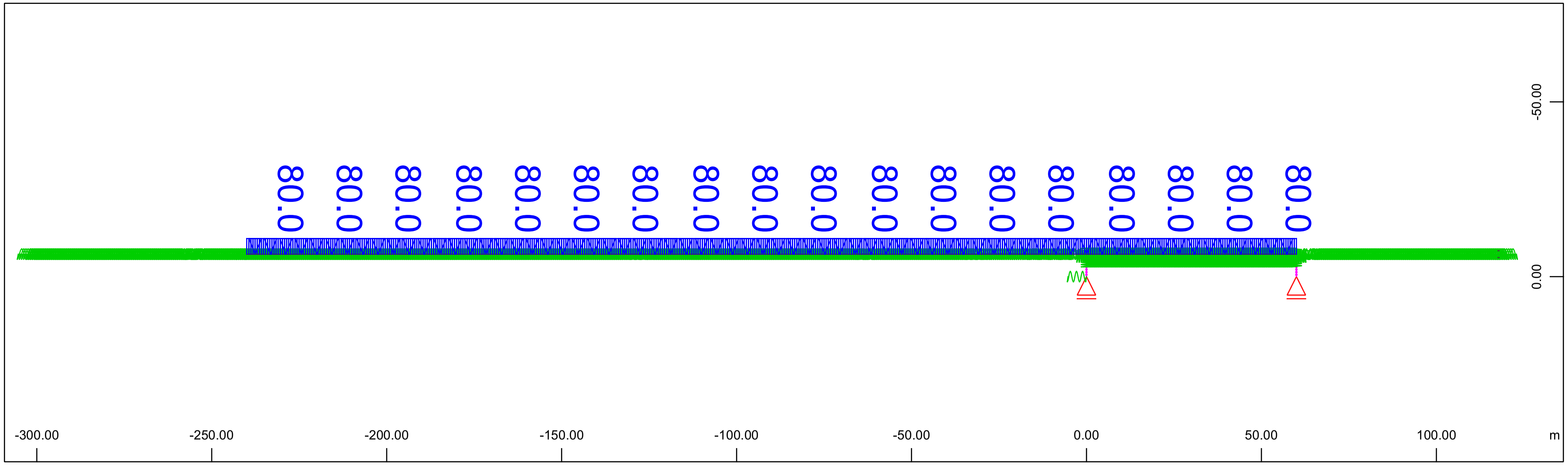
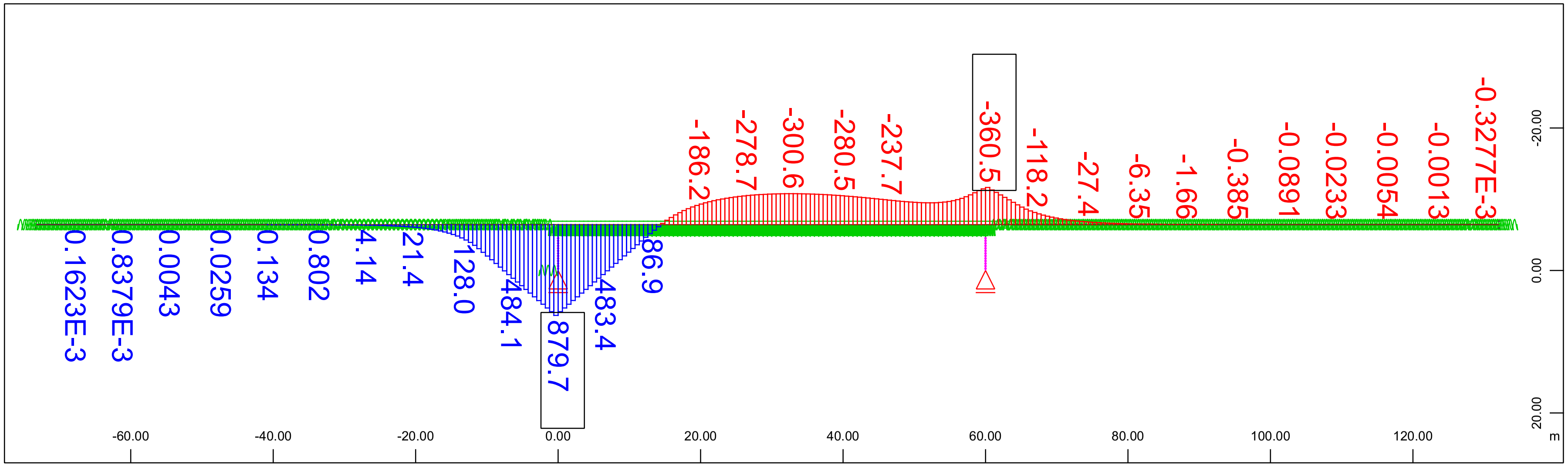
E1.3. Track slab + a floating slab mat with a thickness of 28 mm without a horizontal stiffness - Vertical load

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Vertical load 60 m from the fixe , (1 cm 3D = unit) Beam line load (force) in global Y (Unit=315.6 kN/m) (Max=80.0)
M 1 : 1761



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Vertical load 60 m from the fixe , 1 cm 3D = 597.7 kN (Min=-360.5) (Max=879.7)
M 1 : 865

reduced scale factor 0.936

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WSP Sverige AB | WSP Bridge & Hydraulic Design E1.3. Track slab + a floating slab mat with a thickness of 30 mm without a horizontal stiffness - Temperature variation - deck
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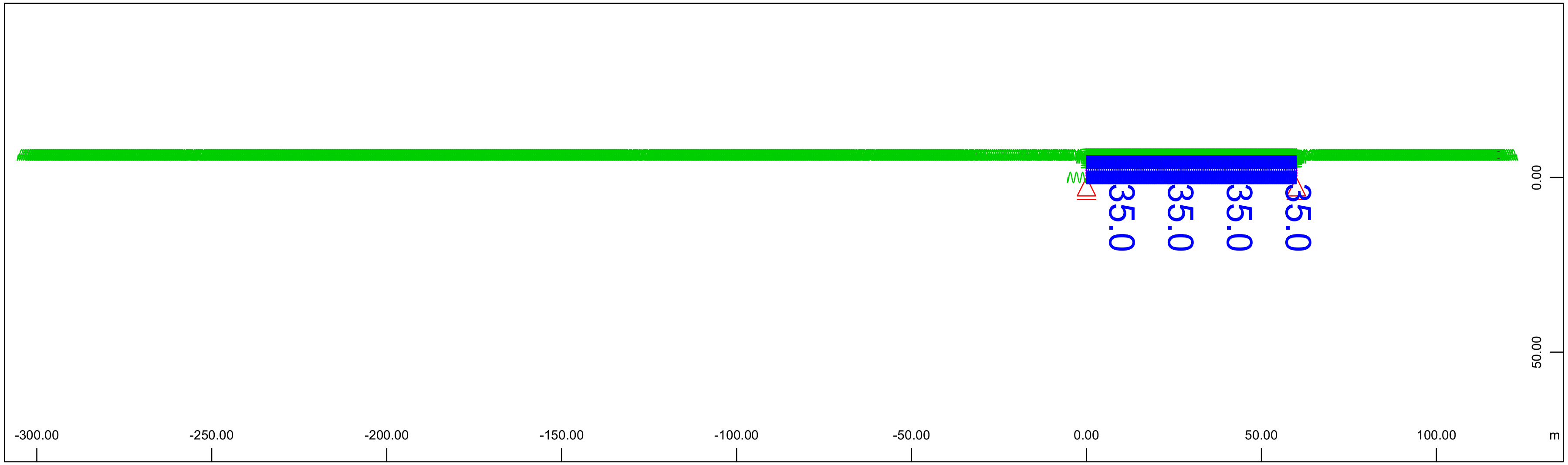
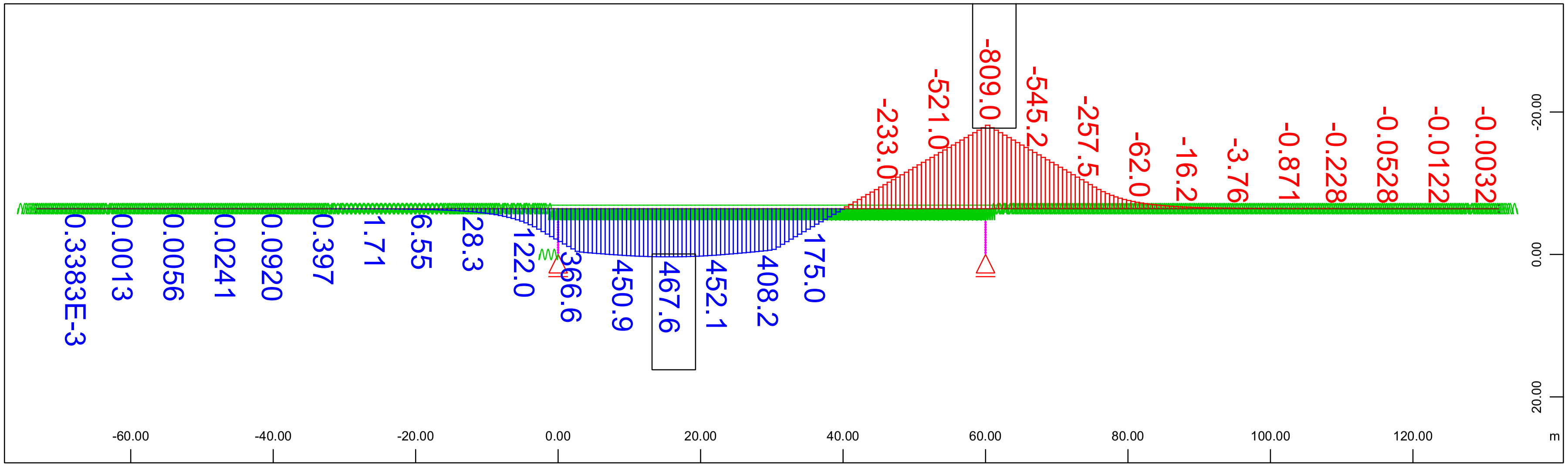
System
Interactive Graphic



Sector of system Beam Elements,Spring Elements M 1 : 1761
All loads, nonlinear Loadcase 1 Temperature variation - deck , (1 cm 3D = unit) Beam line load (uniform temperature change)
(Unit=126.2 °C) (Max=35.0)



Sector of system Group 2...5 102...104 M 1 : 865
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Temperature variation - deck , 1 cm 3D = 597.7 kN (Min=-809.0) (Max=467.6)

reduced scale factor 0.936

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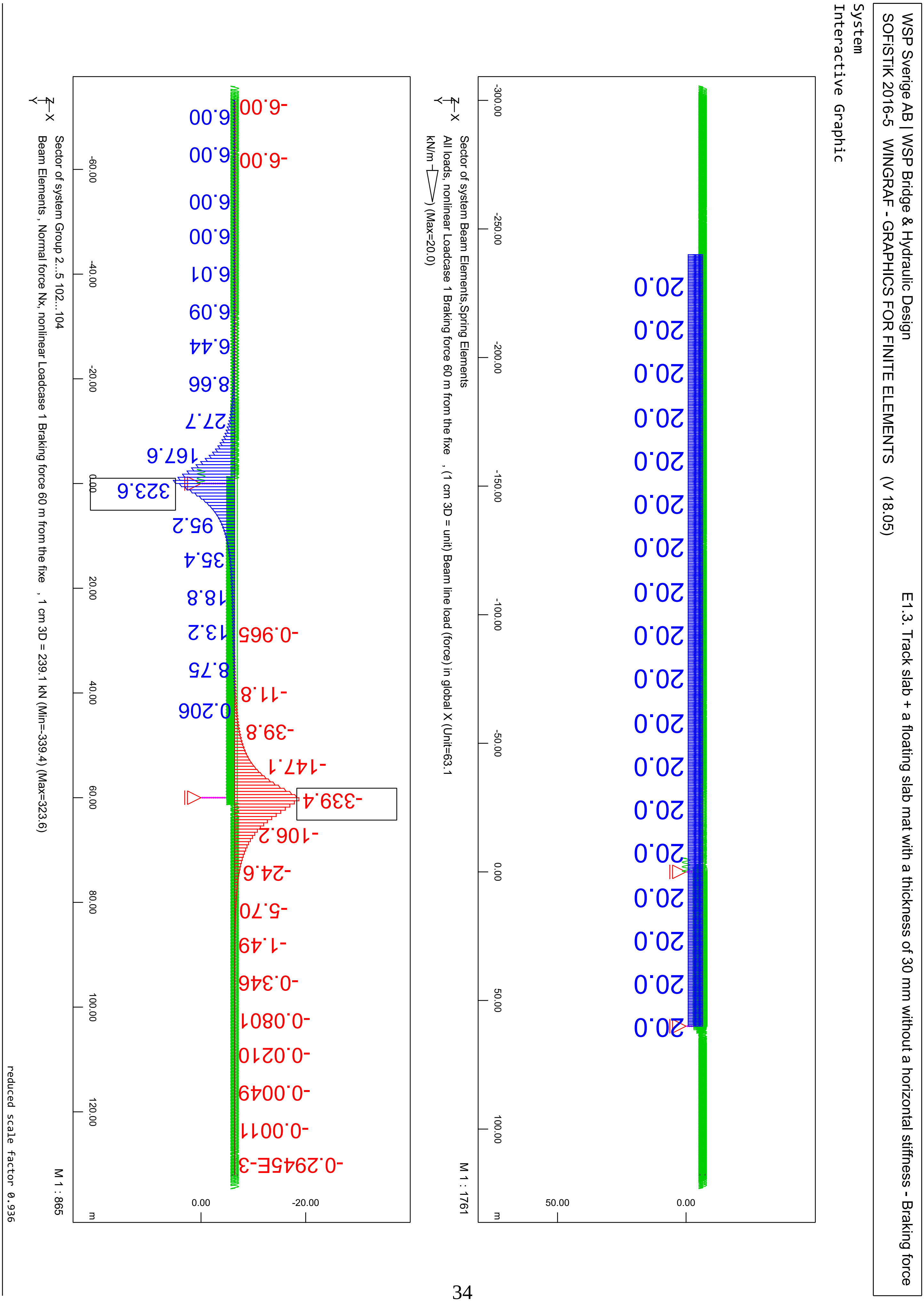

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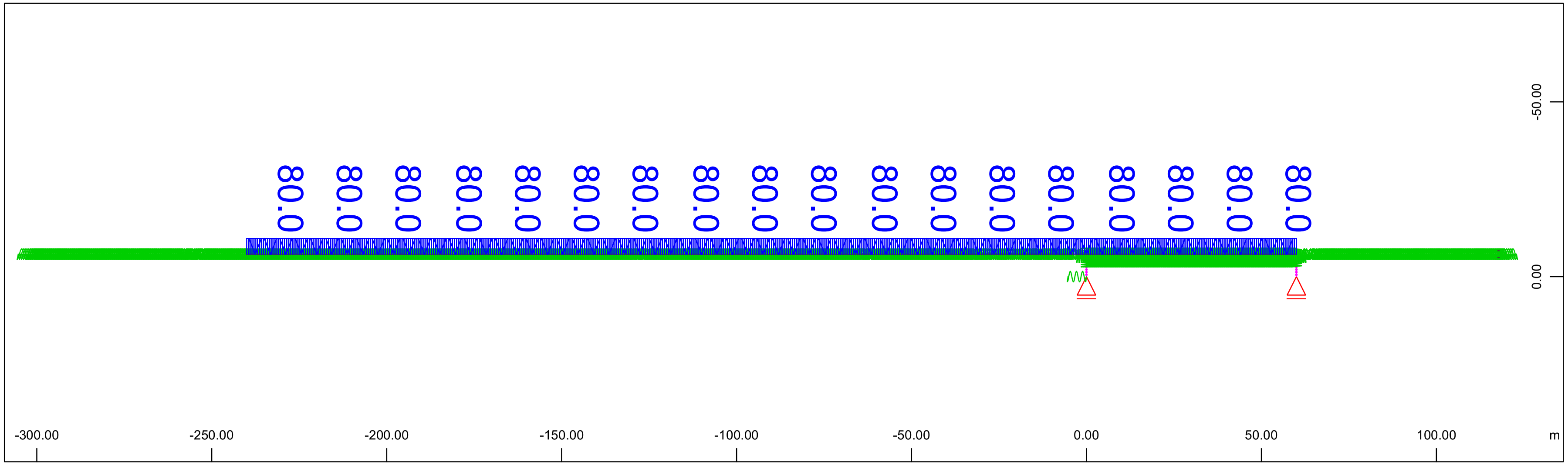
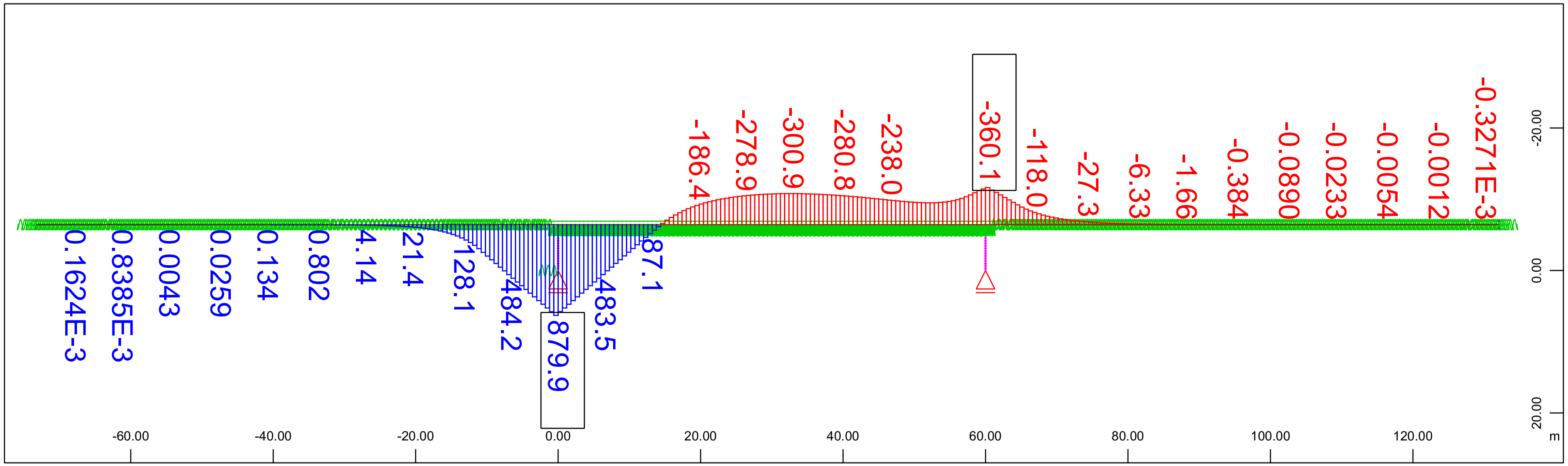
E1.3. Track slab + a floating slab mat with a thickness of 30 mm without a horizontal stiffness - Vertical load

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Vertical load 60 m from the fixe , (1 cm 3D = unit) Beam line load (force) in global Y (Unit=315.6 kN/m) (Max=80.0)
M 1 : 1761



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Vertical load 60 m from the fixe , 1 cm 3D = 597.7 kN (Min=-360.1) (Max=879.9)
M 1 : 865

reduced scale factor 0.936

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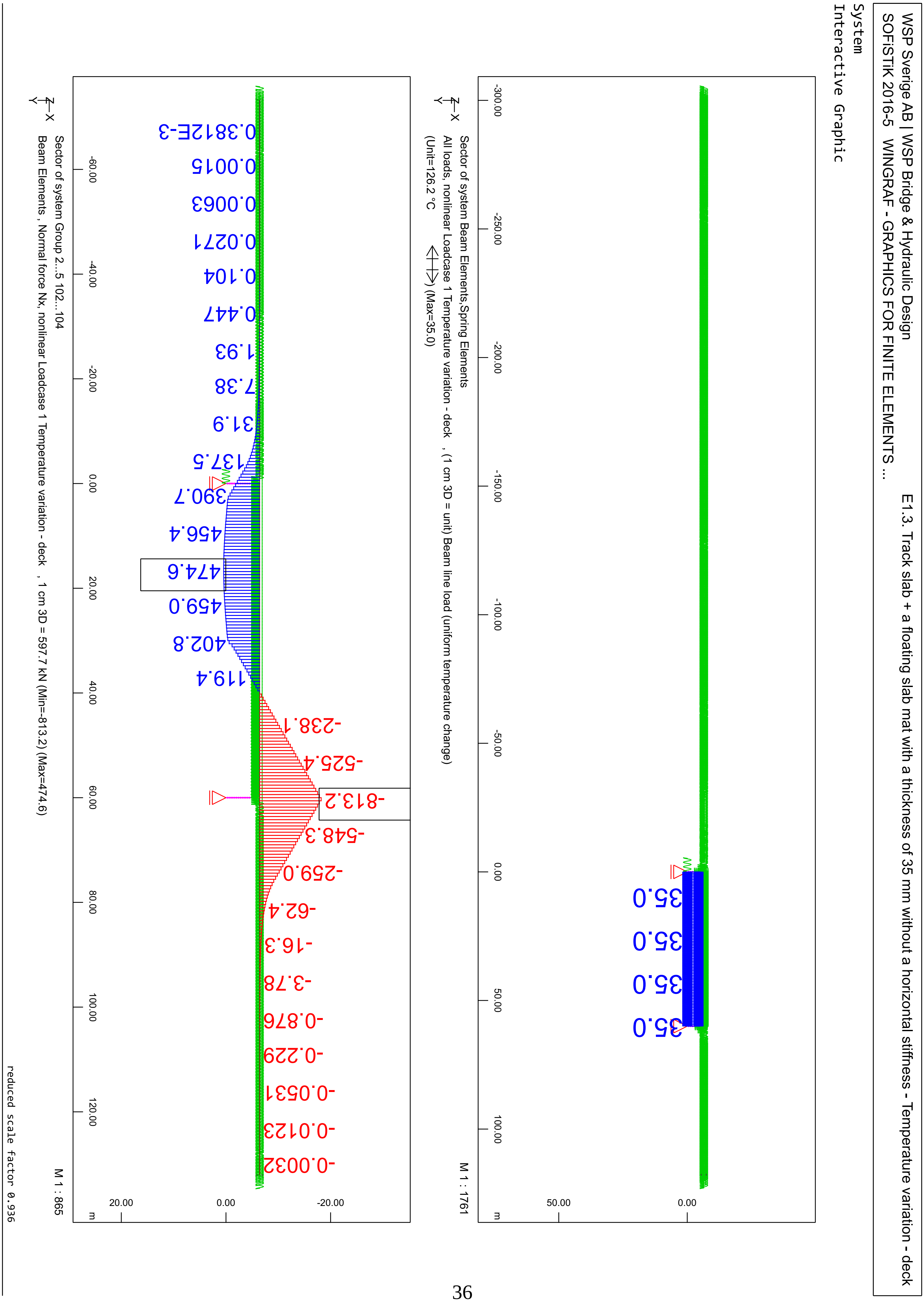

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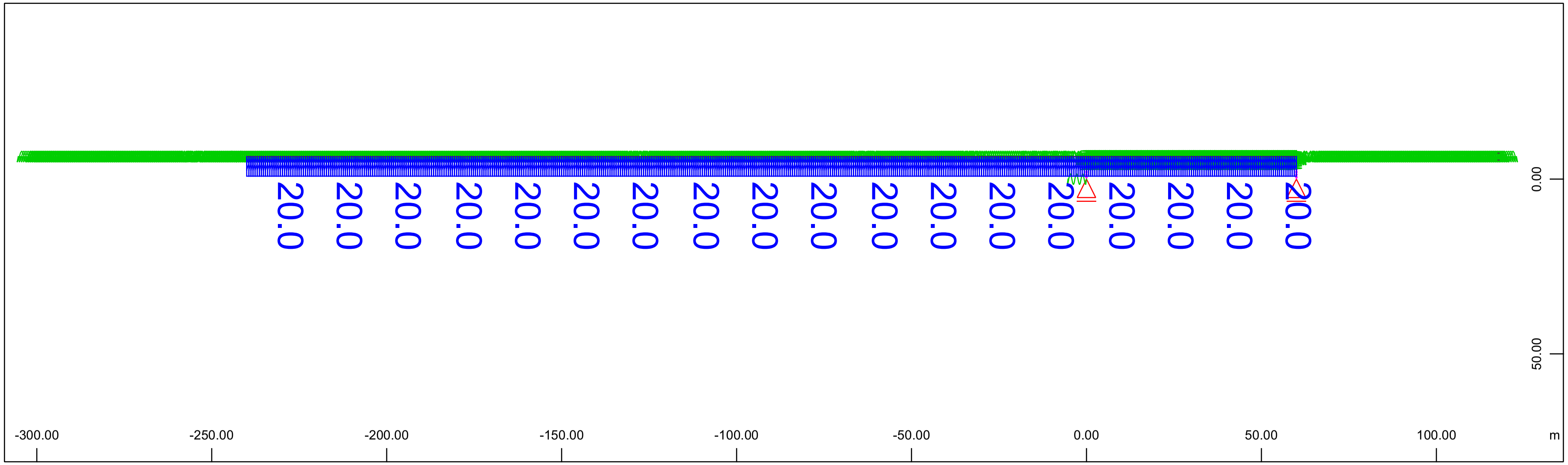
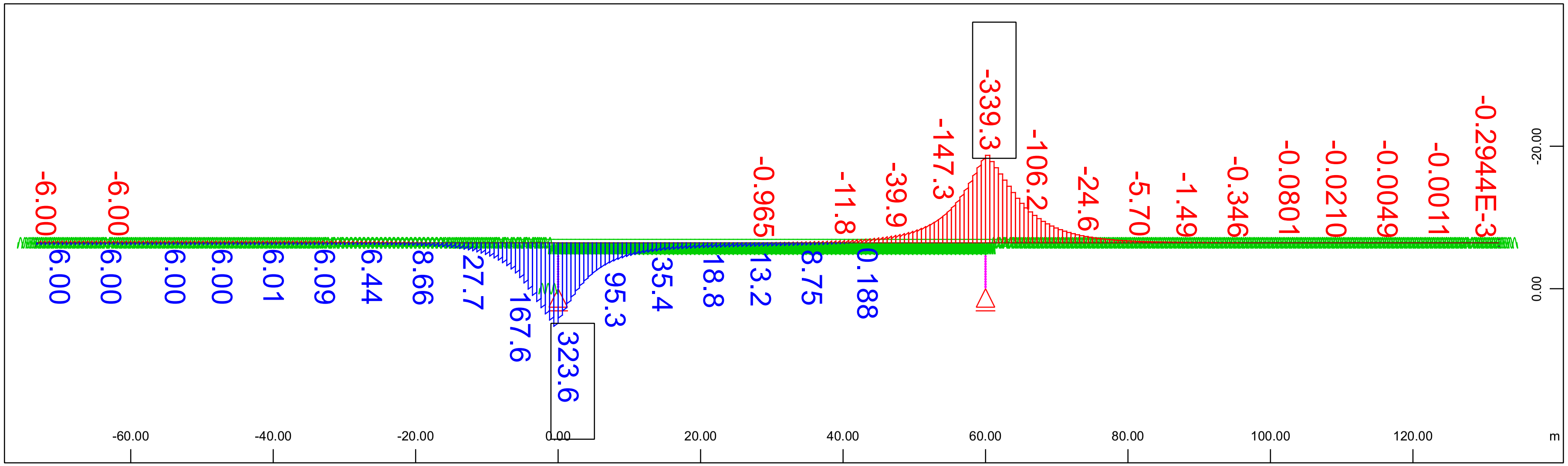
E1.3. Track slab + a floating slab mat with a thickness of 35 mm without a horizontal stiffness - Braking force

System
Interactive Graphic



Z X Y
Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Braking force 60 m from the fixe , (1 cm 3D = unit) Beam line load (force) in global X (Unit=63.1 kN/m) (Max=20.0)
M 1 : 1761



Z X Y
Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Braking force 60 m from the fixe , 1 cm 3D = 239.1 kN (Min=-339.3) (Max=323.6)
M 1 : 865

reduced scale factor 0.936

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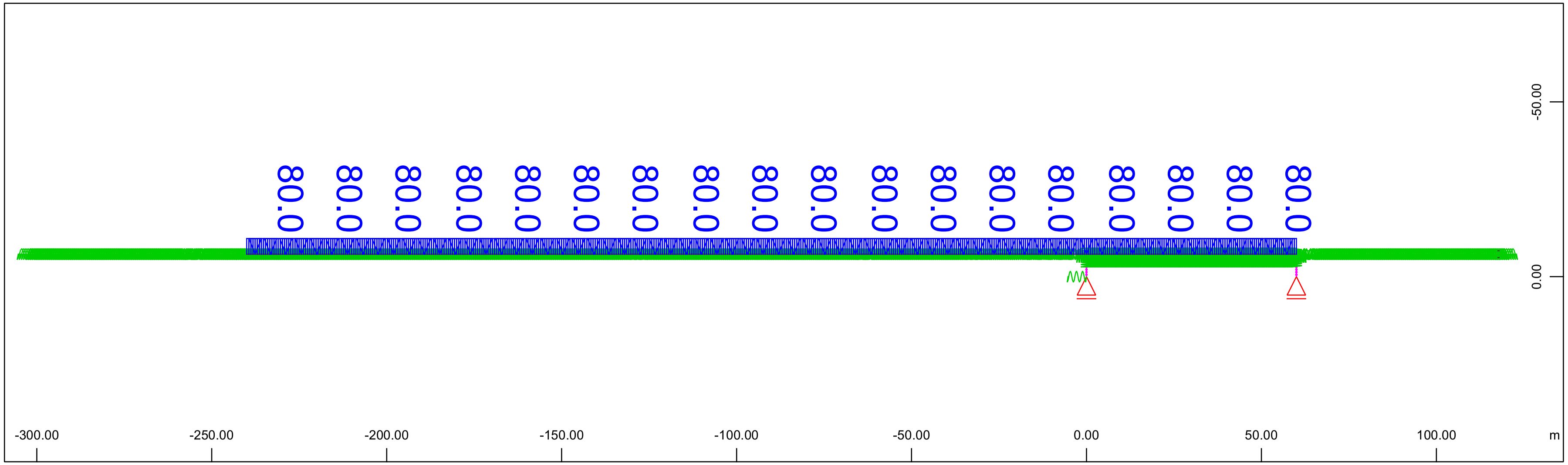
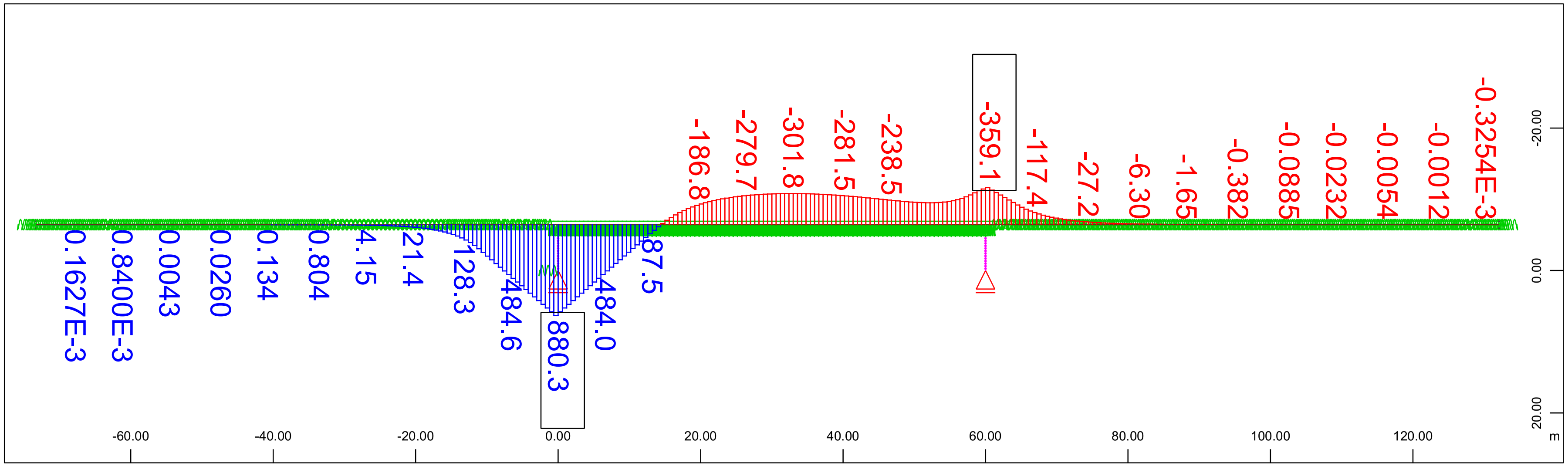
E1.3. Track slab + a floating slab mat with a thickness of 35 mm without a horizontal stiffness - Vertical load

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Vertical load 60 m from the fixe , (1 cm 3D = unit) Beam line load (force) in global Y (Unit=315.6 kN/m) (Max=80.0)

M 1 : 1761



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Vertical load 60 m from the fixe , 1 cm 3D = 597.7 kN (Min=-359.1) (Max=880.3)

M 1 : 865

reduced scale factor 0.936

2.4 E1-3 - Detailed normal force diagrams from the model with a floating slab mat with a horizontal stiffness

On the following pages are detailed normal force diagrams the test case E1-3 with a floating slab mat with a horizontal stiffness presented.

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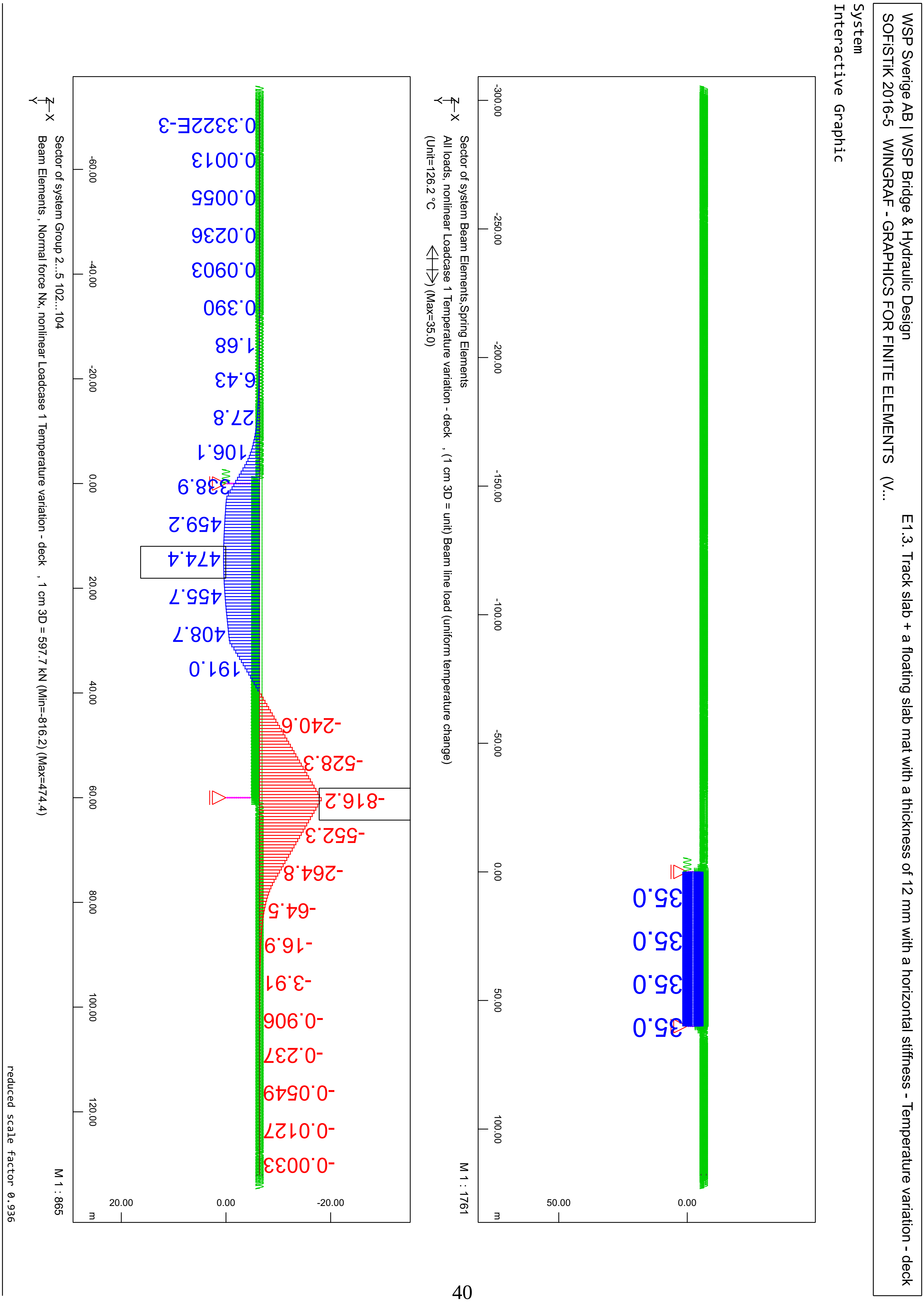

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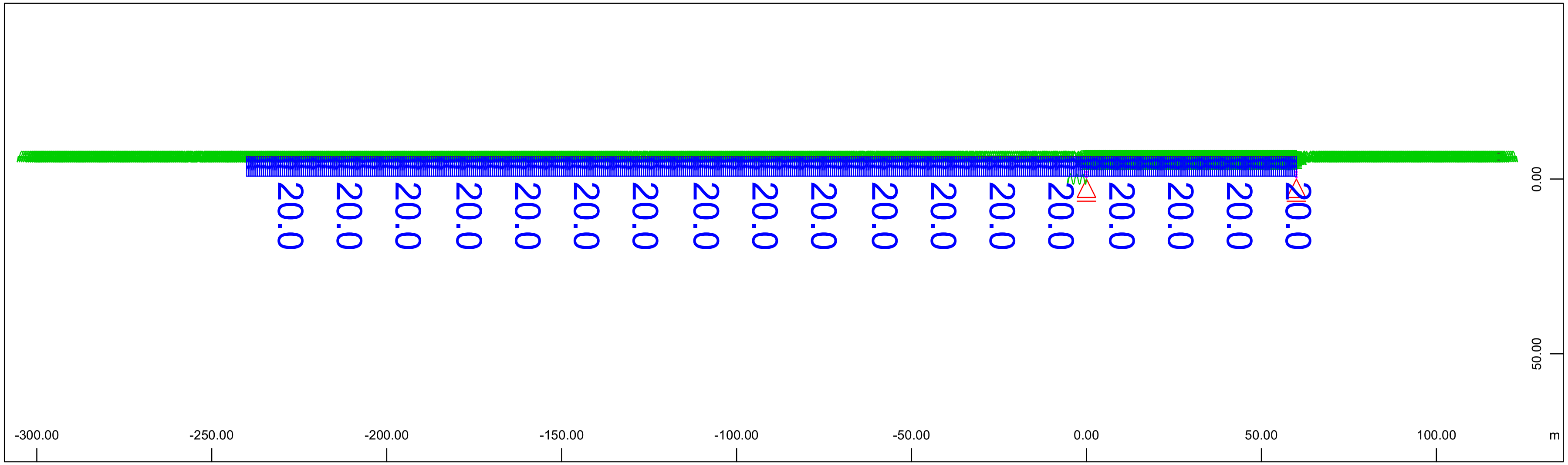
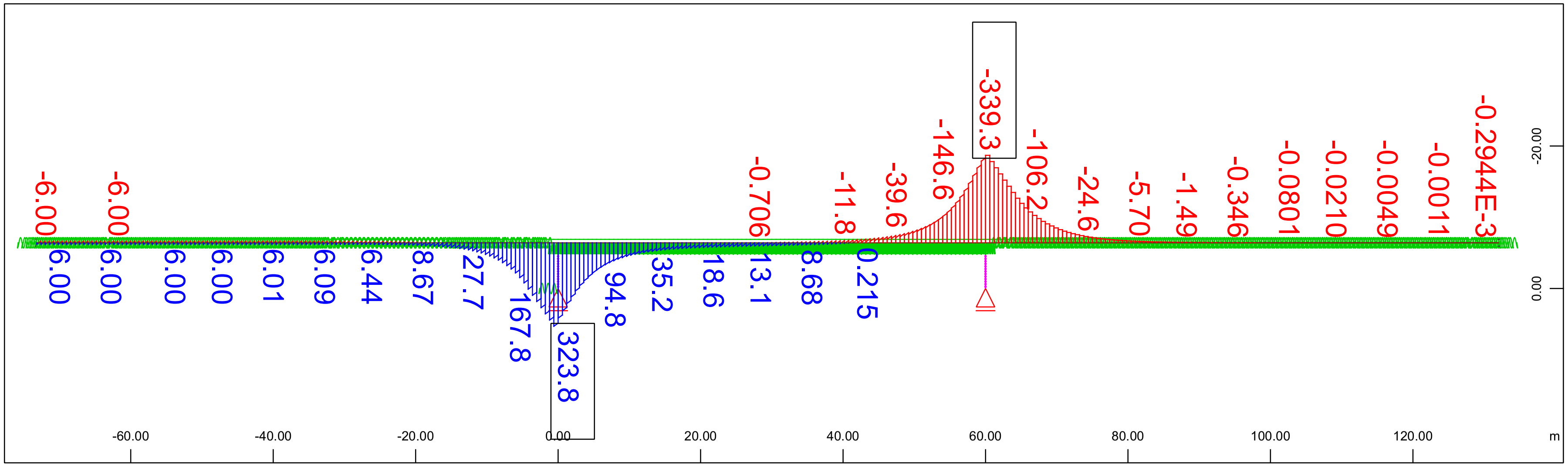
E1.3. Track slab + a floating slab mat with a thickness of 12 mm with a horizontal stiffness - Braking force

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Braking force 60 m from the fixe , (1 cm 3D = unit) Beam line load (force) in global X (Unit=63.1 kN/m) (Max=20.0)
M 1 : 1761



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Braking force 60 m from the fixe , 1 cm 3D = 239.1 kN (Min=-339.3) (Max=323.8)
M 1 : 865

reduced scale factor 0.936

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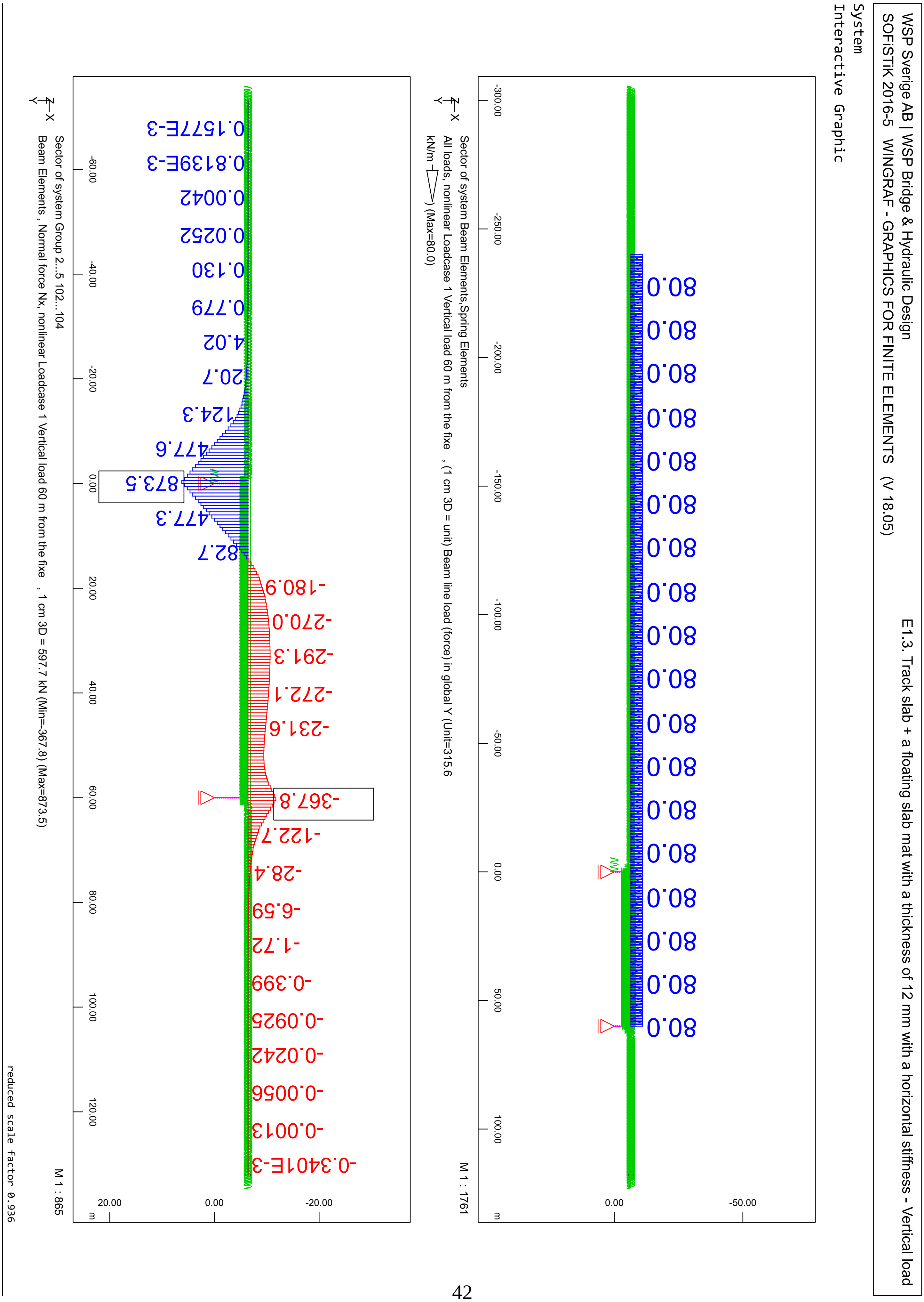

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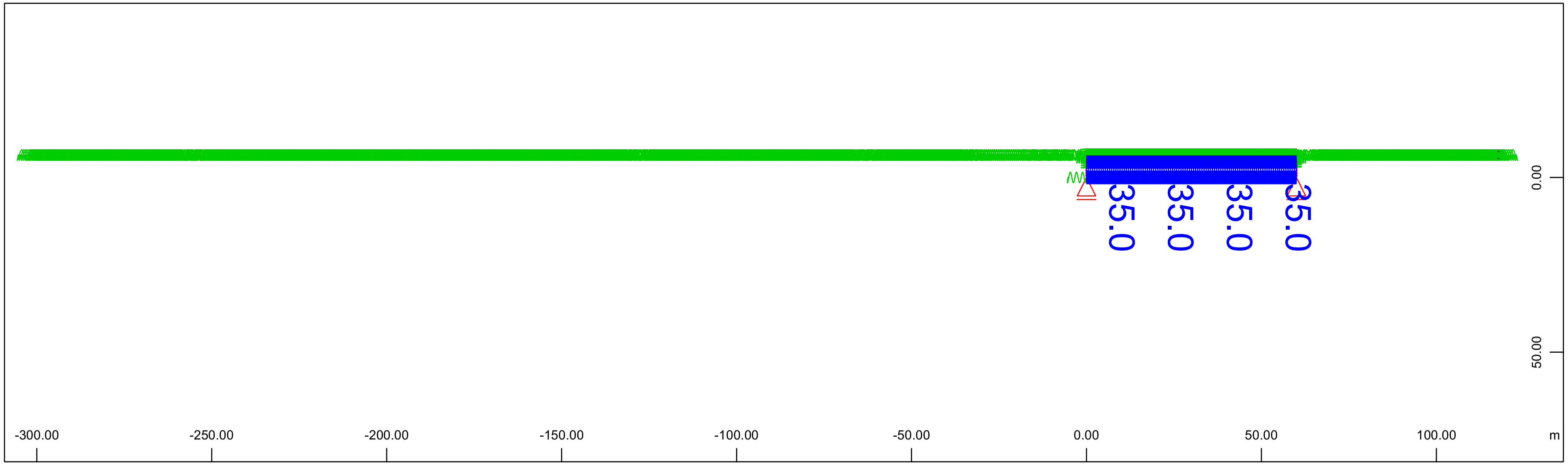
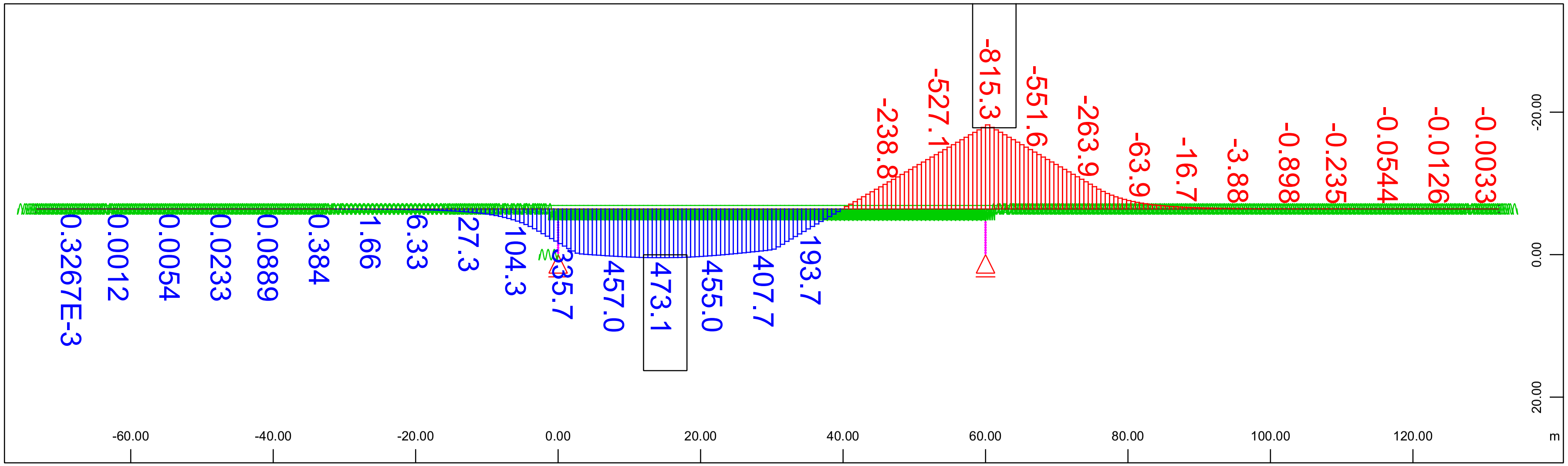
E1.3. Track slab + a floating slab mat with a thickness of 15 mm with a horizontal stiffness - Temperature variation - deck

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Temperature variation - deck , (1 cm 3D = unit) Beam line load (uniform temperature change)
(Unit=126.2 °C) (Max=35.0)
M 1 : 1761



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Temperature variation - deck , 1 cm 3D = 597.7 kN (Min=-815.3) (Max=473.1)
M 1 : 865

reduced scale factor 0.936

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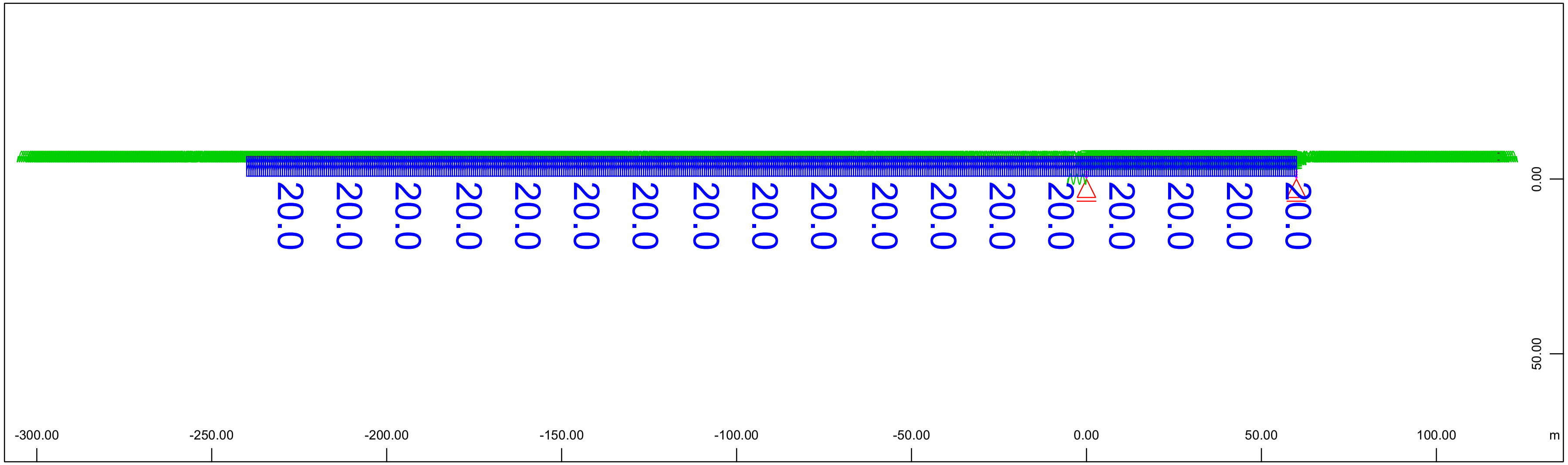
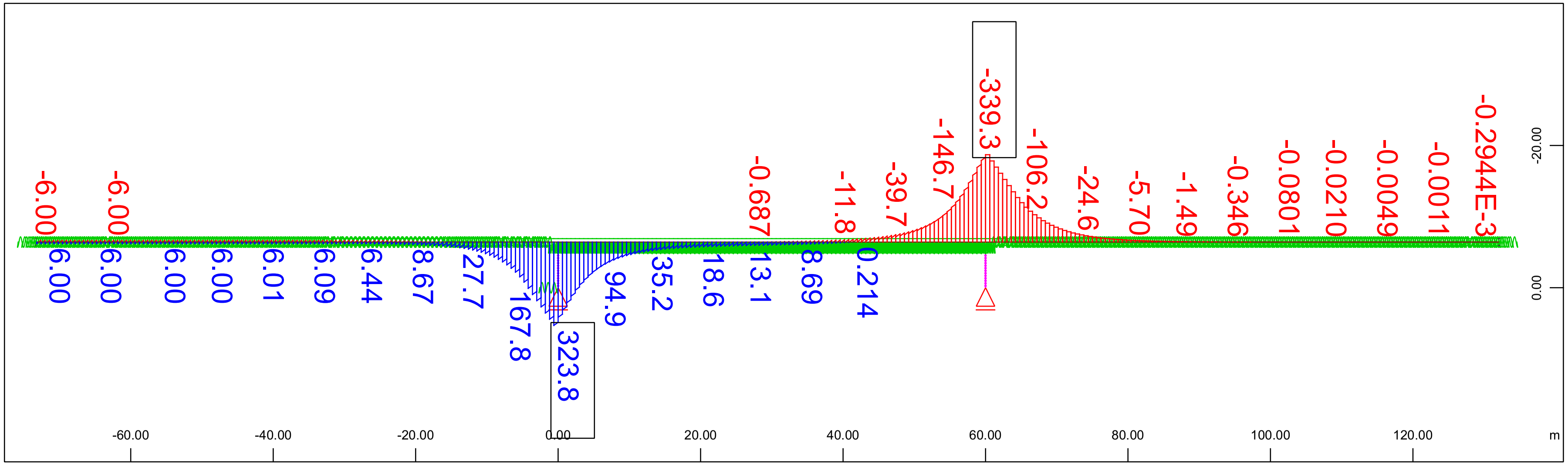
E1.3. Track slab + a floating slab mat with a thickness of 15 mm with a horizontal stiffness - Braking force

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Braking force 60 m from the fixe , (1 cm 3D = unit) Beam line load (force) in global X (Unit=63.1 kN/m) (Max=20.0)
M 1 : 1761



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Braking force 60 m from the fixe , 1 cm 3D = 239.1 kN (Min=-339.3) (Max=323.8)
M 1 : 865

reduced scale factor 0.936

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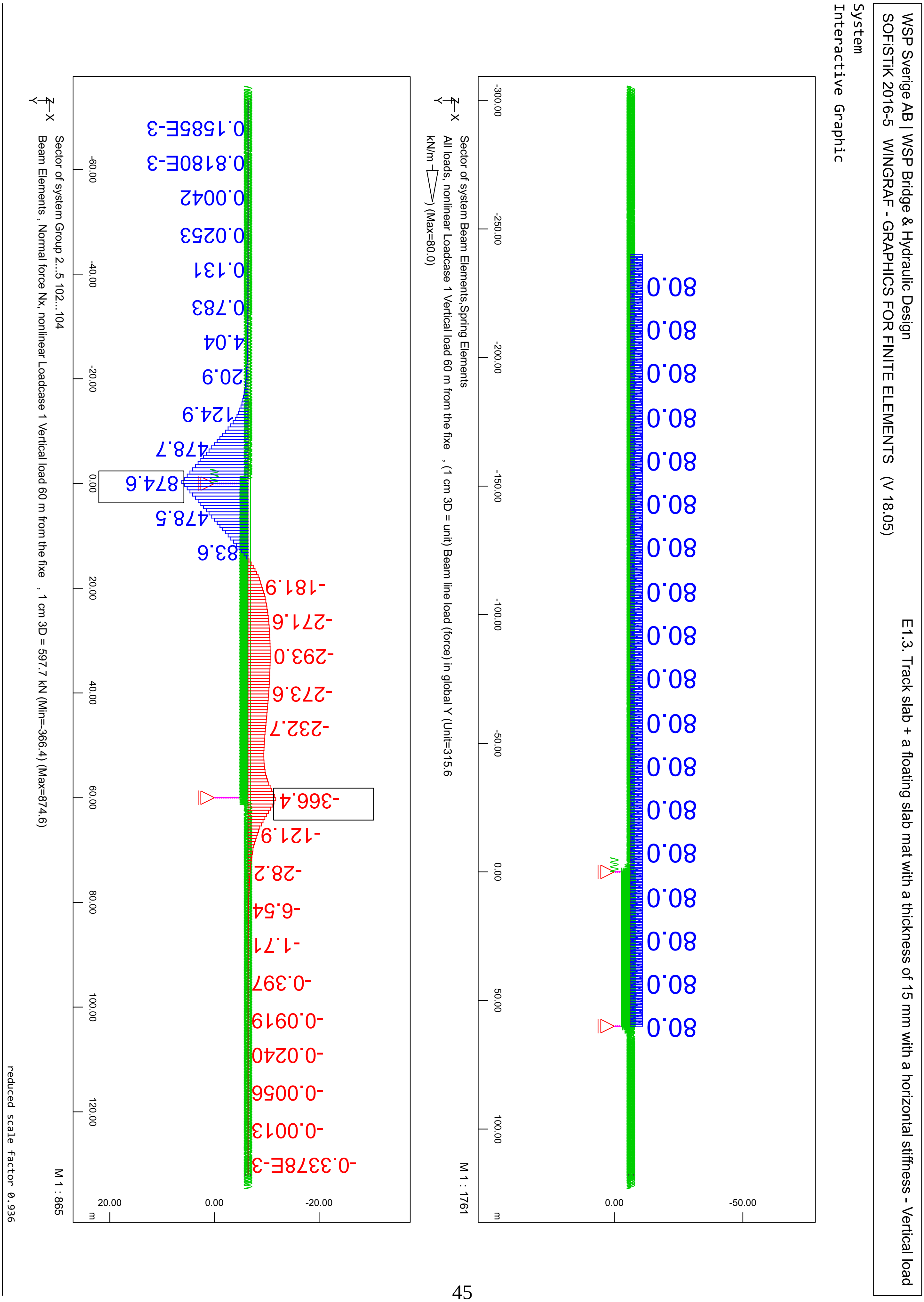
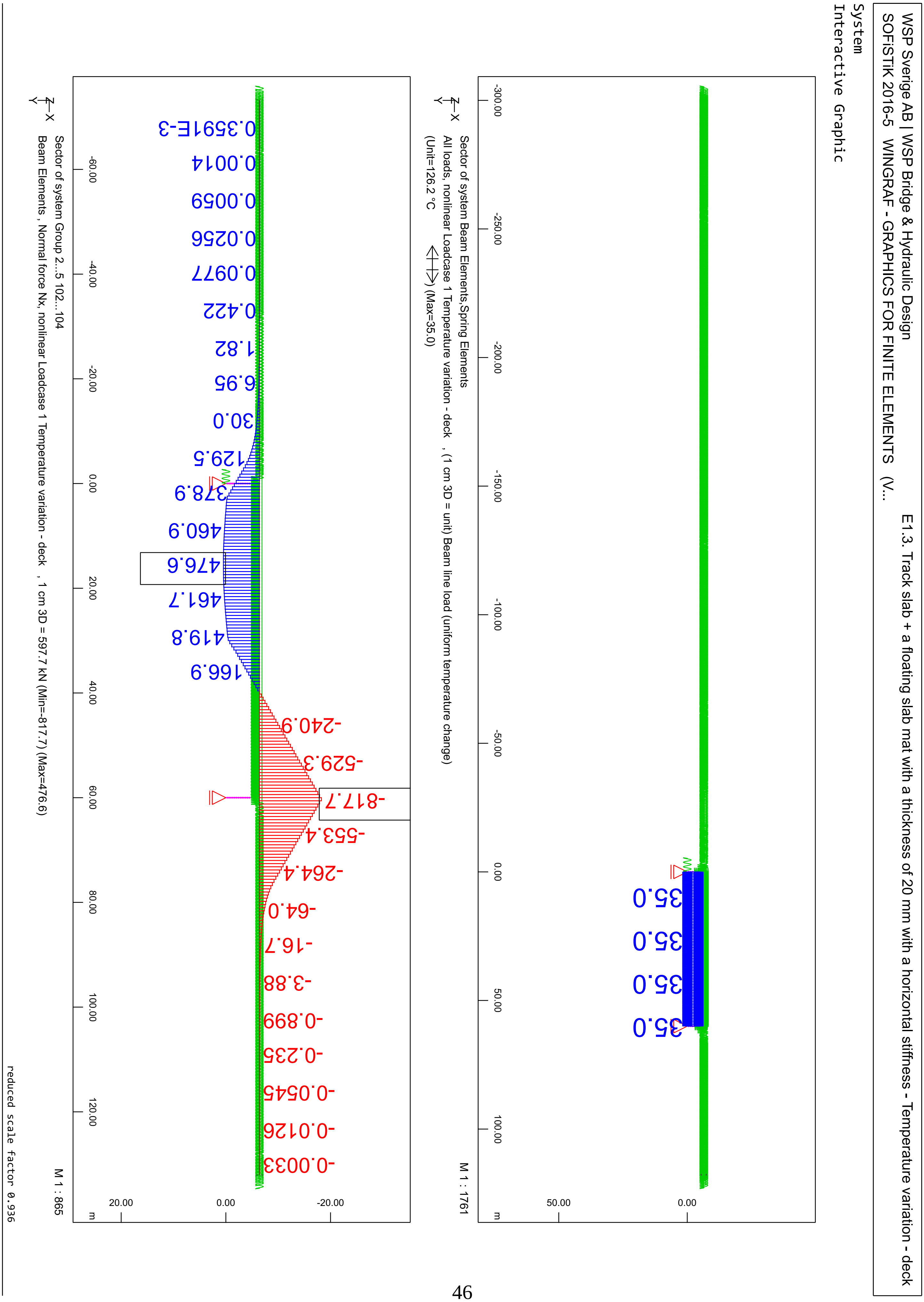


SOFiSTiK AG - www.sofistik.de



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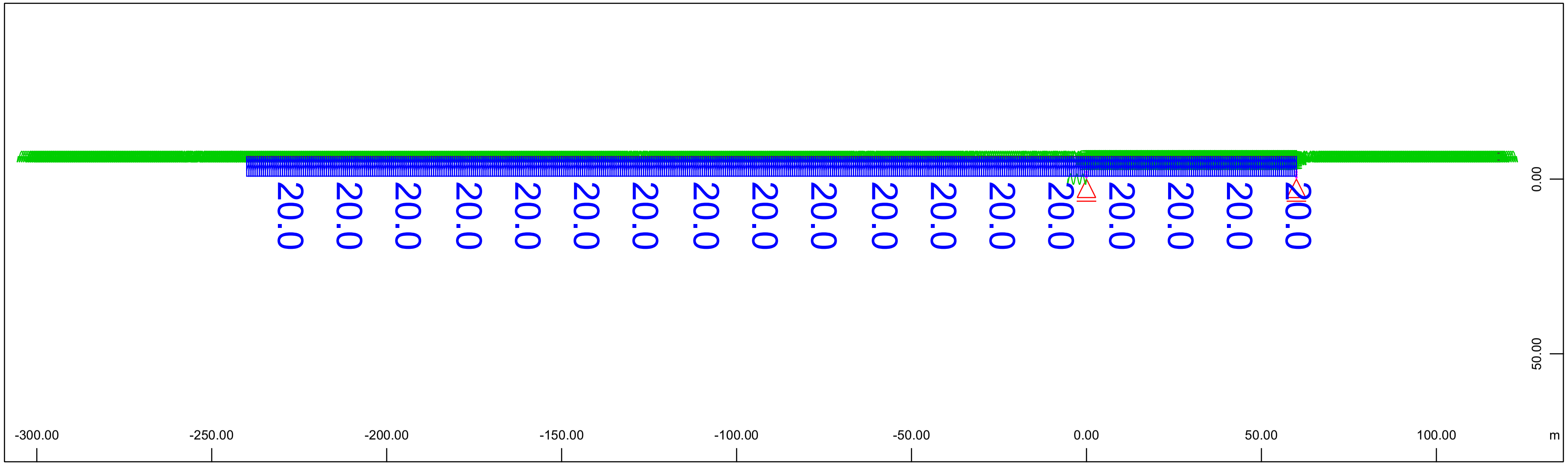
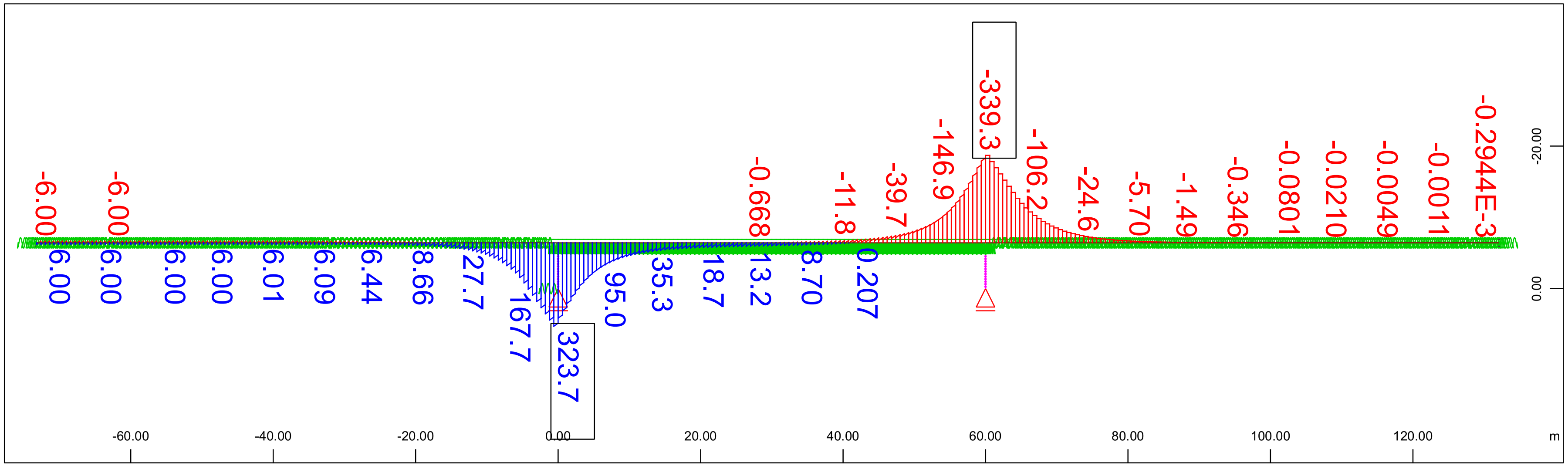
E1.3. Track slab + a floating slab mat with a thickness of 20 mm with a horizontal stiffness - Braking force

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Braking force 60 m from the fixe , (1 cm 3D = unit) Beam line load (force) in global X (Unit=63.1 kN/m) (Max=20.0)

M 1 : 1761



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Braking force 60 m from the fixe , 1 cm 3D = 239.1 kN (Min=-339.3) (Max=323.7)

M 1 : 865

reduced scale factor 0.936

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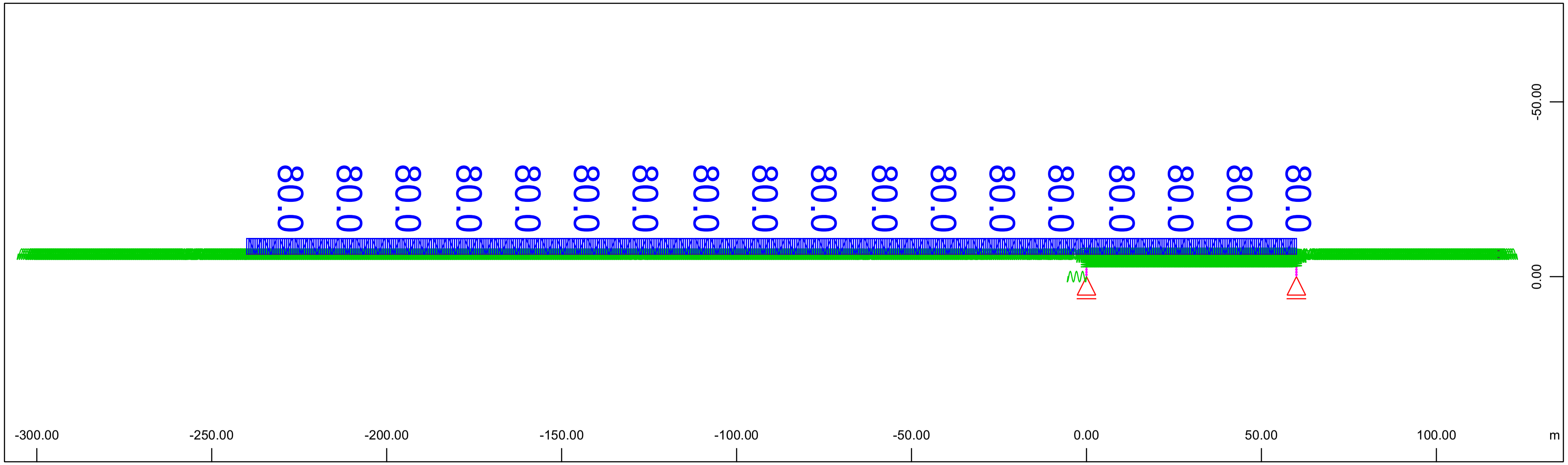
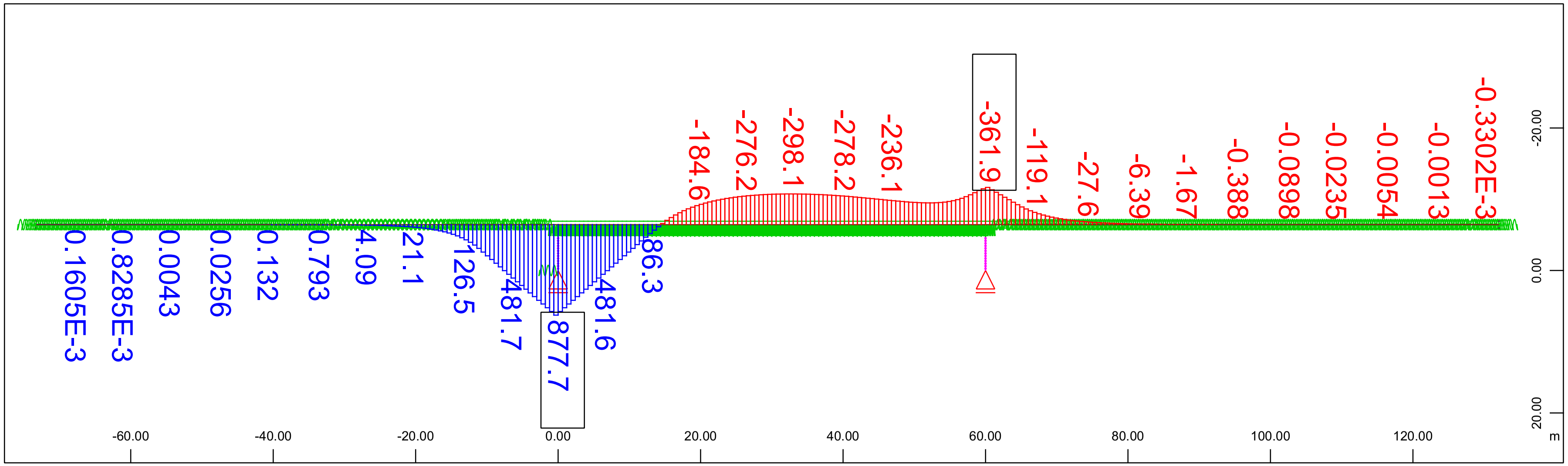
E1.3. Track slab + a floating slab mat with a thickness of 20 mm with a horizontal stiffness - Vertical load

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Vertical load 60 m from the fixe , (1 cm 3D = unit) Beam line load (force) in global Y (Unit=315.6 kN/m) (Max=80.0)

M 1 : 1761



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Vertical load 60 m from the fixe , 1 cm 3D = 597.7 kN (Min=-361.9) (Max=877.7)

M 1 : 865

reduced scale factor 0.936

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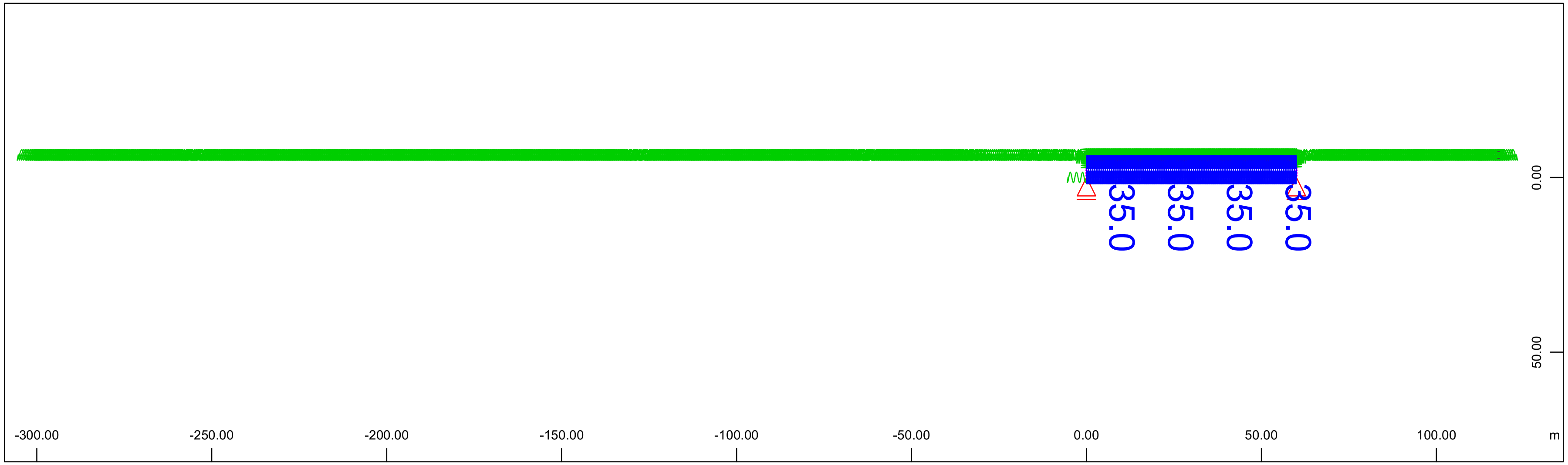
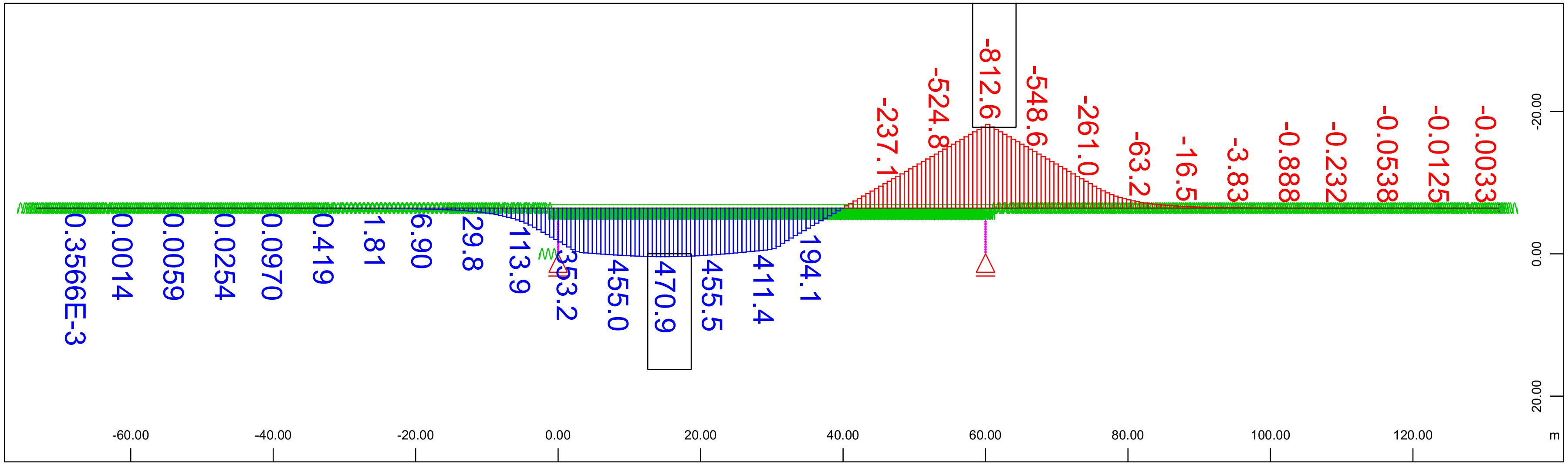
E1.3. Track slab + a floating slab mat with a thickness of 25 mm with a horizontal stiffness - Temperature variation - deck

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Temperature variation - deck , (1 cm 3D = unit) Beam line load (uniform temperature change)
(Unit=126.2 °C) (Max=35.0)

M 1 : 1761



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Temperature variation - deck , 1 cm 3D = 597.7 kN (Min=-812.6) (Max=470.9)

M 1 : 865

reduced scale factor 0.936

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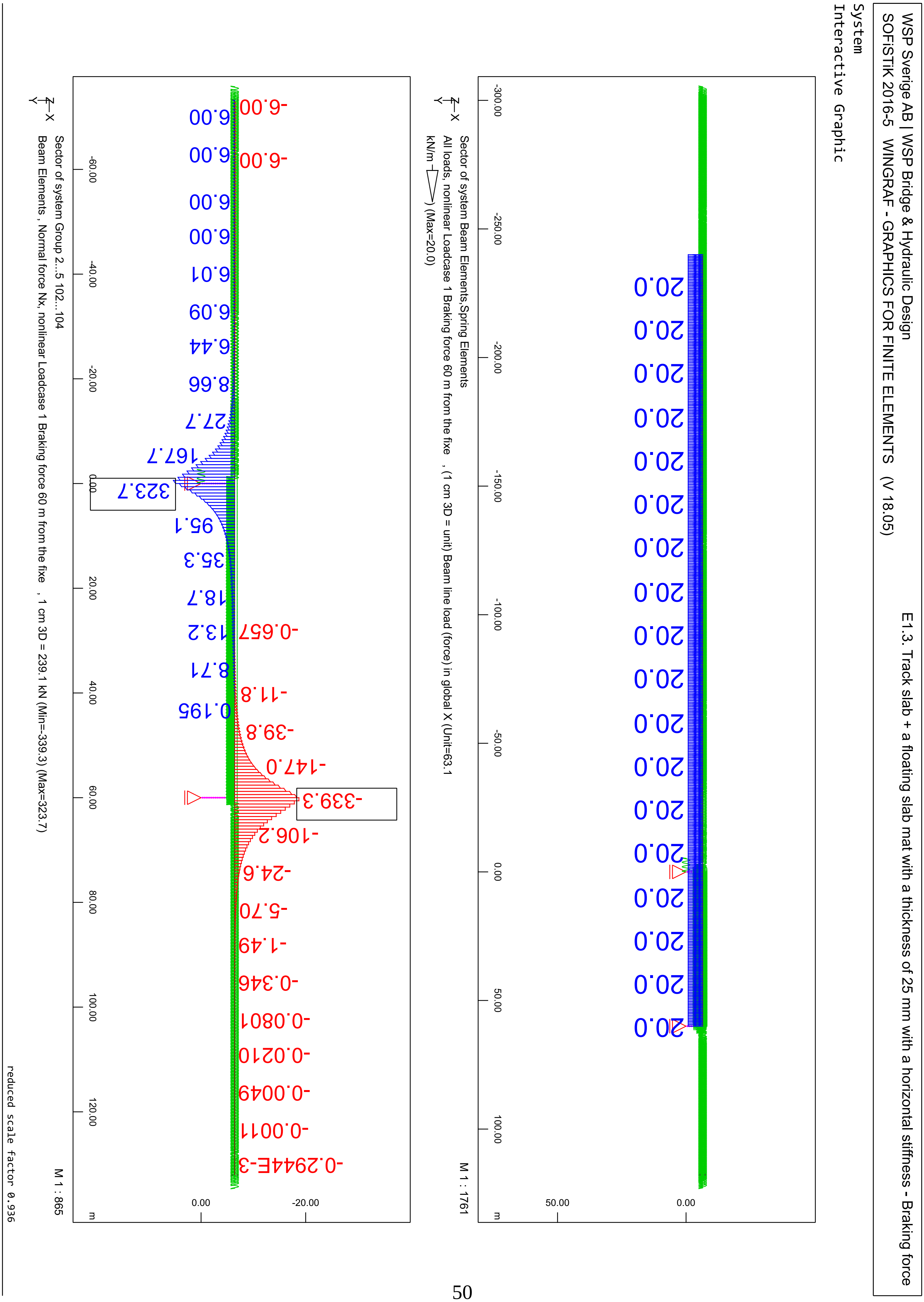

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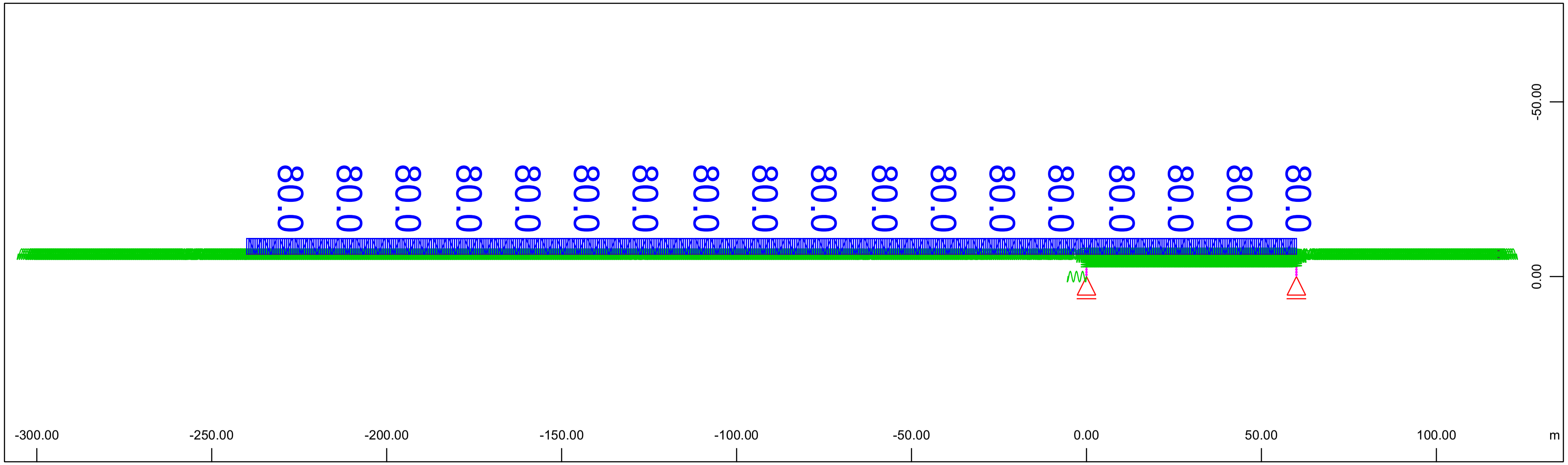
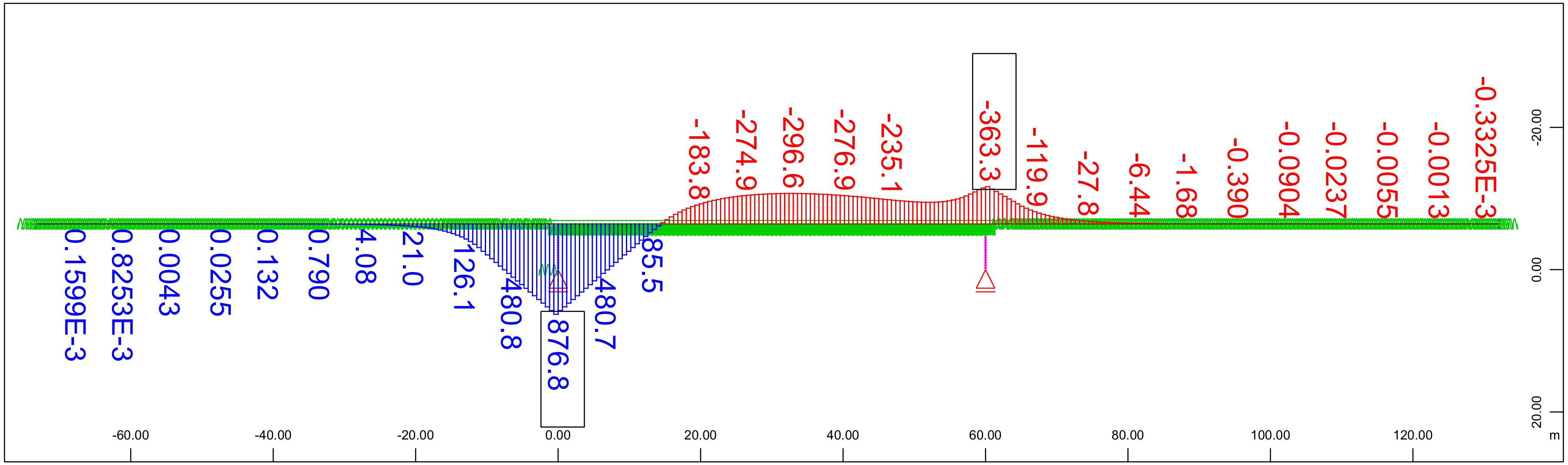
E1.3. Track slab + a floating slab mat with a thickness of 25 mm with a horizontal stiffness - Vertical load

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Vertical load 60 m from the fixe , (1 cm 3D = unit) Beam line load (force) in global Y (Unit=315.6 kN/m) (Max=80.0)

M 1 : 1761



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Vertical load 60 m from the fixe , 1 cm 3D = 597.7 kN (Min=-363.3) (Max=876.8)

M 1 : 865

reduced scale factor 0.936

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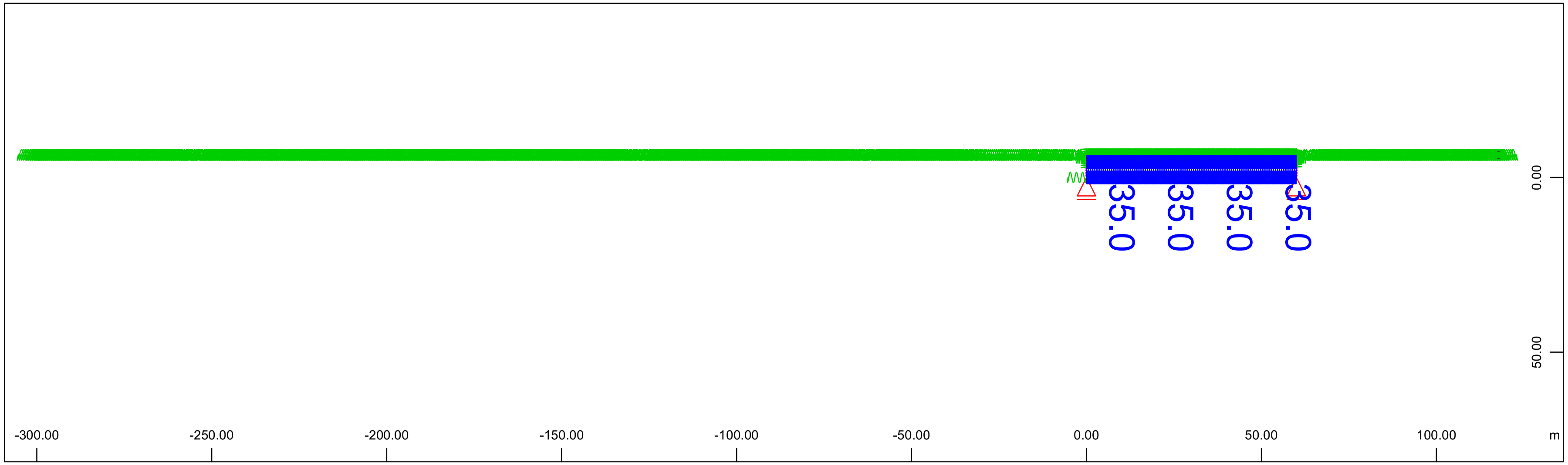
E1.3. Track slab + a floating slab mat with a thickness of 28 mm with a horizontal stiffness - Temperature - deck

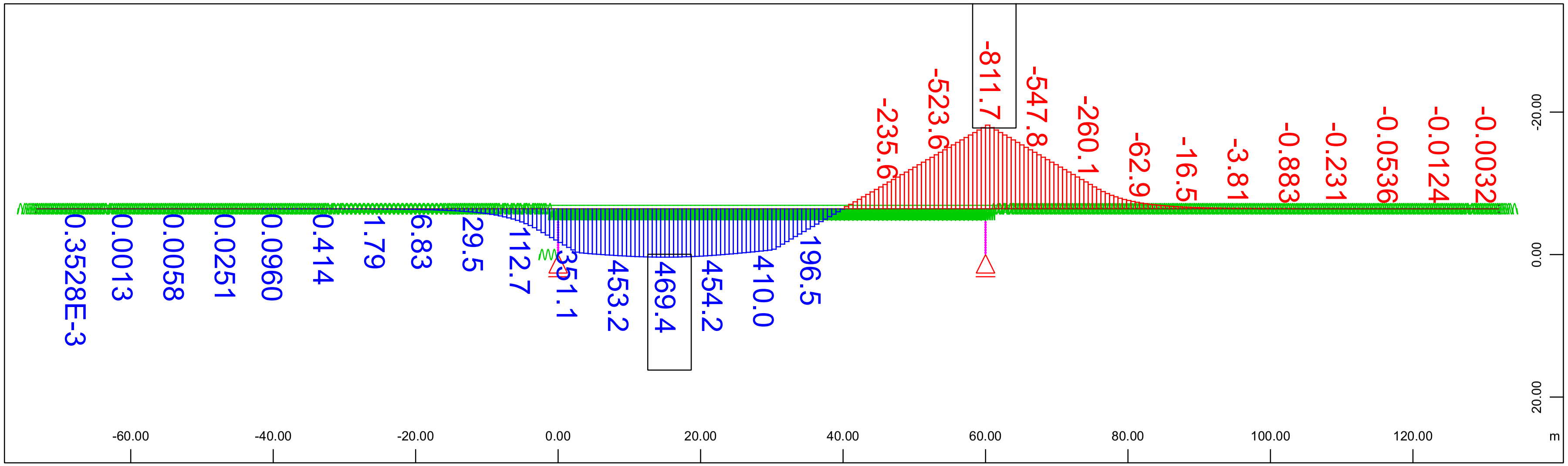
System
Interactive Graphic



Z—X
Y

Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Temperature variation - deck , (1 cm 3D = unit) Beam line load (uniform temperature change)
(Unit=126.2 °C) (Max=35.0)

M 1 : 1761



Z—X
Y

Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Temperature variation - deck , 1 cm 3D = 597.7 kN (Min=-811.7) (Max=469.4)

M 1 : 865

reduced scale factor 0.936

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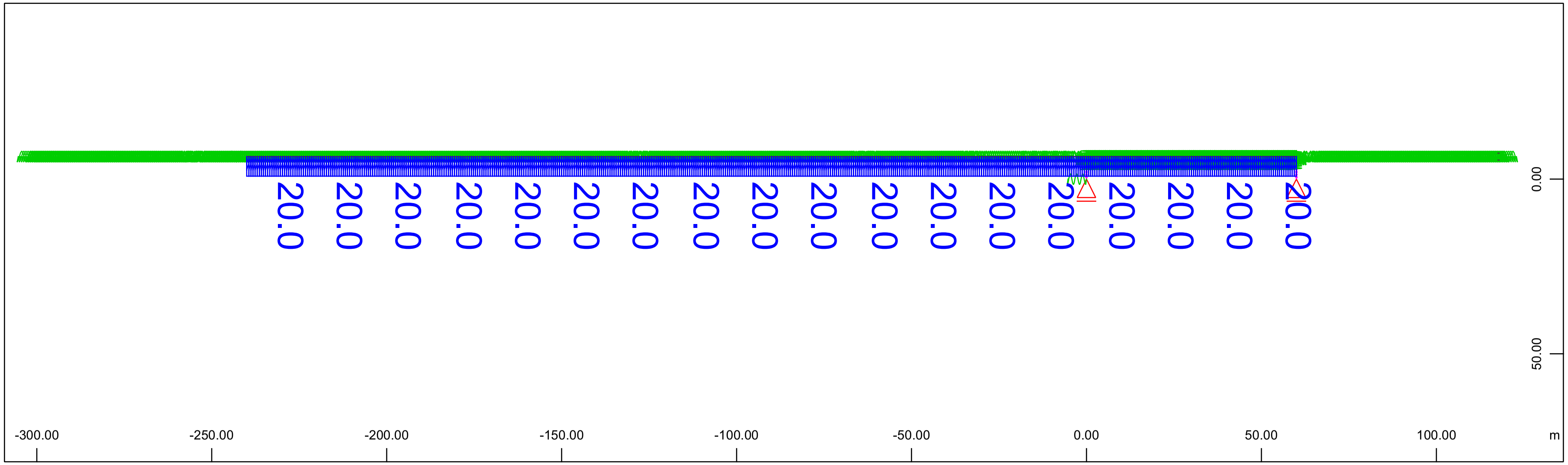
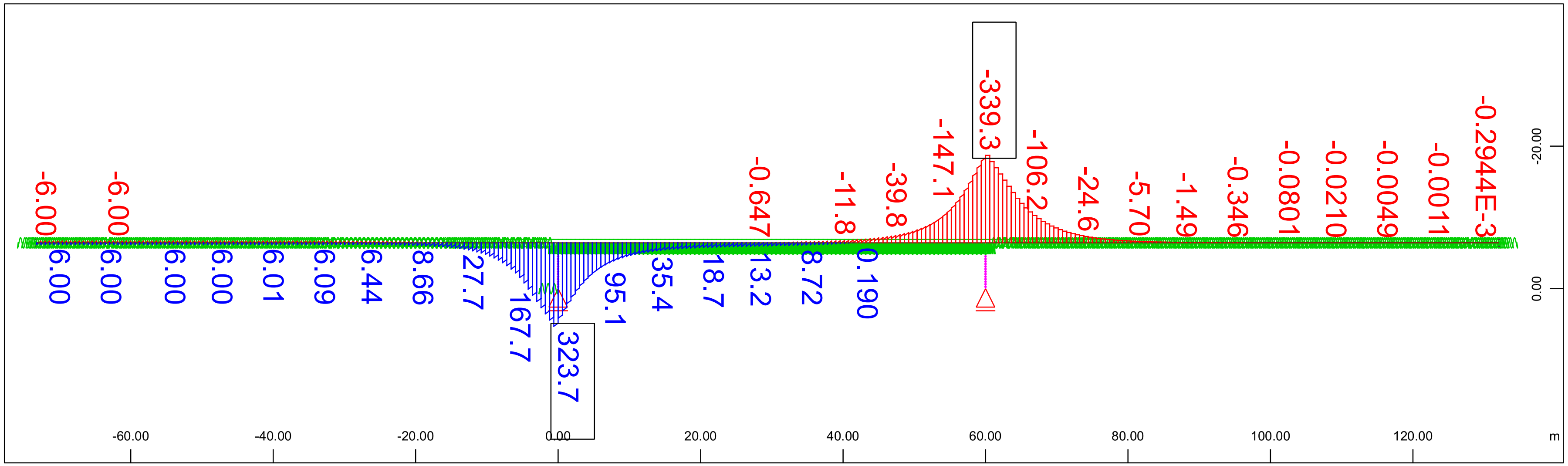
E1.3. Track slab + a floating slab mat with a thickness of 28 mm with a horizontal stiffness - Braking force

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Braking force 60 m from the fixe , (1 cm 3D = unit) Beam line load (force) in global X (Unit=63.1 kN/m) (Max=20.0)

M 1 : 1761



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Braking force 60 m from the fixe , 1 cm 3D = 239.1 kN (Min=-339.3) (Max=323.7)

M 1 : 865

reduced scale factor 0.936

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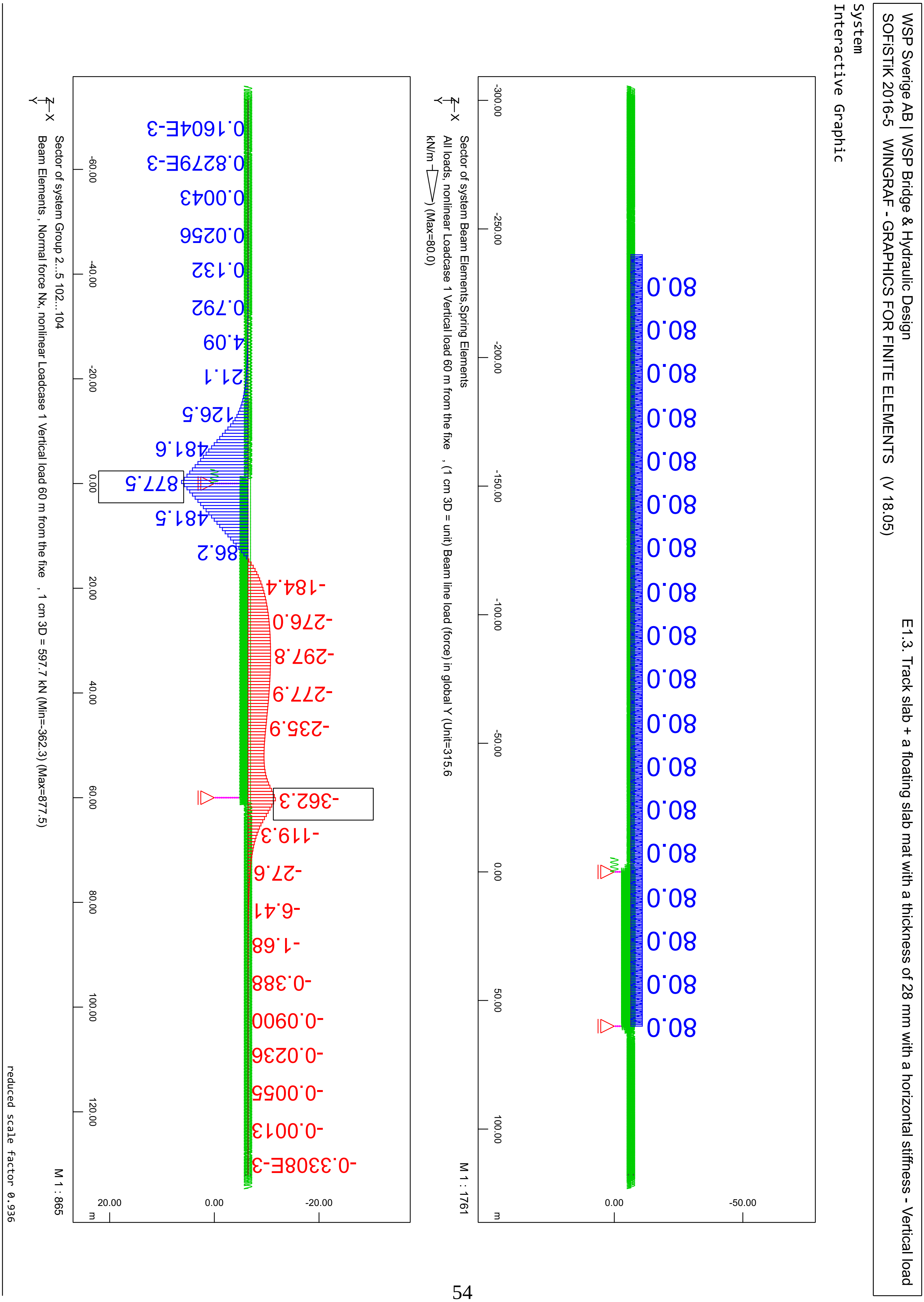

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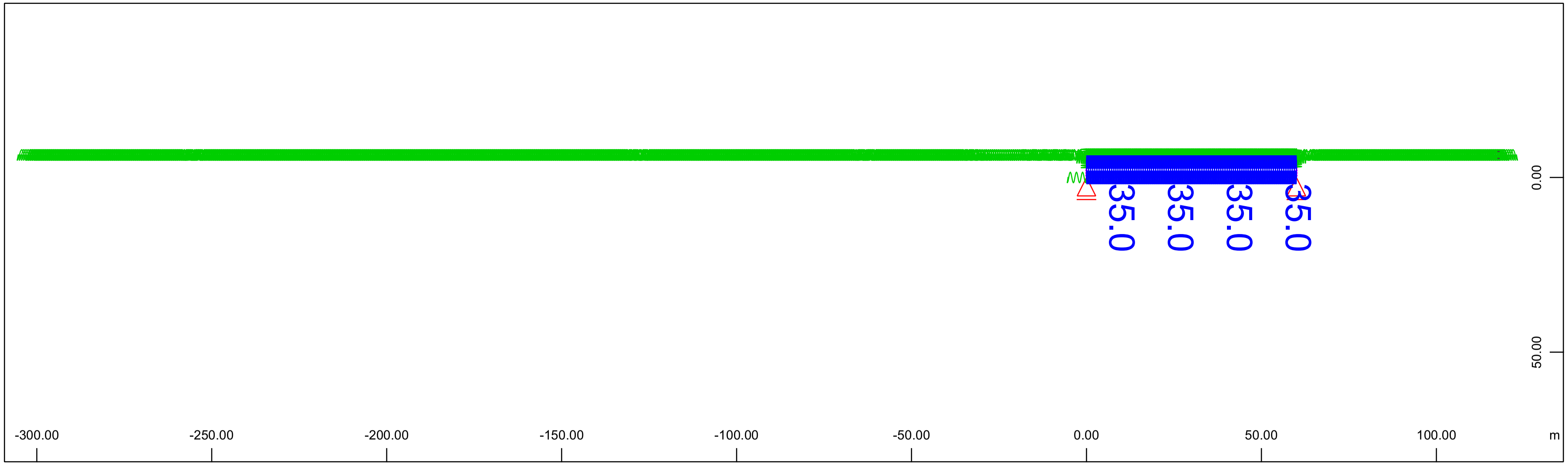
E1.3. Track slab + a floating slab mat with a thickness of 30 mm with a horizontal stiffness - Temperature variation - deck

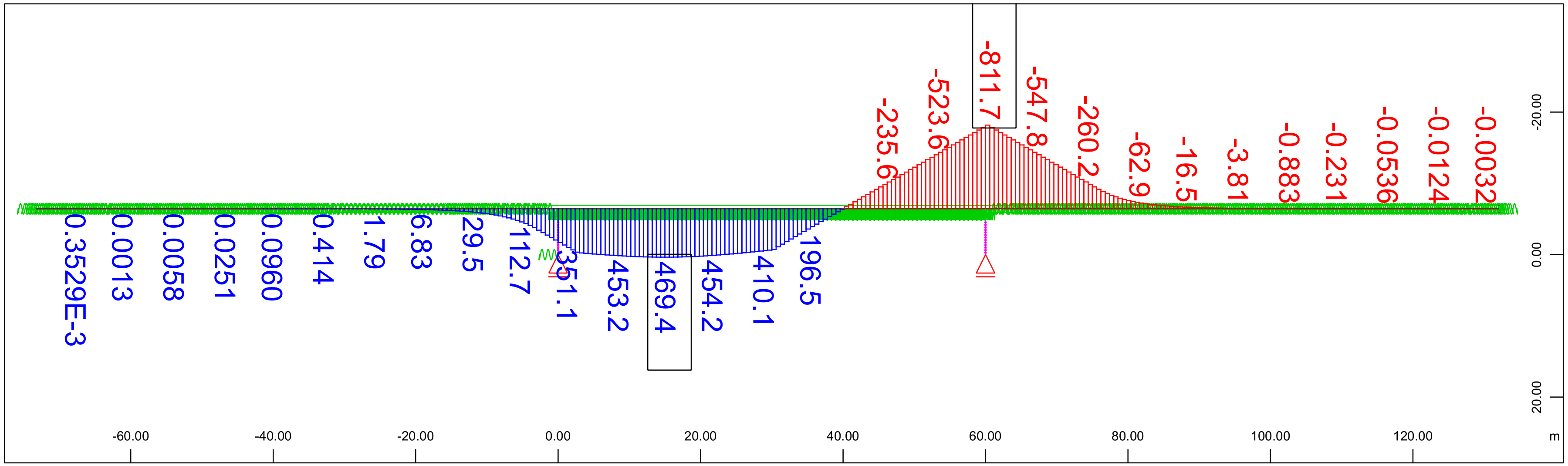
System
Interactive Graphic



Z—X
Y

Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Temperature variation - deck , (1 cm 3D = unit) Beam line load (uniform temperature change)
(Unit=126.2 °C) (Max=35.0)

M 1 : 1761



Z—X
Y

Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Temperature variation - deck , 1 cm 3D = 597.7 kN (Min=-811.7) (Max=469.4)

M 1 : 865

reduced scale factor 0.936

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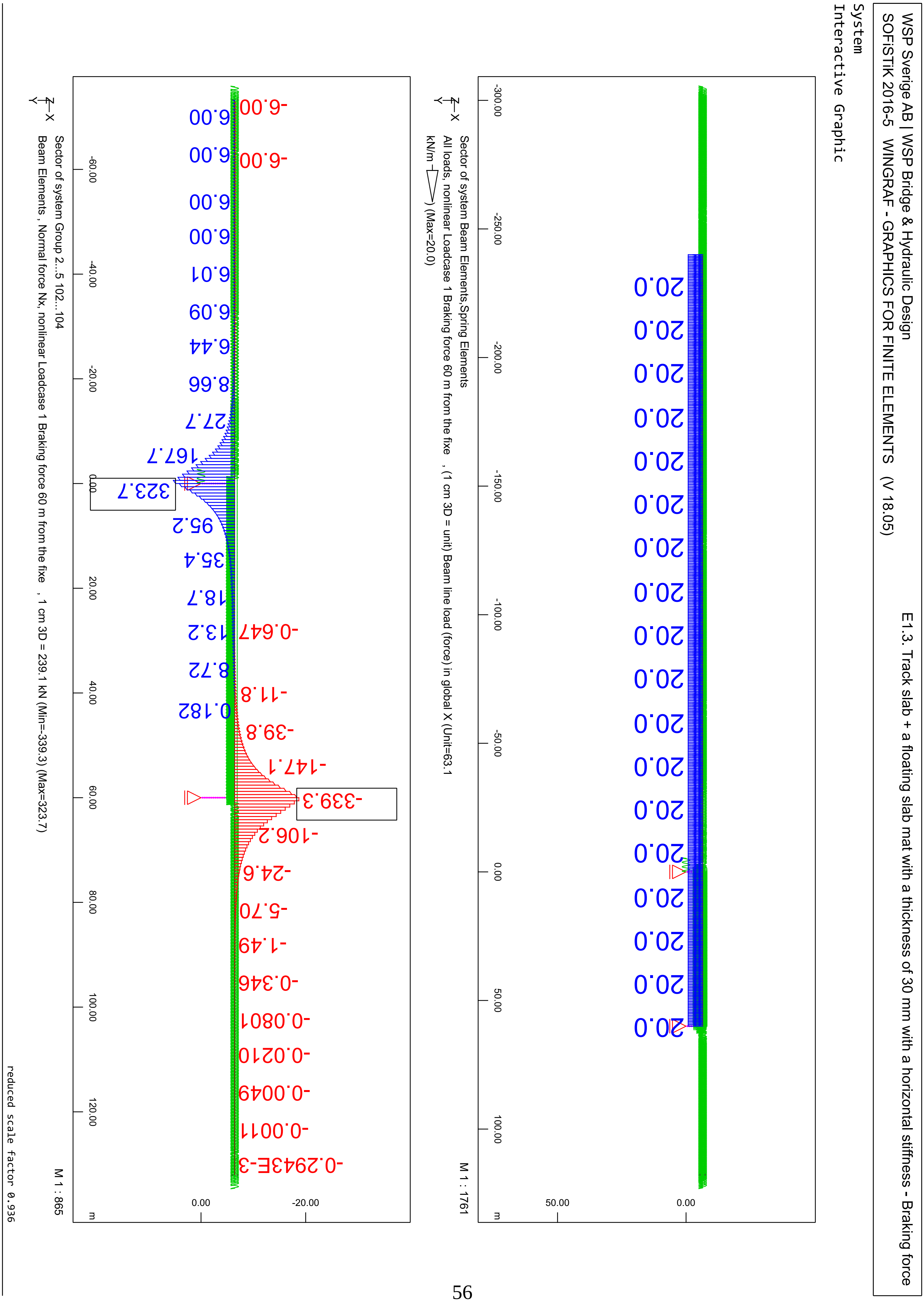

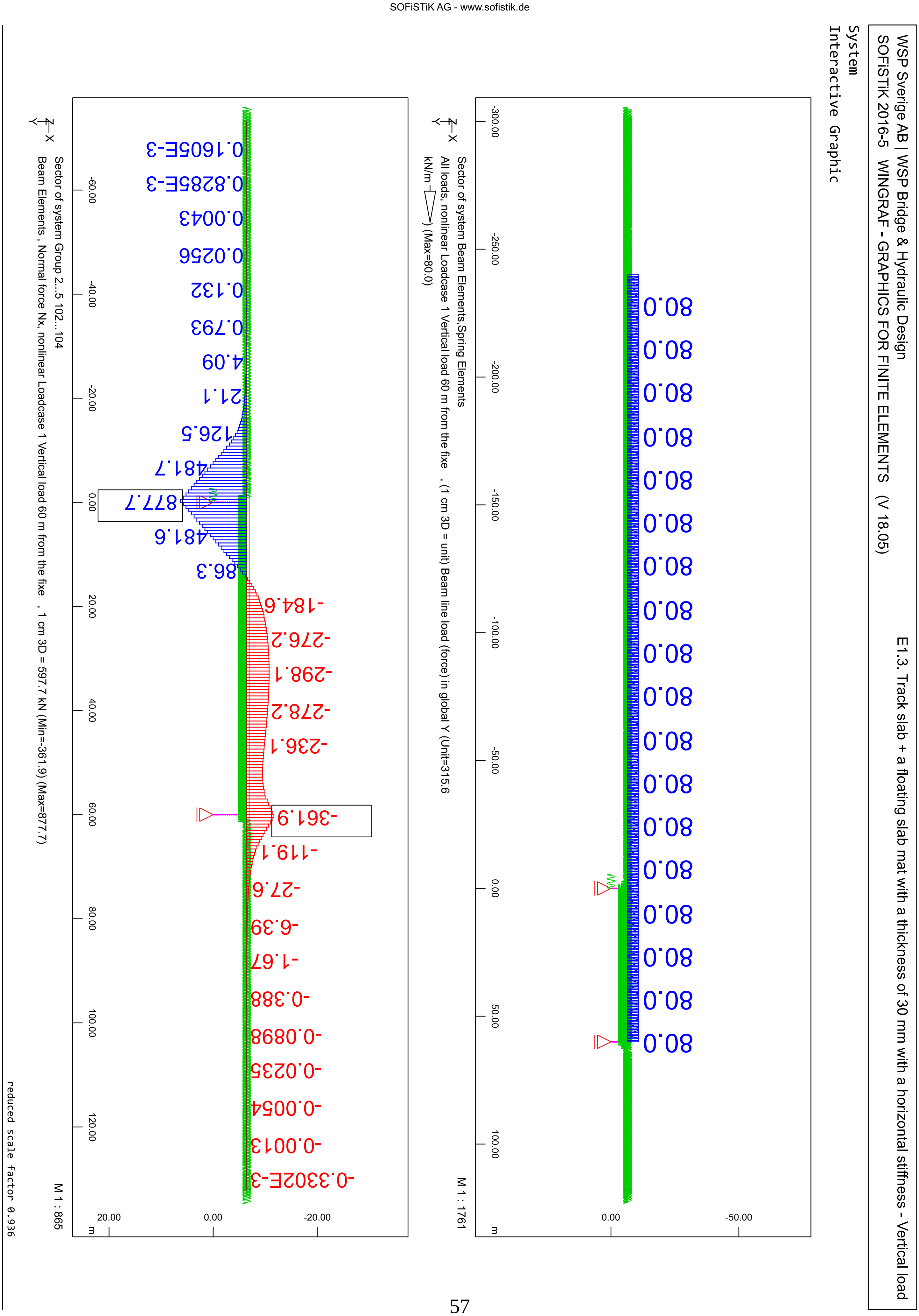
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E1.3. Track slab + a floating slab mat with a thickness of 30 mm with a horizontal stiffness - Vertical load
System
Interactive Graphic
Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Vertical load 60 m from the fixe , (1 cm 3D = unit) Beam line load (force) in global Y (Unit=315.6 kN/m) (Max=80.0)
M 1 : 1761
80.0
Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Vertical load 60 m from the fixe , 1 cm 3D = 597.7 kN (Min=-361.9) (Max=877.7)
M 1 : 865
0.1605E-3
0.8285E-3
0.0043
0.0256
0.132
0.793
4.09
21.1
126.5
481.7
877.7
481.6
86.3
-184.6
-276.2
-298.1
-278.2
-236.1
-361.9
-119.1
-27.6
-6.39
-1.67
-0.388
-0.0898
-0.0235
-0.0054
-0.0013
-0.3302E-3
reduced scale factor 0.936

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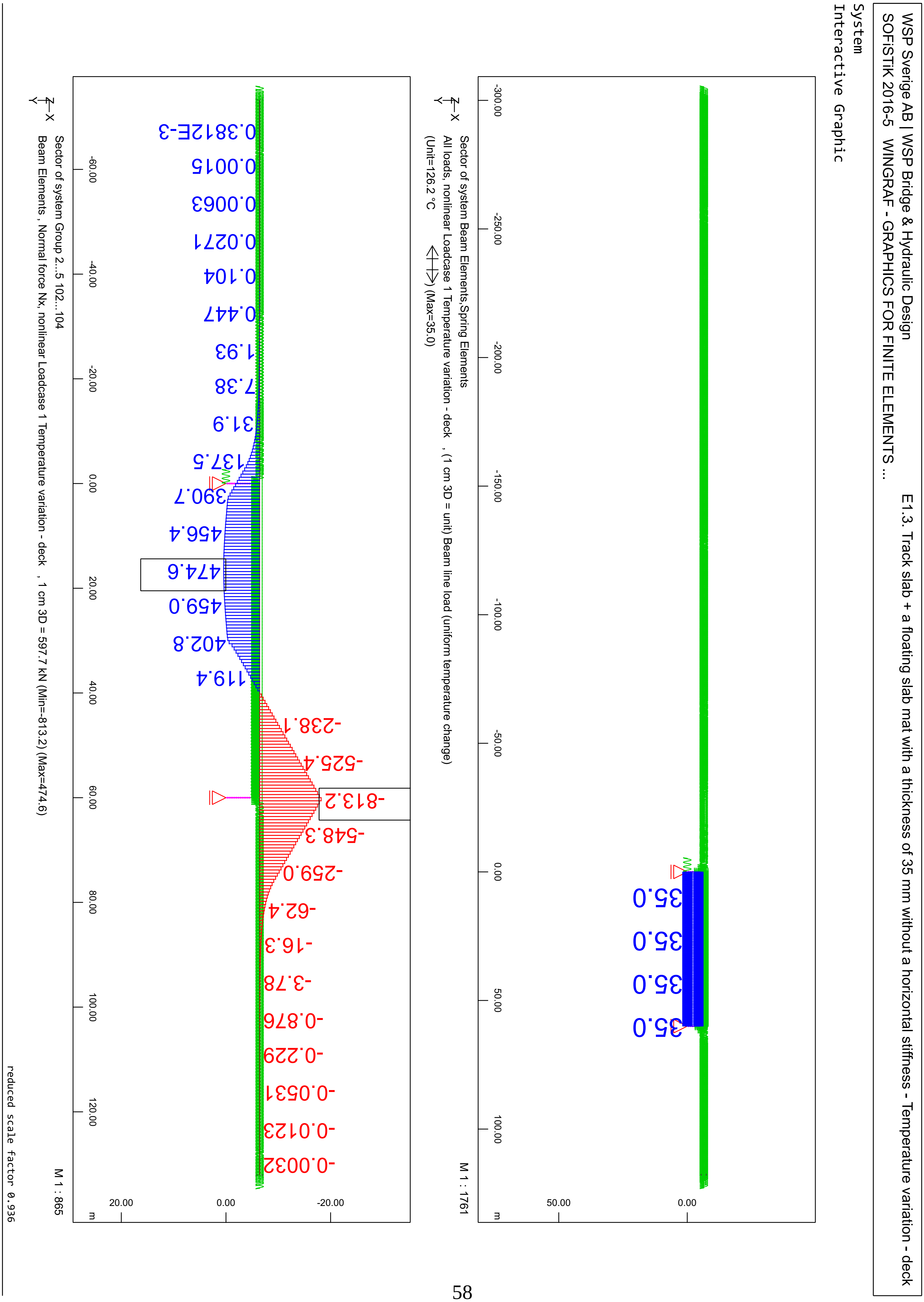

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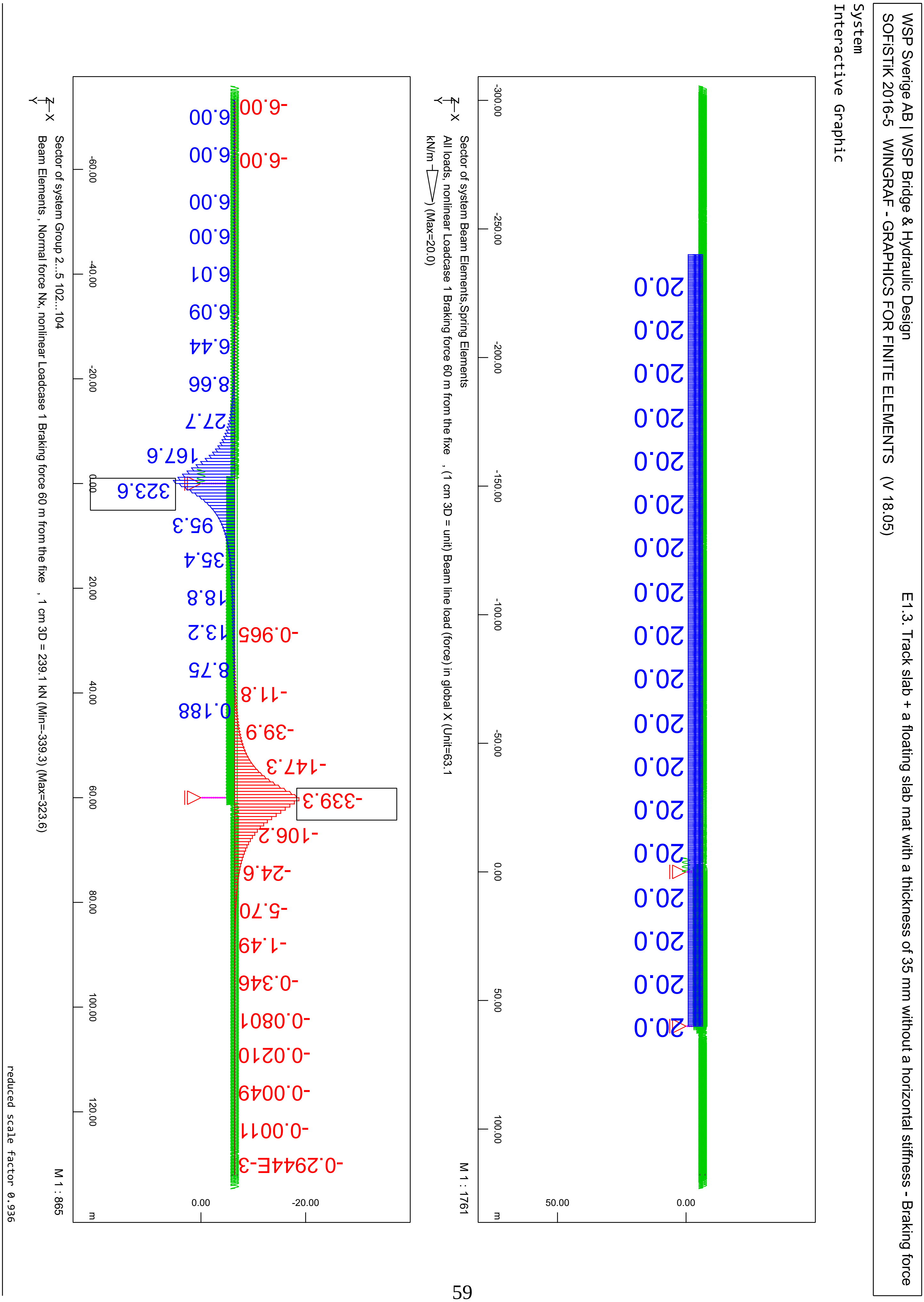
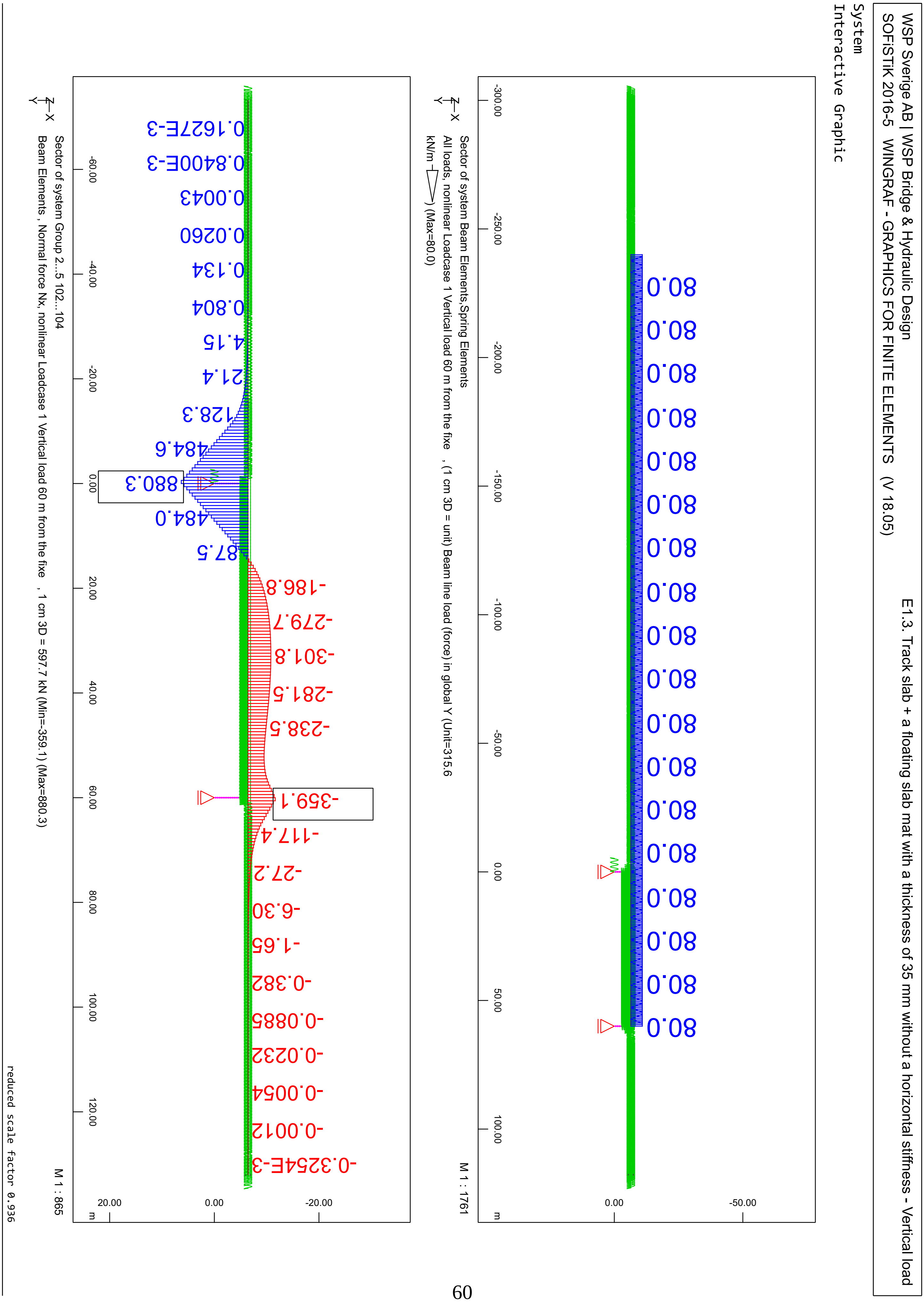


SOFiSTiK AG - www.sofistik.de



2.5 F4-6 - Detailed normal force diagrams from the model with a floating slab mat without a horizontal stiffness

On the following pages are detailed normal force diagrams for test case F4-6 with a floating slab mat without a horizontal stiffness presented.

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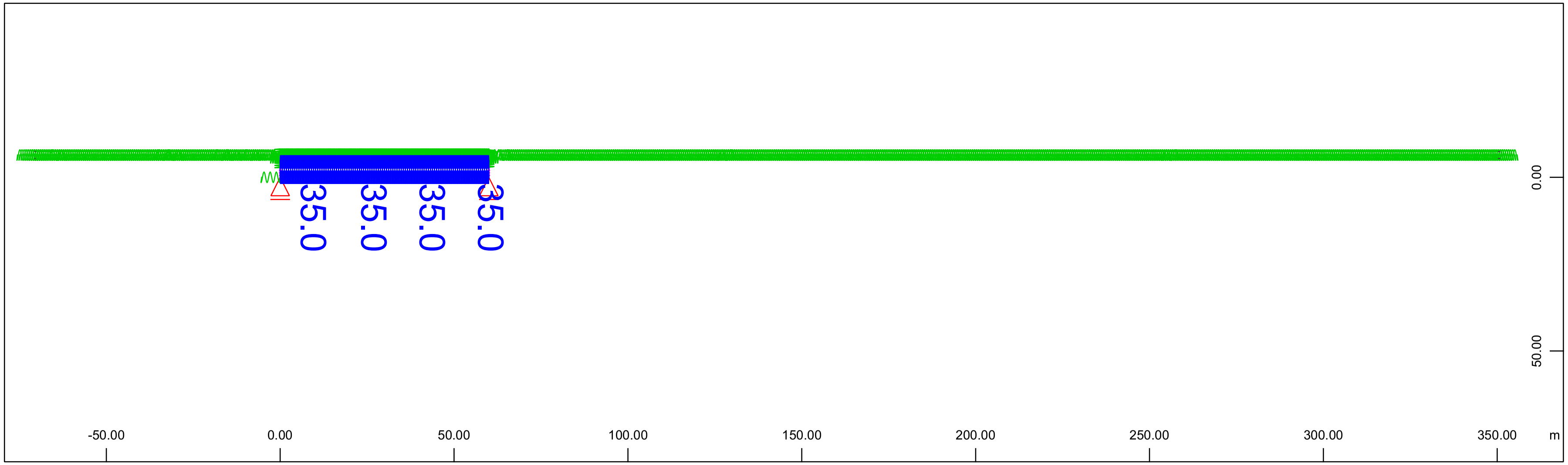
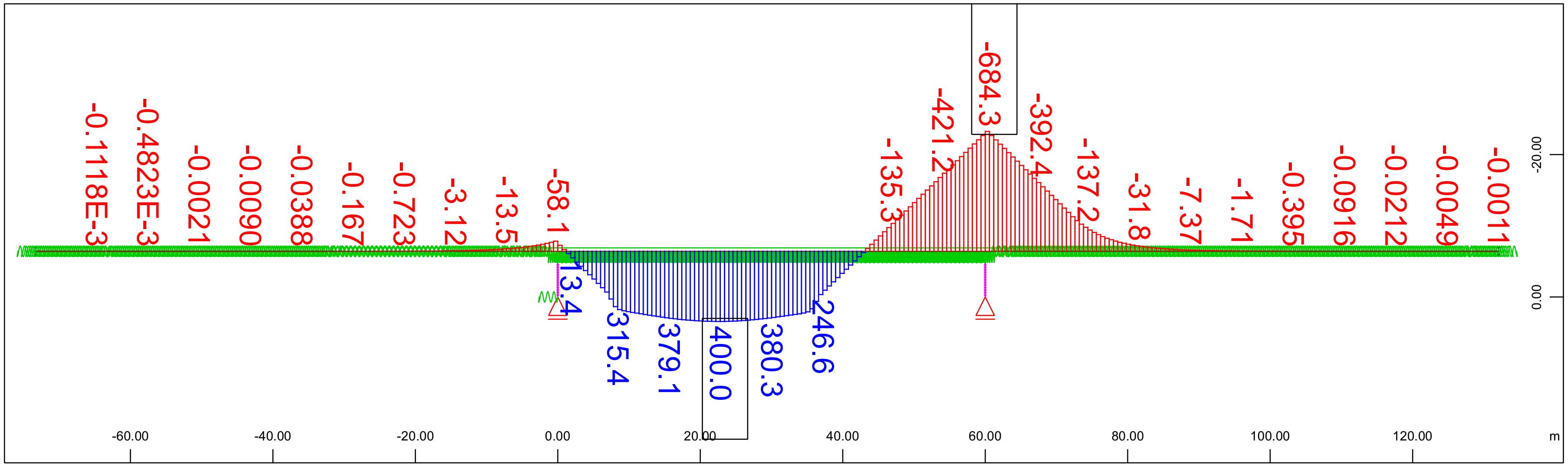
F4-6. Track slab + a floating slab mat with a thickness of 12 mm without a horizontal stiffness - Temperature variation - deck

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Temperature variation - deck , (1 cm 3D = unit) Beam line load (uniform temperature change)
(Unit=126.2 °C) (Max=35.0)

M 1 : 1772



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Temperature variation - deck , 1 cm 3D = 351.6 kN (Min=-684.3) (Max=400.0)

M 1 : 865

reduced scale factor 0.936

WSP Sverige AB | WSP Bridge & Hydraulic Design	F4-6. Track slab + a floating slab mat with a thickness of 12 mm without a horizontal stiffness - Braking force
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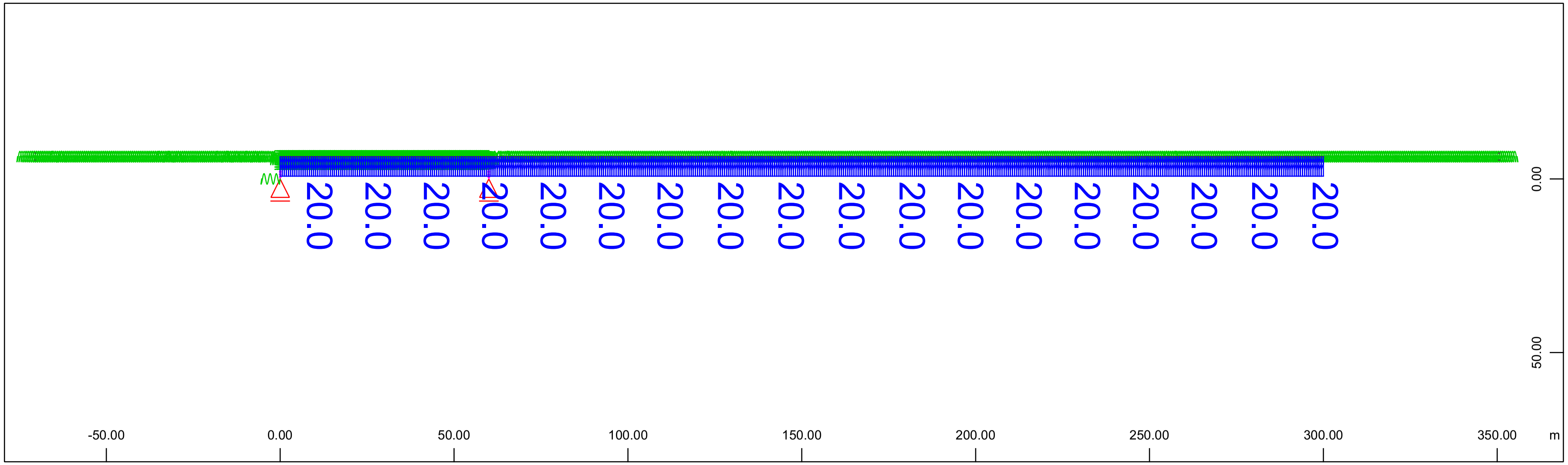
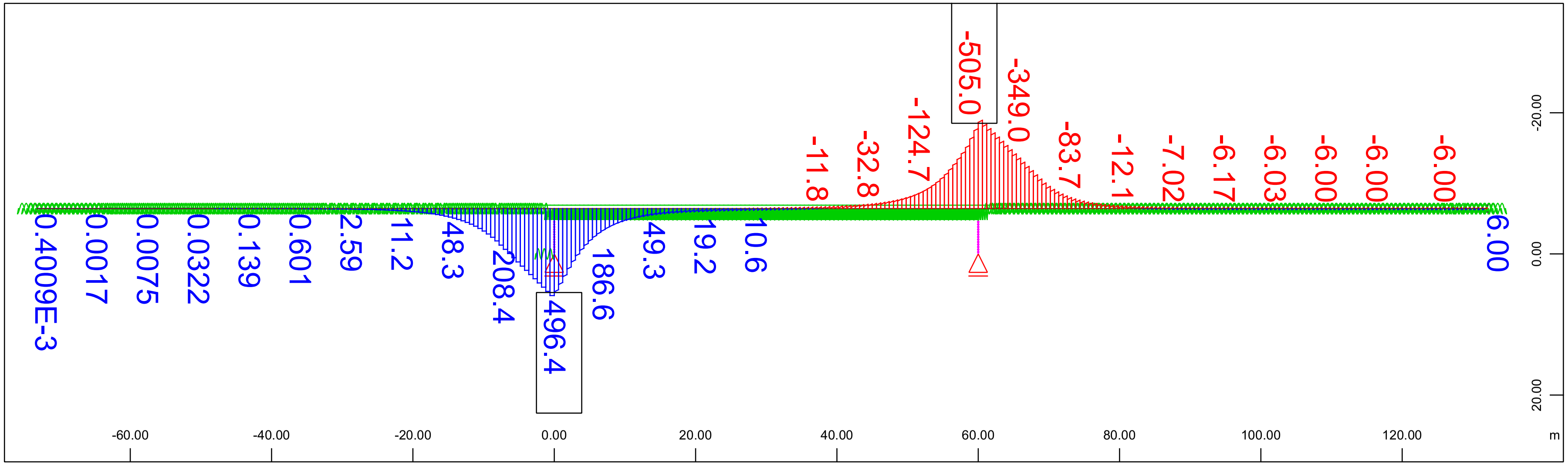
System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Braking force 60 m from the mova , (1 cm 3D = unit) Beam line load (force) in global X (Unit=63.1 kN/m) (Max=20.0)
M 1 : 1772



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Braking force 60 m from the mova , 1 cm 3D = 351.6 kN (Min=-505.0) (Max=496.4)
M 1 : 872

reduced scale factor 0.936

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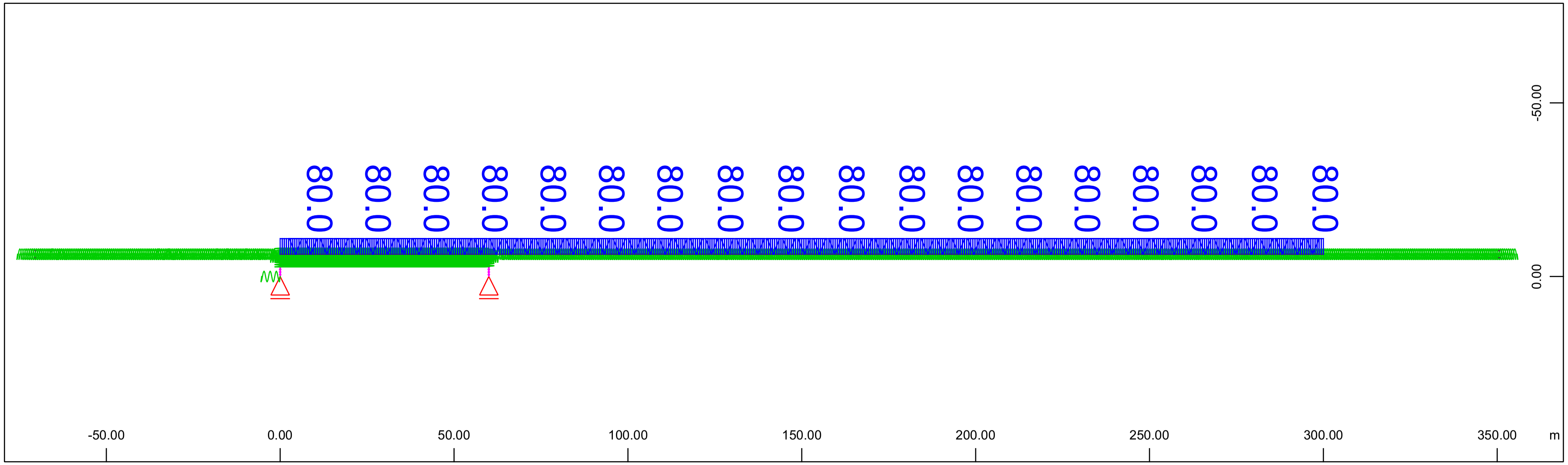
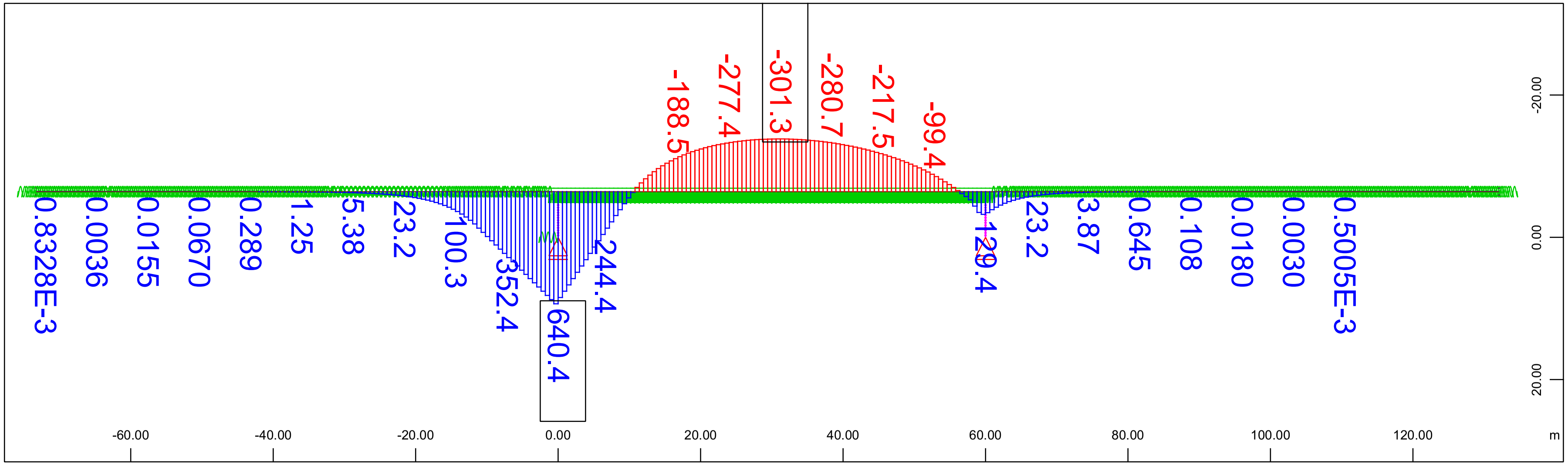
F4-6. Track slab + a floating slab mat with a thickness of 12 mm without a horizontal stiffness - Vertical load

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Vertical load 60 m from the mova , (1 cm 3D = unit) Beam line load (force) in global Y (Unit=315.6 kN/m) (Max=80.0)

M 1 : 1772



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Vertical load 60 m from the mova , 1 cm 3D = 351.6 kN (Min=-301.3) (Max=640.4)

M 1 : 865

reduced scale factor 0.936

WSP Sverige AB | WSP Bridge & Hydraulic Design F4-6. Track slab + a floating slab mat with a thickness of 15 mm without a horizontal stiffness - Temperature variation - deck
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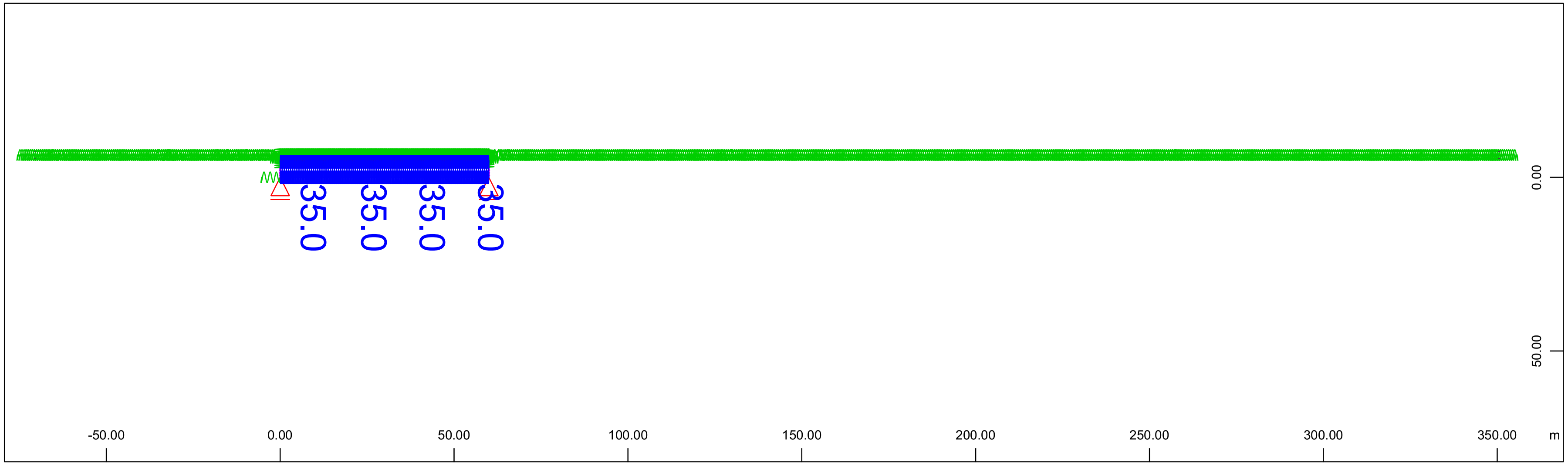
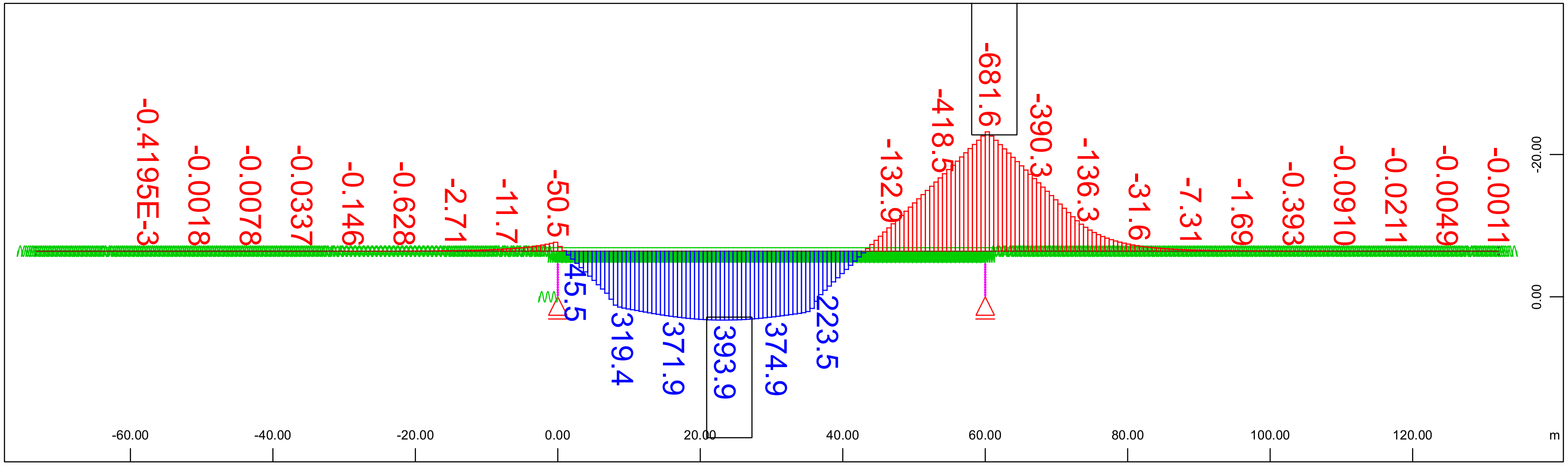
System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Temperature variation - deck , (1 cm 3D = unit) Beam line load (uniform temperature change)
(Unit=126.2 °C) (Max=35.0)
M 1 : 1772



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Temperature variation - deck , 1 cm 3D = 351.6 kN (Min=-681.6) (Max=393.9)
M 1 : 865

reduced scale factor 0.936

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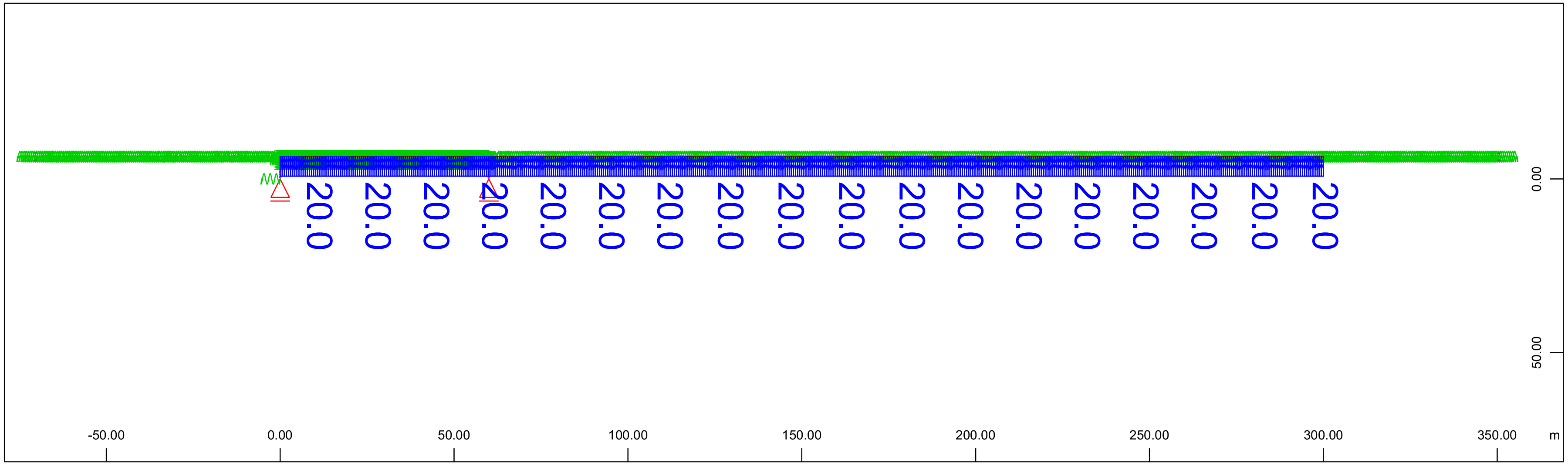
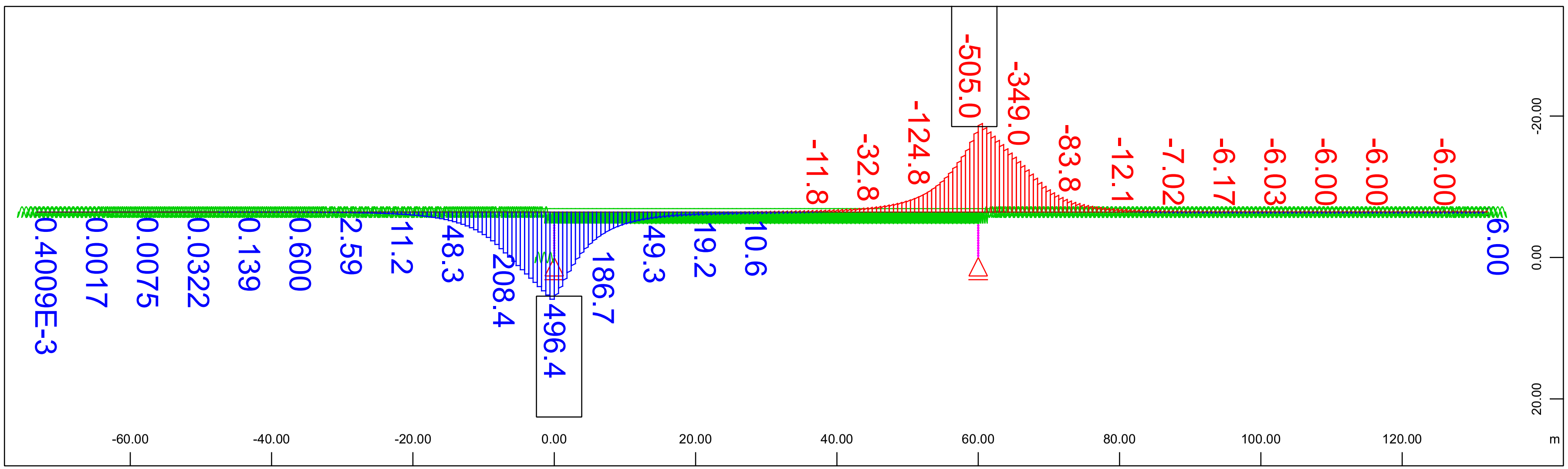
F4-6. Track slab + a floating slab mat with a thickness of 15 mm without a horizontal stiffness - Braking force

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Braking force 60 m from the mova , (1 cm 3D = unit) Beam line load (force) in global X (Unit=63.1 kN/m) (Max=20.0)
M 1 : 1772



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Braking force 60 m from the mova , 1 cm 3D = 351.6 kN (Min=-505.0) (Max=496.4)
M 1 : 872

reduced scale factor 0.936

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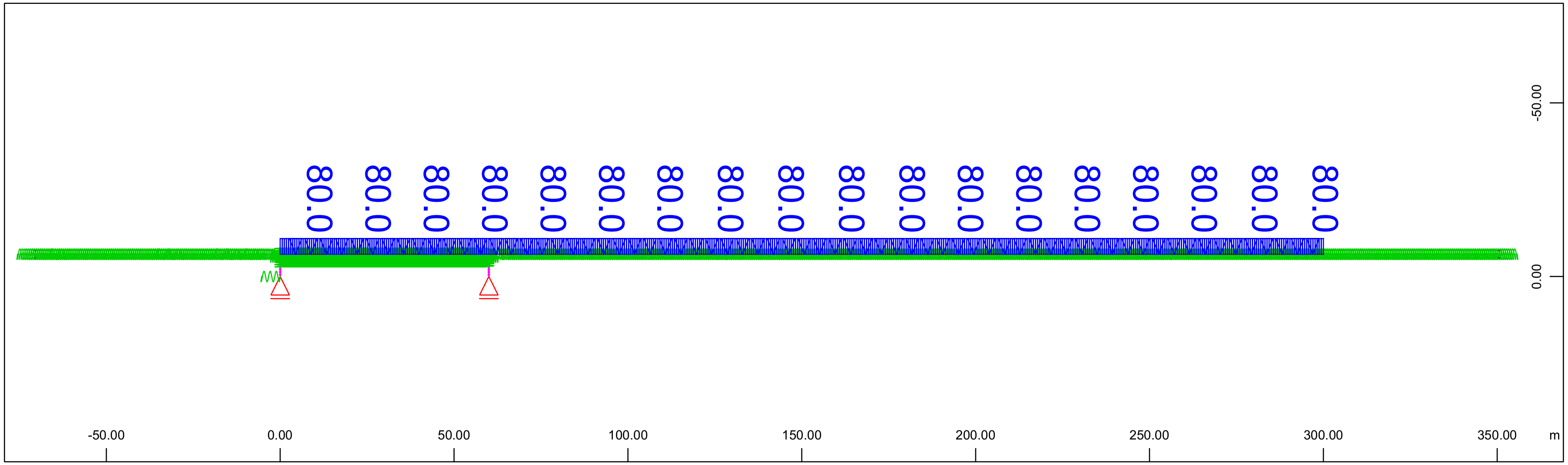
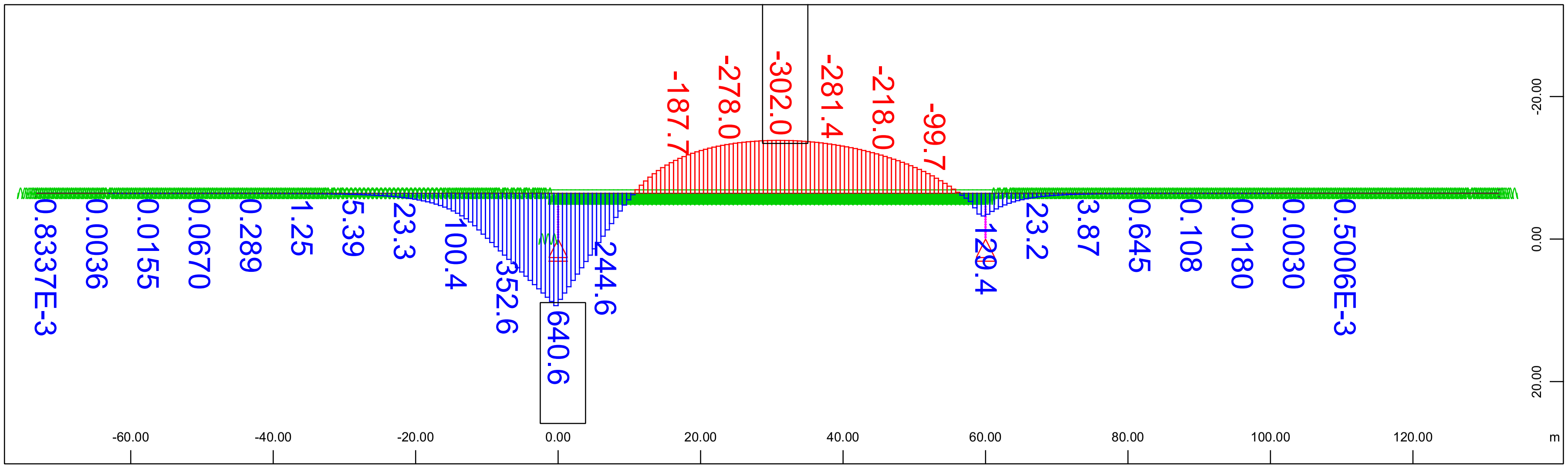
F4-6. Track slab + a floating slab mat with a thickness of 15 mm without a horizontal stiffness - Vertical load

System
Interactive Graphic



Z X Y
Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Vertical load 60 m from the mova , (1 cm 3D = unit) Beam line load (force) in global Y (Unit=315.6 kN/m) (Max=80.0)

M 1 : 1772



Z X Y
Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Vertical load 60 m from the mova , 1 cm 3D = 351.6 kN (Min=-302.0) (Max=640.6)

M 1 : 865

reduced scale factor 0.936

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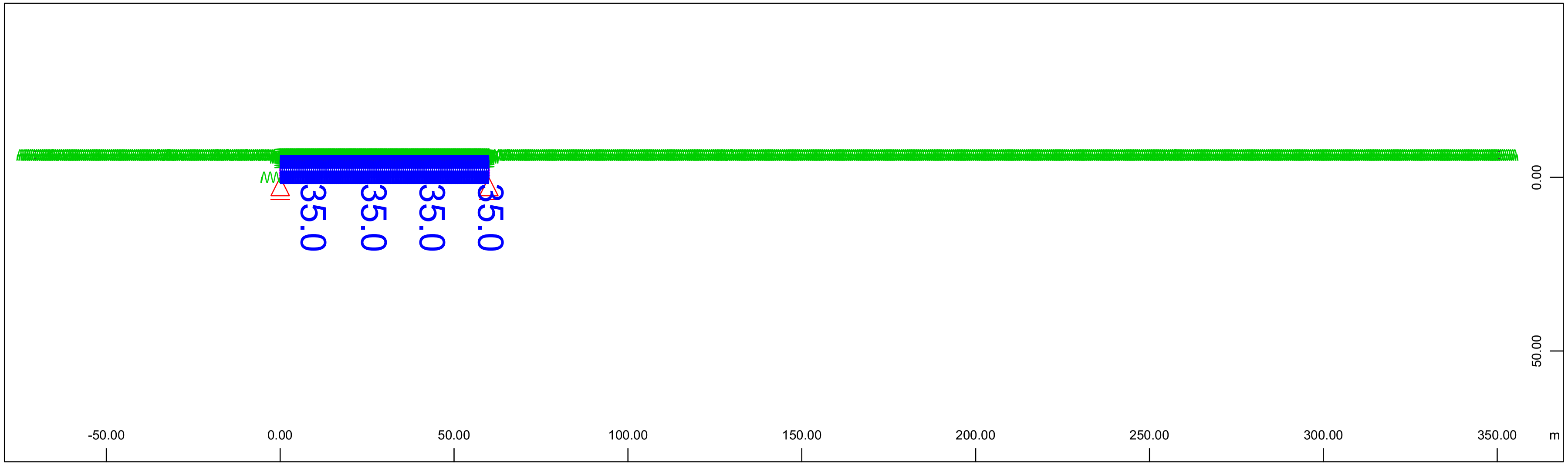
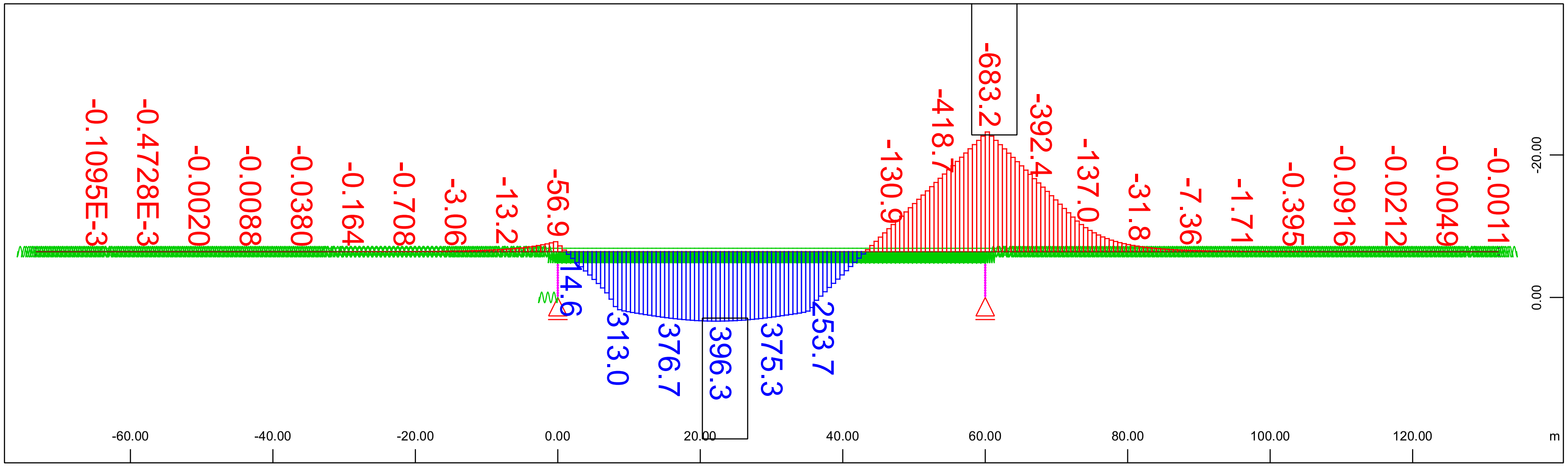
F4-6. Track slab + a floating slab mat with a thickness of 20 mm without a horizontal stiffness - Temperature variation - deck

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Temperature variation - deck , (1 cm 3D = unit) Beam line load (uniform temperature change)
(Unit=126.2 °C) (Max=35.0)

M 1 : 1772



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Temperature variation - deck , 1 cm 3D = 351.6 kN (Min=-683.2) (Max=396.3)

M 1 : 865

reduced scale factor 0.936

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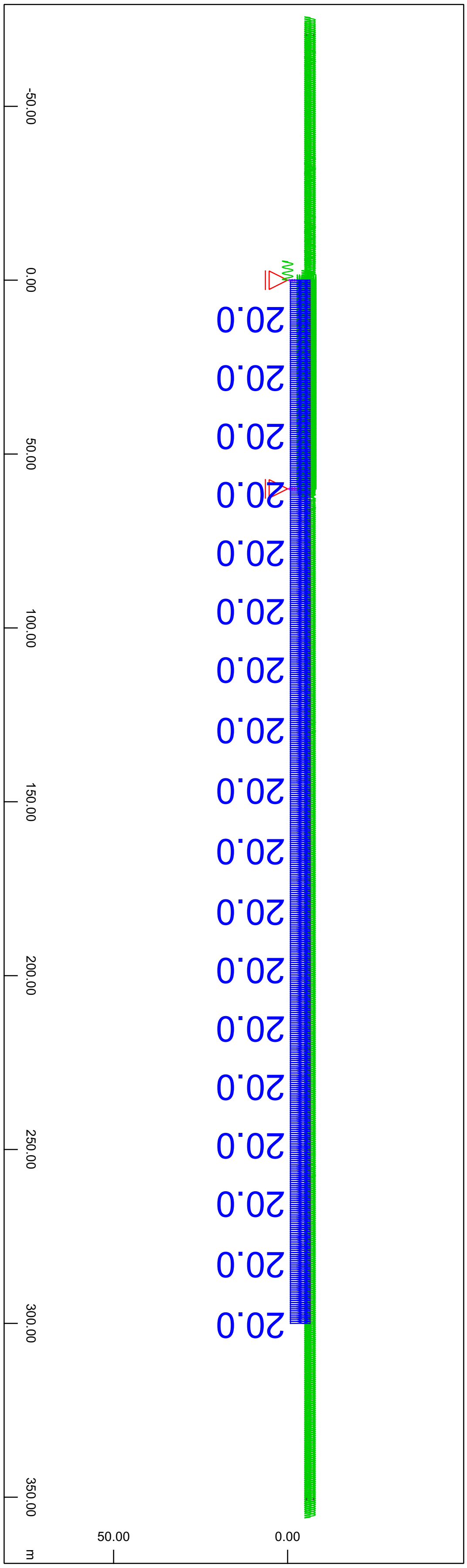
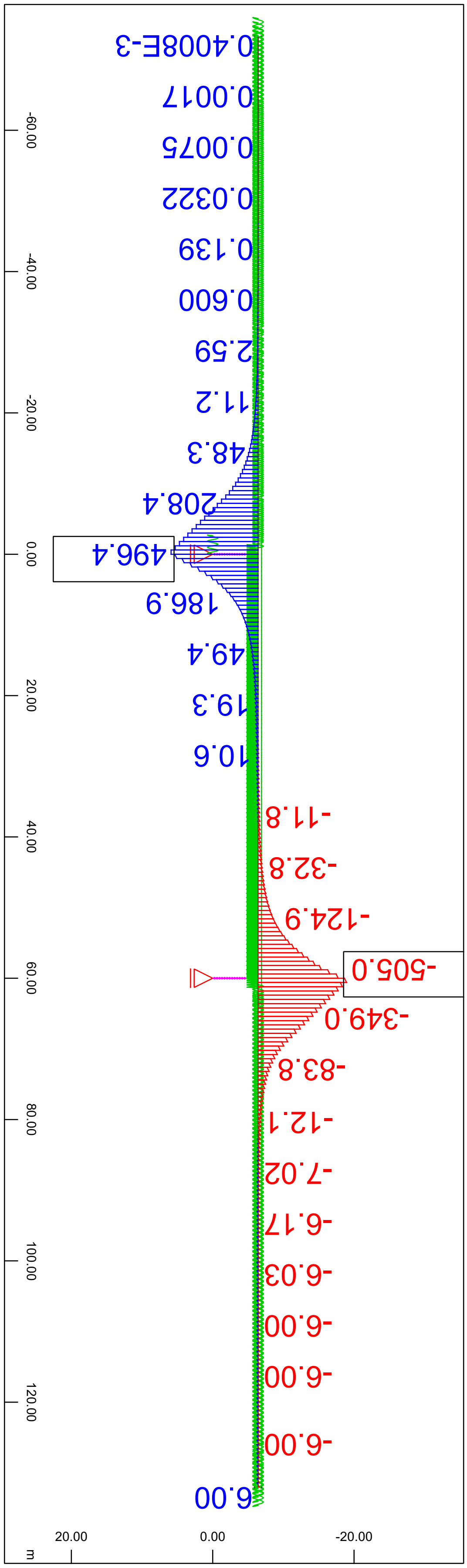
F4-6. Track slab + a floating slab mat with a thickness of 20 mm without a horizontal stiffness - Braking force

System
Interactive Graphic



M 1 : 1772

Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Braking force 60 m from the mova , (1 cm 3D = unit) Beam line load (force) in global X (Unit=63.1 kN/m) (Max=20.0)



M 1 : 872

Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Braking force 60 m from the mova , 1 cm 3D = 351.6 kN (Min=-505.0) (Max=496.4)

reduced scale factor 0.936

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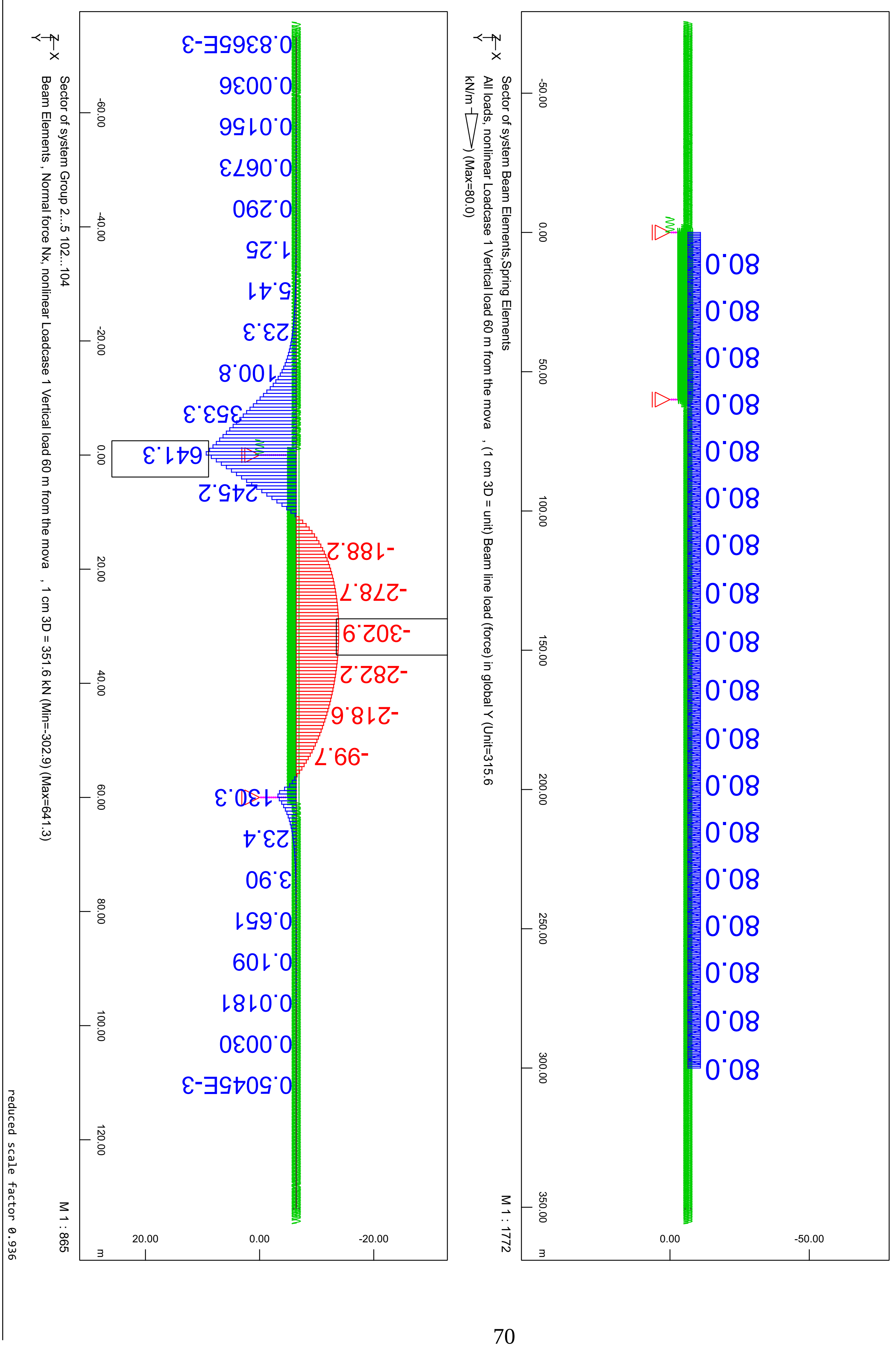
F4-6. Track slab + a floating slab mat with a thickness of 20 mm without a horizontal stiffness - Vertical load

System
Interactive Graphic



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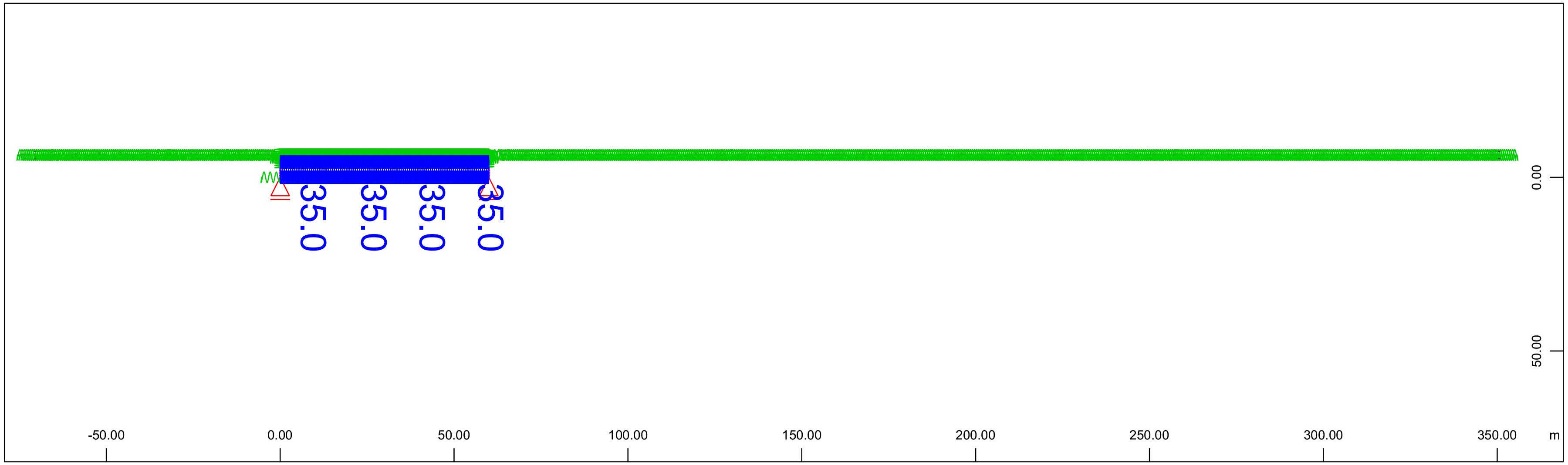
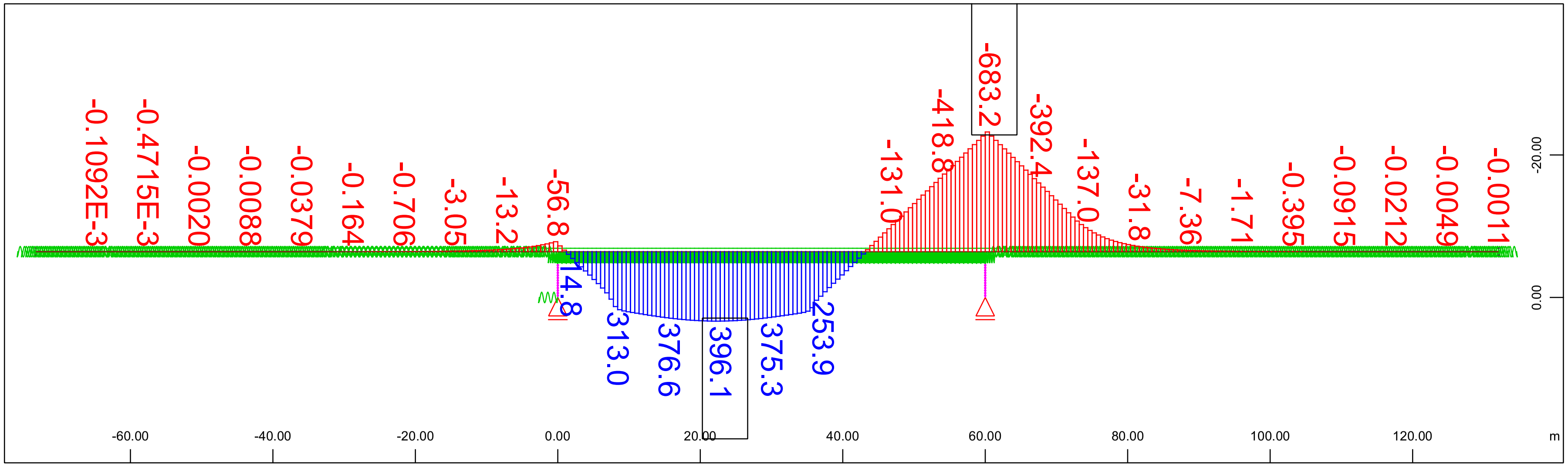
F4-6. Track slab + a floating slab mat with a thickness of 25 mm without a horizontal stiffness - Temperature variation - deck

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Temperature variation - deck , (1 cm 3D = unit) Beam line load (uniform temperature change)
(Unit=126.2 °C) (Max=35.0)

M 1 : 1772



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Temperature variation - deck , 1 cm 3D = 351.6 kN (Min=-683.2) (Max=396.1)

M 1 : 865

reduced scale factor 0.936

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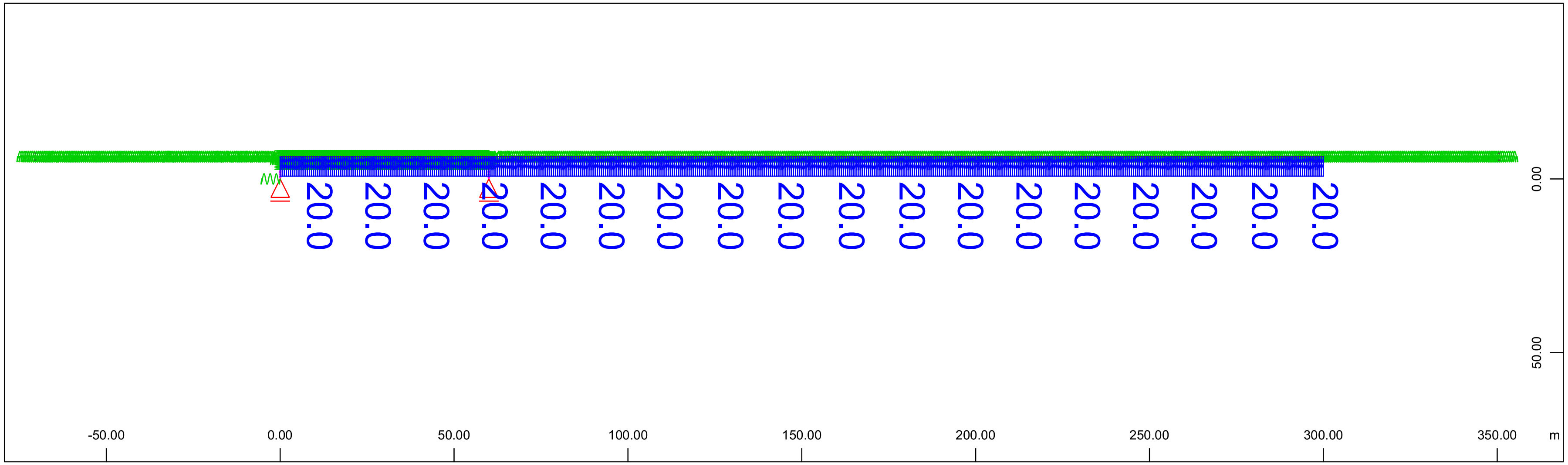
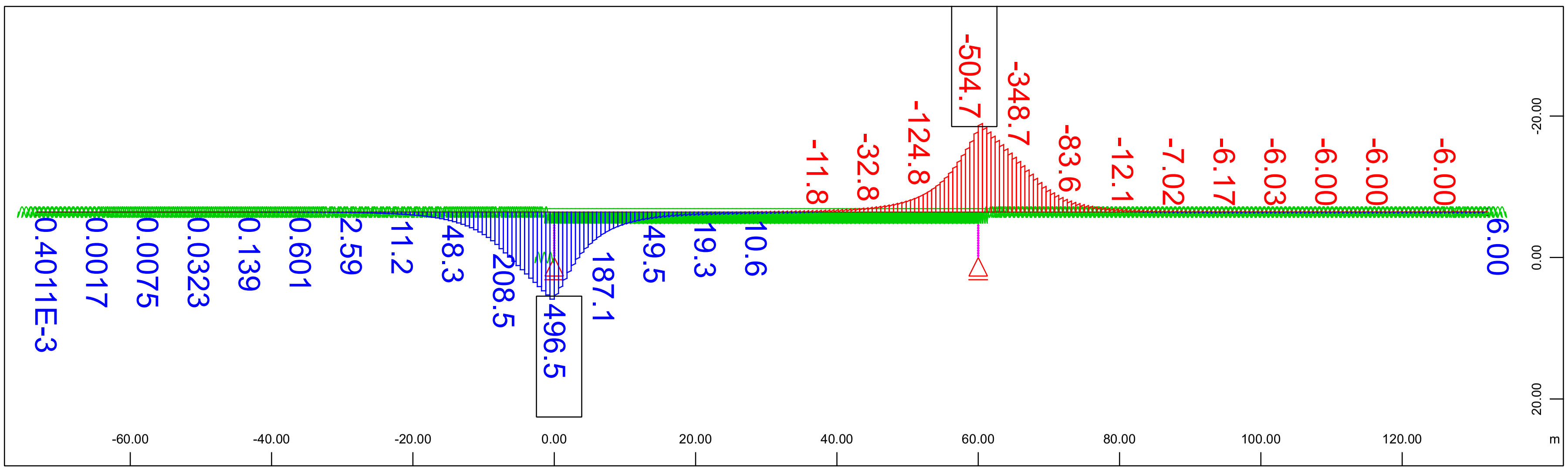
F4-6. Track slab + a floating slab mat with a thickness of 25 mm without a horizontal stiffness - Braking force

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Braking force 60 m from the mova , (1 cm 3D = unit) Beam line load (force) in global X (Unit=63.1 kN/m) (Max=20.0)

M 1 : 1772



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Braking force 60 m from the mova , 1 cm 3D = 351.6 kN (Min=-504.7) (Max=496.5)

M 1 : 872

reduced scale factor 0.936

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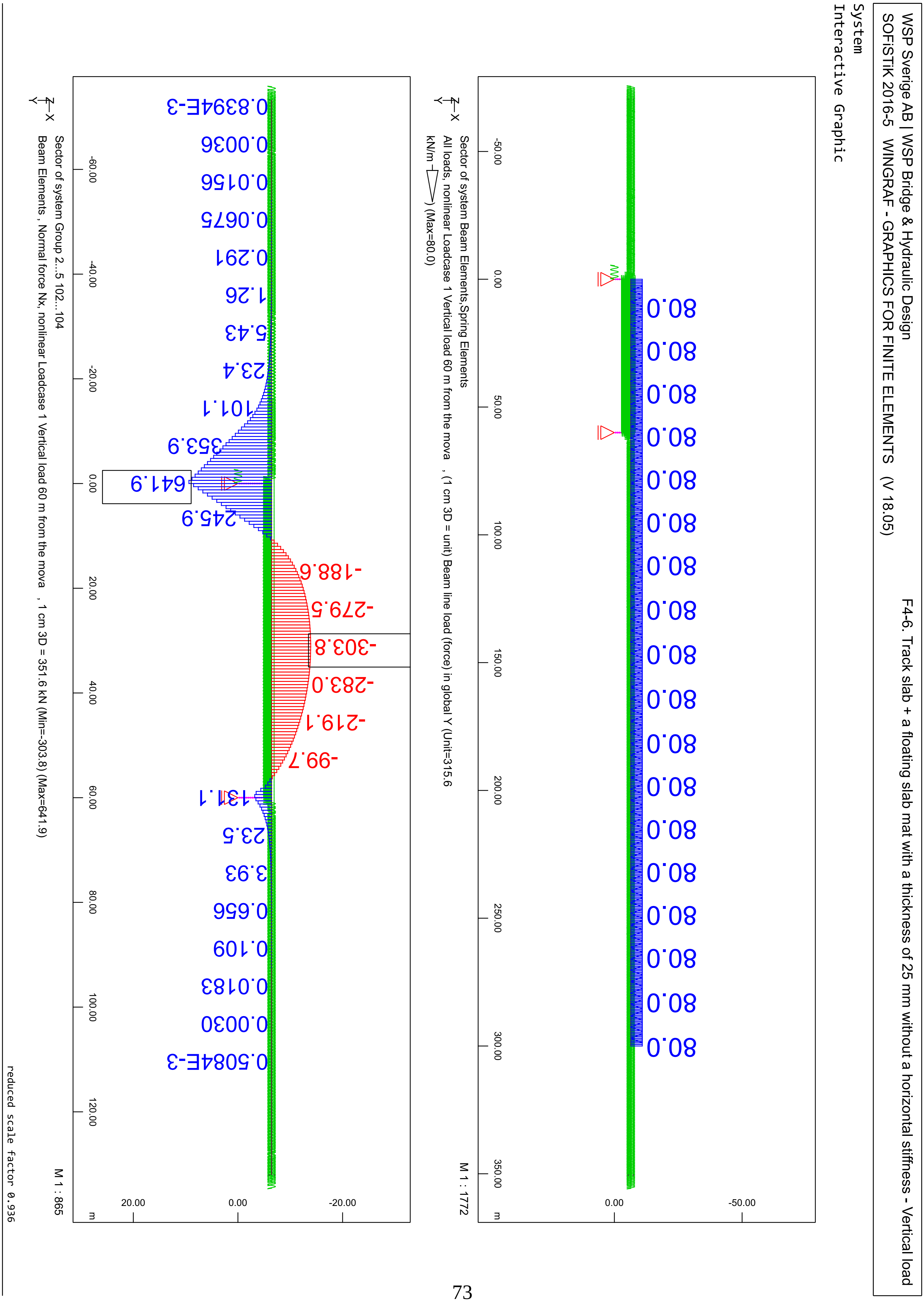

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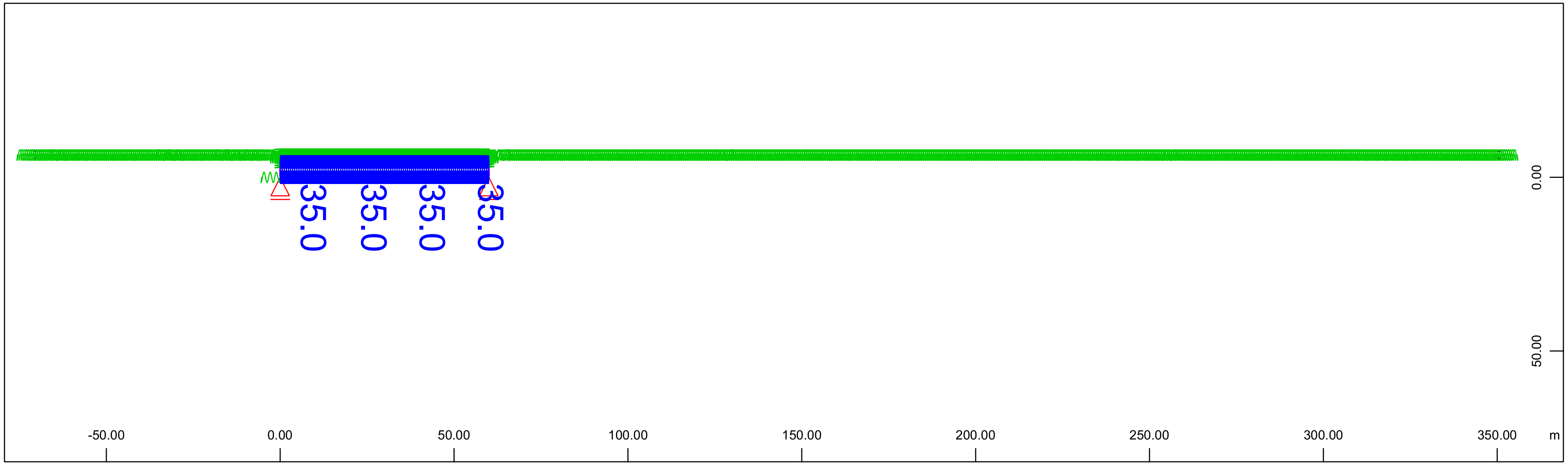
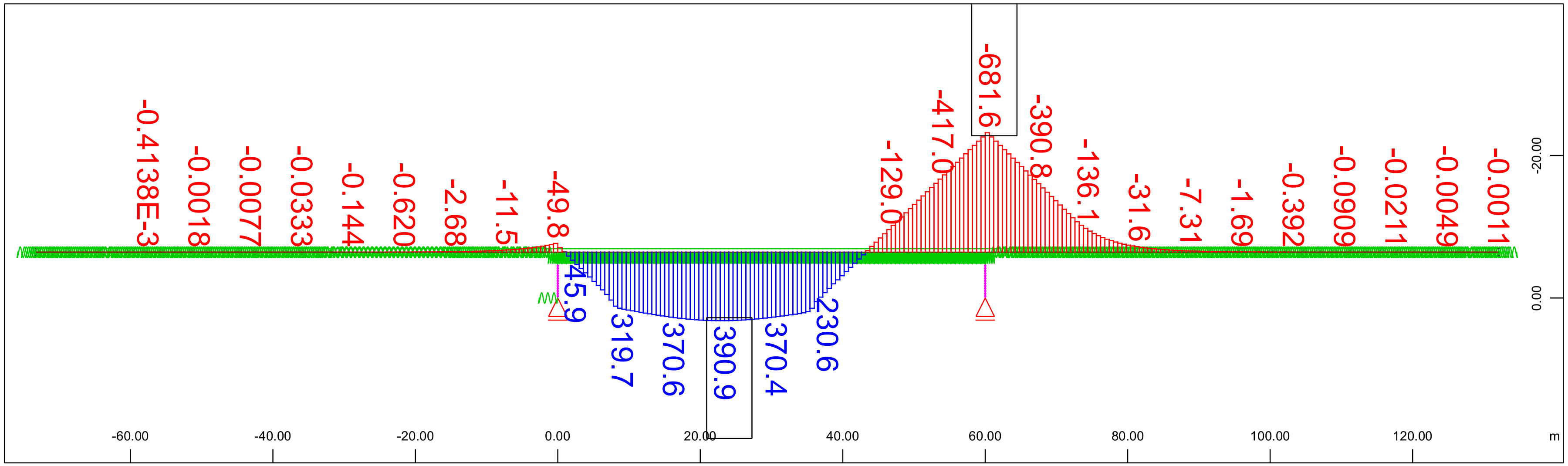
F4-6. Track slab + a floating slab mat with a thickness of 28 mm without a horizontal stiffness - Temperature variation - deck

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Temperature variation - deck , (1 cm 3D = unit) Beam line load (uniform temperature change)
(Unit=126.2 °C) (Max=35.0)
M 1 : 1772



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Temperature variation - deck , 1 cm 3D = 351.6 kN (Min=-681.6) (Max=390.9)
M 1 : 865

reduced scale factor 0.936

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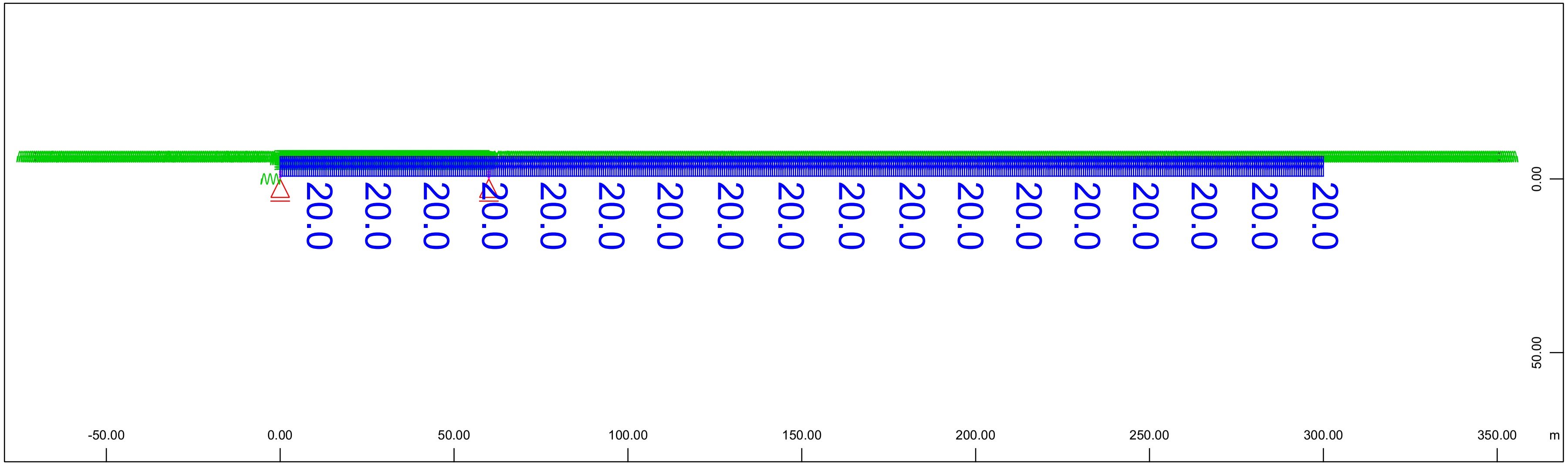
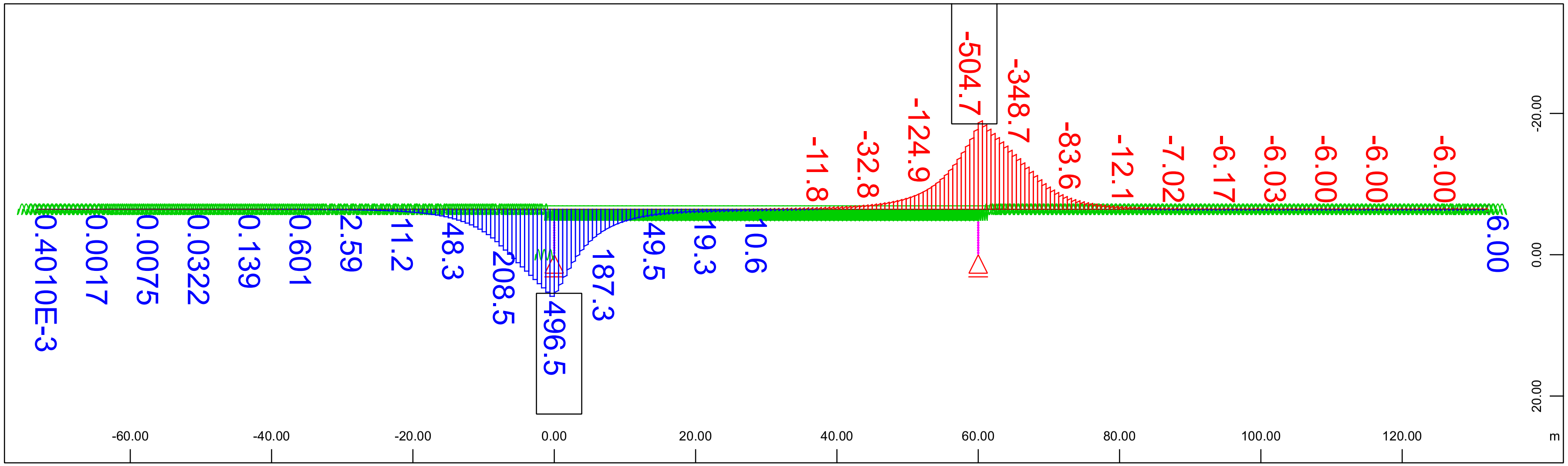
F4-6. Track slab + a floating slab mat with a thickness of 28 mm without a horizontal stiffness - Braking force

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Braking force 60 m from the mova , (1 cm 3D = unit) Beam line load (force) in global X (Unit=63.1 kN/m) (Max=20.0)
M 1 : 1772



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Braking force 60 m from the mova , 1 cm 3D = 351.6 kN (Min=-504.7) (Max=496.5)
M 1 : 872

reduced scale factor 0.936

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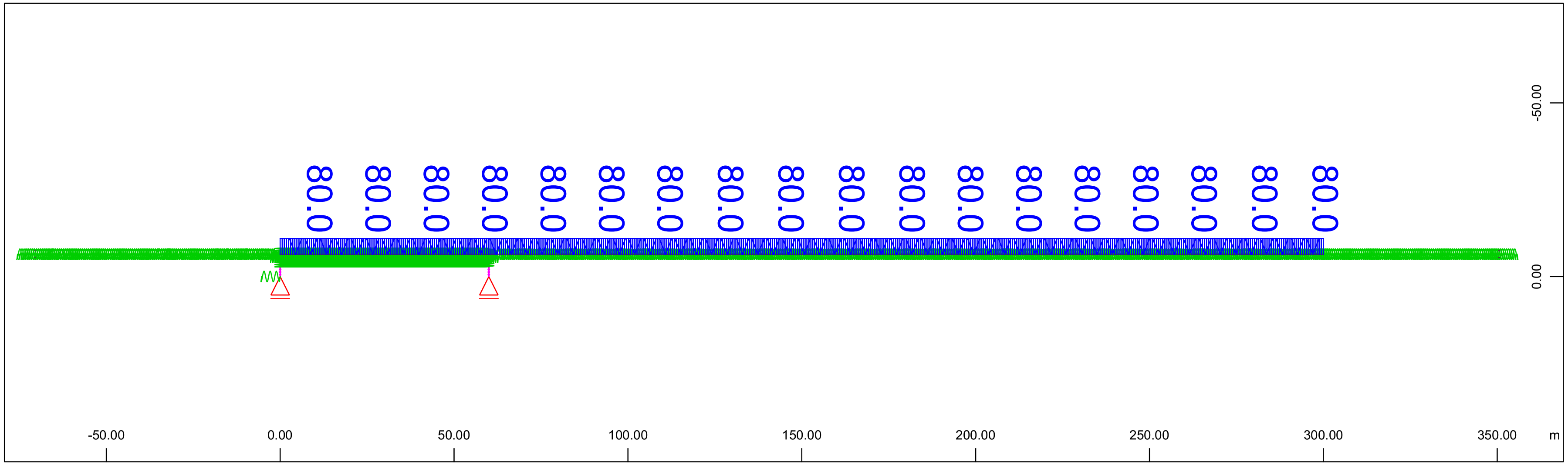
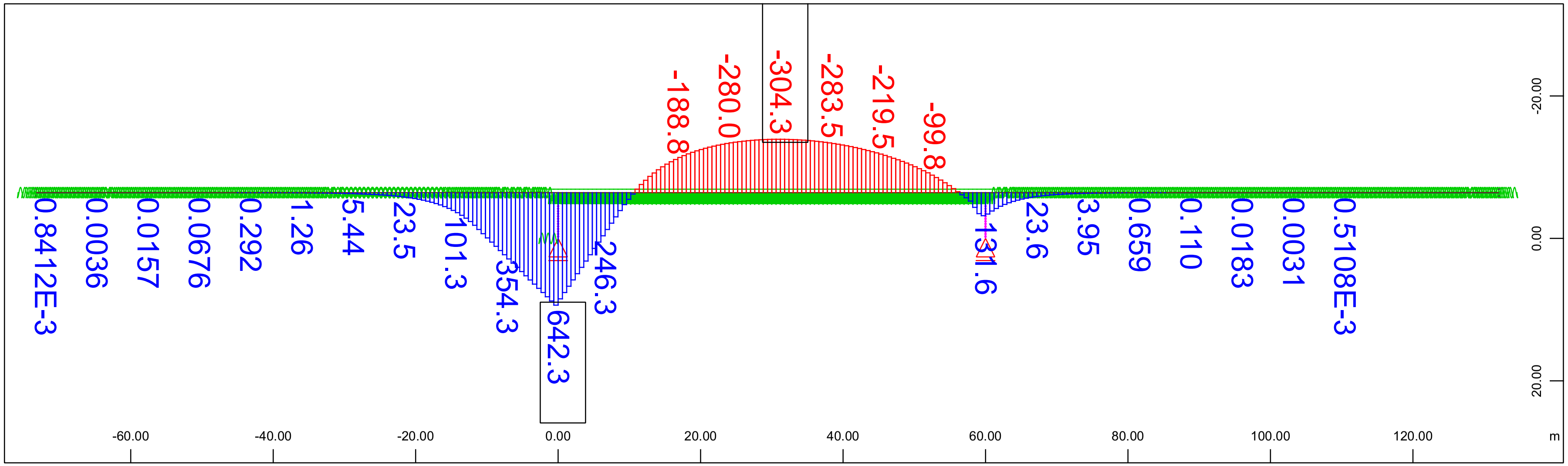
WSP Sverige AB | WSP Bridge & Hydraulic Design	F4-6. Track slab + a floating slab mat with a thickness of 28 mm without a horizontal stiffness - Vertical load
SOFiSTiK 2016-5 WINGRAF - GRAPHICS FOR FINITE ELEMENTS (V 18.05)	2017-11-08

System
Interactive Graphic



Z—X
Y
Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Vertical load 60 m from the mova , (1 cm 3D = unit) Beam line load (force) in global Y (Unit=315.6 kN/m) (Max=80.0)
M 1 : 1772



Z—X
Y
Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Vertical load 60 m from the mova , 1 cm 3D = 351.6 kN (Min=-304.3) (Max=642.3)
M 1 : 865

reduced scale factor 0.936

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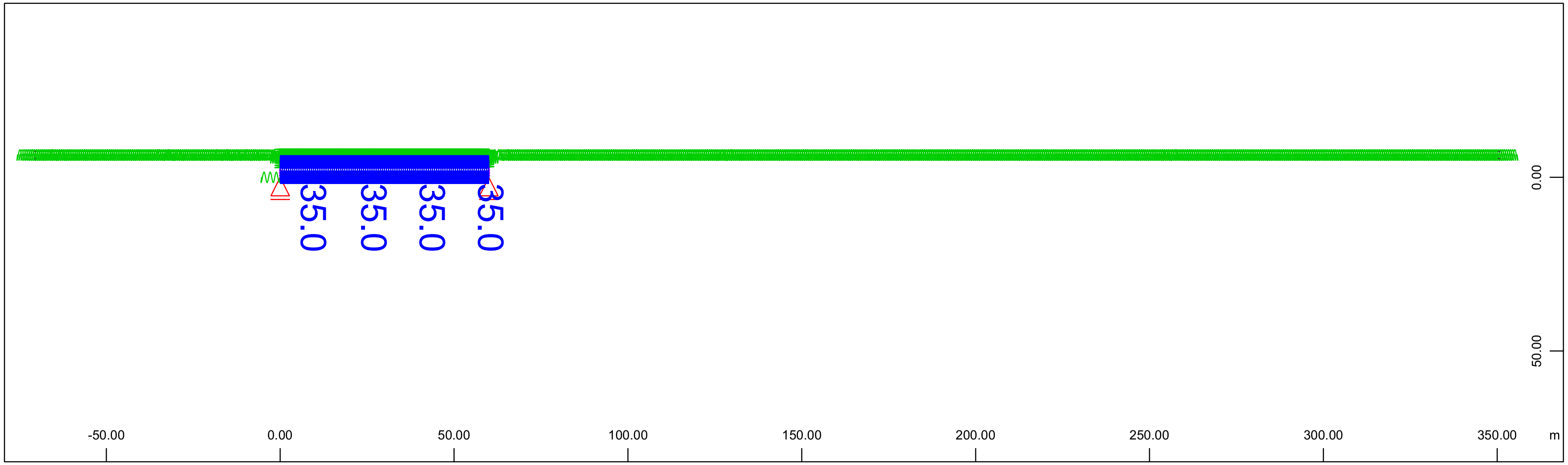
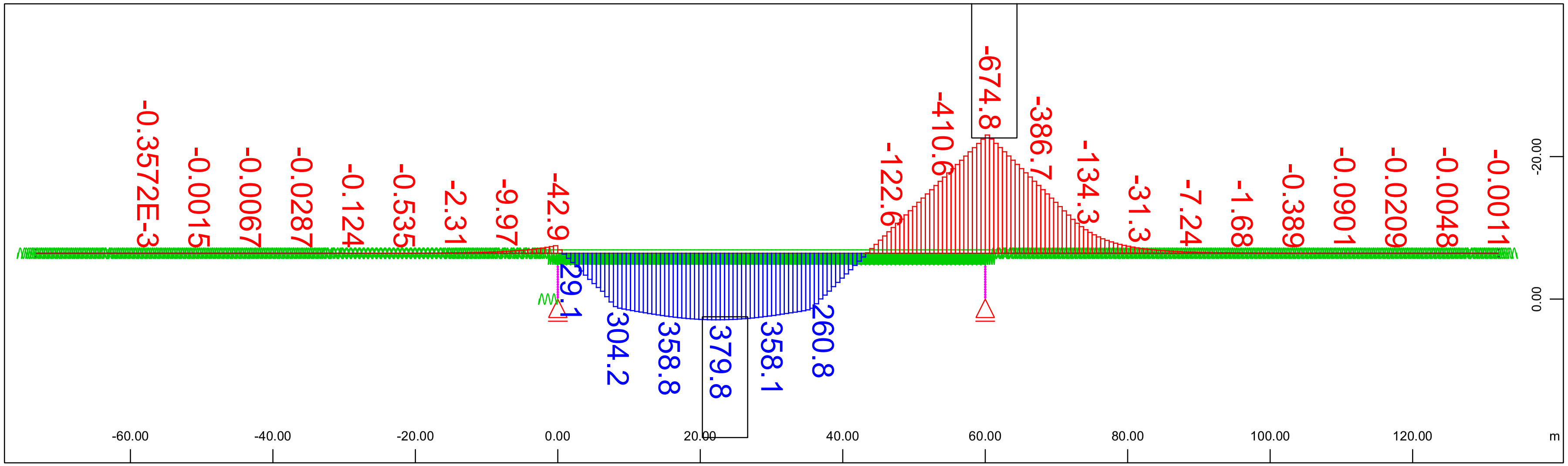
WSP Sverige AB | WSP Bridge & Hydraulic Design F4-6. Track slab + a floating slab mat with a thickness of 30 mm without a horizontal stiffness - Temperature variation - deck
SOFiSTiK 2016-5 WINGRAF - GRAPHICS FOR FINITE ELEMENTS ...

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements M 1 : 1772
All loads, nonlinear Loadcase 1 Temperature variation - deck , (1 cm 3D = unit) Beam line load (uniform temperature change)
(Unit=126.2 °C) (Max=35.0)



Sector of system Group 2...5 102...104 M 1 : 865
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Temperature variation - deck , 1 cm 3D = 351.6 kN (Min=-674.8) (Max=379.8)

reduced scale factor 0.936

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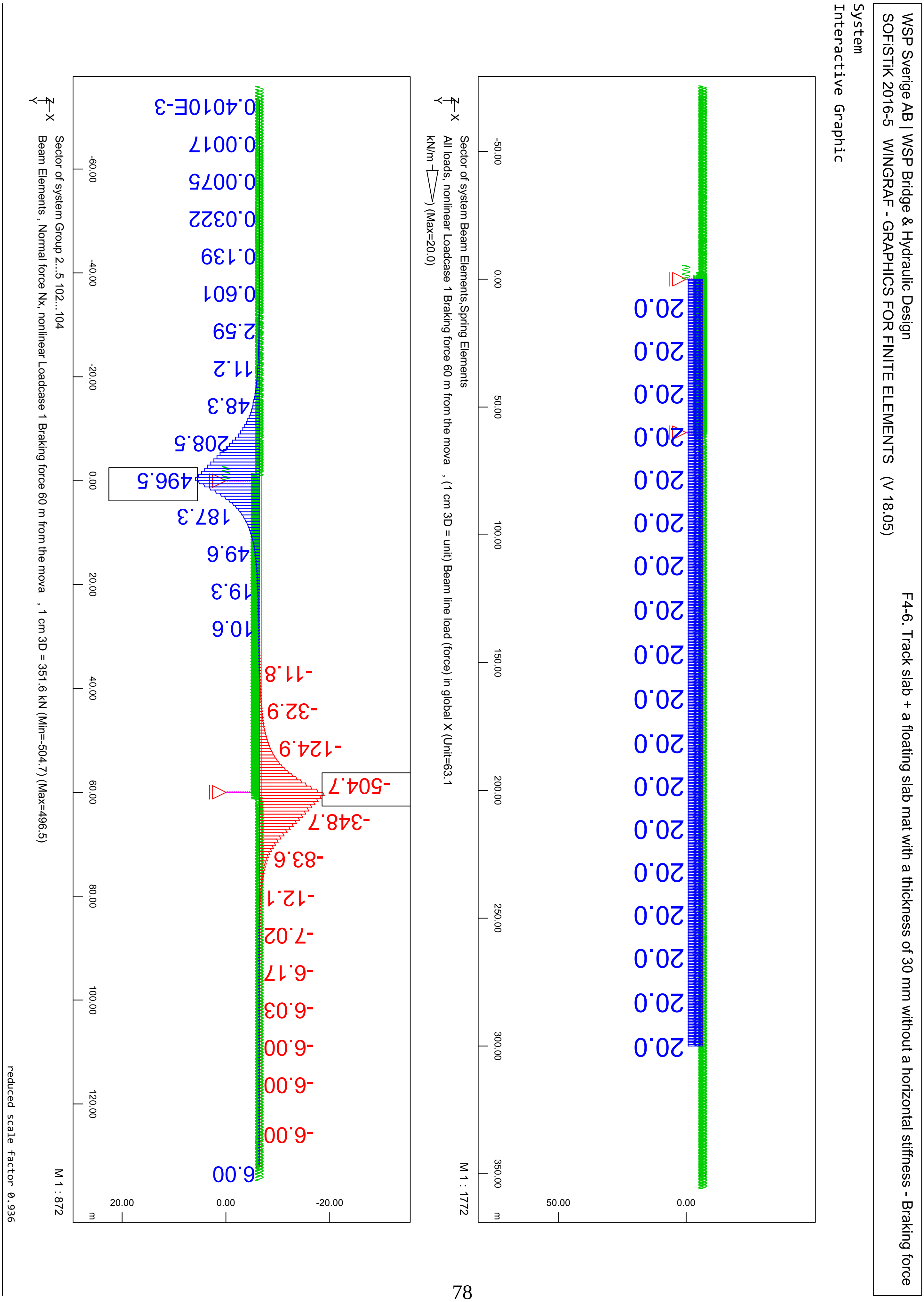

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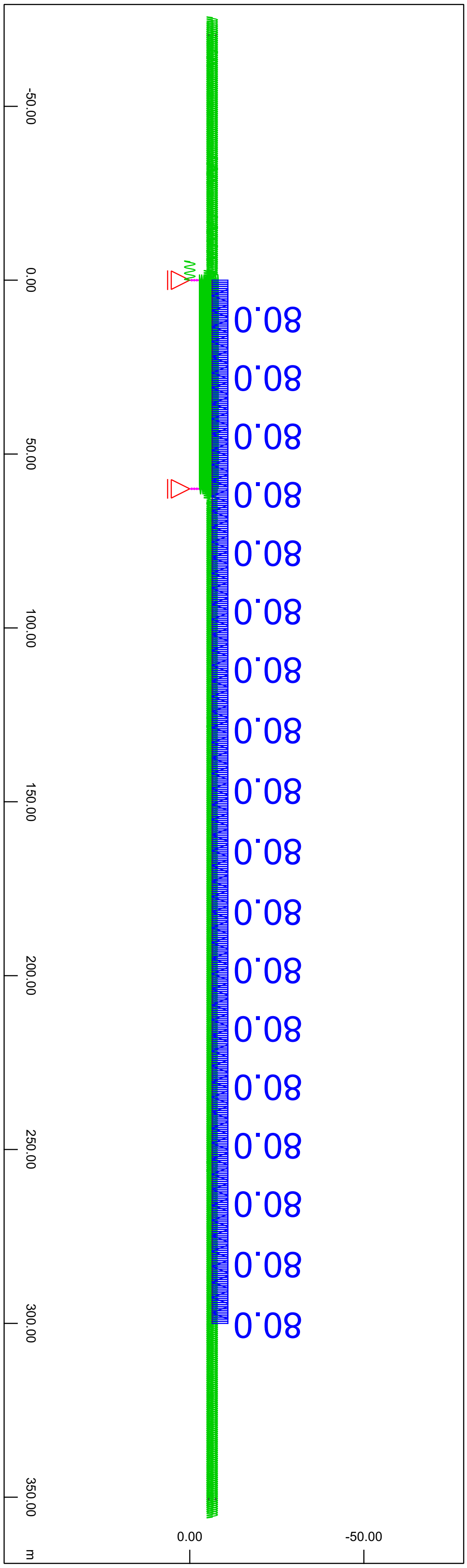
SOFiSTiK 2016-5 WINGRAF - GRAPHICS FOR FINITE ELEMENTS (V 18.05)

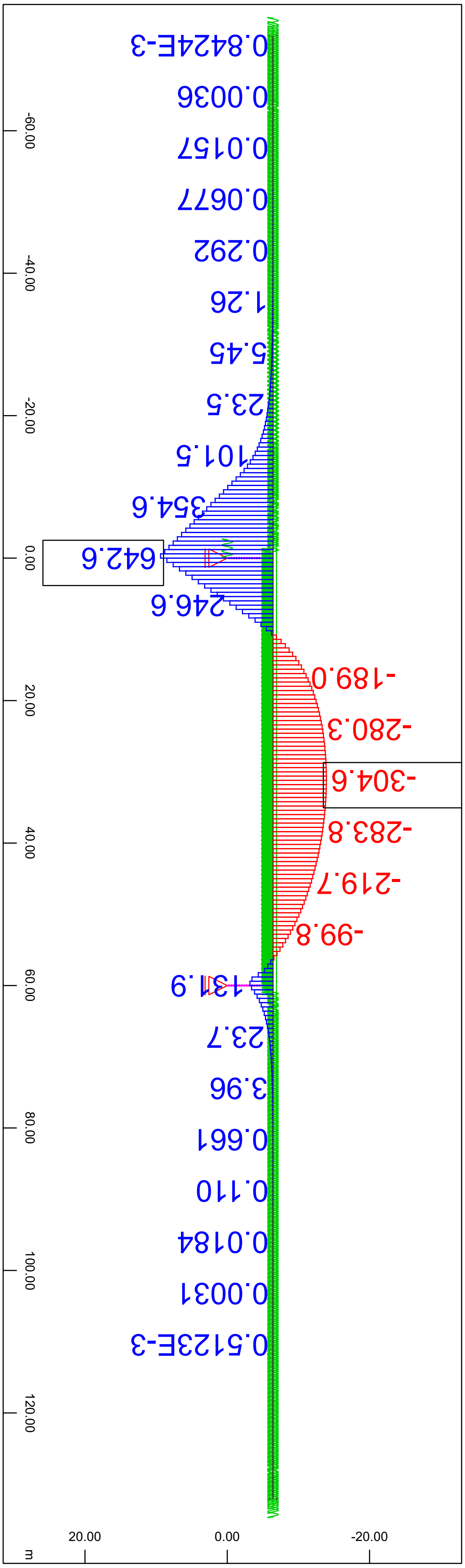
F4-6. Track slab + a floating slab mat with a thickness of 30 mm without a horizontal stiffness - Vertical load

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Vertical load 60 m from the mova , (1 cm 3D = unit) Beam line load (force) in global Y (Unit=315.6 kN/m) (Max=80.0)

M 1 : 1772



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Vertical load 60 m from the mova , 1 cm 3D = 351.6 kN (Min=-304.6) (Max=642.6)

M 1 : 865

reduced scale factor 0.936

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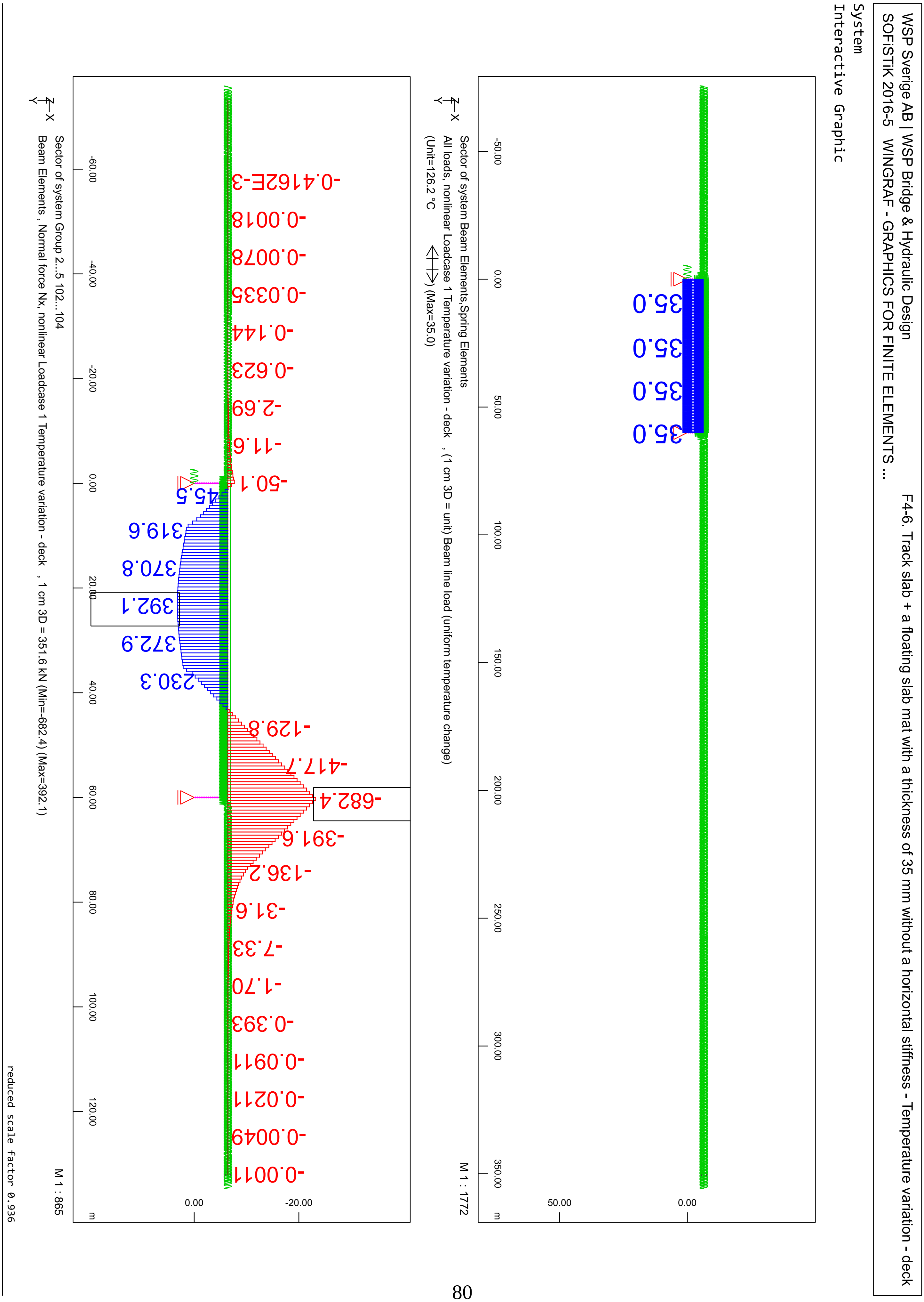

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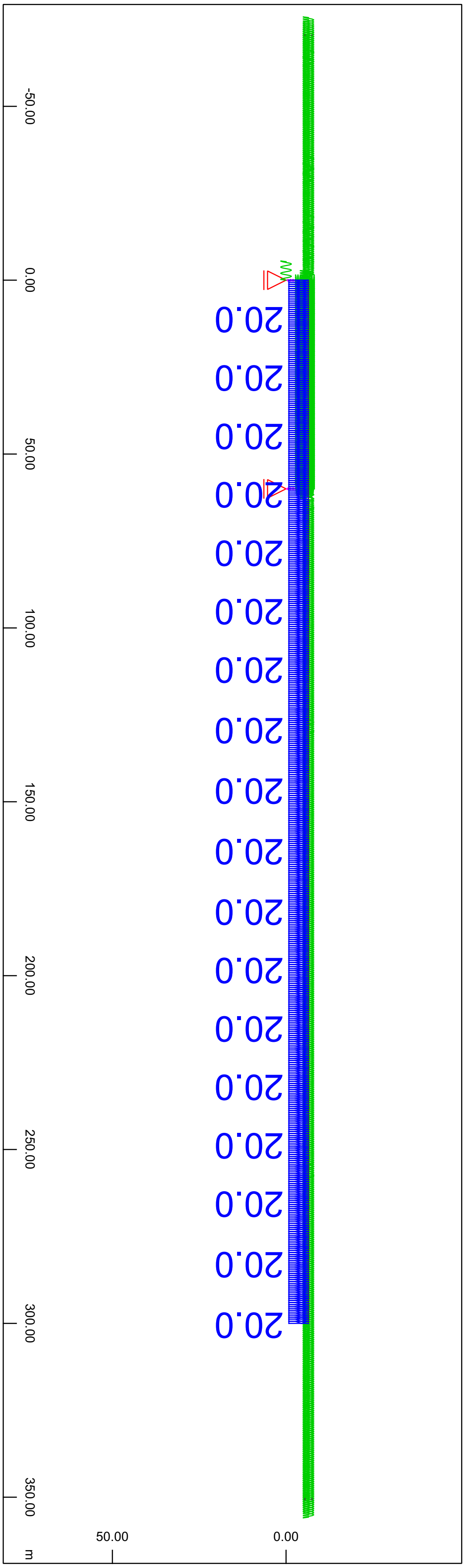
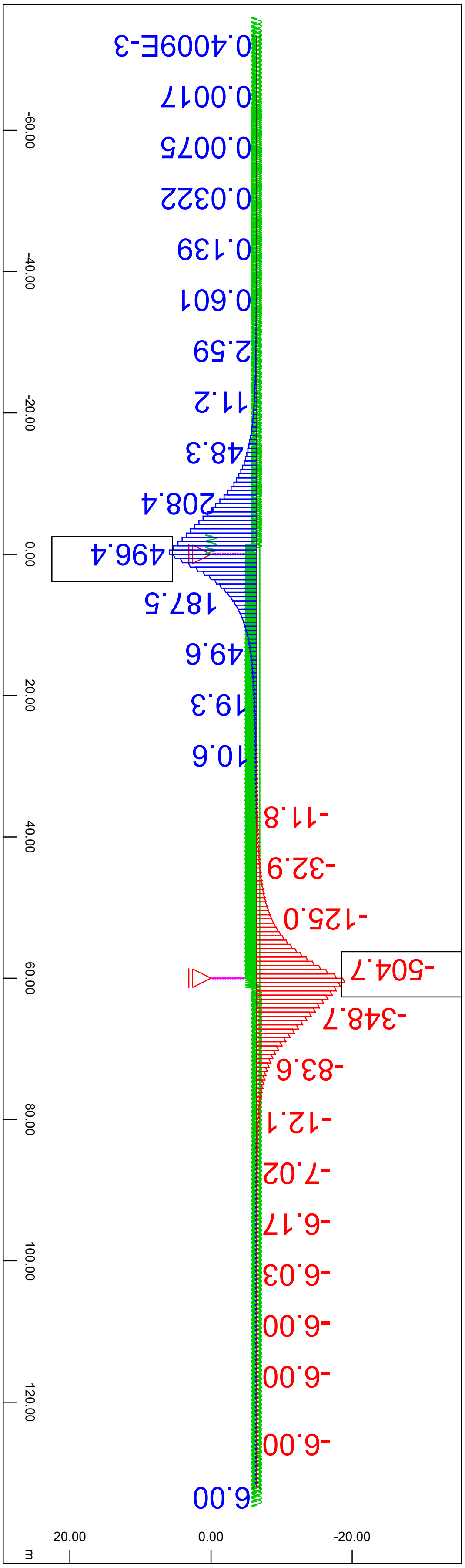
F4-6. Track slab + a floating slab mat with a thickness of 35 mm without a horizontal stiffness - Braking force

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Braking force 60 m from the mova , (1 cm 3D = unit) Beam line load (force) in global X (Unit=63.1 kN/m) (Max=20.0)

M 1 : 1772



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Braking force 60 m from the mova , 1 cm 3D = 351.6 kN (Min=-504.7) (Max=496.4)

M 1 : 872

reduced scale factor 0.936

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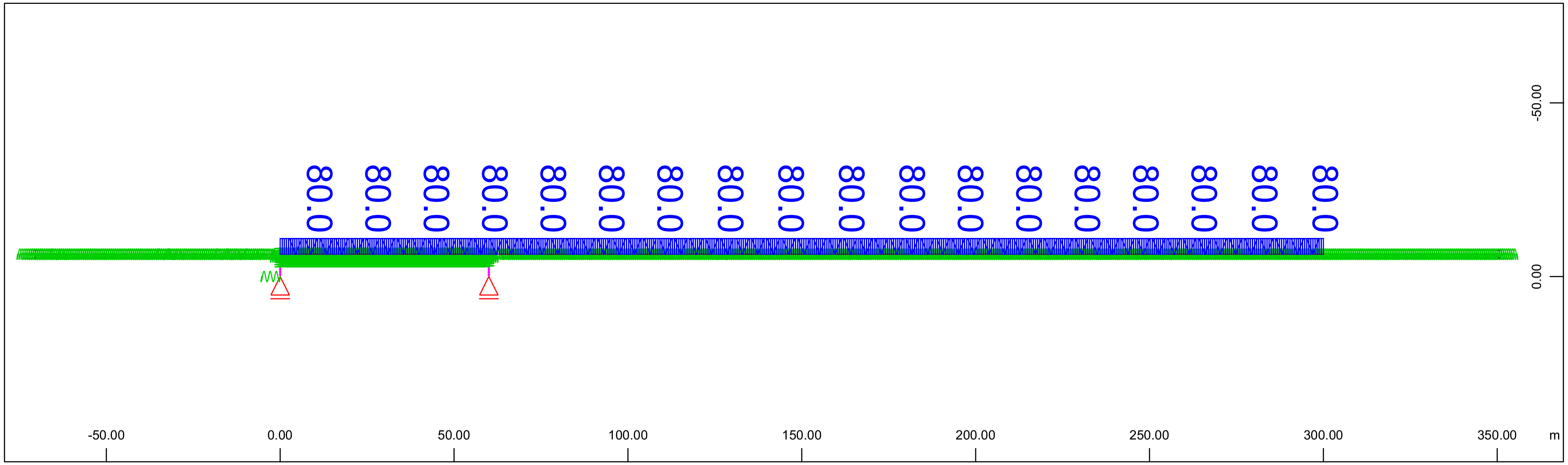
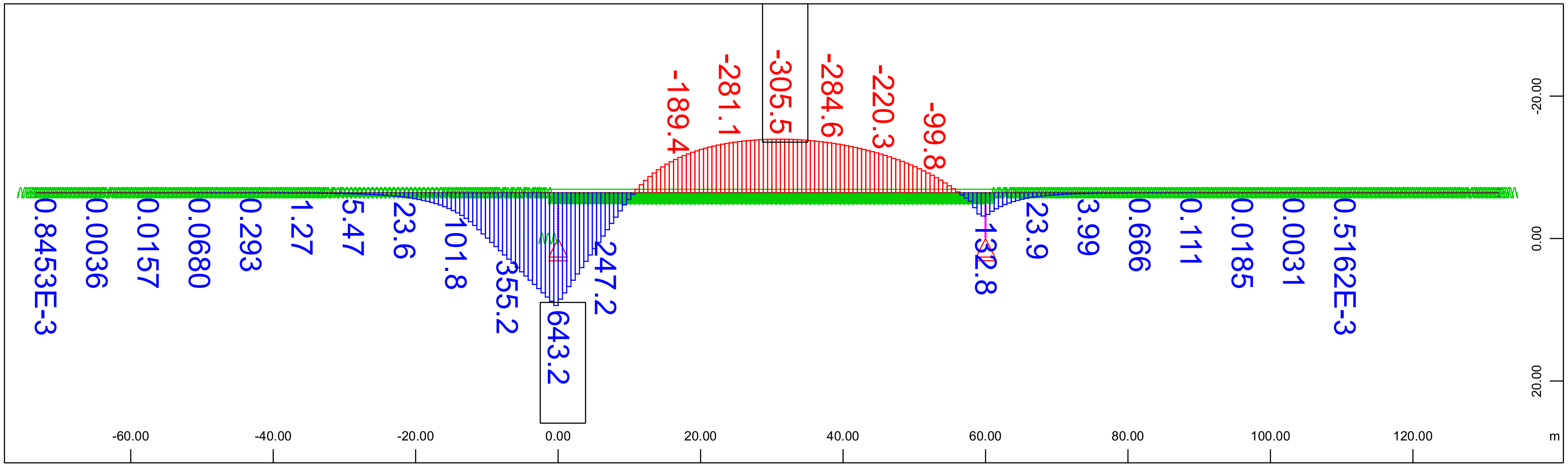
F4-6. Track slab + a floating slab mat with a thickness of 35 mm without a horizontal stiffness - Vertical load

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Vertical load 60 m from the mova , (1 cm 3D = unit) Beam line load (force) in global Y (Unit=315.6 kN/m) (Max=80.0)

M 1 : 1772



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Vertical load 60 m from the mova , 1 cm 3D = 351.6 kN (Min=-305.5) (Max=643.2)

M 1 : 865

reduced scale factor 0.936

2.6 F4-6 - Detailed normal force diagrams from the model with a floating slab mat with a horizontal stiffness

On the following pages are detailed normal force diagrams for test case F4-6 with a floating slab mat with a horizontal stiffness presented.

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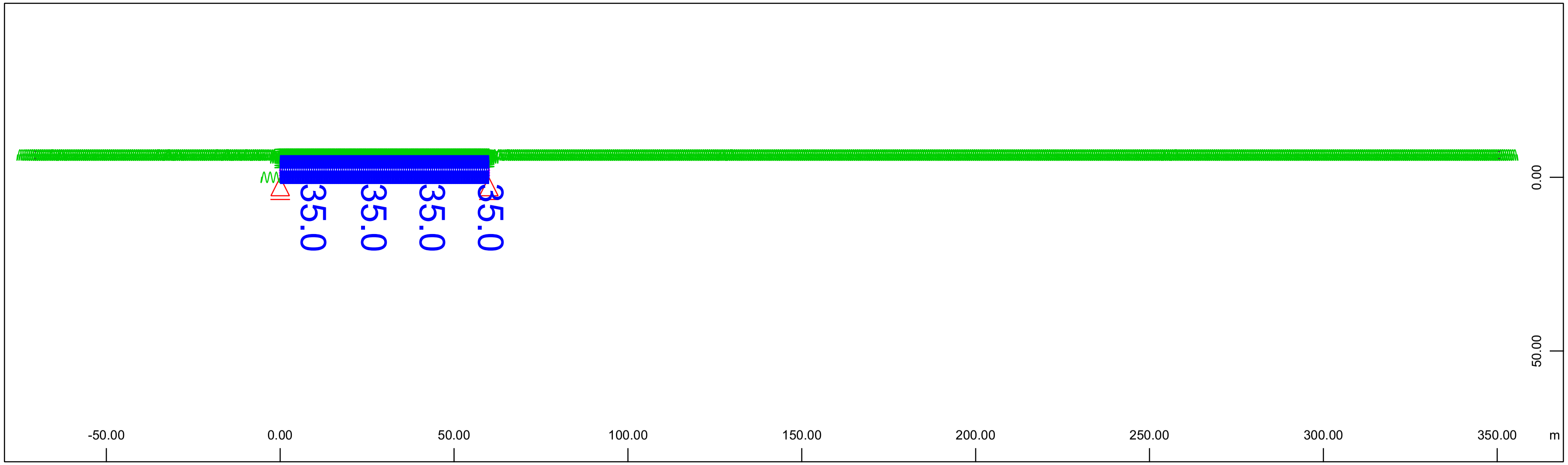
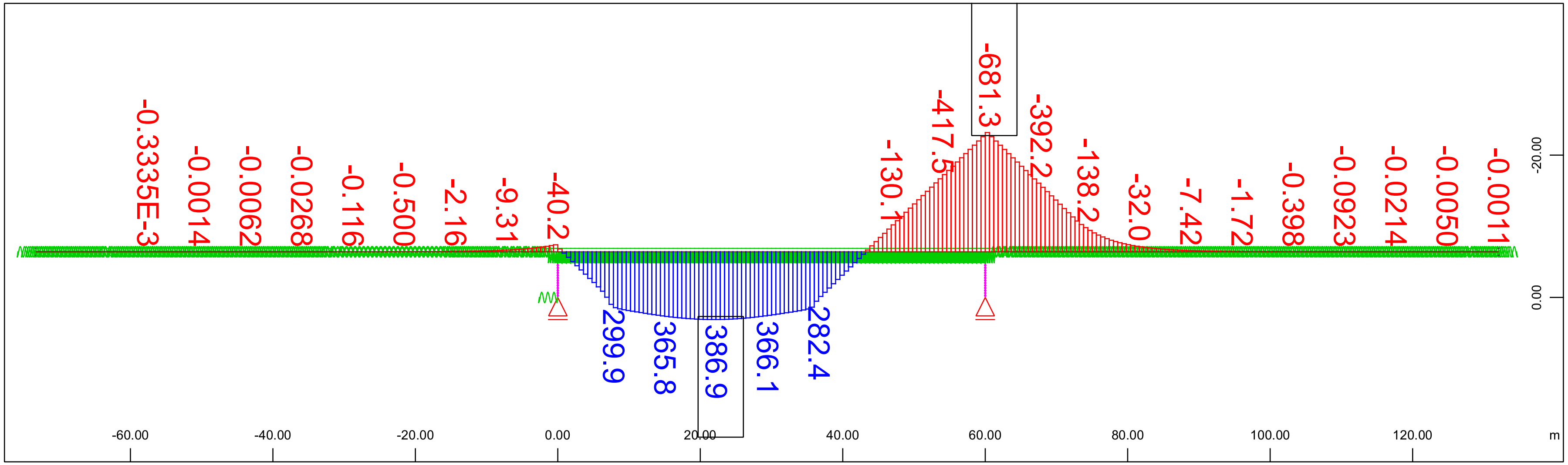
F4-6. Track slab + a floating slab mat with a thickness of 12 mm with a horizontal stiffness - Temperature variation - deck

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Temperature variation - deck , (1 cm 3D = unit) Beam line load (uniform temperature change)
(Unit=126.2 °C) (Max=35.0)

M 1 : 1772



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Temperature variation - deck , 1 cm 3D = 351.6 kN (Min=-681.3) (Max=386.9)

M 1 : 865

reduced scale factor 0.936

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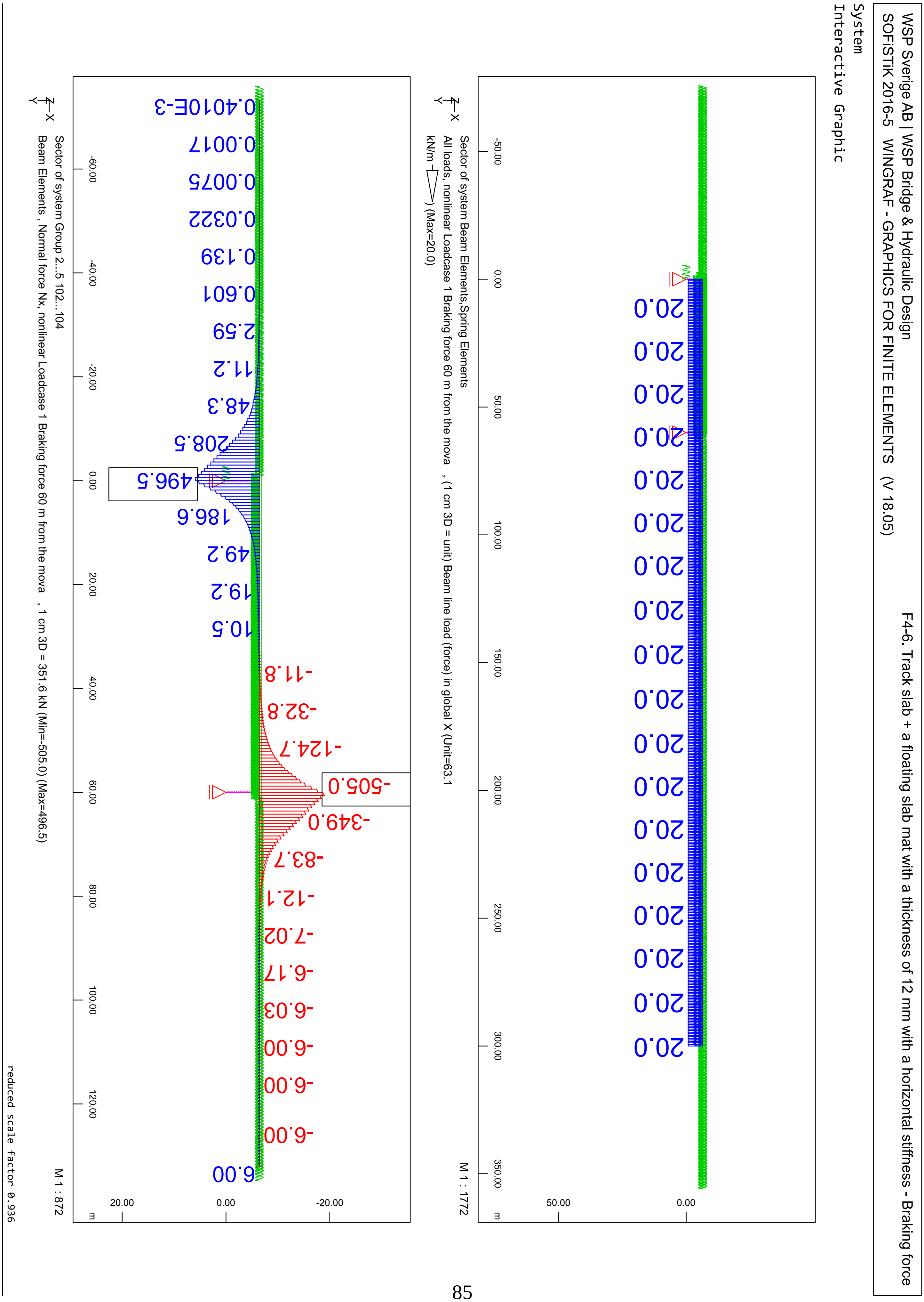

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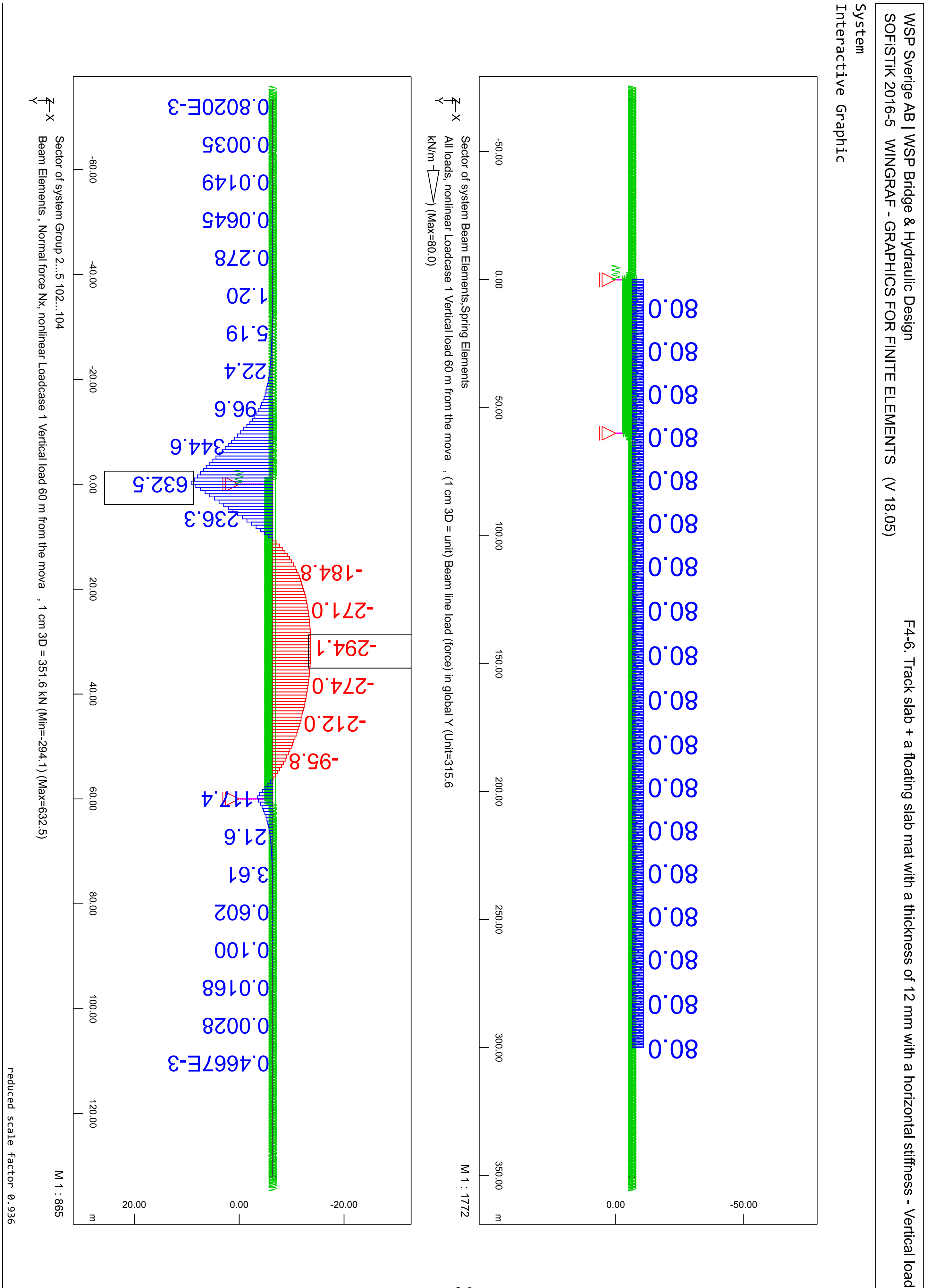

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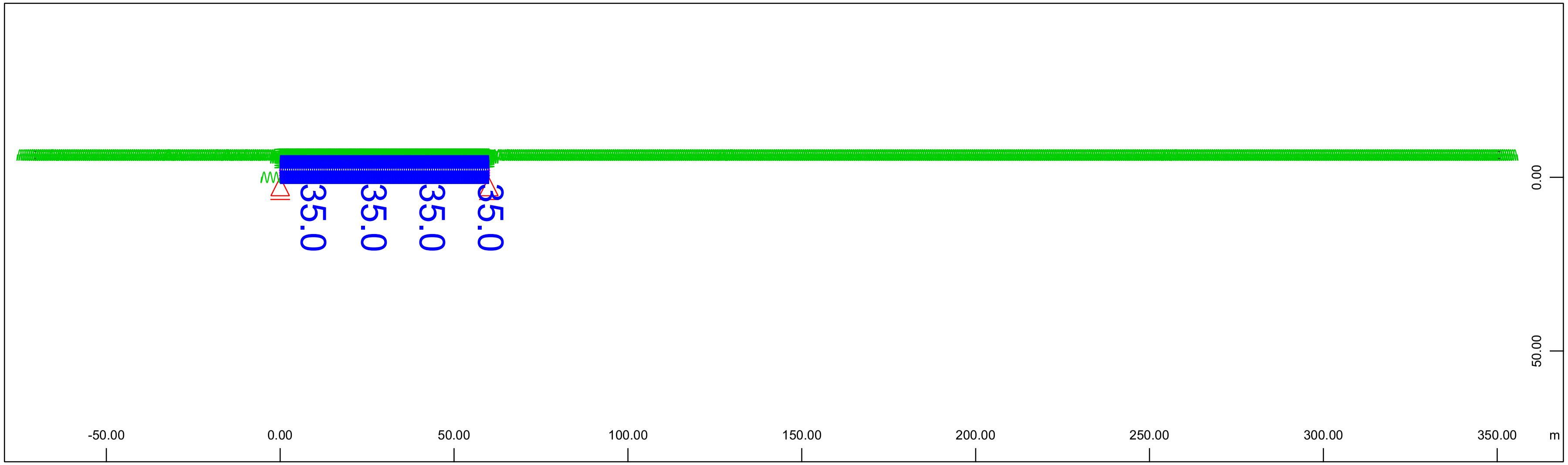
SOFiSTiK 2016-5 WINGRAF - GRAPHICS FOR FINITE ELEMENTS (V...

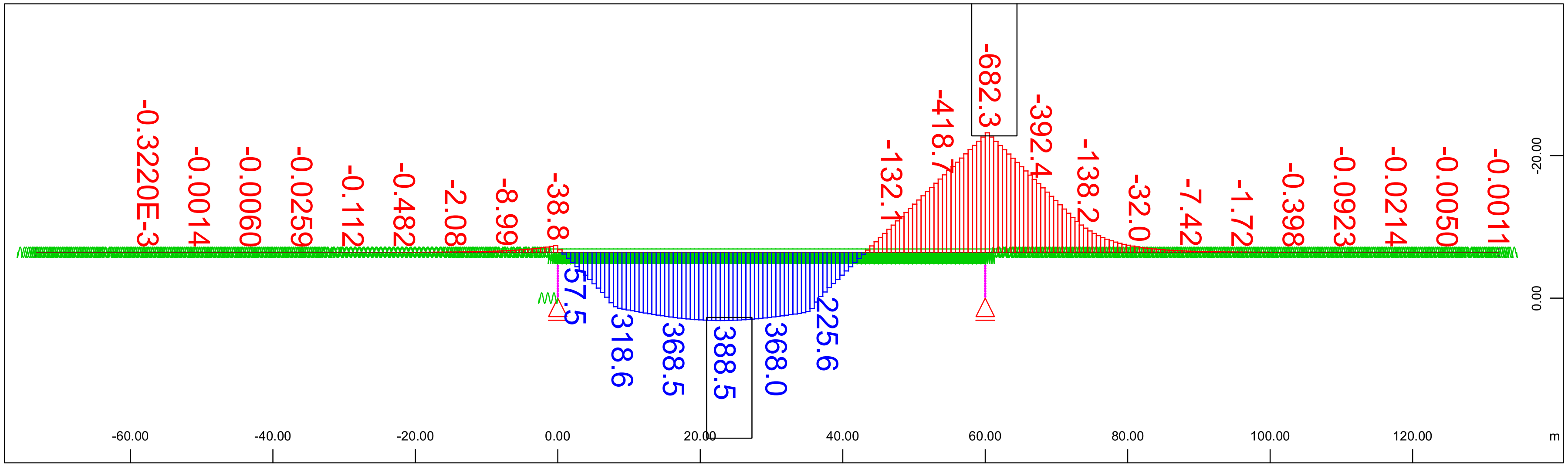
F4-6. Track slab + a floating slab mat with a thickness of 15 mm with a horizontal stiffness - Temperature variation - deck

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Temperature variation - deck , (1 cm 3D = unit) Beam line load (uniform temperature change)
(Unit=126.2 °C) (Max=35.0)

M 1 : 1772



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Temperature variation - deck , 1 cm 3D = 351.6 kN (Min=-682.3) (Max=388.5)

M 1 : 865

reduced scale factor 0.936

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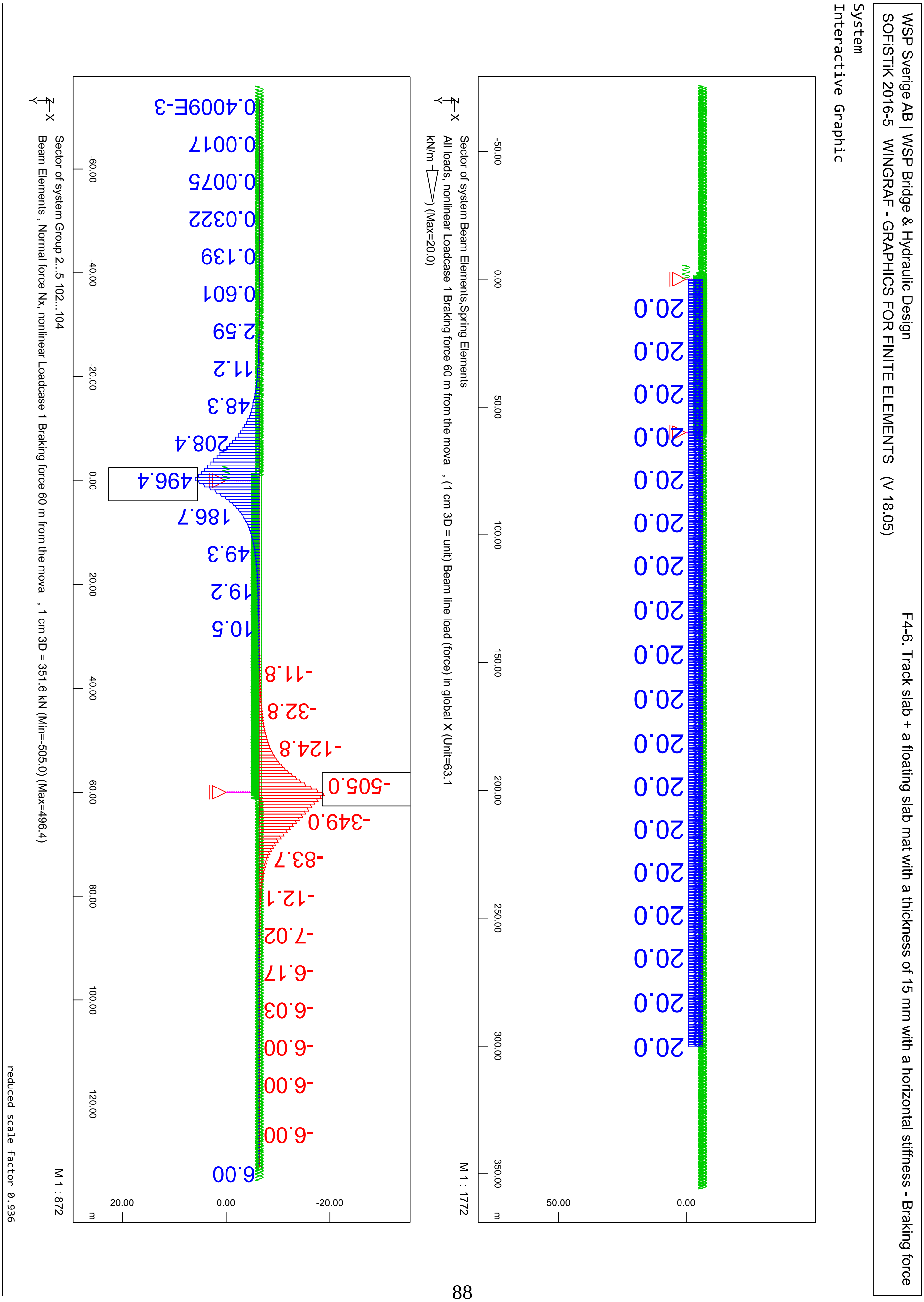

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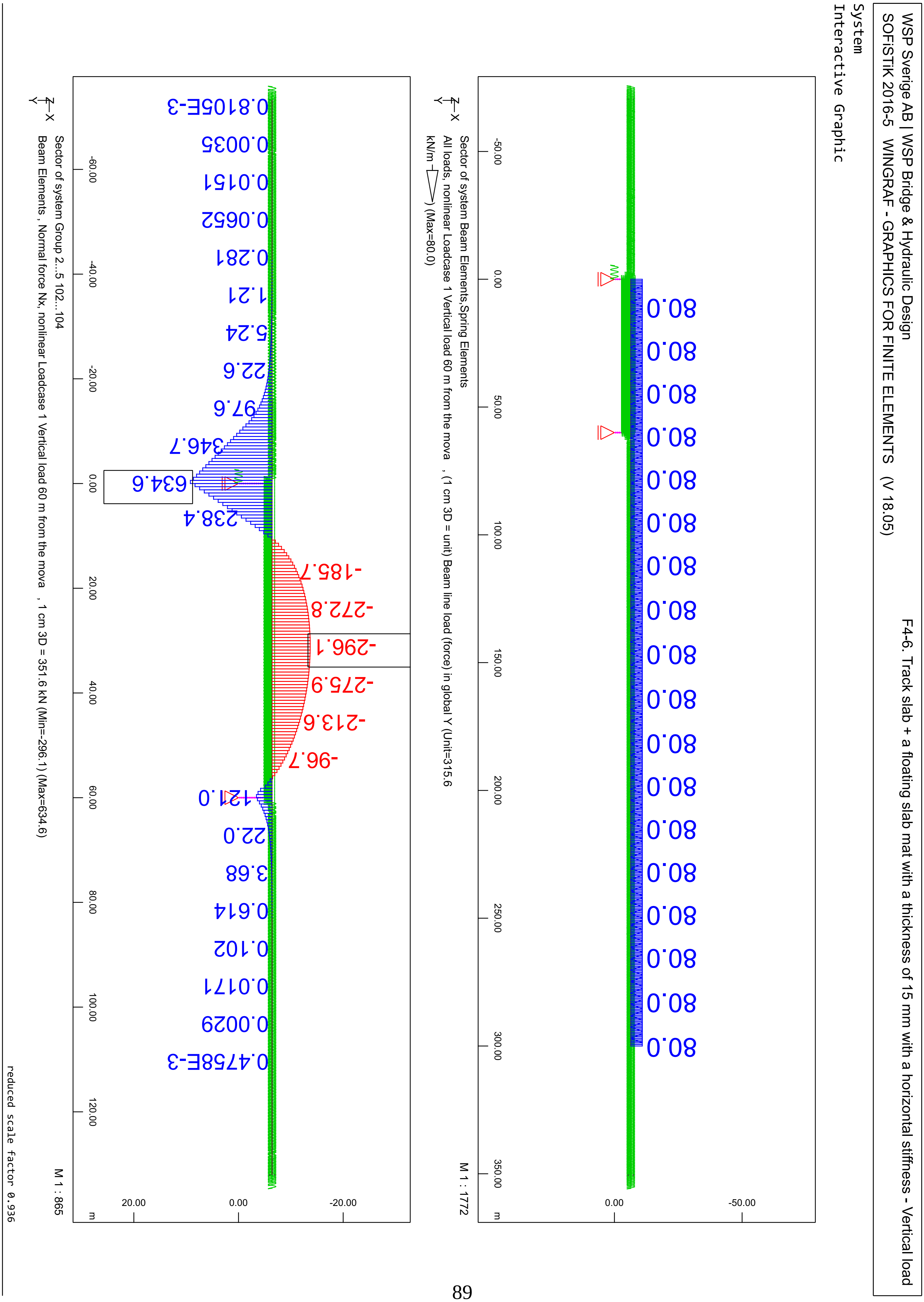
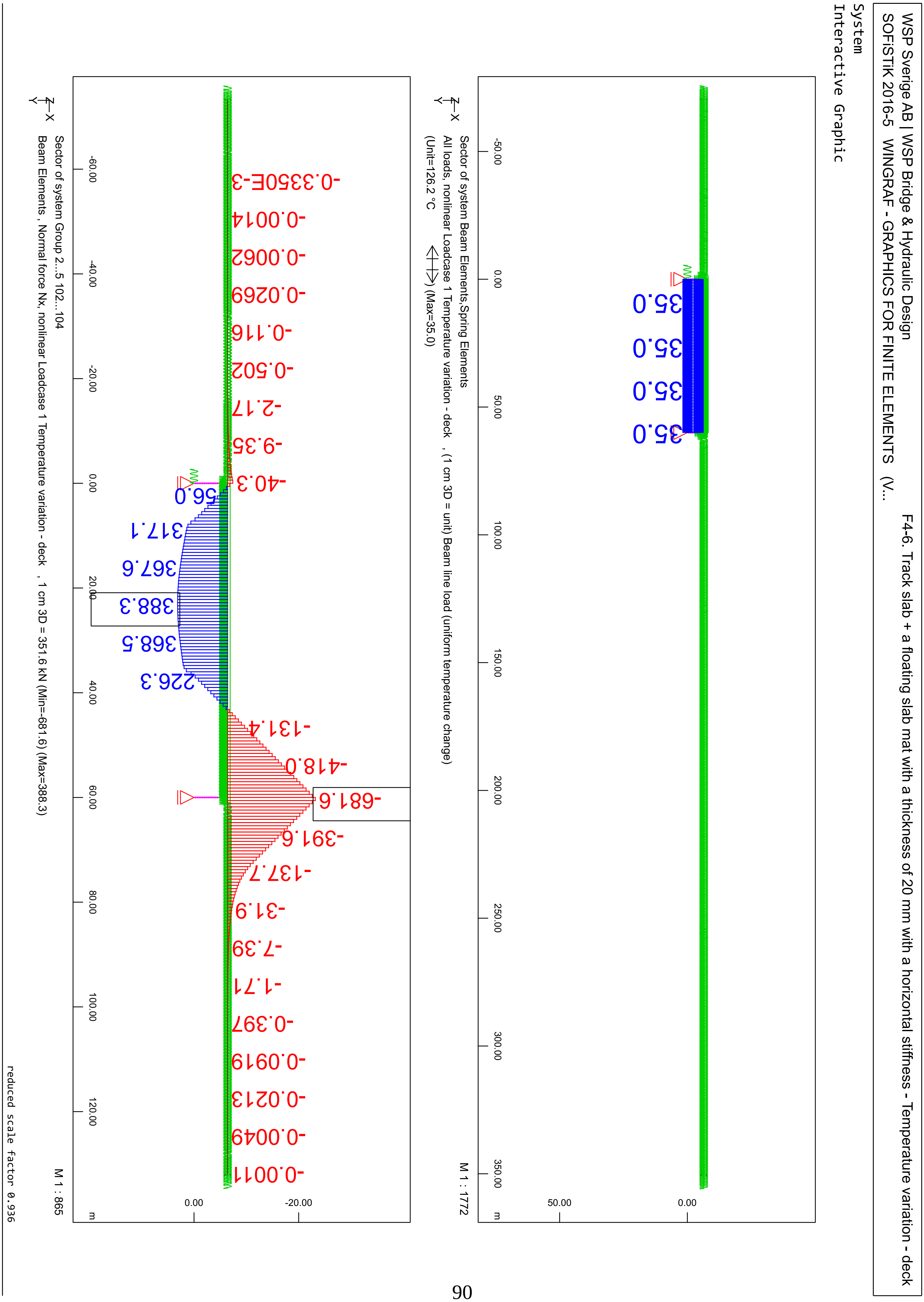


SOFiSTiK AG - www.sofistik.de



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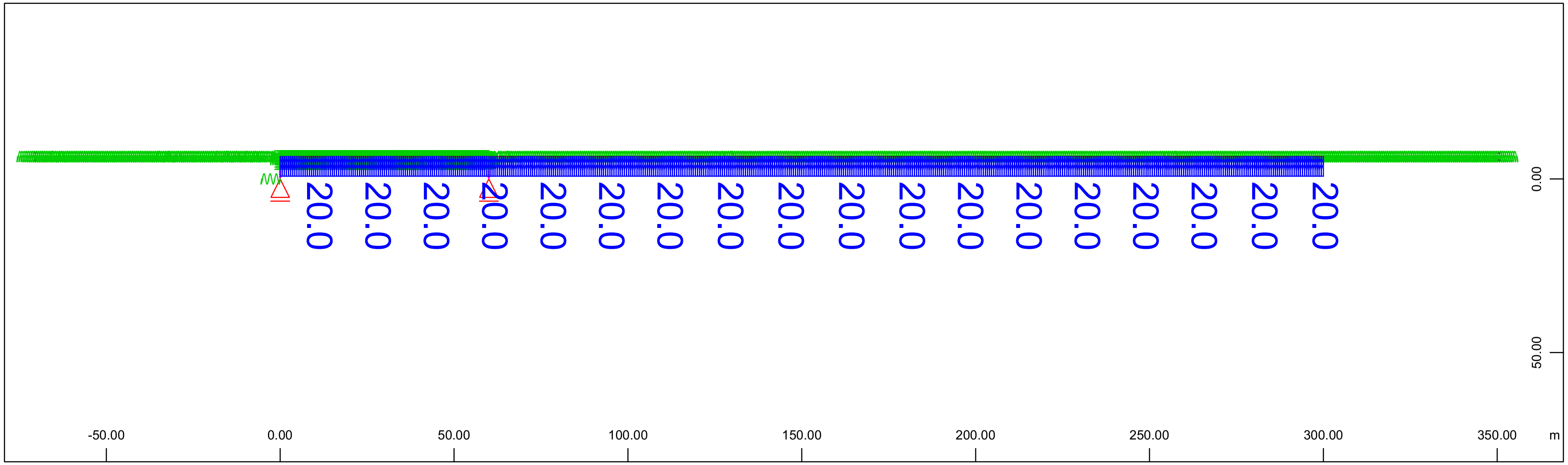
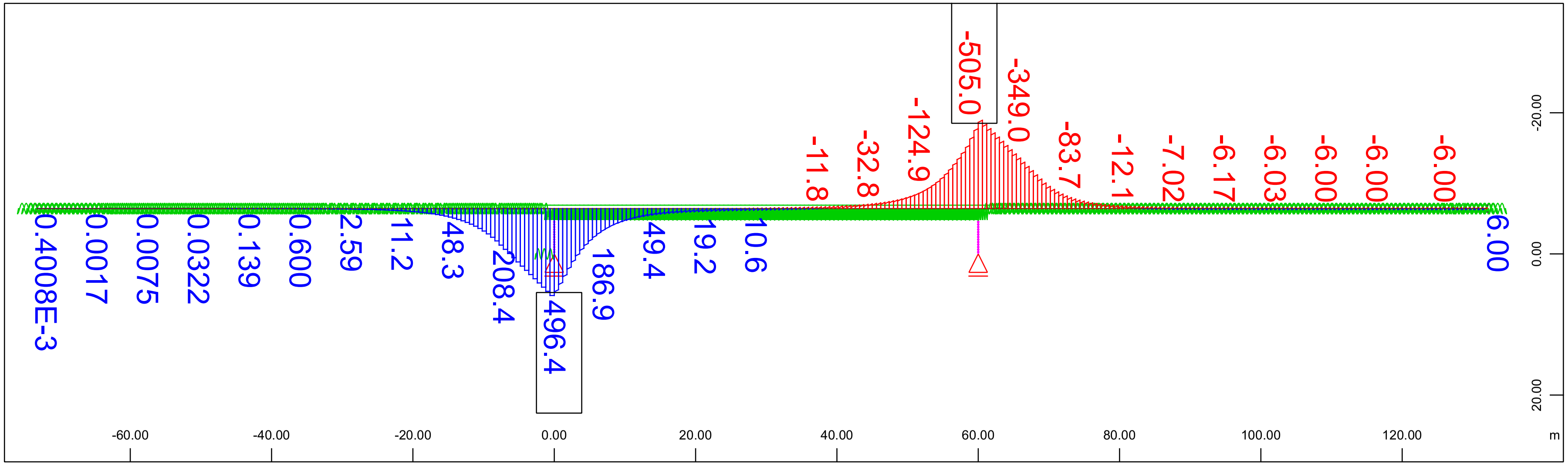
F4-6. Track slab + a floating slab mat with a thickness of 20 mm with a horizontal stiffness - Braking force

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Braking force 60 m from the mova , (1 cm 3D = unit) Beam line load (force) in global X (Unit=63.1 kN/m) (Max=20.0)

M 1 : 1772



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Braking force 60 m from the mova , 1 cm 3D = 351.6 kN (Min=-505.0) (Max=496.4)

M 1 : 872

reduced scale factor 0.936

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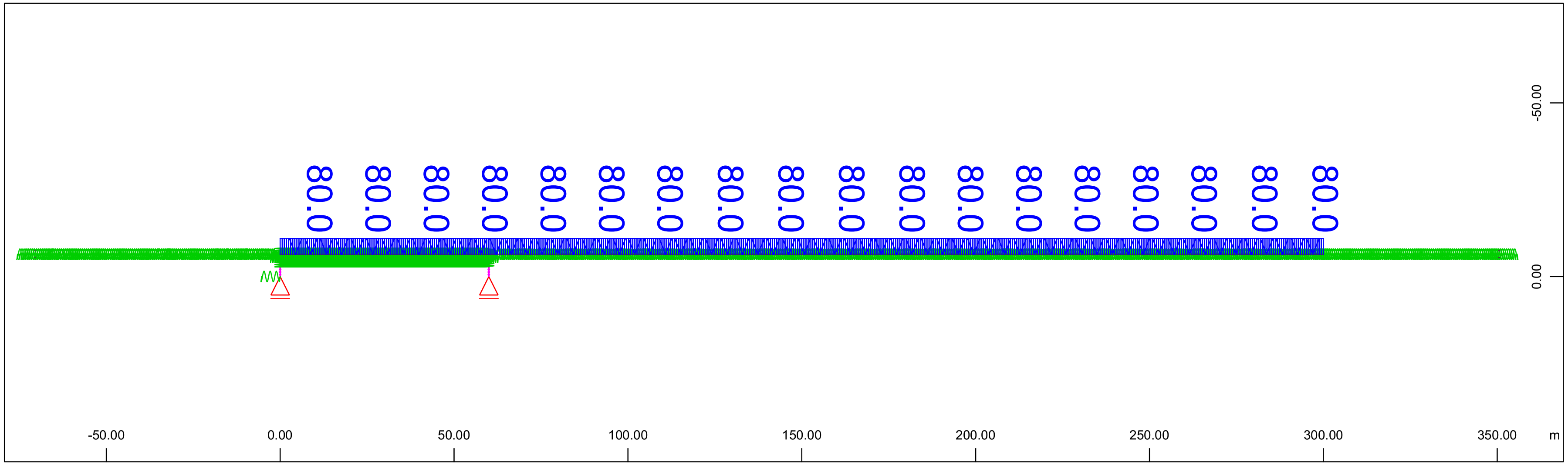
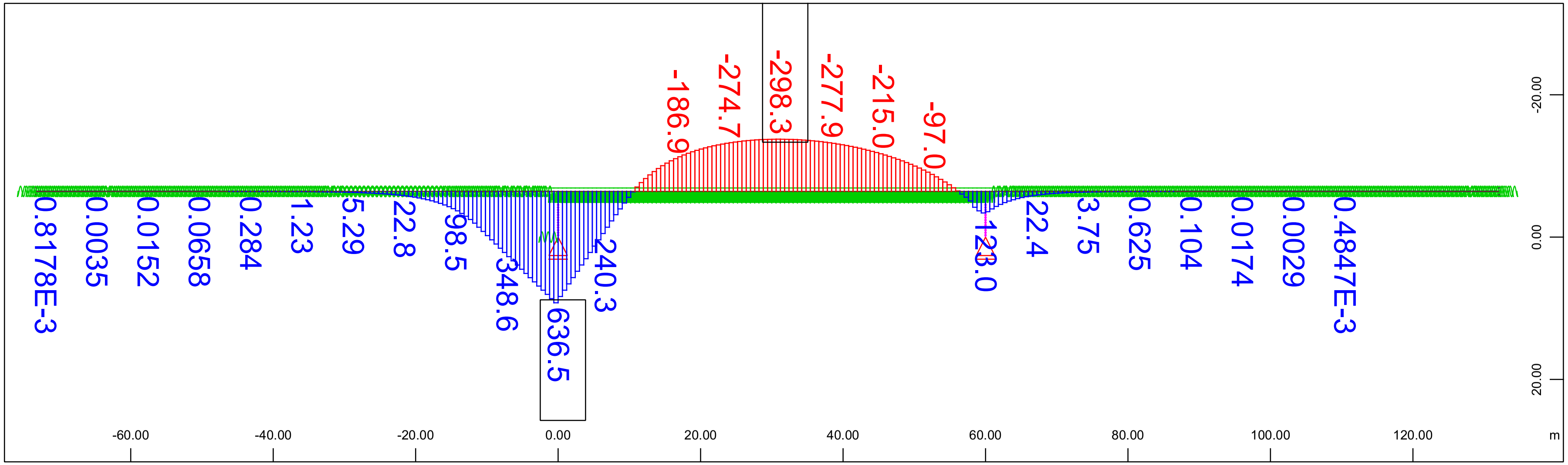
F4-6. Track slab + a floating slab mat with a thickness of 20 mm with a horizontal stiffness - Vertical load

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Vertical load 60 m from the mova , (1 cm 3D = unit) Beam line load (force) in global Y (Unit=315.6 kN/m) (Max=80.0)

M 1 : 1772



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Vertical load 60 m from the mova , 1 cm 3D = 351.6 kN (Min=-298.3) (Max=636.5)

M 1 : 865

reduced scale factor 0.936

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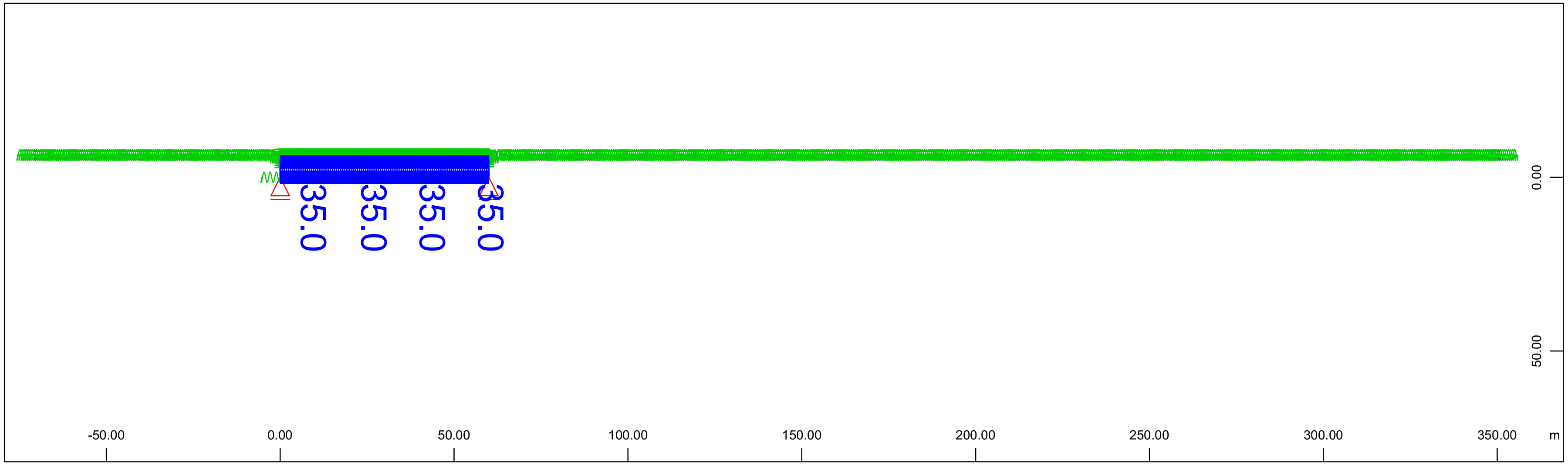
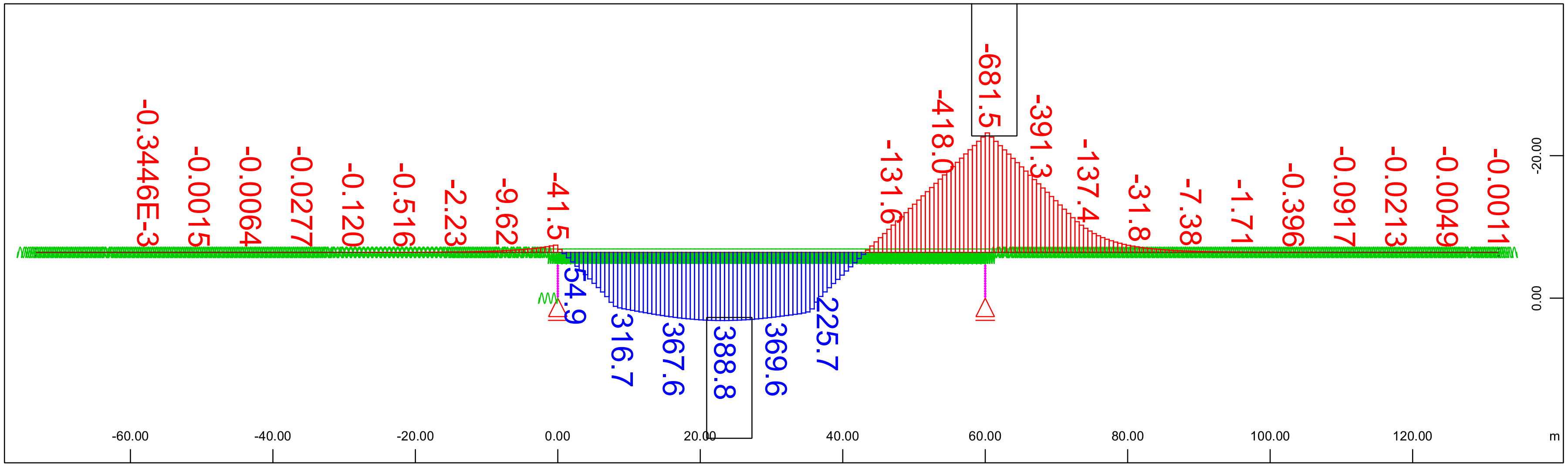
F4-6. Track slab + a floating slab mat with a thickness of 25 mm with a horizontal stiffness - Temperature variation - deck

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Temperature variation - deck , (1 cm 3D = unit) Beam line load (uniform temperature change)
(Unit=126.2 °C) (Max=35.0)

M 1 : 1772



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Temperature variation - deck , 1 cm 3D = 351.6 kN (Min=-681.5) (Max=388.8)

M 1 : 865

reduced scale factor 0.936

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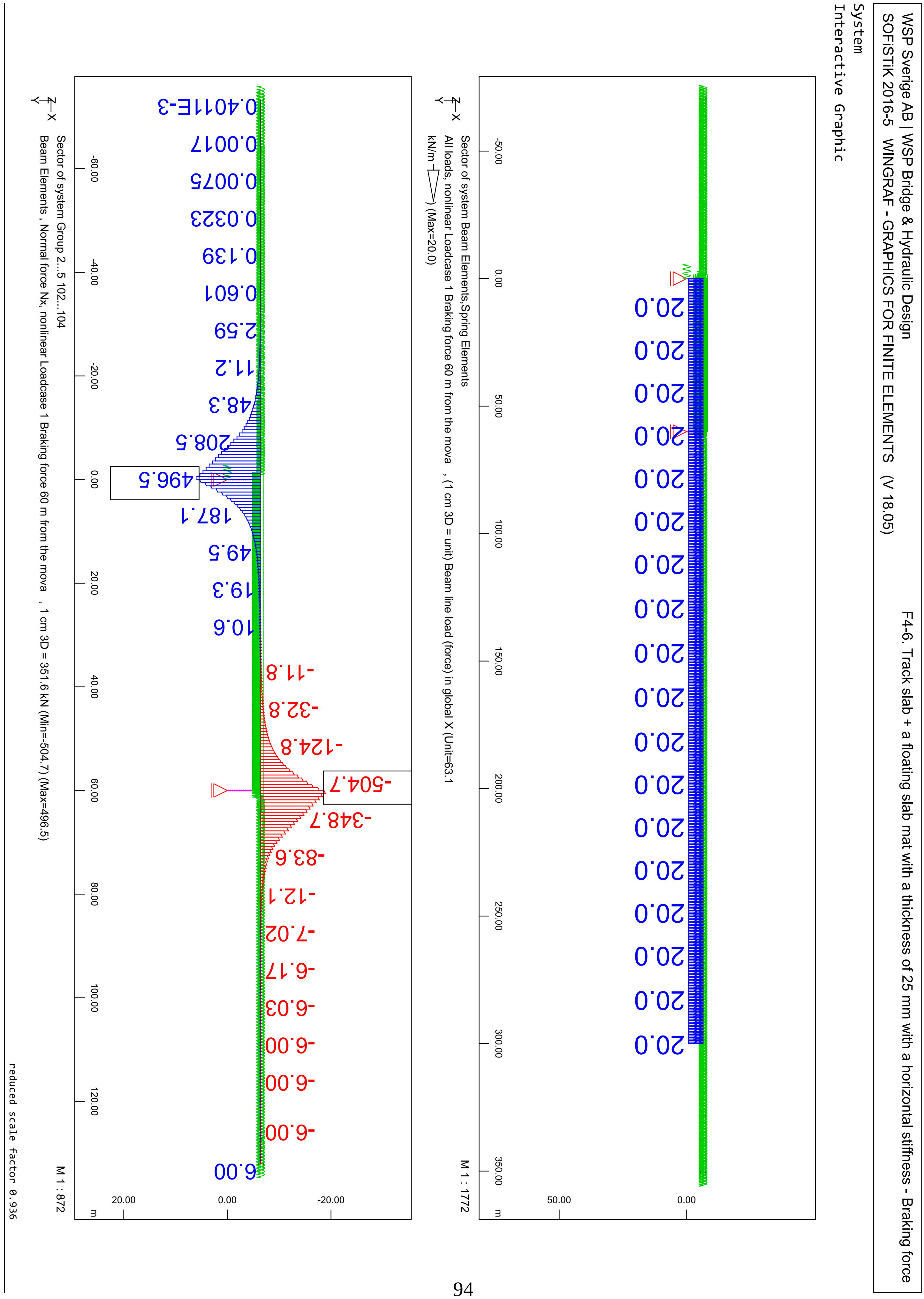

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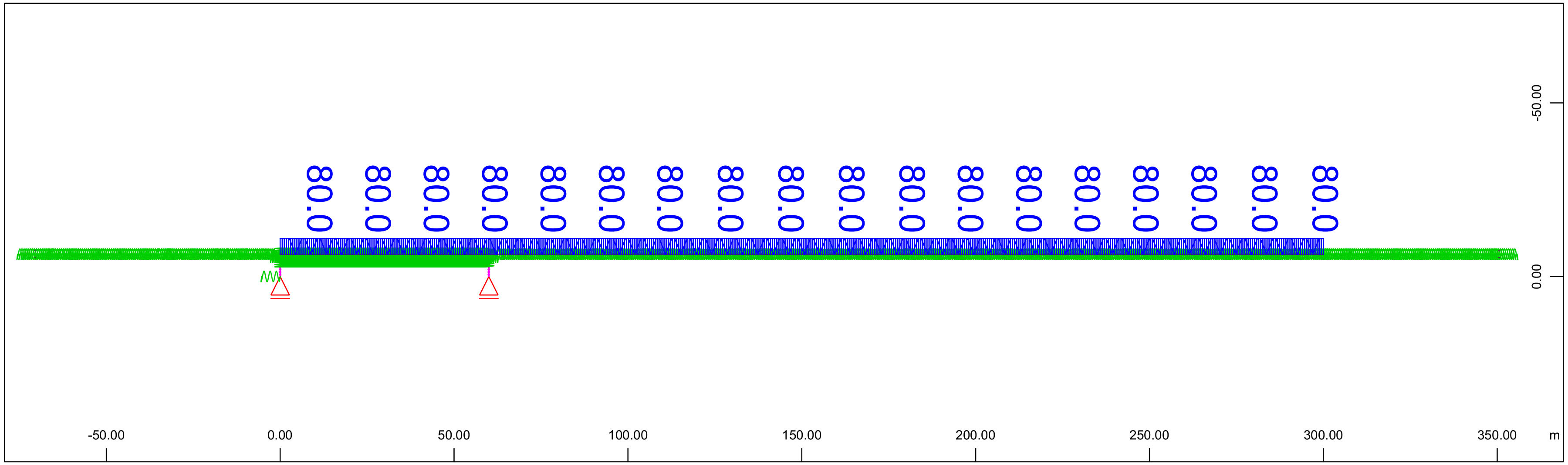
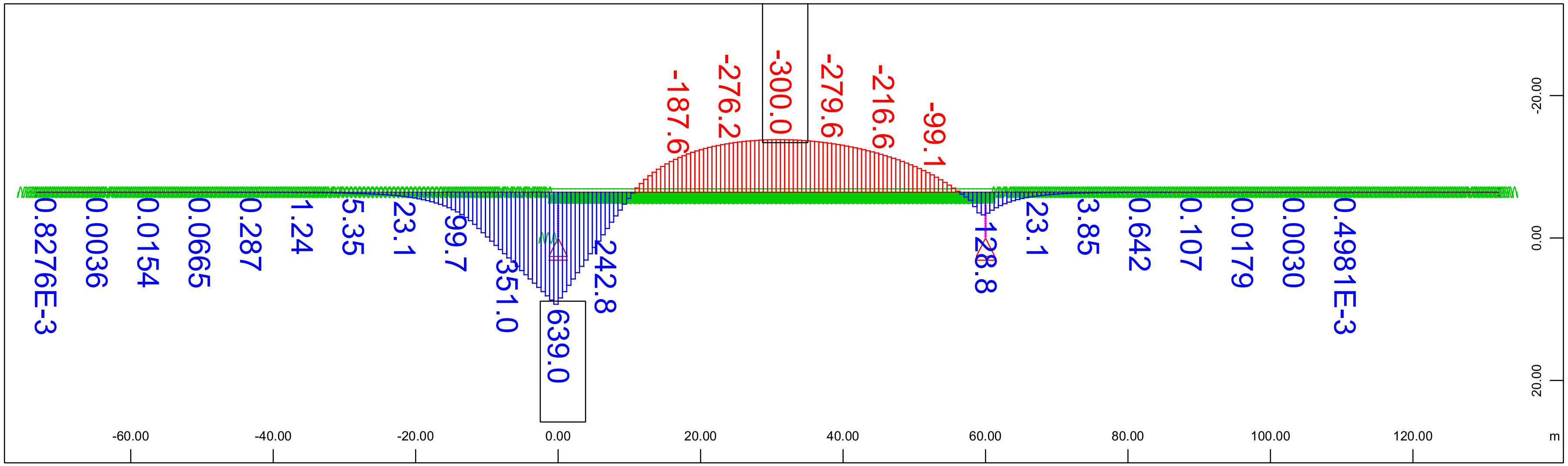
F4-6. Track slab + a floating slab mat with a thickness of 25 mm with a horizontal stiffness - Vertical load

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Vertical load 60 m from the mova , (1 cm 3D = unit) Beam line load (force) in global Y (Unit=315.6 kN/m) (Max=80.0)

M 1 : 1772



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Vertical load 60 m from the mova , 1 cm 3D = 351.6 kN (Min=-300.0) (Max=639.0)

M 1 : 865

reduced scale factor 0.936

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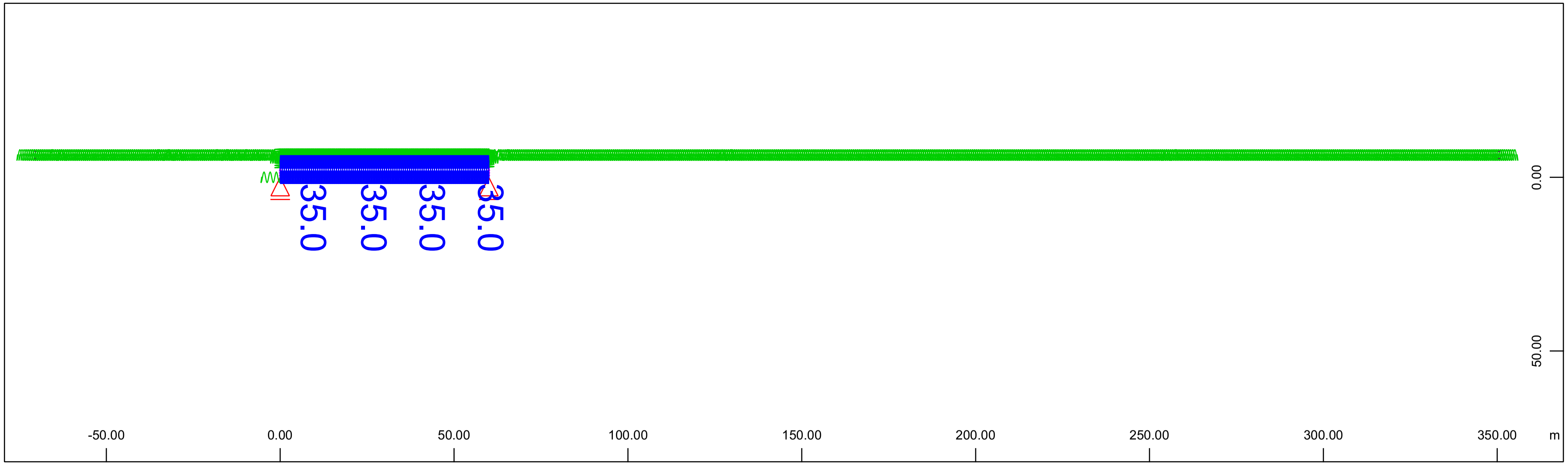
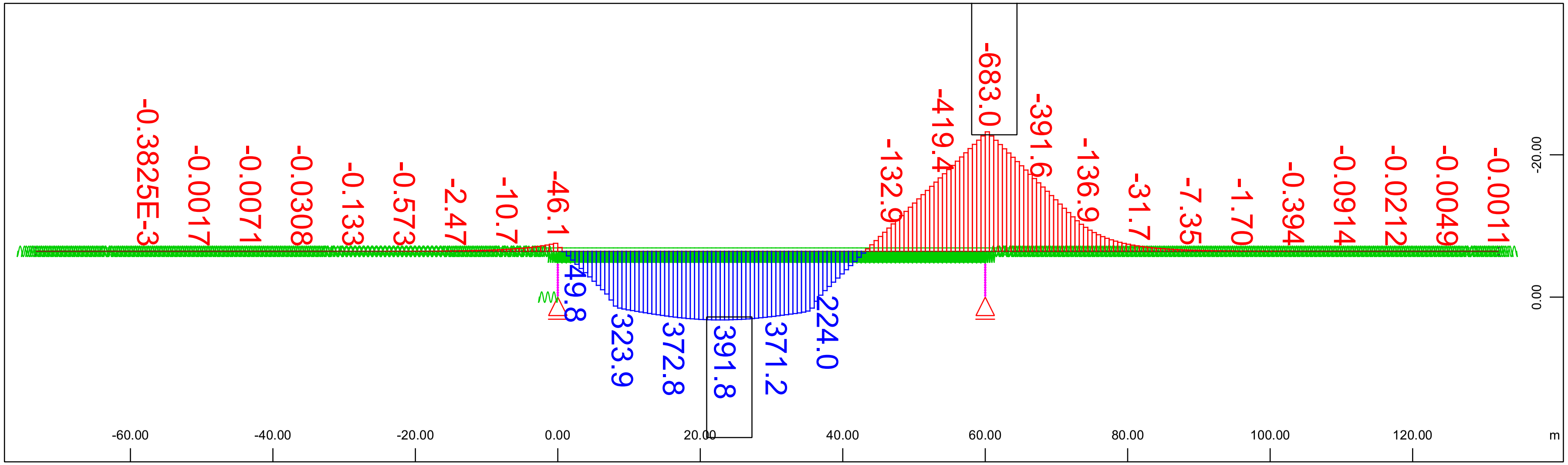
F4-6. Track slab + a floating slab mat with a thickness of 28 mm with a horizontal stiffness - Temperature variation - deck

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Temperature variation - deck , (1 cm 3D = unit) Beam line load (uniform temperature change)
(Unit=126.2 °C) (Max=35.0)
M 1 : 1772



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Temperature variation - deck , 1 cm 3D = 351.6 kN (Min=-683.0) (Max=391.8)
M 1 : 865

reduced scale factor 0.936

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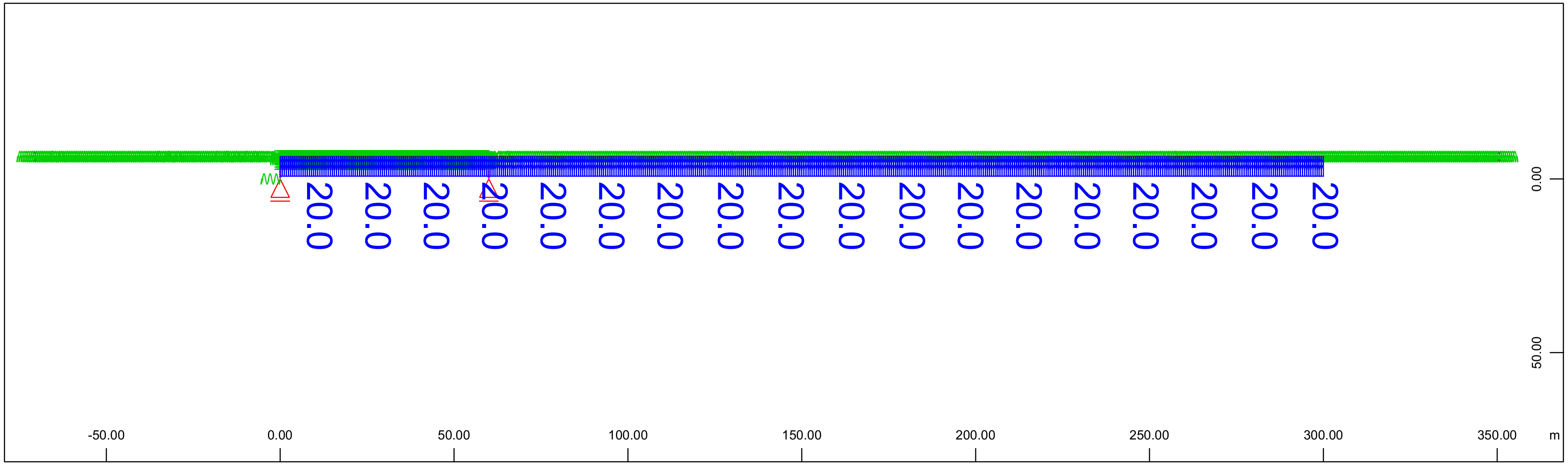
SOFiSTiK 2016-5 WINGRAF - GRAPHICS FOR FINITE ELEMENTS (V 18.05)

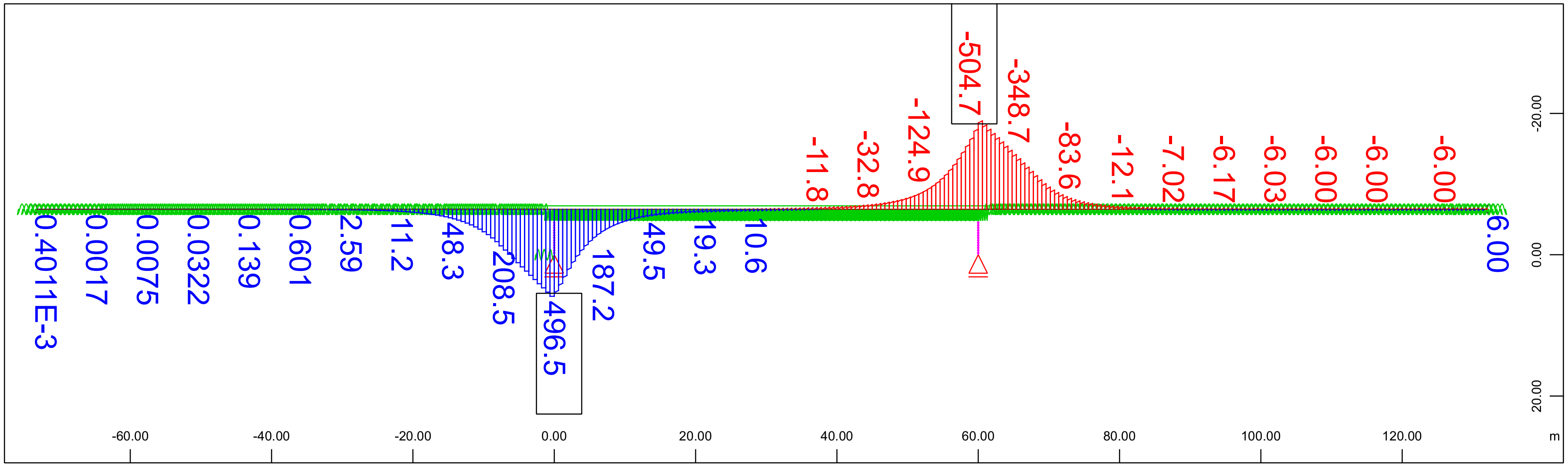
F4-6. Track slab + a floating slab mat with a thickness of 28 mm with a horizontal stiffness - Braking force

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Braking force 60 m from the mova , (1 cm 3D = unit) Beam line load (force) in global X (Unit=63.1 kN/m) (Max=20.0)

M 1 : 1772



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Braking force 60 m from the mova , 1 cm 3D = 351.6 kN (Min=-504.7) (Max=496.5)

M 1 : 872

reduced scale factor 0.936

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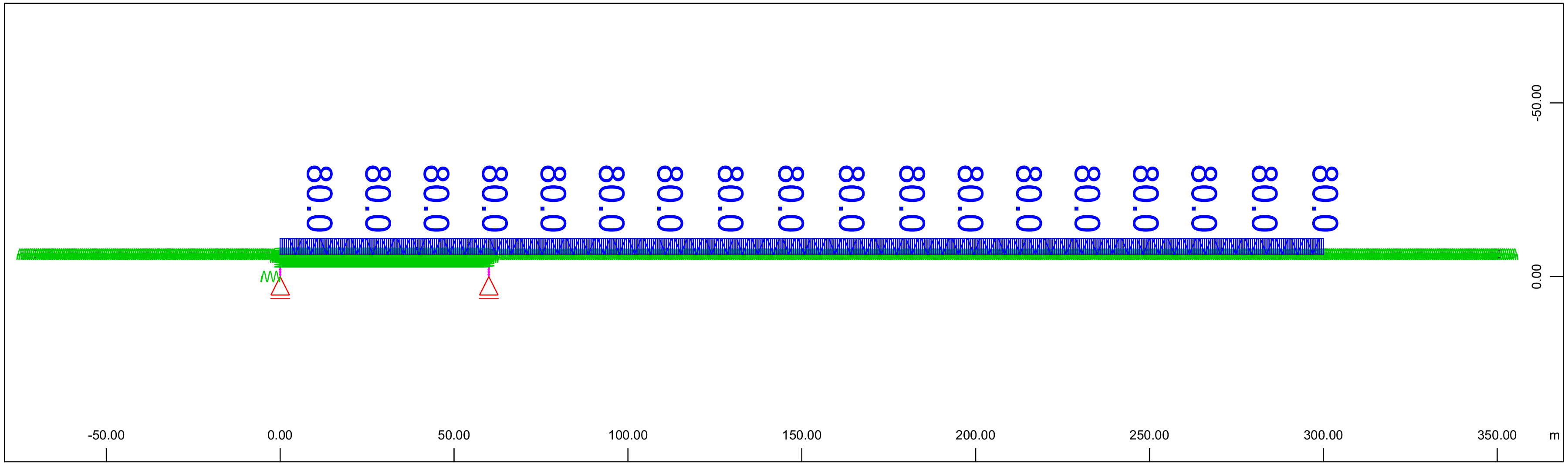
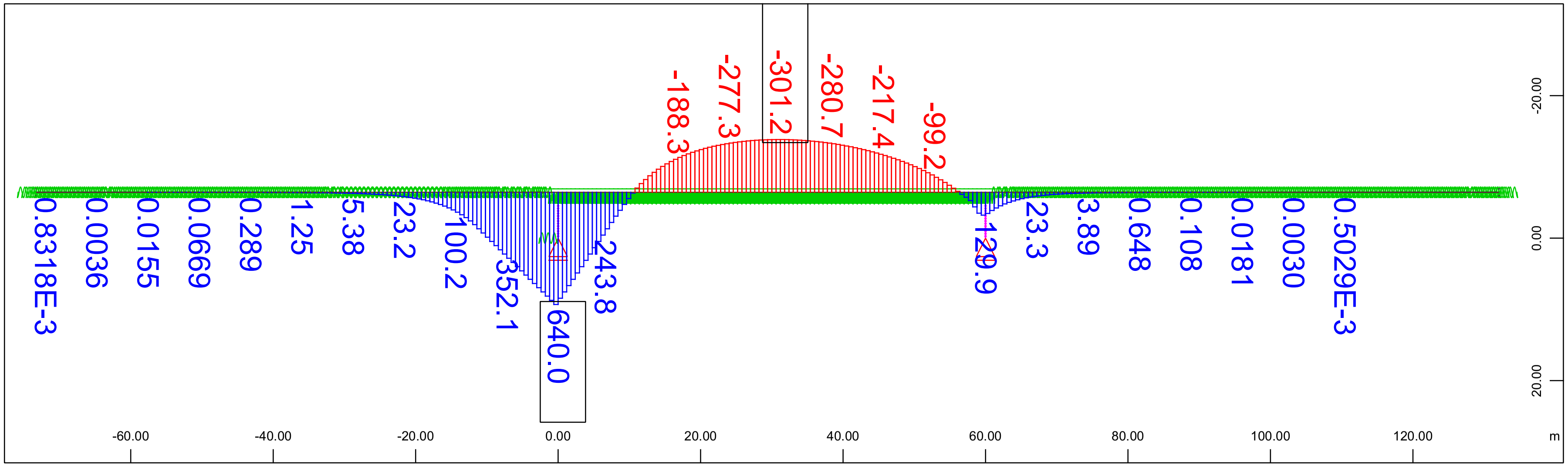
F4-6. Track slab + a floating slab mat with a thickness of 28 mm with a horizontal stiffness - Vertical load

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Vertical load 60 m from the mova , (1 cm 3D = unit) Beam line load (force) in global Y (Unit=315.6 kN/m) (Max=80.0)
M 1 : 1772



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Vertical load 60 m from the mova , 1 cm 3D = 351.6 kN (Min=-301.2) (Max=640.0)
M 1 : 865

reduced scale factor 0.936

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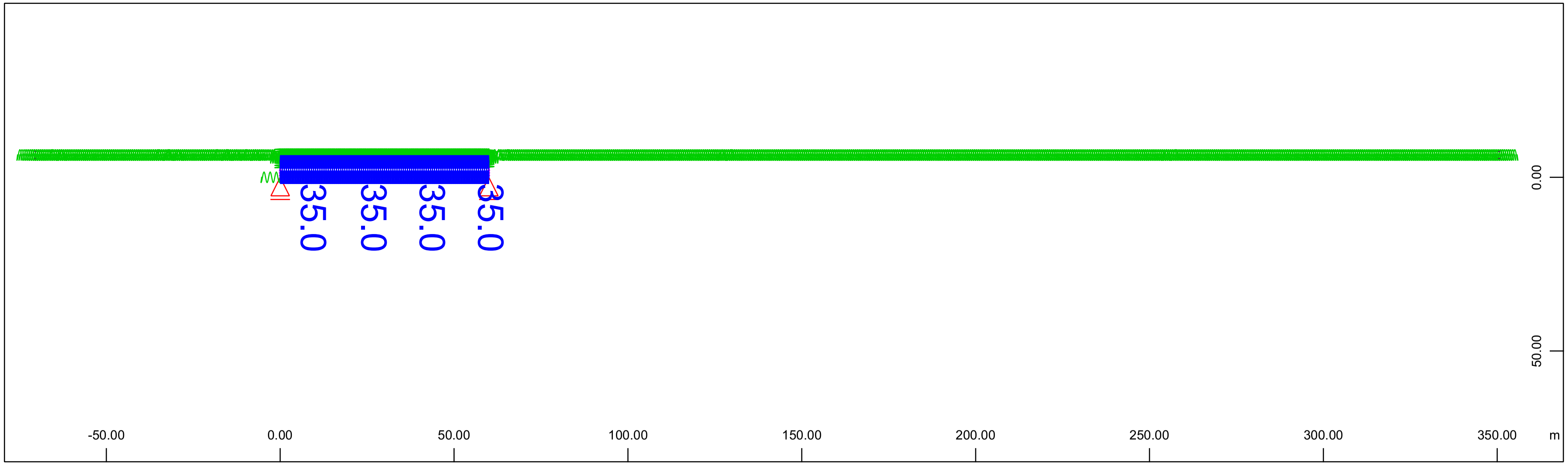
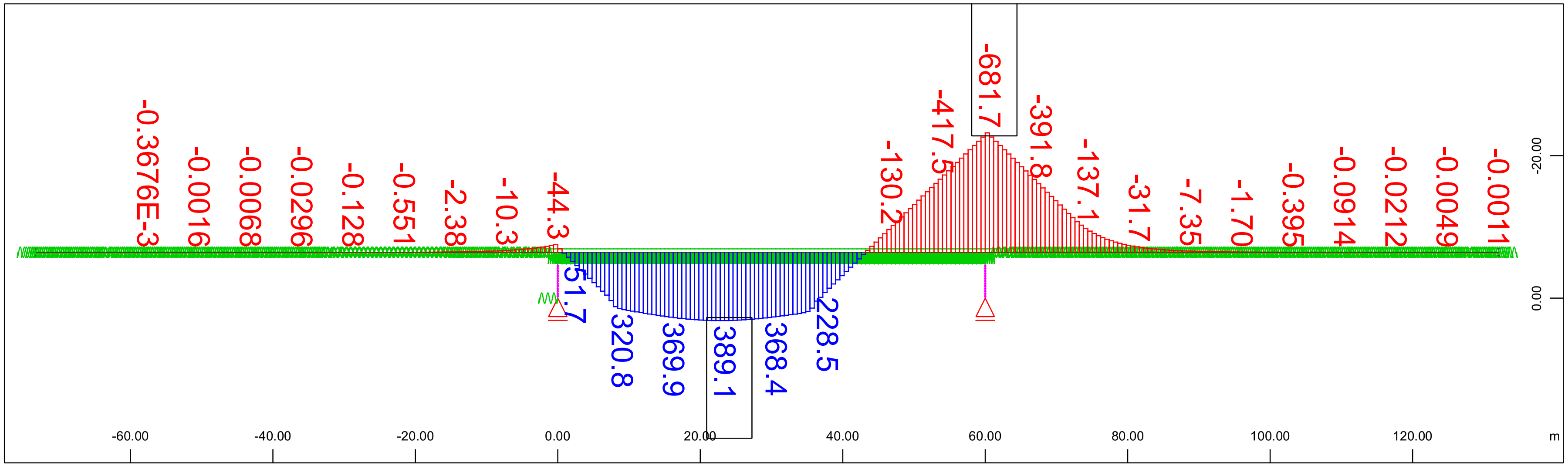
F4-6. Track slab + a floating slab mat with a thickness of 30 mm with a horizontal stiffness - Temperature variation - deck

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Temperature variation - deck , (1 cm 3D = unit) Beam line load (uniform temperature change)
(Unit=126.2 °C) (Max=35.0)
M 1 : 1772



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Temperature variation - deck , 1 cm 3D = 351.6 kN (Min=-681.7) (Max=389.1)
M 1 : 865

reduced scale factor 0.936

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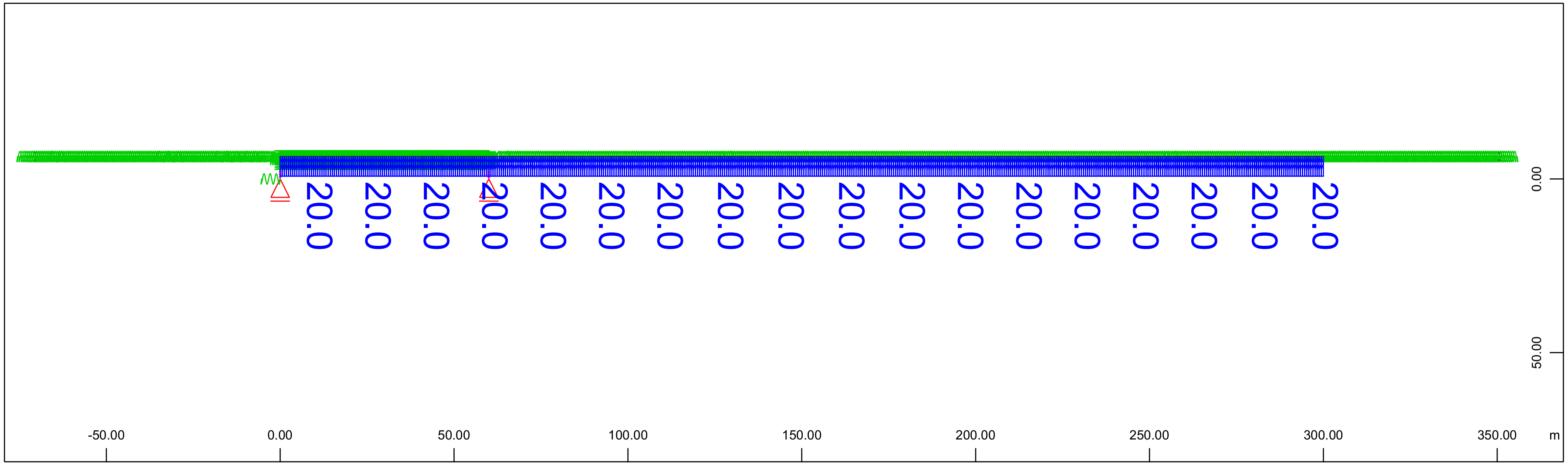
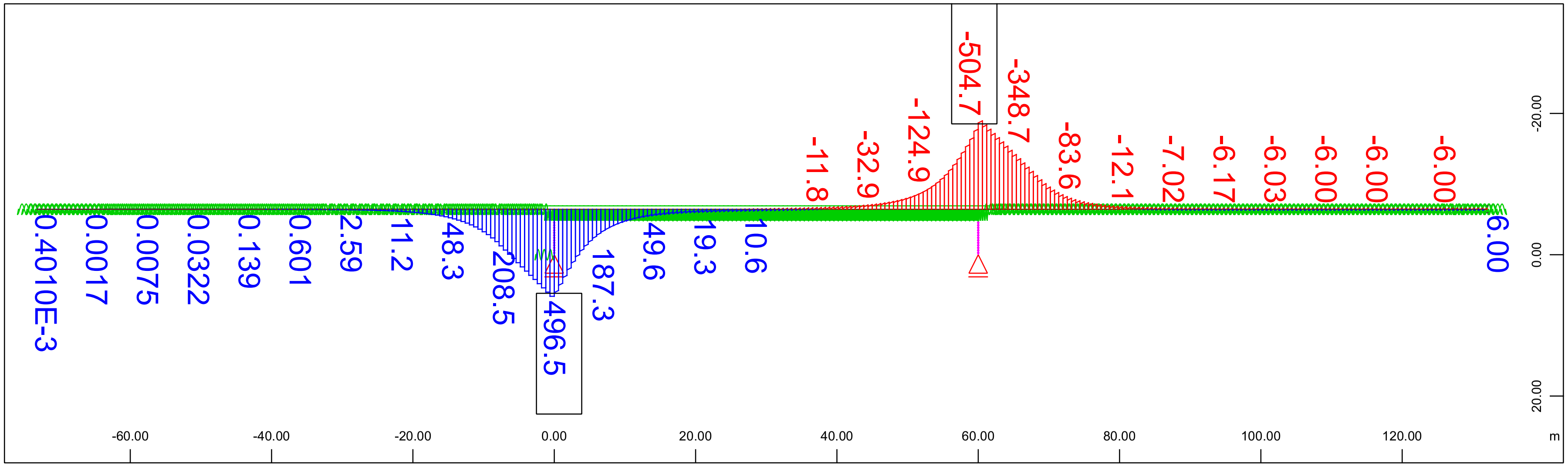
F4-6. Track slab + a floating slab mat with a thickness of 30 mm with a horizontal stiffness - Braking force

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Braking force 60 m from the mova , (1 cm 3D = unit) Beam line load (force) in global X (Unit=63.1 kN/m) (Max=20.0)

M 1 : 1772



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Braking force 60 m from the mova , 1 cm 3D = 351.6 kN (Min=-504.7) (Max=496.5)

M 1 : 872

reduced scale factor 0.936

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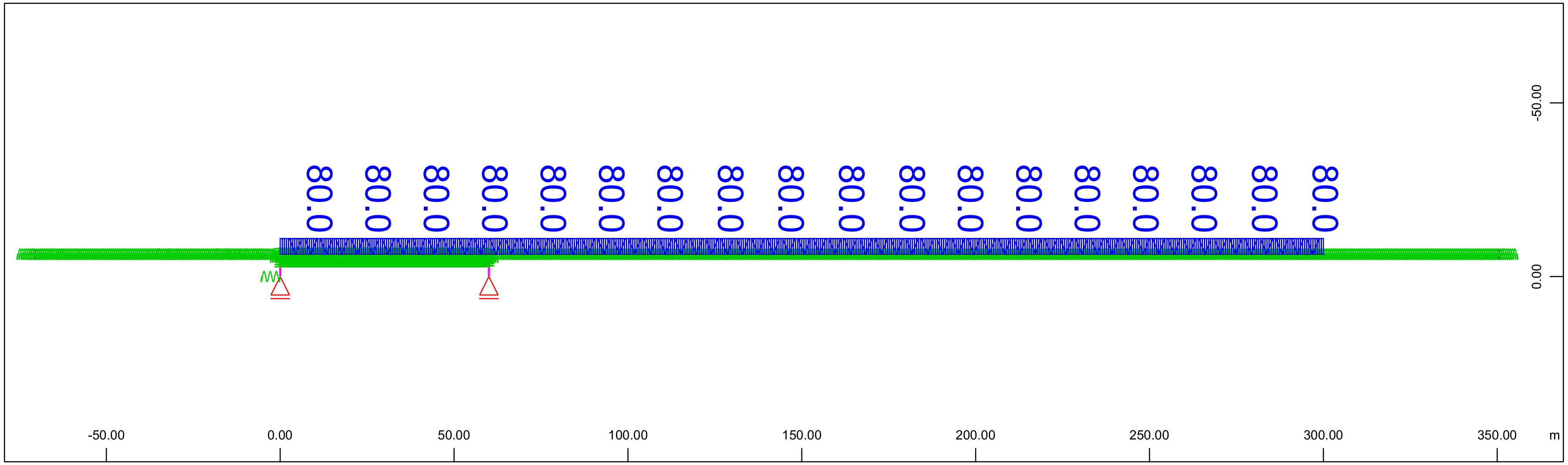
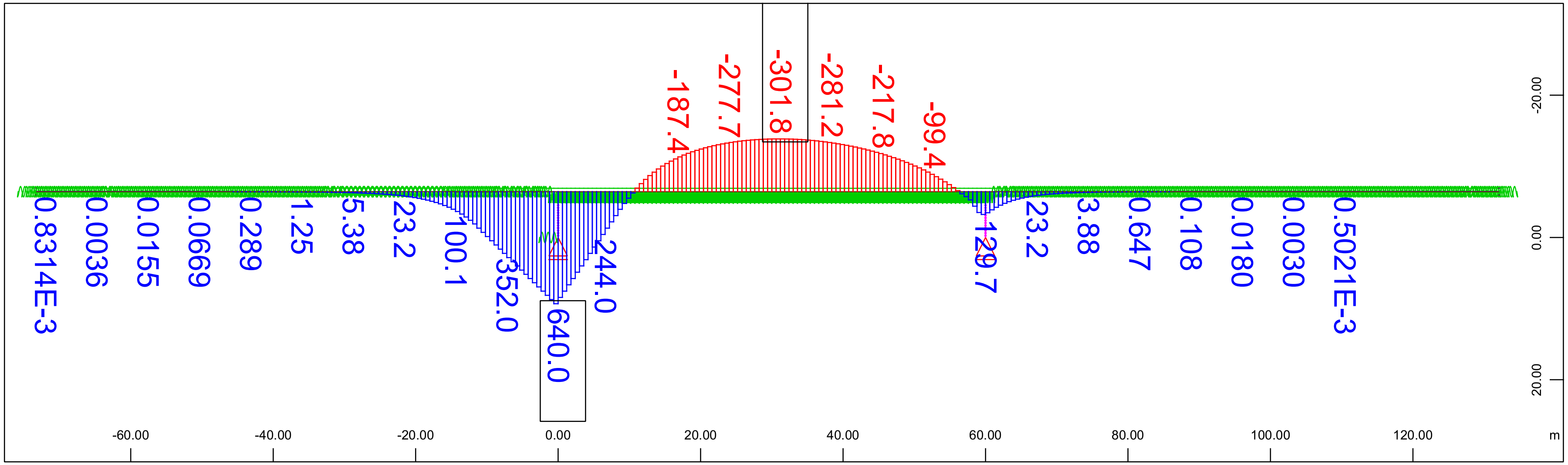
F4-6. Track slab + a floating slab mat with a thickness of 30 mm with a horizontal stiffness - Vertical load

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Vertical load 60 m from the mova , (1 cm 3D = unit) Beam line load (force) in global Y (Unit=315.6 kN/m) (Max=80.0)
M 1 : 1772



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Vertical load 60 m from the mova , 1 cm 3D = 351.6 kN (Min=-301.8) (Max=640.0)
M 1 : 865

reduced scale factor 0.936

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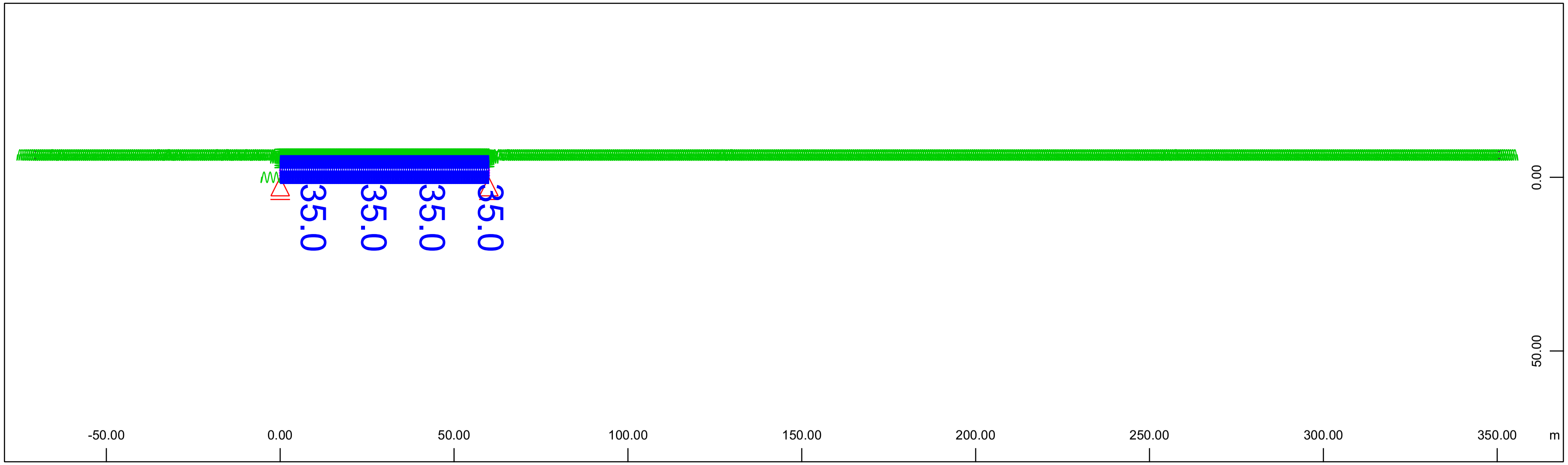
SOFiSTiK 2016-5 WINGRAF - GRAPHICS FOR FINITE ELEMENTS (V...

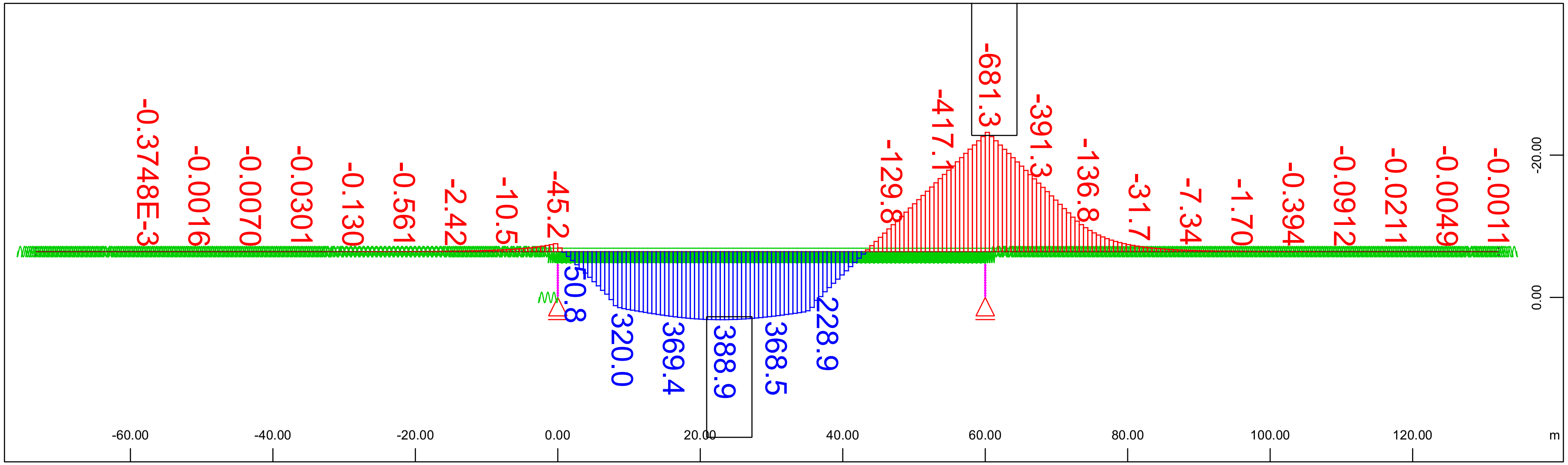
F4-6. Track slab + a floating slab mat with a thickness of 35 mm with a horizontal stiffness - Temperature variation - deck

System
Interactive Graphic



Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Temperature variation - deck , (1 cm 3D = unit) Beam line load (uniform temperature change)
(Unit=126.2 °C) (Max=35.0)

M 1 : 1772



Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Temperature variation - deck , 1 cm 3D = 351.6 kN (Min=-681.3) (Max=388.9)

M 1 : 865

reduced scale factor 0.936

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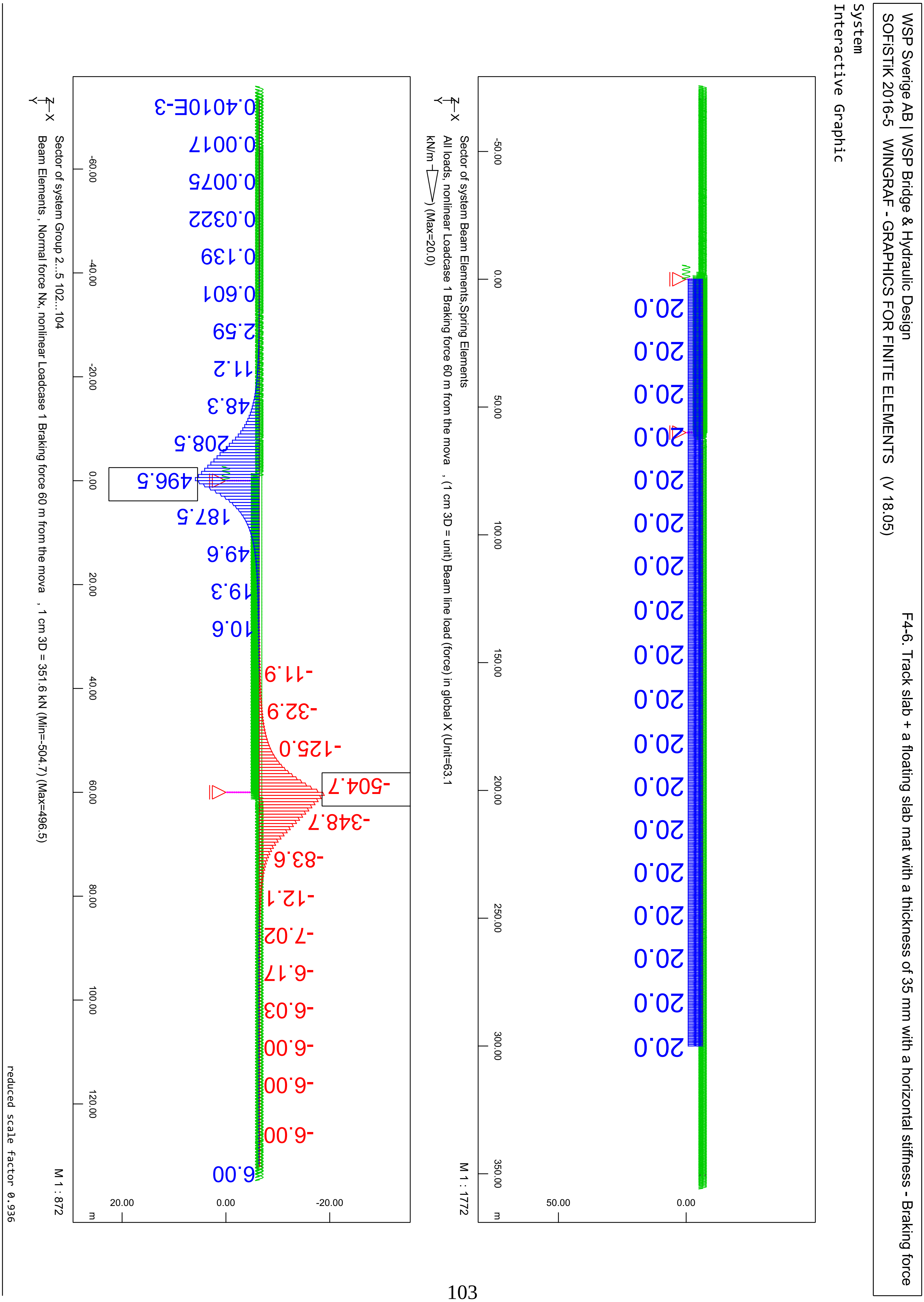

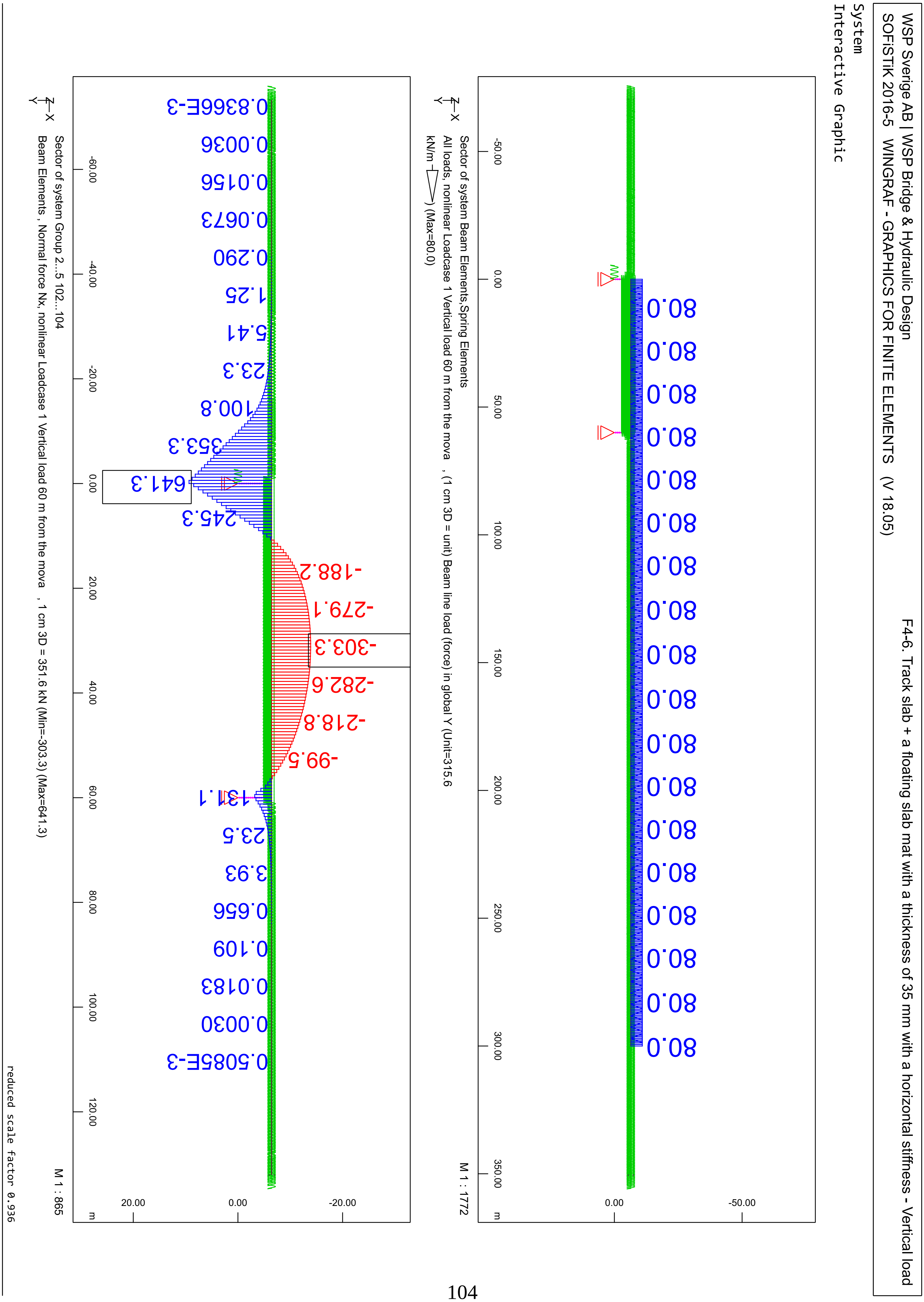
WSP Sverige AB | WSP Bridge & Hydraulic Design
SOFiSTiK 2016-5 WINGRAF - GRAPHICS FOR FINITE ELEMENTS (V 18.05)
F4-6. Track slab + a floating slab mat with a thickness of 35 mm with a horizontal stiffness - Vertical load
System
Interactive Graphic
Sector of system Beam Elements,Spring Elements
All loads, nonlinear Loadcase 1 Vertical load 60 m from the mova , (1 cm 3D = unit) Beam line load (force) in global Y (Unit=315.6 kN/m) (Max=80.0)
M 1 : 1772
80.0
Sector of system Group 2...5 102...104
Beam Elements , Normal force Nx, nonlinear Loadcase 1 Vertical load 60 m from the mova , 1 cm 3D = 351.6 kN (Min=-303.3) (Max=641.3)
M 1 : 865
0.8366E-3
0.0036
0.0156
0.0673
0.290
1.25
5.41
23.3
100.8
353.3
641.3
245.3
-188.2
-279.1
-303.3
-282.6
-218.8
-99.5
131.1
23.5
3.93
0.656
0.109
0.0183
0.0030
0.5085E-3
reduced scale factor 0.936

3 Comparison of the rail stress at the movable support in figures

3.1 E1-3 – comparison figures of the results from the slab track models with and without a floating slab mat

In Figure 3.1 are the results for the slab track models with and without a floating slab mat compared. The train are positioned in *z* = 60 m in the models.

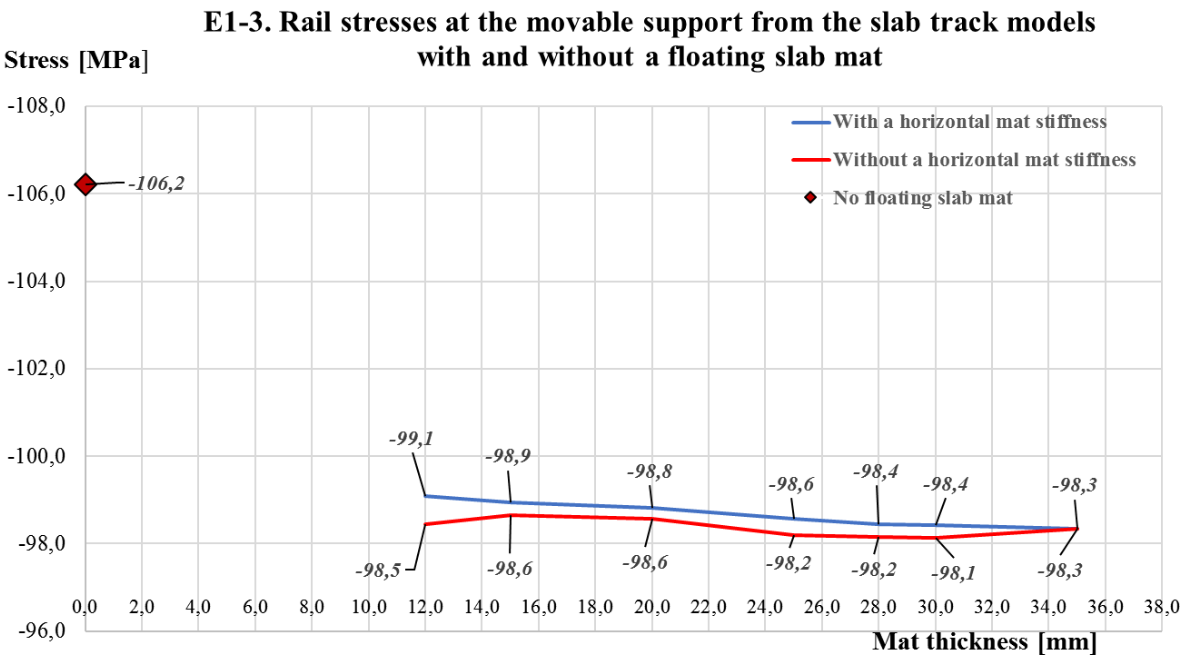

Figure 3.1 E1-3. E1-3. Rail stresses at the movable support from the slab track models with and without a floating slab mat.

3.2 F4-6 – comparison figures of the results from the slab track models with and without a floating slab mat

In Figure 3.2 are the results for the slab track models with and without a floating slab mat compared. The train are positioned in z = 60 m in the models.

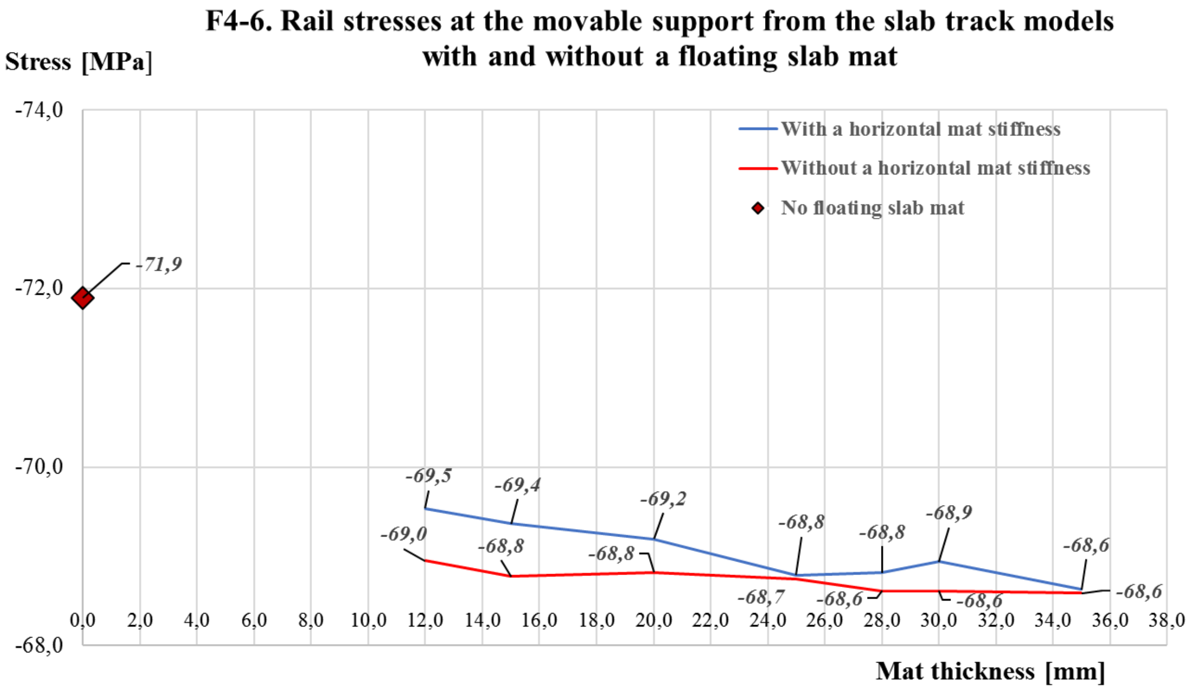

Figure 3.2 F4-6. E1-3. Rail stresses at the movable support from the slab track models with and without a floating slab mat.

Appendix 5

CADINP input codes for the different models

Table of Contents

1 Ballasted track – test case E1-3

1.1 Input code for AQUA – Material and cross section properties

```
!#!chapter Material and cross section properties

+prog aqua urs:18.1

head Material and cross sections

$------------- Input parameters-------------------


$ To use different load positions and load cases: Uncomment the desired position and
$ comment the undesired positions in the System section and in the Loads section

$ Remember to change the stiffness of the bridge deck below:
$ Rigid deck for the braking force and the real bridge deck stiffness for the temperature and
$ vertical load

$ For the braking load case is the deck considered to be
$ rigid to be able to evaluate the effects of braking
$ forces alone. E*I for the deck -> infinity


LET#Alfa_deck 1.0E-5  $ Deck: Thermal expansion coefficient [1/K]
LET#Alfa_rail 1.2E-5  $ Rail: Thermal expansion coefficient [1/K]

LET#A_deck 0.74       $ The decks cross section area    [m^2]
LET#A_rail 0.007686   $ Cross section area for 1 rail   [m^2]

$LET#Iy_deck 1E16      $ Moment of inertia for the deck for the braking load case
                      $ E*I for the deck -> infinity [m^4]

LET#Iy_deck 2.59     $ Moment of inertia for the deck for the temperature and
                      $ vertical load cases [m^4]

LET#Iy_rail 30.383E-6 $ Moment of inertia for 1 rail      [m^4/rail]

echo full
stee NO 1 TYPE S CLAS 355 ALFA #Alfa_deck  $ Deck material
stee NO 2 TYPE S CLAS 355 ALFA #Alfa_rail  $ Track material

sval 1 MNO 1 A #A_deck IY #Iy_deck         $ Deck cross section
sval 2 MNO 2 A 2*#A_rail IY 2*#Iy_rail     $ 2 rail cross sections / track
                                           $ total track properties
end
```

SOFiSTiK CADINP Input File System

1.2 Input code for SOFIMSHA – System / model properties

```
!#!chapter System

+PROG SOFIMSHA urs:5.1 $ Text Interface for Model Creation
HEAD System
SYST 2D


$$$---------Input data------------------------------------------------$$$

$----Bridge geometry----$
LET#h -6     $ Height of the cross section [m]
LET#CG -4.79 $ Center of gravity from the bottom of the cross section [m]
LET#L 60     $ Span length [m]

LET#divide 100  $ Choose divide so that the distance between each node
                $ is equal to L/divide = 0.6 m


$----Elastic spring - fixed support, horizontal stiffness----$
let#k_fixed 600000 $ Stiffness K against horizontal disp.[kN/m^3]


$----Non-linear springs parameters----$
let#dL 0.6     $ Distance between each node and spring [m]

let#u0 2.0E-3  $ Displacement between the elastic
               $ and plastic zones [m]

$ Resistance against longitudinal disp.

let#kp_loaded 60                       $ Plastic shear resistance for
                                       $ the loaded track [kN/m]

let#kep_loaded #kp_loaded/(#dL*#u0)    $ Elastic shear resistance for the
                                       $ loaded track [kN/m^2]
let#ket_loaded #kep_loaded

let#kp_unloaded 20                     $ Plastic shear resistance for
                                       $ the unloaded track [kN/m]

let#kep_unloaded #kp_unloaded/(#dL*#u0) $ Elastic shear resistance for
                                       $ the unloaded track [kN/m^2]
let#ket_unloaded #kep_unloaded

$---------------------------------------------------------------------------



$$$----------System---------------------------------------------------$$$


$----Supports----$
grp 5
$ Fixed support
node NO 1 X 0 Y 0 fix PY
spri NO 1 NA 1 DX -1 CP #k_fixed

$ Movable support
node NO 2 X #L Y 0 fix PY
```

SOFiSTiK CADINP Input File
System

```
$----Deck----$
grp 1
$ Creates 101 nodes with a distance of 0.6 m between each node
$ in the center of gravity for the cross section

node NO 1000 X 0 Y #CG
node NO 1000 FIX KF NR1 1

node NO 1100 X #L Y #CG
node NO 1100 FIX KF NR1 2

node NO (1001 1099 1) X (0.6 #L/#divide) Y #CG

$ Creates 100 beam elements between node 1000-1100
beam NO fit NA 1000 NE 1100 NCS 1 DIV #divide


$ Top of the deck nodes - used to see the horizontal
$ displacement of the top of the deck
grp 6
node NO 10 X 0 Y #h
node NO 10 FIX KF NR1 1000

node NO 11 X #L Y #h
node NO 11 FIX KF NR1 1100



$----Rail elements----$

$ 499 rail elements to the left of the bridge:
$ Creates 500 nodes with a distance of 0.6 m between them
grp 2
node NO (2000 2499 1) X (-300 299.4/499) Y #h
beam NO mesh NA 2000 NE 2499 NCS 2 DIV 499


$ 499 rail elements to the right of the bridge:
$ Creates 500 nodes with a distance of 0.6 m between them
grp 4
node NO (4000 4499 1) X (#L+0.6 299.4/499) Y #h
beam NO mesh NA 4000 NE 4499 NCS 2 DIV 499


$ 102 rail elements on top of the bridge:
$ Creates 102 nodes with a distance of 0.6 m between them
grp 3
node NO (3000 3100 1) X (0 #L/#divide) Y #h
beam NO mesh NA 2499 NE 4000 NCS 2 DIV #divide+2


$ Rail nodes - used to see the horizontal displacement
$ of the rail on top of the bridge
grp  8
node NO 12 X 0 Y #h
node NO 12 FIX KF NR1 3000

node NO 13 X #L Y #h
node NO 13 FIX KF NR1 3100
```

SOFiSTiK CADINP Input File
System


```
$----Non-linear springs for different load positions----$

$ Direction of principal and lateral direction of the springs
let#d_x -1     $ X-component of direction
let#d_y 0     $ Y-component of direction


$ To use different load positions: Uncomment the desired position and
$ comment the undesired positions below.

$ Remember to change the position and load case for the different load
$ positions in the Loads section.

$ Remember to change the stiffness of the bridge deck in the Material section:
$ Rigid deck för braking and the real bridge deck stiffness for the vertical load
$ and temperature load


$$----Temperature variation load----$$

$$ All springs are unloaded

$$ Input of non-linear spring elements between node 2000-2499
$$ to the left of the bridge. Embankment track.
$grp 102
$spri mesh NA 2000 NE 2499 DX #d_x CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded
$spri NA 2499 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3


$$ Input of non-linear spring elements between the track and the bridge deck
$grp 103
$spri NA 3000 NE 1000 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
$spri mesh NA 3000 NE 3100 DX #d_x CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded NARE 1000 NERE 110
$spri NA 3100 NE 1100 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3


$$ Input of non-linear spring elements between node 4000-4499
$$ to the left of the bridge. Embankment track
$grp 104
$spri NA 4000 DX -#d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
$spri mesh NA 4000 NE 4499 DX -#d_x CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded

$$----End of the temperature variation load----$$




$$----Different positions - braking and vertical load cases----$$

$$----Position 0 m from the movable support-----$$

$$ Input of non-linear spring elements between node 2000-2499
$$ to the left of the bridge. Embankment track.
$grp 102

$$ The track is loaded between node 2000-2499.
$spri mesh NA 2000 NE 2499 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded yiel #kp_loaded
$spri NA 2499 DX #d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3

$$ Input of non-linear spring elements between the track and the bridge deck
```

SOFiSTiK CADINP Input File
System

```
$grp 103

$$ The bridge track is unloaded between node 3000 - 3100
$spri mesh NA 3000 NE 3100 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded NARE 1000
$spri NA 3100 NE 1100 DX #d_x DY #d_y CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3



$$ Input of non-linear spring elements between node 4000-4499
$$ to the right of the bridge. Embankment track.
$grp 104

$$ The track is unloaded between node 4000-4499.
$spri NA 4000 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
$spri mesh NA 4000 NE 4499 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded

$$----End of position 0 m-----------------------$$




$$----Position 15 m from the movable support----$$


$ Input of non-linear spring elements between node 2000-2499
$ to the left of the bridge. Embankment track.
$grp 102

$$ The track is unloaded between node 2000-2025.
$spri mesh NA 2000 NE 2025 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded

$$ The track is loaded between node 2025-2499.
$spri mesh NA 2025 NE 2499 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded yiel #kp_loaded
$spri NA 2499 DX #d_x CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3


$$ Input of non-linear spring elements between the track and the bridge deck
$$ The bridge track is loaded between node 3000 - 3025
$grp 103
$spri NA 3000 NE 1000 DX #d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3
$spri mesh NA 3000 NE 3025 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded YIEL #kp_loaded NARE 1000 NERE 1

$$ The bridge track is unloaded between node 3025 - 3100
$grp 103
$spri mesh NA 3025 NE 3100 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded NARE 1025
$spri NA 3100 NE 1100 DX -#d_x DY #d_y CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3


$$ Input of non-linear spring elements between node 4000-4499
$$ to the left of the bridge. Embankment track.
$grp 104

$$ The track is unloaded between node 4000-4499.
$spri NA 4000 DX -#d_x CP #kep_unloaded CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
$spri mesh NA 4000 NE 4499 DX -#d_x DY #d_y CP #kep_unloaded ct #ket_unloaded yiel #kp_unloaded

$$----End of position 15 m------------------------------------------------------------------------------
```

SOFiSTiK CADINP Input File
System

```
$$----Position 30 m from the movable support----$$

$$ Input of non-linear spring elements between node 2000-2499
$$ to the left of the bridge. Embankment track.
$grp 102

$$ The track is unloaded between node 2000-2051.
$spri mesh NA 2000 NE 2051 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded

$$ The track is loaded between node 2051-2499.
$spri mesh NA 2051 NE 2499 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded yiel #kp_loaded
$spri NA 2499 DX #d_x CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3


$$ Input of non-linear spring elements between the track and the bridge deck
$$ The bridge track is loaded between node 3000 - 3050
$grp 103
$spri NA 3000 NE 1000 DX #d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3
$spri mesh NA 3000 NE 3050 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded YIEL #kp_loaded NARE 1000 NERE 1

$$ The bridge track is unloaded between node 3050 - 3100
$grp 103
$spri mesh NA 3050 NE 3100 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded NARE 1050
$spri NA 3100 NE 1100 DX -#d_x DY #d_y CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3


$$ Input of non-linear spring elements between node 4000-4499
$$ to the left of the bridge. Embankment track.
$grp 104

$$ The track is unloaded between node 4000-4499.
$spri NA 4000 DX -#d_x CP #kep_unloaded CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
$spri mesh NA 4000 NE 4499 DX -#d_x DY #d_y CP #kep_unloaded ct #ket_unloaded yiel #kp_unloaded

$$----End of position 30 m--------------------------------------------------------------------$$




$$----Position 45 m from the movable support----$$

$ Input of non-linear spring elements between node 2000-2499
$ to the left of the bridge. Embankment track.
$grp 102

$$ The track is unloaded between node 2000-2075.
$spri mesh NA 2000 NE 2075 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded

$$ The track is loaded between node 2075-2499.
$spri mesh NA 2075 NE 2499 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded yiel #kp_loaded
$spri NA 2499 DX #d_x CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3


$$ Input of non-linear spring elements between the track and the bridge deck
$$ The bridge track is loaded between node 3000 - 3075
$grp 103
$spri NA 3000 NE 1000 DX #d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3
$spri mesh NA 3000 NE 3075 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded YIEL #kp_loaded NARE 1000 NERE 1

$$ The bridge track is unloaded between node 3075 - 3100
```

SOFiSTiK CADINP Input File
System

```
$grp 103
$spri mesh NA 3075 NE 3100 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded NARE 1075
$spri NA 3100 NE 1100 DX -#d_x DY #d_y CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3


$$ Input of non-linear spring elements between node 4000-4499
$$ to the left of the bridge. Embankment track.
$grp 104

$$ The track is unloaded between node 4000-4499.
$spri NA 4000 DX -#d_x CP #kep_unloaded CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
$spri mesh NA 4000 NE 4499 DX -#d_x DY #d_y CP #kep_unloaded ct #ket_unloaded yiel #kp_unloaded

$$----End of position 45 m----------------------$$




$$----Position 60 m from the movable support----$$


$ Input of non-linear spring elements between node 2000-2499
$ to the left of the bridge. Embankment track.
grp 102

$ The track is unloaded between node 2000-2100.
spri mesh NA 2000 NE 2100 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded

$ The track is loaded between node 2100-2499.
spri mesh NA 2100 NE 2499 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded yiel #kp_loaded
spri NA 2499 DX #d_x CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3


$ Input of non-linear spring elements between the track and the bridge deck
$ The bridge track is loaded (between node 3000 - 3100)
grp 103
spri NA 3000 NE 1000 DX #d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3
spri mesh NA 3000 NE 3100 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded YIEL #kp_loaded NARE 1000 NERE 11


$ Input of non-linear spring elements between node 4000-4499
$ to the left of the bridge. Embankment track.
grp 104

$ The track is unloaded between node 3100-4499.
spri NA 3100 NE 1100 DX -#d_x DY #d_y CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
spri NA 4000 DX -#d_x CP #kep_unloaded CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
spri mesh NA 4000 NE 4499 DX -#d_x DY #d_y CP #kep_unloaded ct #ket_unloaded yiel #kp_unloaded

$$----End of position 60 m-------------------------$$


END
```

SOFiSTiK CADINP Input File
Loads

1.3 Input code for SOFILOAD – Load cases and load positions

```
!#!chapter Loads

+PROG SOFILOAD urs:6.1 $ Text Interface for Loads
HEAD Text Interface for Loads
$ Actions
ACT G   $ dead load
ACT Q   $ variable load



$-------------Input data------------------------------------------------------------

$ Temperature variation
LET#delta_T_deck 35  $ Thermal variation in the deck  ['C]


$ Braking force

$ If the braking force acts from the movable support
$ towards the fixed support: -20 [kN/m]

$ If the braking force acts from the fixed support
$ towards the movable support: 20 [kN/m]

LET#F_braking 20 $ Horizontal braking force [kN/m]


$ Vertical load from the train
LET#F_vertical 80 $ Vertical train load [kN/m]




$--------------Loadcases and load positions---------------------------------------------

$ To use different load positions: Uncomment the desired position and
$ comment the undesired positions below.

$ Uncomment the desired position and load case below, comment all the
$ undesired positions and load cases below (temperature, braking or vertical load).

$ Remember to change the spring stiffnesses (unloaded or loaded) for the different load
$ positions for the braking load and vertical loac case in the System section.
$ For the temperature variation load should all springs be unloaded.

$ Remember to change the stiffness of the bridge deck in the Material section:
$ Rigid deck för braking and the real brdige deck stiffness for the vertical load




$$----Temperature variation load case----$$

$LC 1 Q TITL 'Temperature variation - deck'
$  BEAM FROM GRP 1 TYPE DT PA #delta_T_deck


$$----End of the temperature variation load----$$
```

SOFiSTiK CADINP Input File
Loads

```
$$----Different positions - braking and vertical load cases----$$

$$----Position 0 m from the movable support----$$

$ The length of the train is 300 m, each element is
$ 0.6 m:

$ Uncomment the desired load case below (braking or vertical load)

$LC 1 Q TITL 'Braking force 0 m from the fixed support'
$  BEAM FROM 20001 TO 20499 TYPE PXX PA #F_braking
$  BEAM FROM 30001 TO 30001 TYPE PXX PA #F_braking


$LC 1 Q TITL 'Vertical load 0 m from the fixed support'
$  BEAM FROM 20001 TO 20499 TYPE PG PA #F_vertical
$  BEAM FROM 30001 TO 30001 TYPE PG PA #F_vertical

$$----End of position 0 m----------------------$$




$$----Position 15 m from the movable support----$$

$ The length of the train is 300 m, each element is
$ 0.6 m:

$ Uncomment the desired load case below (braking or vertical load)


$LC 1 Q TITL 'Braking force 15 m from the fixed support'
$  BEAM FROM 20026 TO 20499 TYPE PXX PA #F_braking
$  BEAM FROM 30001 TO 30025 TYPE PXX PA #F_braking

$LC 1 Q TITL 'Vertical load 15 m from the fixed support'
$  BEAM FROM 20026 TO 20499 TYPE PG PA #F_vertical
$  BEAM FROM 30001 TO 30025 TYPE PG PA #F_vertical

$$----End of position 15 m--------------------$$




$$----Position 30 m from the movable support----$$

$$ The length of the train is 300 m, each element is
$$ 0.6 m:

$ Uncomment the desired load case below (braking or vertical load)

$LC 1 Q TITL 'Braking force 30 m from the fixed support'
$  BEAM FROM 20052 TO 20499 TYPE PXX PA #F_braking
$  BEAM FROM 30001 TO 30050 TYPE PXX PA #F_braking

$LC 1 Q TITL 'Vertical load 30 m from the fixed support'
$  BEAM FROM 20052 TO 20499 TYPE PG PA #F_vertical
$  BEAM FROM 30001 TO 30050 TYPE PG PA #F_vertical

$$----End of position 30 m----------------------$$
```

SOFiSTiK CADINP Input File
Loads

```
$$----Position 45 m from the movable support----$$

$$ The length of the train is 300 m, each element is
$$ 0.6 m:

$ Uncomment the desired load case below (braking or vertical load)

$LC 1 Q TITL 'Braking force 45 m from the fixed support'
$  BEAM FROM 20076 TO 20499 TYPE PXX PA #F_braking
$  BEAM FROM 30001 TO 30075 TYPE PXX PA #F_braking

$LC 1 Q TITL 'Vertical load 45 m from the fixed support'
$  BEAM FROM 20076 TO 20499 TYPE PG PA #F_vertical
$  BEAM FROM 30001 TO 30075 TYPE PG PA #F_vertical

$$----End of position 45 m--------------------------$$



$$----Position 60 m from the movable support----$$

$ The length of the train is 300 m, each element is
$ 0.6 m:

$ Uncomment the desired load case below (braking or vertical load)


LC 1 Q TITL 'Braking force 60 m from the fixed support'
  BEAM FROM 20101 TO 20499 TYPE PXX PA #F_braking
  BEAM FROM 30001 TO 30101 TYPE PXX PA #F_braking

$LC 1 Q TITL 'Vertical load 60 m from the fixed support'
$  BEAM FROM 20101 TO 20499 TYPE PG PA #F_vertical
$  BEAM FROM 30001 TO 30101 TYPE PG PA #F_vertical

$$----End of position 60 m--------------------------$$


END
```

1.4 Input code for ASE – Calculation

```
!#!chapter Calculation

+PROG ASE urs:20.1 $ Linear Analysis
HEAD Calculation of forces and moments
PAGE UNII 0
echo  OPT full yes
CTRL OPT SOLV VAL - $  Solution of the system
SYST prob NONL
LC 1

END
```

2 Ballasted track – test case F4-6

2.1 Input code for AQUA – Material and cross section properties

```
!#!chapter Material and cross section properties

+prog aqua urs:18.1

head Material and cross sections

$------------- Input parameters-------------------


$ To use different load positions and load cases: Uncomment the desired position and
$ comment the undesired positions in the System section and in the Loads section

$ Remember to change the stiffness of the bridge deck below:
$ Rigid deck for the braking force and the real bridge deck stiffness for the temperature and
$ vertical load

$ For the braking load case is the deck considered to be
$ rigid to be able to evaluate the effects of braking
$ forces alone. E*I for the deck -> infinity



LET#Alfa_deck 1.0E-5  $ Deck: Thermal expansion coefficient [1/K]
LET#Alfa_rail 1.2E-5  $ Rail: Thermal expansion coefficient [1/K]

LET#A_deck 0.74       $ The decks cross section area   [m^2]
LET#A_rail 0.007686   $ Cross section area for 1 rail  [m^2]

$LET#Iy_deck 1E16      $ Moment of inertia for the deck for the braking load case
                     $ E*I for the deck -> infinity [m^4]

LET#Iy_deck 2.59     $ Moment of inertia for the deck for the temperature and
                     $ vertical load cases [m^4]

LET#Iy_rail 30.383E-6 $ Moment of inertia for 1 rail      [m^4/rail]

echo full
stee NO 1 TYPE S CLAS 355 ALFA #Alfa_deck  $ Deck material
stee NO 2 TYPE S CLAS 355 ALFA #Alfa_rail  $ Track material

sval 1 MNO 1 A #A_deck IY #Iy_deck         $ Deck cross section
sval 2 MNO 2 A 2*#A_rail IY 2*#Iy_rail     $ 2 rail cross sections / track
                                           $ total track properties
end
```

SOFiSTiK CADINP Input File System

2.2 Input code for SOFIMSHA – System / model properties

```
!#!chapter System

+PROG SOFIMSHA urs:5.1 $ Text Interface for Model Creation
HEAD System
SYST 2D


$$$---------Input data------------------------------------------------$$$

$----Bridge geometry----$
LET#h -6     $ Height of the cross section [m]
LET#CG -4.79 $ Center of gravity from the bottom of the cross section [m]
LET#L 60     $ Span length [m]

LET#divide 100  $ Choose divide so that the distance between each node
                $ is equal to L/divide = 0.6 m


$----Elastic spring - fixed support, horizontal stiffness----$
let#k_fixed 120000 $ Stiffness K against horizontal disp.[kN/m^3]


$----Non-linear springs parameters----$
let#dL 0.6     $ Distance between each node and spring [m]

let#u0 2.0E-3  $ Displacement between the elastic
               $ and plastic zones [m]

$ Resistance against longitudinal disp.

let#kp_loaded 60                       $ Plastic shear resistance for
                                       $ the loaded track [kN/m]

let#kep_loaded #kp_loaded/(#dL*#u0)    $ Elastic shear resistance for the
                                       $ loaded track [kN/m^2]
let#ket_loaded #kep_loaded

let#kp_unloaded 20                     $ Plastic shear resistance for
                                       $ the unloaded track [kN/m]

let#kep_unloaded #kp_unloaded/(#dL*#u0) $ Elastic shear resistance for
                                       $ the unloaded track [kN/m^2]
let#ket_unloaded #kep_unloaded

$--------------------------------------------------------------------------



$$$----------System---------------------------------------------------$$$


$----Supports----$
grp 5
$ Fixed support
node NO 1 X 0 Y 0 fix PY
spri NO 1 NA 1 DX -1 CP #k_fixed

$ Movable support
node NO 2 X #L Y 0 fix PY
```

SOFiSTiK CADINP Input File
System

```
$----Deck----$
grp 1
$ Creates 101 nodes with a distance of 0.6 m between each node
$ in the center of gravity for the cross section

node NO 1000 X 0 Y #CG
node NO 1000 FIX KF NR1 1

node NO 1100 X #L Y #CG
node NO 1100 FIX KF NR1 2

node NO (1001 1099 1) X (0.6 #L/#divide) Y #CG

$ Creates 100 beam elements between node 1000-1100
beam NO fit NA 1000 NE 1100 NCS 1 DIV #divide


$ Top of the deck nodes - used to see the horizontal
$ displacement of the top of the deck
grp 6
node NO 10 X 0 Y #h
node NO 10 FIX KF NR1 1000

node NO 11 X #L Y #h
node NO 11 FIX KF NR1 1100



$----Rail elements----$

$ 499 rail elements to the left of the bridge:
$ Creates 500 nodes with a distance of 0.6 m between them
grp 2
node NO (2000 2499 1) X (-300 299.4/499) Y #h
beam NO mesh NA 2000 NE 2499 NCS 2 DIV 499


$ 499 rail elements to the right of the bridge:
$ Creates 500 nodes with a distance of 0.6 m between them
grp 4
node NO (4000 4499 1) X (#L+0.6 299.4/499) Y #h
beam NO mesh NA 4000 NE 4499 NCS 2 DIV 499


$ 102 rail elements on top of the bridge:
$ Creates 102 nodes with a distance of 0.6 m between them
grp 3
node NO (3000 3100 1) X (0 #L/#divide) Y #h
beam NO mesh NA 2499 NE 4000 NCS 2 DIV #divide+2


$ Rail nodes - used to see the horizontal displacement
$ of the rail on top of the bridge
grp  8
node NO 12 X 0 Y #h
node NO 12 FIX KF NR1 3000

node NO 13 X #L Y #h
node NO 13 FIX KF NR1 3100
```

SOFiSTiK CADINP Input File
System

```
$----Spring elements---------------------$


$----Non-linear springs for different load positions----$

$ Direction of principal and lateral direction of the springs
let#d_x -1     $ X-component of direction
let#d_y 0     $ Y-component of direction


$ To use different load positions: Uncomment the desired position and
$ comment the undesired positions below.

$ Remember to change the position and load case for the different load
$ positions in the Loads section.

$ Remember to change the stiffness of the bridge deck in the Material section:
$ Rigid deck för braking and the real bridge deck stiffness for the vertical load
$ and temperature load


$----Temperature variation load----$$

$ All springs are unloaded

$ Input of non-linear spring elements between node 2000-2499
$ to the left of the bridge. Embankment track.
$grp 102
$spri mesh NA 2000 NE 2499 DX #d_x CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded
$spri NA 2499 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3


$$ Input of non-linear spring elements between the track and the bridge deck
$grp 103
$spri NA 3000 NE 1000 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
$spri mesh NA 3000 NE 3100 DX #d_x CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded NARE 1000 NERE 110
$spri NA 3100 NE 1100 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3


$$ Input of non-linear spring elements between node 4000-4499
$$ to the left of the bridge. Embankment track
$grp 104
$spri NA 4000 DX -#d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
$spri mesh NA 4000 NE 4499 DX -#d_x CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded

$$----End of the temperature variation load----$$




$$----Different positions - braking and vertical load cases----$$

$$----Position 0 m from the movable support-----$$

$$ Input of non-linear spring elements between node 2000-2499
$$ to the left of the bridge. Embankment track.
$grp 102

$$ The track is unloaded between node 2000-2499.
```

SOFiSTiK CADINP Input File
System

```
$spri mesh NA 2000 NE 2499 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded
$spri NA 2499 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3



$$ Input of non-linear spring elements between the track and the bridge deck
$grp 103

$$ The bridge track is unloaded between node 3000 - 3100
$spri mesh NA 3000 NE 3100 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded NARE 1000
$spri NA 3100 NE 1100 DX #d_x DY #d_y CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3



$$ Input of non-linear spring elements between node 4000-4499
$$ to the right of the bridge. Embankment track.
$grp 104

$$ The track is loaded between node 4000-4499.
$spri NA 4000 DX -#d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3
$spri mesh NA 4000 NE 4499 DX -#d_x DY #d_y CP #kep_loaded CT #ket_loaded yiel #kp_loaded

$$----End of position 0 m-----------------------$$




$$----Position 15 m from the movable support----$$

$$ Input of non-linear spring elements between node 2000-2499
$$ to the left of the bridge. Embankment track.
$grp 102

$$ The track is unloaded between node 2000-2499.
$spri mesh NA 2000 NE 2499 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded
$spri NA 2499 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3



$$ Input of non-linear spring elements between the track and the bridge deck
$grp 103

$$ The bridge track is unloaded between node 3000 - 3075
$spri NA 3000 NE 1000 DX #d_x DY #d_y CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
$spri mesh NA 3000 NE 3075 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded NARE 1000

$$ The bridge track is loaded between node 3075 - 3100
$spri mesh NA 3075 NE 3100 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded YIEL #kp_loaded NARE 1075 NERE 1
$spri NA 3100 NE 1100 DX #d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3



$$ Input of non-linear spring elements between node 4000-4499
$$ to the right of the bridge. Embankment track.
$grp 104

$$ The track is loaded between node 4000-4474.
$spri NA 4000 DX -#d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3
$spri mesh NA 4000 NE 4474 DX -#d_x DY #d_y CP #kep_loaded CT #ket_loaded yiel #kp_loaded

$$ The track is unloaded between node 4474-4499.
```

SOFiSTiK CADINP Input File
System

```
$spri mesh NA 4474 NE 4499  DX -#d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded

$$----End of position 15 m------------------------------------------------------------------------------



$$----Position 30 m from the movable support----$$

$$ Input of non-linear spring elements between node 2000-2499
$$ to the left of the bridge. Embankment track.
$grp 102

$$ The track is unloaded between node 2000-2499.
$spri mesh NA 2000 NE 2499 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded
$spri NA 2499 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3



$$ Input of non-linear spring elements between the track and the bridge deck
$grp 103

$$ The bridge track is unloaded between node 3000 - 3050
$spri NA 3000 NE 1000 DX #d_x DY #d_y CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
$spri mesh NA 3000 NE 3050 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded NARE 1000

$$ The bridge track is loaded between node 3050 - 3100
$spri mesh NA 3050 NE 3100 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded YIEL #kp_loaded NARE 1050 NERE 1
$spri NA 3100 NE 1100 DX #d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3



$$ Input of non-linear spring elements between node 4000-4499
$$ to the right of the bridge. Embankment track.
$grp 104

$$ The track is loaded between node 4000-4449.
$spri NA 4000 DX -#d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3
$spri mesh NA 4000 NE 4474 DX -#d_x DY #d_y CP #kep_loaded CT #ket_loaded yiel #kp_loaded

$$ The track is unloaded between node 4449-4499.
$spri mesh NA 4449 NE 4499  DX -#d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded

$$----End of position 30 m---------------------------------------------------------------------$$



$$----Position 45 m from the movable support----$$

$$ Input of non-linear spring elements between node 2000-2499
$$ to the left of the bridge. Embankment track.
$grp 102

$$ The track is unloaded between node 2000-2499.
$spri mesh NA 2000 NE 2499 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded
$spri NA 2499 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
```

SOFiSTiK CADINP Input File
System

```
$$ Input of non-linear spring elements between the track and the bridge deck
$grp 103

$$ The bridge track is unloaded between node 3000 - 3025
$spri NA 3000 NE 1000 DX #d_x DY #d_y CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
$spri mesh NA 3000 NE 3025 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded NARE 1000

$$ The bridge track is loaded between node 3025 - 3100
$spri mesh NA 3025 NE 3100 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded YIEL #kp_loaded NARE 1025 NERE 1
$spri NA 3100 NE 1100 DX #d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3



$$ Input of non-linear spring elements between node 4000-4499
$$ to the right of the bridge. Embankment track.
$grp 104

$$ The track is loaded between node 4000-4424.
$spri NA 4000 DX -#d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3
$spri mesh NA 4000 NE 4424 DX -#d_x DY #d_y CP #kep_loaded CT #ket_loaded yiel #kp_loaded

$$ The track is unloaded between node 4424-4499.
$spri mesh NA 4424 NE 4499  DX -#d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded

$$----End of position 45 m----------------------$$




$$----Position 60 m from the movable support----$$


$ Input of non-linear spring elements between node 2000-2499
$ to the left of the bridge. Embankment track.
grp 102

$ The track is unloaded between node 2000-2499.
spri mesh NA 2000 NE 2499 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded
spri NA 2499 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3



$ Input of non-linear spring elements between the track and the bridge deck
grp 103

$ The bridge track is loaded between node 3000 - 3100
spri NA 3000 NE 1000 DX -#d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3
spri mesh NA 3000 NE 3100 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded YIEL #kp_loaded NARE 1000 NERE 11
spri NA 3100 NE 1100 DX #d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3



$ Input of non-linear spring elements between node 4000-4499
$ to the right of the bridge. Embankment track.
grp 104

$ The track is loaded between node 4000-4399.
spri NA 4000 DX -#d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3
spri mesh NA 4000 NE 4399 DX -#d_x DY #d_y CP #kep_loaded CT #ket_loaded yiel #kp_loaded

$ The track is unloaded between node 4399-4499.
```

SOFiSTiK CADINP Input File
System

```
spri mesh NA 4399 NE 4499  DX -#d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded

$$----End of position 60 m--------------------------$$

END
```

2.3 Input code for SOFILOAD – Load cases and load positions

```
!#!chapter Loads

+PROG SOFILOAD urs:6.1 $ Text Interface for Loads
HEAD Text Interface for Loads
$ Actions
ACT G   $ dead load
ACT Q   $ variable load


$------------Input data---------------------------------------------------------------

$ Temperature variation
LET#delta_T_deck 35  $ Thermal variation in the deck ['C]


$ Braking force

$ If the braking force acts from the movable support
$ towards the fixed support: -20 [kN/m]

$ If the braking force acts from the fixed support
$ towards the movable support: 20 [kN/m]

LET#F_braking 20 $ Horizontal braking force [kN/m]


$ Vertical load from the train
LET#F_vertical 80 $ Vertical train load [kN/m]




$-------------Loadcases and load positions---------------------------------------------

$ To use different load positions: Uncomment the desired position and
$ comment the undesired positions below.

$ Uncomment the desired position and load case below, comment all the
$ undesired positions and load cases below (temperature, braking or vertical load).

$ Remember to change the spring stiffnesses (unloaded or loaded) for the different load
$ positions for the braking load and vertical loac case in the System section.
$ For the temperature variation load should all springs be unloaded.

$ Remember to change the stiffness of the bridge deck in the Material section:
$ Rigid deck för braking and the real brdige deck stiffness for the vertical load

LC 1 Q TITL 'Combined loads'

$$----Temperature variation load case----$$

$LC 1 Q TITL 'Temperature variation - deck'
  BEAM FROM GRP 1 TYPE DT PA #delta_T_deck


$$----End of the temperature variation load----$$




$$----Different positions - braking and vertical load cases----$$
```

SOFiSTiK CADINP Input File
Loads

```
$$----Position 0 m from the movable support----$$

$ The length of the train is 300 m, each element is
$ 0.6 m:

$ Uncomment the desired load case below (braking or vertical load)

$LC 1 Q TITL 'Braking force 0 m from the movable support'
$  BEAM FROM 40001 TO 40499 TYPE PXX PA #F_braking

$LC 1 Q TITL 'Vertical load 0 m from the movable support'
$  BEAM FROM 40001 TO 40499 TYPE PG PA #F_vertical

$$----End of position 0 m----------------------$$




$$----Position 15 m from the movable support----$$

$ The length of the train is 300 m, each element is
$ 0.6 m:

$ Uncomment the desired load case below (braking or vertical load)


$LC 1 Q TITL 'Braking force 15 m from the movable support'
$  BEAM FROM 30077 TO 30102 TYPE PXX PA #F_braking
$  BEAM FROM 40001 TO 40474 TYPE PXX PA #F_braking

$LC 1 Q TITL 'Vertical load 15 m from the movable support'
$  BEAM FROM 30077 TO 30102 TYPE PG PA #F_vertical
$  BEAM FROM 40001 TO 40474 TYPE PG PA #F_vertical

$$----End of position 15 m--------------------$$




$$----Position 30 m from the movable support----$$

$$ The length of the train is 300 m, each element is
$$ 0.6 m:

$ Uncomment the desired load case below (braking or vertical load)

$LC 1 Q TITL 'Braking force 30 m from the movable support'
$  BEAM FROM 30052 TO 30102 TYPE PXX PA #F_braking
$  BEAM FROM 40001 TO 40449 TYPE PXX PA #F_braking

$LC 1 Q TITL 'Vertical load 30 m from the movable support'
$  BEAM FROM 30052 TO 30102 TYPE PG PA #F_vertical
$  BEAM FROM 40001 TO 40449 TYPE PG PA #F_vertical

$$----End of position 30 m----------------------$$
```

SOFiSTiK CADINP Input File
Loads

```
$$----Position 45 m from the movable support----$$

$$ The length of the train is 300 m, each element is
$$ 0.6 m:

$ Uncomment the desired load case below (braking or vertical load)

$LC 1 Q TITL 'Braking force 45 m from the movable support'
$  BEAM FROM 30027 TO 30102 TYPE PXX PA #F_braking
$  BEAM FROM 40001 TO 40424 TYPE PXX PA #F_braking

$LC 1 Q TITL 'Vertical load 45 m from the movable support'
$  BEAM FROM 30027 TO 30102 TYPE PG PA #F_vertical
$  BEAM FROM 40001 TO 40424 TYPE PG PA #F_vertical

$$----End of position 45 m-------------------------$$




$$----Position 60 m from the movable support----$$

$ The length of the train is 300 m, each element is
$ 0.6 m:

$ Uncomment the desired load case below (braking or vertical load)

$LC 1 Q TITL 'Braking force 60 m from the movable support'
  BEAM FROM 30002 TO 30102 TYPE PXX PA #F_braking
  BEAM FROM 40001 TO 40399 TYPE PXX PA #F_braking

$LC 1 Q TITL 'Vertical load 60 m from the movable support'
  BEAM FROM 30002 TO 30102 TYPE PG PA #F_vertical
  BEAM FROM 40001 TO 40399 TYPE PG PA #F_vertical

$$----End of position 60 m-------------------------$$


END
```

SOFiSTiK CADINP Input File
Calculation

2.4 Input code for ASE – Calculation

```
!#!chapter Calculation

+PROG ASE urs:20.1 $ Linear Analysis
HEAD Calculation of forces and moments
PAGE UNII 0
echo  OPT full yes
CTRL OPT SOLV VAL - $  Solution of the system
SYST prob NONL
LC 1

END
```

3 Slab track without a floating slab mat – test case E1-3

3.1 Input code for AQUA – Material and cross section properties

```
!#!chapter Material and cross section properties

+prog aqua urs:18.1

head Material and cross sections

$------------- Input parameters-------------------


$ To use different load positions and load cases: Uncomment the desired position and
$ comment the undesired positions in the System section and in the Loads section

$ Remember to change the stiffness of the bridge deck below:
$ Rigid deck for the braking force and the real bridge deck stiffness for the temperature and
$ vertical load

$ For the braking load case is the deck considered to be
$ rigid to be able to evaluate the effects of braking
$ forces alone. E*I for the deck -> infinity


LET#Alfa_deck 1.0E-5  $ Deck: Thermal expansion coefficient [1/K]
LET#Alfa_rail 1.2E-5  $ Rail: Thermal expansion coefficient [1/K]

LET#A_deck 0.74       $ The decks cross section area       [m^2]
LET#A_rail 0.007686   $ Cross section area for 1 rail      [m^2]
LET#A_slab 1.12       $ The track slabs cross section area [m^2]


LET#Iy_deck 1E16      $ Moment of inertia for the deck for the braking load case
                      $ E*I for the deck -> infinity [m^4]

$LET#Iy_deck 2.59     $ Moment of inertia for the deck for the temperature and
                      $ vertical load cases [m^4]

LET#Iy_rail 30.383E-6 $ Moment of inertia for 1 rail      [m^4/rail]
LET#Iy_slab 0.0149    $ Moment of inertia for the track slab [m^4]

echo full
stee NO 1 TYPE S CLAS 355 ALFA #Alfa_deck  $ Deck material
stee NO 2 TYPE S CLAS 355 ALFA #Alfa_rail  $ Track material
conc NO 3 TYPE C FCN  30                   $ Track slab material

sval 1 MNO 1 A #A_deck IY #Iy_deck         $ Deck cross section
sval 2 MNO 2 A 2*#A_rail IY 2*#Iy_rail     $ 2 rail cross sections / track
                                           $ total track properties
sval 3 MNO 3 A #A_slab IY #Iy_slab         $ Track slab cross section

end
```

SOFiSTiK CADINP Input File System

3.2 Input code for SOFIMSHA – System / model properties

```
!#!chapter System

+PROG SOFIMSHA urs:5.1 $ Text Interface for Model Creation
HEAD System
SYST 2D


$$$---------Input data----------------------------------------------------------------$$$

$----Model geometry----$

$ If the span lenght is changed it is necessary to change the parameters in the System
$ input below to get the model to work for the new geometry.

let#L 60  $ Span length [m]

$ If the user want to change the element length /distance between each node
$ it is necessary to change the parameters in the System input below to get
$ the model to work for the new geometry.

let#divide 100       $ Choose divide so that the distance dL between each node/spring
                     $ is equal to L/divide = 0.6 m

let#dL #L/#divide    $ Distance between each node/spring
                     $ length of each beam element dL = 0.6 m

$----Bridge parameters----$

let#h_deck -6        $ Height of the deck cross section [m]

let#h_slab -0.4     $ Height of the track slab cross section [m]

let#t_mat 0          $ Thickness of the floating slab mat - no mat in this case [m]

let#CG_deck -4.79    $ Center of gravity from the bottom of the deck cross section [m]

let#CG_slab #h_deck+#t_mat+#h_slab/2 $ Center of gravity for the track  slab from the
                                     $ bottom of the deck cross section [m]

let#h_tot #h_deck+#t_mat+#h_slab $ Total height, deck cross section + mat thickness +
                                 $ track slab height [m]

$----Elastic springs parameters----$

$ Fixed support, horizontal stiffness

let#k_fixed 600000 $ Stiffness K against horizontal disp.[kN/m^2]


$ Horizontal and vertical stiffness - rigid connection between track slab and deck,
$ no mat in this case

let#k_h 1E16        $ Stiffness K against horizontal disp.[kN/m^2]
let#k_v 1E16        $ Stiffness K against vertical disp.  [kN/m^2]


$----Non-linear springs parameters----$

let#u0 0.5E-3      $ Displacement between the elastic and plastic zones [m]

$ Resistance against longitudinal disp.
```

SOFiSTiK CADINP Input File
System

```
let#kp_loaded 60                        $ Plastic shear resistance for
                                        $ the loaded track [kN/m]

let#kep_loaded #kp_loaded/(#dL*#u0)     $ Elastic shear resistance for the
                                        $ loaded track [kN/m^2]
let#ket_loaded #kep_loaded

let#kp_unloaded 40                      $ Plastic shear resistance for
                                        $ the unloaded track [kN/m]

let#kep_unloaded #kp_unloaded/(#dL*#u0) $ Elastic shear resistance for
                                        $ the unloaded track [kN/m^2]
let#ket_unloaded #kp_unloaded

$-------------------------------------------------------------------------



$$$-----------System---------------------------------------------------$$$


$----Supports----$
grp 5
$ Fixed support
node NO 1 X 0 Y 0 fix PY
spri NO 1 NA 1 DX -1 CP #k_fixed

$ Movable support
node NO 2 X #L Y 0 fix PY



$----Deck elements----$
grp 1
$ Creates 101 nodes with a distance of dL between each node
$ in the center of gravity for the deck cross section

node NO 1000 X 0 Y #CG_deck
node NO 1000 FIX KF NR1 1

node NO 1100 X #L Y #CG_deck
node NO 1100 FIX KF NR1 2

node NO (1001 1099 1) X (#dL #dL) Y #CG_deck

$ Creates 100 deck beam elements between node 1000-1100
beam NO fit NA 1000 NE 1100 NCS 1 DIV #divide

$ Top of the deck nodes - used to see the horizontal
$ displacement of the top of the deck
grp 6
node NO 10 X 0 Y #h_deck
node NO 10 FIX KF NR1 1000

node NO 11 X #L Y #h_deck
node NO 11 FIX KF NR1 1100



$----Track slab elements----$
grp 7
$ Creates 101 nodes with a distance of dL between each node
```

SOFiSTiK CADINP Input File
System

```
$ in the center of gravity for the track slab cross section

node NO (7000 7100 1) X (0 #dL) Y #CG_slab

$ Creates 100 track slab beam elements between node 7000-7100
beam NO fit NA 7000 NE 7100 NCS 3 DIV #divide



$----Rail elements----$

$ 499 rail elements to the left of the bridge:
$ Creates 500 nodes with a distance of 0.6 m between them
grp 2
node NO (2000 2499 1) X (-300 #dL) Y #h_tot
beam NO mesh NA 2000 NE 2499 NCS 2 DIV 499


$ 499 rail elements to the right of the bridge:
$ Creates 500 nodes with a distance of dL between them
grp 4
node NO (4000 4499 1) X (#L+#dL #dL) Y #h_tot
beam NO mesh NA 4000 NE 4499 NCS 2 DIV 499


$ 102 rail elements on top of the bridge:
$ Creates 102 nodes with a distance of dL between them
grp 3
node NO (3000 3100 1) X (0 #dL) Y #h_tot
beam NO mesh NA 2499 NE 4000 NCS 2 DIV #divide+2


$ Rail nodes - used to see the horizontal displacement
$ of the rail on top of the bridge
grp  6
node NO 12 X 0 Y #h_tot
node NO 12 FIX KF NR1 3000

node NO 13 X #L Y #h_tot
node NO 13 FIX KF NR1 3100




$----Spring elements--------------------$

$----Elastic springs----$

$ Input of elastic spring elements between the slab and the deck - rigid connection
grp 105
spri mesh NA 7000 NE 7100 CP #k_h CT #k_v NARE 1000 NERE 1100



$----Non-linear springs for different load positions----$

$ Direction of principal and lateral direction of the springs
let#d_x -1     $ X-component of direction
let#d_y 0     $ Y-component of direction
```

SOFiSTiK CADINP Input File
System

```
$ To use different load positions: Uncomment the desired position and
$ comment the undesired positions below.

$ Remember to change the position and load case for the different load
$ positions in the Loads section.

$ Remember to change the stiffness of the bridge deck in the Material section:
$ Rigid deck för braking and the real bridge deck stiffness for the vertical load
$ and temperature load


$$----Temperature variation load----$$

$ All springs are unloaded

$ Input of non-linear spring elements between node 2000-2499
$ to the left of the bridge. Embankment track.
$grp 102
$spri mesh NA 2000 NE 2499 DX #d_x CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded
$spri NA 2499 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3


$$ Input of non-linear spring elements between the track and the bridge deck
$grp 103
$spri NA 3000 NE 1000 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
$spri mesh NA 3000 NE 3100 DX #d_x CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded NARE 1000 NERE 110
$spri NA 3100 NE 1100 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3


$$ Input of non-linear spring elements between node 4000-4499
$$ to the left of the bridge. Embankment track
$grp 104
$spri NA 4000 DX -#d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
$spri mesh NA 4000 NE 4499 DX -#d_x CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded

$$----End of the temperature variation load----$$




$$----Different positions - braking and vertical load cases----$$

$$----Position 0 m from the movable support-----$$

$$ Input of non-linear spring elements between node 2000-2499
$$ to the left of the bridge. Embankment track.
$grp 102

$$ The track is loaded between node 2000-2499.
$spri mesh NA 2000 NE 2499 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded yiel #kp_loaded
$spri NA 2499 DX #d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3

$$ Input of non-linear spring elements between the track and the bridge deck
$grp 103

$$ The bridge track is unloaded between node 3000 - 3100
$spri mesh NA 3000 NE 3100 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded NARE 1000
$spri NA 3100 NE 1100 DX #d_x DY #d_y CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
```

SOFiSTiK CADINP Input File
System

```
$$ Input of non-linear spring elements between node 4000-4499
$$ to the right of the bridge. Embankment track.
$grp 104

$$ The track is unloaded between node 4000-4499.
$spri NA 4000 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
$spri mesh NA 4000 NE 4499 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded

$$----End of position 0 m-----------------------$$




$$----Position 15 m from the movable support----$$


$$ Input of non-linear spring elements between node 2000-2499
$$ to the left of the bridge. Embankment track.
$grp 102

$$ The track is unloaded between node 2000-2025.
$spri mesh NA 2000 NE 2025 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded

$$ The track is loaded between node 2025-2499.
$spri mesh NA 2025 NE 2499 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded yiel #kp_loaded
$spri NA 2499 DX #d_x CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3


$$ Input of non-linear spring elements between the track and the bridge deck
$$ The bridge track is loaded between node 3000 - 3025
$grp 103
$spri NA 3000 NE 1000 DX #d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3
$spri mesh NA 3000 NE 3025 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded YIEL #kp_loaded NARE 1000 NERE 1

$$ The bridge track is unloaded between node 3025 - 3100
$grp 103
$spri mesh NA 3025 NE 3100 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded NARE 1025
$spri NA 3100 NE 1100 DX -#d_x DY #d_y CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3


$$ Input of non-linear spring elements between node 4000-4499
$$ to the left of the bridge. Embankment track.
$grp 104

$$ The track is unloaded between node 4000-4499.
$spri NA 4000 DX -#d_x CP #kep_unloaded CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
$spri mesh NA 4000 NE 4499 DX -#d_x DY #d_y CP #kep_unloaded ct #ket_unloaded yiel #kp_unloaded

$$----End of position 15 m-------------------------------------------------------------------




$$----Position 30 m from the movable support----$$

$$ Input of non-linear spring elements between node 2000-2499
$$ to the left of the bridge. Embankment track.
$grp 102

$$ The track is unloaded between node 2000-2051.
```

SOFiSTiK CADINP Input File
System

```
$spri mesh NA 2000 NE 2051 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded

$$ The track is loaded between node 2051-2499.
$spri mesh NA 2051 NE 2499 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded yiel #kp_loaded
$spri NA 2499 DX #d_x CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3


$$ Input of non-linear spring elements between the track and the bridge deck
$$ The bridge track is loaded between node 3000 - 3050
$grp 103
$spri NA 3000 NE 1000 DX #d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3
$spri mesh NA 3000 NE 3050 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded YIEL #kp_loaded NARE 1000 NERE 1

$$ The bridge track is unloaded between node 3050 - 3100
$grp 103
$spri mesh NA 3050 NE 3100 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded NARE 1050
$spri NA 3100 NE 1100 DX -#d_x DY #d_y CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3


$$ Input of non-linear spring elements between node 4000-4499
$$ to the left of the bridge. Embankment track.
$grp 104

$$ The track is unloaded between node 4000-4499.
$spri NA 4000 DX -#d_x CP #kep_unloaded CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
$spri mesh NA 4000 NE 4499 DX -#d_x DY #d_y CP #kep_unloaded ct #ket_unloaded yiel #kp_unloaded

$$----End of position 30 m---------------------------------------------------------------------$$




$$----Position 45 m from the movable support----$$

$$ Input of non-linear spring elements between node 2000-2499
$$ to the left of the bridge. Embankment track.
$grp 102

$$ The track is unloaded between node 2000-2075.
$spri mesh NA 2000 NE 2075 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded

$$ The track is loaded between node 2075-2499.
$spri mesh NA 2075 NE 2499 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded yiel #kp_loaded
$spri NA 2499 DX #d_x CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3


$$ Input of non-linear spring elements between the track and the bridge deck
$$ The bridge track is loaded between node 3000 - 3075
$grp 103
$spri NA 3000 NE 1000 DX #d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3
$spri mesh NA 3000 NE 3075 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded YIEL #kp_loaded NARE 1000 NERE 1

$$ The bridge track is unloaded between node 3075 - 3100
$grp 103
$spri mesh NA 3075 NE 3100 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded NARE 1075
$spri NA 3100 NE 1100 DX -#d_x DY #d_y CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3


$$ Input of non-linear spring elements between node 4000-4499
$$ to the left of the bridge. Embankment track.
$grp 104
```

SOFiSTiK CADINP Input File
System

```
$$ The track is unloaded between node 4000-4499.
$spri NA 4000 DX -#d_x CP #kep_unloaded CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
$spri mesh NA 4000 NE 4499 DX -#d_x DY #d_y CP #kep_unloaded ct #ket_unloaded yiel #kp_unloaded

$$----End of position 45 m----------------------$$




$$----Position 60 m from the movable support----$$


$ Input of non-linear spring elements between node 2000-2499
$ to the left of the bridge. Embankment track.
grp 102

$ The track is unloaded between node 2000-2100.
spri mesh NA 2000 NE 2100 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded

$ The track is loaded between node 2100-2499.
spri mesh NA 2100 NE 2499 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded yiel #kp_loaded
spri NA 2499 DX #d_x CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3


$ Input of non-linear spring elements between the track and the bridge deck
$ The bridge track is loaded (between node 3000 - 3100)
grp 103
spri NA 3000 NE 1000 DX #d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3
spri mesh NA 3000 NE 3100 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded YIEL #kp_loaded NARE 1000 NERE 11


$ Input of non-linear spring elements between node 4000-4499
$ to the left of the bridge. Embankment track.
grp 104

$ The track is unloaded between node 3100-4499.
spri NA 3100 NE 1100 DX -#d_x DY #d_y CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
spri NA 4000 DX -#d_x CP #kep_unloaded CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
spri mesh NA 4000 NE 4499 DX -#d_x DY #d_y CP #kep_unloaded ct #ket_unloaded yiel #kp_unloaded

$$----End of position 60 m--------------------------$$

END
```

3.3 Input code for SOFILOAD – Load cases and load positions

```
!#!chapter Loads

+PROG SOFILOAD urs:6.1 $ Text Interface for Loads
HEAD Text Interface for Loads
$ Actions
ACT G   $ dead load
ACT Q   $ variable load


$------------Input data--------------------------------------------------------------

$ Temperature variation
LET#delta_T_deck 35  $ Thermal variation in the deck ['C]


$ Braking force

$ If the braking force acts from the movable support
$ towards the fixed support: -20 [kN/m]

$ If the braking force acts from the fixed support
$ towards the movable support: 20 [kN/m]

LET#F_braking 20 $ Horizontal braking force [kN/m]



$ Vertical load from the train
LET#F_vertical 80 $ Vertical train load [kN/m]




$--------------Loadcases and load positions--------------------------------------------

$ To use different load positions: Uncomment the desired position and
$ comment the undesired positions below.

$ Uncomment the desired position and load case below, comment all the
$ undesired positions and load cases below (temperature, braking or vertical load).

$ Remember to change the spring stiffnesses (unloaded or loaded) for the different load
$ positions for the braking load and vertical loac case in the System section.
$ For the temperature variation load should all springs be unloaded.

$ Remember to change the stiffness of the bridge deck in the Material section:
$ Rigid deck för braking and the real brdige deck stiffness for the vertical load



$$----Temperature variation load case----$$

$LC 1 Q TITL 'Temperature variation - deck'
$  BEAM FROM GRP 1 TYPE DT PA #delta_T_deck


$$----End of the temperature variation load----$$




$$----Different positions - braking and vertical load cases----$$
```

SOFiSTiK CADINP Input File
Loads

```
$$----Position 0 m from the fixed support----$$

$ The length of the train is 300 m, each element is
$ 0.6 m:

$ Uncomment the desired load case below (braking or vertical load)

$LC 1 Q TITL 'Braking force 0 m from the fixed support'
$  BEAM FROM 20001 TO 20499 TYPE PXX PA #F_braking
$  BEAM FROM 30001 TO 30001 TYPE PXX PA #F_braking


$$LC 1 Q TITL 'Vertical load 0 m from the fixed support'
$  BEAM FROM 20001 TO 20449 TYPE PG PA #F_vertical
$  BEAM FROM 30001 TO 30001 TYPE PG PA #F_vertical

$$----End of position 0 m----------------------$$





$$----Position 15 m from the fixed support----$$

$ The length of the train is 300 m, each element is
$ 0.6 m:

$ Uncomment the desired load case below (braking or vertical load)


$LC 1 Q TITL 'Braking force 15 m from the fixed support'
$  BEAM FROM 20026 TO 20499 TYPE PXX PA #F_braking
$  BEAM FROM 30001 TO 30025 TYPE PXX PA #F_braking

$LC 1 Q TITL 'Vertical load 15 m from the fixed support'
$  BEAM FROM 20026 TO 20499 TYPE PG PA #F_vertical
$  BEAM FROM 30001 TO 30025 TYPE PG PA #F_vertical

$$----End of position 15 m--------------------$$





$$----Position 30 m from the fixed support----$$

$$ The length of the train is 300 m, each element is
$$ 0.6 m:

$ Uncomment the desired load case below (braking or vertical load)

$LC 1 Q TITL 'Braking force 30 m from the fixed support'
$  BEAM FROM 20052 TO 20499 TYPE PXX PA #F_braking
$  BEAM FROM 30001 TO 30050 TYPE PXX PA #F_braking

$LC 1 Q TITL 'Vertical load 30 m from the fixed support'
$  BEAM FROM 20052 TO 20499 TYPE PG PA #F_vertical
$  BEAM FROM 30001 TO 30050 TYPE PG PA #F_vertical

$$----End of position 30 m----------------------$$
```

SOFiSTiK CADINP Input File
Loads

```
$$----Position 45 m from the fixed support----$$

$$ The length of the train is 300 m, each element is
$$ 0.6 m:

$ Uncomment the desired load case below (braking or vertical load)

$LC 1 Q TITL 'Braking force 45 m from the fixed support'
$  BEAM FROM 20076 TO 20499 TYPE PXX PA #F_braking
$  BEAM FROM 30001 TO 30075 TYPE PXX PA #F_braking

$LC 1 Q TITL 'Vertical load 45 m from the fixed support'
$  BEAM FROM 20076 TO 20499 TYPE PG PA #F_vertical
$  BEAM FROM 30001 TO 30075 TYPE PG PA #F_vertica

$$----End of position 45 m-------------------------$$




$$----Position 60 m from the fixed support----$$

$ The length of the train is 300 m, each element is
$ 0.6 m:

$ Uncomment the desired load case below (braking or vertical load)


LC 1 Q TITL 'Braking force 60 m from the fixed support'
  BEAM FROM 20101 TO 20499 TYPE PXX PA #F_braking
  BEAM FROM 30001 TO 30101 TYPE PXX PA #F_braking

$LC 1 Q TITL 'Vertical load 60 m from the fixed support'
$  BEAM FROM 20101 TO 20499 TYPE PG PA #F_vertical
$  BEAM FROM 30001 TO 30101 TYPE PG PA #F_vertical

$$----End of position 60 m-------------------------$$


END
```

SOFiSTiK CADINP Input File
Calculation

3.4 Input code for ASE – Calculation

```
!#!chapter Calculation

+PROG ASE urs:20.1 $ Linear Analysis
HEAD Calculation of forces and moments
PAGE UNII 0
echo  OPT full yes
CTRL OPT SOLV VAL - $  Solution of the system
SYST prob NONL
LC 1

END
```

4 Slab track without a floating slab mat – test case F4-6

4.1 Input code for AQUA – Material and cross section properties

```
!#!chapter Material and cross section properties

+prog aqua urs:18.1

head Material and cross sections

$------------- Input parameters-------------------


$ To use different load positions and load cases: Uncomment the desired position and
$ comment the undesired positions in the System section and in the Loads section

$ Remember to change the stiffness of the bridge deck below:
$ Rigid deck for the braking force and the real bridge deck stiffness for the temperature and
$ vertical load

$ For the braking load case is the deck considered to be
$ rigid to be able to evaluate the effects of braking
$ forces alone. E*I for the deck -> infinity



LET#Alfa_deck 1.0E-5  $ Deck: Thermal expansion coefficient [1/K]
LET#Alfa_rail 1.2E-5  $ Rail: Thermal expansion coefficient [1/K]

LET#A_deck 0.74       $ The decks cross section area       [m^2]
LET#A_rail 0.007686   $ Cross section area for 1 rail      [m^2]
LET#A_slab 1.12       $ The track slabs cross section area [m^2]


$LET#Iy_deck 1E16      $ Moment of inertia for the deck for the braking load case
                      $ E*I for the deck -> infinity [m^4]

LET#Iy_deck 2.59     $ Moment of inertia for the deck for the temperature and
                      $ vertical load cases [m^4]

LET#Iy_rail 30.383E-6 $ Moment of inertia for 1 rail      [m^4/rail]
LET#Iy_slab 0.0149    $ Moment of inertia for the track slab [m^4]

echo full
stee NO 1 TYPE S CLAS 355 ALFA #Alfa_deck  $ Deck material
stee NO 2 TYPE S CLAS 355 ALFA #Alfa_rail  $ Track material
conc NO 3 TYPE C FCN  30                   $ Track slab material

sval 1 MNO 1 A #A_deck IY #Iy_deck         $ Deck cross section
sval 2 MNO 2 A 2*#A_rail IY 2*#Iy_rail     $ 2 rail cross sections / track
                                           $ total track properties
sval 3 MNO 3 A #A_slab IY #Iy_slab         $ Track slab cross section

end
```

SOFiSTiK CADINP Input File
System

4.2 Input code for SOFIMSHA – System / model properties

```
!#!chapter System

+PROG SOFIMSHA urs:5.1 $ Text Interface for Model Creation
HEAD System
SYST 2D


$$$---------Input data----------------------------------------------------------------$$$

$----Model geometry----$

$ If the span lenght is changed it is necessary to change the parameters in the System
$ input below to get the model to work for the new geometry.

let#L 60  $ Span length [m]

$ If the user want to change the element length /distance between each node
$ it is necessary to change the parameters in the System input below to get
$ the model to work for the new geometry.

let#divide 100       $ Choose divide so that the distance dL between each node/spring
                     $ is equal to L/divide = 0.6 m

let#dL #L/#divide    $ Distance between each node/spring
                     $ length of each beam element dL = 0.6 m

$----Bridge parameters----$

let#h_deck -6        $ Height of the deck cross section [m]

let#h_slab -0.4     $ Height of the track slab cross section [m]

let#t_mat 0          $ Thickness of the floating slab mat - no mat in this case [m]

let#CG_deck -4.79    $ Center of gravity from the bottom of the deck cross section [m]

let#CG_slab #h_deck+#t_mat+#h_slab/2 $ Center of gravity for the track  slab from the
                                     $ bottom of the deck cross section [m]

let#h_tot #h_deck+#t_mat+#h_slab $ Total height, deck cross section + mat thickness +
                                 $ track slab height [m]

$----Elastic springs parameters----$

$ Fixed support, horizontal stiffness

let#k_fixed 120000 $ Stiffness K against horizontal disp.[kN/m^2]


$ Horizontal and vertical stiffness - rigid connection between track slab and deck,
$ no mat in this case

let#k_h 1E16        $ Stiffness K against horizontal disp.[kN/m^2]
let#k_v 1E16        $ Stiffness K against vertical disp.  [kN/m^2]


$----Non-linear springs parameters----$

let#u0 0.5E-3      $ Displacement between the elastic and plastic zones [m]

$ Resistance against longitudinal disp.
```

SOFiSTiK CADINP Input File
System

```
let#kp_loaded 60                       $ Plastic shear resistance for
                                       $ the loaded track [kN/m]

let#kep_loaded #kp_loaded/(#dL*#u0)    $ Elastic shear resistance for the
                                       $ loaded track [kN/m^2]
let#ket_loaded #kep_loaded

let#kp_unloaded 40                     $ Plastic shear resistance for
                                       $ the unloaded track [kN/m]

let#kep_unloaded #kp_unloaded/(#dL*#u0) $ Elastic shear resistance for
                                       $ the unloaded track [kN/m^2]
let#ket_unloaded #kp_unloaded

$--------------------------------------------------------------------------


$$$-----------System---------------------------------------------------$$$


$----Supports----$
grp 5
$ Fixed support
node NO 1 X 0 Y 0 fix PY
spri NO 1 NA 1 DX -1 CP #k_fixed

$ Movable support
node NO 2 X #L Y 0 fix PY



$----Deck elements----$
grp 1
$ Creates 101 nodes with a distance of dL between each node
$ in the center of gravity for the deck cross section

node NO 1000 X 0 Y #CG_deck
node NO 1000 FIX KF NR1 1

node NO 1100 X #L Y #CG_deck
node NO 1100 FIX KF NR1 2

node NO (1001 1099 1) X (#dL #dL) Y #CG_deck

$ Creates 100 deck beam elements between node 1000-1100
beam NO fit NA 1000 NE 1100 NCS 1 DIV #divide

$ Top of the deck nodes - used to see the horizontal
$ displacement of the top of the deck
grp 6
node NO 10 X 0 Y #h_deck
node NO 10 FIX KF NR1 1000

node NO 11 X #L Y #h_deck
node NO 11 FIX KF NR1 1100



$----Track slab elements----$
grp 7
$ Creates 101 nodes with a distance of dL between each node
```

SOFiSTiK CADINP Input File
System

```
$ in the center of gravity for the track slab cross section

node NO (7000 7100 1) X (0 #dL) Y #CG_slab

$ Creates 100 track slab beam elements between node 7000-7100
beam NO fit NA 7000 NE 7100 NCS 3 DIV #divide



$----Rail elements----$

$ 499 rail elements to the left of the bridge:
$ Creates 500 nodes with a distance of 0.6 m between them
grp 2
node NO (2000 2499 1) X (-300 #dL) Y #h_tot
beam NO mesh NA 2000 NE 2499 NCS 2 DIV 499


$ 499 rail elements to the right of the bridge:
$ Creates 500 nodes with a distance of dL between them
grp 4
node NO (4000 4499 1) X (#L+#dL #dL) Y #h_tot
beam NO mesh NA 4000 NE 4499 NCS 2 DIV 499


$ 102 rail elements on top of the bridge:
$ Creates 102 nodes with a distance of dL between them
grp 3
node NO (3000 3100 1) X (0 #dL) Y #h_tot
beam NO mesh NA 2499 NE 4000 NCS 2 DIV #divide+2


$ Rail nodes - used to see the horizontal displacement
$ of the rail on top of the bridge
grp  6
node NO 12 X 0 Y #h_tot
node NO 12 FIX KF NR1 3000

node NO 13 X #L Y #h_tot
node NO 13 FIX KF NR1 3100




$----Spring elements---------------------$

$----Elastic springs----$

$ Input of elastic spring elements between the slab and the deck - rigid connection
grp 105
spri mesh NA 7000 NE 7100 CP #k_h CT #k_v NARE 1000 NERE 1100



$----Non-linear springs for different load positions----$

$ Direction of principal and lateral direction of the springs
let#d_x -1     $ X-component of direction
let#d_y 0     $ Y-component of direction
```

SOFiSTiK CADINP Input File
System

```
$ To use different load positions: Uncomment the desired position and
$ comment the undesired positions below.

$ Remember to change the position and load case for the different load
$ positions in the Loads section.

$ Remember to change the stiffness of the bridge deck in the Material section:
$ Rigid deck för braking and the real bridge deck stiffness for the vertical load
$ and temperature load


$$----Temperature variation load----$$

$$ All springs are unloaded

$$ Input of non-linear spring elements between node 2000-2499
$$ to the left of the bridge. Embankment track.
$grp 102
$spri mesh NA 2000 NE 2499 DX #d_x CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded
$spri NA 2499 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3


$$ Input of non-linear spring elements between the track and the bridge deck
$grp 103
$spri NA 3000 NE 1000 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
$spri mesh NA 3000 NE 3100 DX #d_x CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded NARE 1000 NERE 110
$spri NA 3100 NE 1100 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3


$$ Input of non-linear spring elements between node 4000-4499
$$ to the left of the bridge. Embankment track
$grp 104
$spri NA 4000 DX -#d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
$spri mesh NA 4000 NE 4499 DX -#d_x CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded

$$----End of the temperature variation load----$$




$$----Different positions - braking and vertical load cases----$$

$$----Position 0 m from the movable support-----$$

$$ Input of non-linear spring elements between node 2000-2499
$$ to the left of the bridge. Embankment track.
$grp 102

$$ The track is unloaded between node 2000-2499.
$spri mesh NA 2000 NE 2499 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded
$spri NA 2499 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3



$$ Input of non-linear spring elements between the track and the bridge deck
$grp 103

$$ The bridge track is unloaded between node 3000 - 3100
$spri mesh NA 3000 NE 3100 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded NARE 1000
$spri NA 3100 NE 1100 DX #d_x DY #d_y CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
```

SOFiSTiK CADINP Input File
System

```
$$ Input of non-linear spring elements between node 4000-4499
$$ to the right of the bridge. Embankment track.
$grp 104

$$ The track is loaded between node 4000-4499.
$spri NA 4000 DX -#d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3
$spri mesh NA 4000 NE 4499 DX -#d_x DY #d_y CP #kep_loaded CT #ket_loaded yiel #kp_loaded

$$----End of position 0 m-----------------------$$




$$----Position 15 m from the movable support----$$

$$ Input of non-linear spring elements between node 2000-2499
$$ to the left of the bridge. Embankment track.
$grp 102

$$ The track is unloaded between node 2000-2499.
$spri mesh NA 2000 NE 2499 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded
$spri NA 2499 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3



$$ Input of non-linear spring elements between the track and the bridge deck
$grp 103

$$ The bridge track is unloaded between node 3000 - 3075
$spri NA 3000 NE 1000 DX #d_x DY #d_y CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
$spri mesh NA 3000 NE 3075 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded NARE 1000

$$ The bridge track is loaded between node 3075 - 3100
$spri mesh NA 3075 NE 3100 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded YIEL #kp_loaded NARE 1075 NERE 1
$spri NA 3100 NE 1100 DX #d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3



$$ Input of non-linear spring elements between node 4000-4499
$$ to the right of the bridge. Embankment track.
$grp 104

$$ The track is loaded between node 4000-4474.
$spri NA 4000 DX -#d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3
$spri mesh NA 4000 NE 4474 DX -#d_x DY #d_y CP #kep_loaded CT #ket_loaded yiel #kp_loaded

$$ The track is unloaded between node 4474-4499.
$spri mesh NA 4474 NE 4499  DX -#d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded

$$----End of position 15 m----------------------------------------------------------------------------




$$----Position 30 m from the movable support----$$

$$ Input of non-linear spring elements between node 2000-2499
$$ to the left of the bridge. Embankment track.
```

SOFiSTiK CADINP Input File
System

```
$grp 102

$$ The track is unloaded between node 2000-2499.
$spri mesh NA 2000 NE 2499 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded
$spri NA 2499 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3



$$ Input of non-linear spring elements between the track and the bridge deck
$grp 103

$$ The bridge track is unloaded between node 3000 - 3050
$spri NA 3000 NE 1000 DX #d_x DY #d_y CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
$spri mesh NA 3000 NE 3050 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded NARE 1000

$$ The bridge track is loaded between node 3050 - 3100
$spri mesh NA 3050 NE 3100 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded YIEL #kp_loaded NARE 1050 NERE 1
$spri NA 3100 NE 1100 DX #d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3



$$ Input of non-linear spring elements between node 4000-4499
$$ to the right of the bridge. Embankment track.
$grp 104

$$ The track is loaded between node 4000-4449.
$spri NA 4000 DX -#d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3
$spri mesh NA 4000 NE 4474 DX -#d_x DY #d_y CP #kep_loaded CT #ket_loaded yiel #kp_loaded

$$ The track is unloaded between node 4449-4499.
$spri mesh NA 4449 NE 4499  DX -#d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded

$$----End of position 30 m--------------------------------------------------------------------$$




$$----Position 45 m from the movable support----$$

$$ Input of non-linear spring elements between node 2000-2499
$$ to the left of the bridge. Embankment track.
$grp 102

$$ The track is unloaded between node 2000-2499.
$spri mesh NA 2000 NE 2499 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded
$spri NA 2499 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3



$$ Input of non-linear spring elements between the track and the bridge deck
$grp 103

$$ The bridge track is unloaded between node 3000 - 3025
$spri NA 3000 NE 1000 DX #d_x DY #d_y CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
$spri mesh NA 3000 NE 3025 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded NARE 1000

$$ The bridge track is loaded between node 3025 - 3100
$spri mesh NA 3025 NE 3100 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded YIEL #kp_loaded NARE 1035 NERE 1
$spri NA 3100 NE 1100 DX #d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3
```

SOFiSTiK CADINP Input File
System

```
$$ Input of non-linear spring elements between node 4000-4499
$$ to the right of the bridge. Embankment track.
$grp 104

$$ The track is loaded between node 4000-4424.
$spri NA 4000 DX -#d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3
$spri mesh NA 4000 NE 4424 DX -#d_x DY #d_y CP #kep_loaded CT #ket_loaded yiel #kp_loaded

$$ The track is unloaded between node 4424-4499.
$spri mesh NA 4424 NE 4499  DX -#d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded

$$----End of position 45 m----------------------$$




$$----Position 60 m from the movable support----$$


$ Input of non-linear spring elements between node 2000-2499
$ to the left of the bridge. Embankment track.
grp 102

$ The track is unloaded between node 2000-2499.
spri mesh NA 2000 NE 2499 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded
spri NA 2499 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3



$ Input of non-linear spring elements between the track and the bridge deck
grp 103

$ The bridge track is loaded between node 3000 - 3100
spri NA 3000 NE 1000 DX #d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3
spri mesh NA 3000 NE 3100 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded YIEL #kp_loaded NARE 1000 NERE 11
spri NA 3100 NE 1100 DX #d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3



$ Input of non-linear spring elements between node 4000-4499
$ to the right of the bridge. Embankment track.
grp 104

$ The track is loaded between node 4000-4399.
spri NA 4000 DX -#d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3
spri mesh NA 4000 NE 4399 DX -#d_x DY #d_y CP #kep_loaded CT #ket_loaded yiel #kp_loaded

$ The track is unloaded between node 4399-4499.
spri mesh NA 4399 NE 4499  DX -#d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded

$$----End of position 60 m-------------------------$$


END
```

SOFiSTiK CADINP Input File
Loads

4.3 Input code for SOFILOAD – Load cases and load positions

```
!#!chapter Loads

+PROG SOFILOAD urs:6.1 $ Text Interface for Loads
HEAD Text Interface for Loads
$ Actions
ACT G   $ dead load
ACT Q   $ variable load


$-------------Input data---------------------------------------------------------------

$ Temperature variation
LET#delta_T_deck 35  $ Thermal variation in the deck ['C]


$ Braking force

$ If the braking force acts from the movable support
$ towards the fixed support: -20 [kN/m]

$ If the braking force acts from the fixed support
$ towards the movable support: 20 [kN/m]

LET#F_braking 20 $ Horizontal braking force [kN/m]


$ Vertical load from the train
LET#F_vertical 80 $ Vertical train load [kN/m]




$--------------Loadcases and load positions----------------------------------------------

$ To use different load positions: Uncomment the desired position and
$ comment the undesired positions below.

$ Uncomment the desired position and load case below, comment all the
$ undesired positions and load cases below (temperature, braking or vertical load).

$ Remember to change the spring stiffnesses (unloaded or loaded) for the different load
$ positions for the braking load and vertical loac case in the System section.
$ For the temperature variation load should all springs be unloaded.

$ Remember to change the stiffness of the bridge deck in the Material section:
$ Rigid deck för braking and the real brdige deck stiffness for the vertical load



$$----Temperature variation load case----$$

$LC 1 Q TITL 'Temperature variation - deck'
$  BEAM FROM GRP 1 TYPE DT PA #delta_T_deck


$$----End of the temperature variation load----$$




$$----Different positions - braking and vertical load cases----$$
```

SOFiSTiK CADINP Input File
Loads

```
$$----Position 0 m from the movable support----$$

$ The length of the train is 300 m, each element is
$ 0.6 m:

$ Uncomment the desired load case below (braking or vertical load)

$LC 1 Q TITL 'Braking force 0 m from the movable support'
$  BEAM FROM 40001 TO 40449 TYPE PXX PA #F_braking

$$LC 1 Q TITL 'Vertical load 0 m from the movable support'
$  BEAM FROM 40001 TO 40449 TYPE PG PA #F_vertical

$$----End of position 0 m----------------------$$




$$----Position 15 m from the movable support----$$

$ The length of the train is 300 m, each element is
$ 0.6 m:

$ Uncomment the desired load case below (braking or vertical load)


$LC 1 Q TITL 'Braking force 15 m from the movable support'
$  BEAM FROM 30077 TO 30102 TYPE PXX PA #F_braking
$  BEAM FROM 40001 TO 40474 TYPE PXX PA #F_braking

$LC 1 Q TITL 'Vertical load 15 m from the movable support'
$  BEAM FROM 30077 TO 30102 TYPE PG PA #F_vertical
$  BEAM FROM 40001 TO 40474 TYPE PG PA #F_vertical

$$----End of position 15 m--------------------$$




$$----Position 30 m from the movable support----$$

$$ The length of the train is 300 m, each element is
$$ 0.6 m:

$ Uncomment the desired load case below (braking or vertical load)

$LC 1 Q TITL 'Braking force 30 m from the movable support'
$  BEAM FROM 30052 TO 30102 TYPE PXX PA #F_braking
$  BEAM FROM 40001 TO 40449 TYPE PXX PA #F_braking

$LC 1 Q TITL 'Vertical load 30 m from the movable support'
$  BEAM FROM 30052 TO 30102 TYPE PG PA #F_vertical
$  BEAM FROM 40001 TO 40449 TYPE PG PA #F_vertical

$$----End of position 30 m----------------------$$
```

SOFiSTiK CADINP Input File
Loads

```
$$----Position 45 m from the movable support----$$

$$ The length of the train is 300 m, each element is
$$ 0.6 m:

$ Uncomment the desired load case below (braking or vertical load)

$LC 1 Q TITL 'Braking force 45 m from the movable support'
$  BEAM FROM 30027 TO 30102 TYPE PXX PA #F_braking
$  BEAM FROM 40001 TO 40424 TYPE PXX PA #F_braking

$LC 1 Q TITL 'Vertical load 45 m from the movable support'
$  BEAM FROM 30027 TO 30102 TYPE PG PA #F_vertical
$  BEAM FROM 40001 TO 40424 TYPE PG PA #F_vertical

$$----End of position 45 m-------------------------$$




$$----Position 60 m from the movable support----$$

$ The length of the train is 300 m, each element is
$ 0.6 m:

$ Uncomment the desired load case below (braking or vertical load)

$LC 1 Q TITL 'Braking force 60 m from the movable support'
$  BEAM FROM 30002 TO 30102 TYPE PXX PA #F_braking
$  BEAM FROM 40001 TO 40399 TYPE PXX PA #F_braking

LC 1 Q TITL 'Vertical load 60 m from the movable support'
  BEAM FROM 30002 TO 30102 TYPE PG PA #F_vertical
  BEAM FROM 40001 TO 40399 TYPE PG PA #F_vertical

$$----End of position 60 m-------------------------$$


END
```

SOFiSTiK CADINP Input File
Calculation

4.4 Input code for ASE – Calculation

```
!#!chapter Calculation

+PROG ASE urs:20.1 $ Linear Analysis
HEAD Calculation of forces and moments
PAGE UNII 0
echo  OPT full yes
CTRL OPT SOLV VAL - $  Solution of the system
SYST prob NONL
LC 1

END
```

5 Slab track with a floating slab mat – test case E1-3

5.1 Input code for AQUA – Material and cross section properties

```
!#!chapter Material and cross section properties

+prog aqua urs:18.1

head Material and cross sections

$------------- Input parameters-------------------


$ To use different load positions and load cases: Uncomment the desired position and
$ comment the undesired positions in the System section and in the Loads section

$ Remember to change the stiffness of the bridge deck below:
$ Rigid deck for the braking force and the real bridge deck stiffness for the temperature and
$ vertical load

$ For the braking load case is the deck considered to be
$ rigid to be able to evaluate the effects of braking
$ forces alone. E*I for the deck -> infinity



LET#Alfa_deck 1.0E-5  $ Deck: Thermal expansion coefficient [1/K]
LET#Alfa_rail 1.2E-5  $ Rail: Thermal expansion coefficient [1/K]

LET#A_deck 0.74       $ The decks cross section area       [m^2]
LET#A_rail 0.007686   $ Cross section area for 1 rail      [m^2]
LET#A_slab 1.12       $ The track slabs cross section area [m^2]


$LET#Iy_deck 1E16      $ Moment of inertia for the deck for the braking load case
                      $ E*I for the deck -> infinity [m^4]

LET#Iy_deck 2.59     $ Moment of inertia for the deck for the temperature and
                      $ vertical load cases [m^4]

LET#Iy_rail 30.383E-6 $ Moment of inertia for 1 rail      [m^4/rail]
LET#Iy_slab 0.0149    $ Moment of inertia for the track slab [m^4]

echo full
stee NO 1 TYPE S CLAS 355 ALFA #Alfa_deck  $ Deck material
stee NO 2 TYPE S CLAS 355 ALFA #Alfa_rail  $ Track material
conc NO 3 TYPE C FCN  30                   $ Track slab material

sval 1 MNO 1 A #A_deck IY #Iy_deck         $ Deck cross section
sval 2 MNO 2 A 2*#A_rail IY 2*#Iy_rail     $ 2 rail cross sections / track
                                           $ total track properties
sval 3 MNO 3 A #A_slab IY #Iy_slab         $ Track slab cross section

end
```

SOFiSTiK CADINP Input File
System

5.2 Input code for SOFIMSHA – System / model properties

```
!#!chapter System

+PROG SOFIMSHA urs:5.1 $ Text Interface for Model Creation
HEAD System
SYST 2D


$$$---------Input data----------------------------------------------------------------$$$

$----Model geometry----$

$ If the span lenght is changed it is necessary to change the parameters in the System
$ input below to get the model to work for the new geometry.

let#L 60  $ Span length [m]

$ If the user want to change the element length /distance between each node
$ it is necessary to change the parameters in the System input below to get
$ the model to work for the new geometry.

let#divide 100       $ Choose divide so that the distance dL between each node/spring
                     $ is equal to L/divide = 0.6 m

let#dL #L/#divide    $ Distance between each node/spring
                     $ length of each beam element dL = 0.6 m

$----Bridge parameters----$

let#h_deck -6        $ Height of the deck cross section [m]

let#h_slab -0.4      $ Height of the track slab cross section [m]

let#b_slab 2.8       $ Breadth of the track slab cross section [m]

let#b_mat #b_slab    $ Breadth of the floating slab mat [m]

let#h_shear_key 0.1  $ Height of the shear key cross section [m]

let#b_shear_key 0.6  $ Breadth of the shear key cross section [m]

let#CG_deck -4.79    $ Center of gravity from the bottom of the deck cross section [m]


let#A_ref_sk #h_shear_key*#b_shear_key     $ Reference area for the horizontal resistance
                                           $ against disp. for the shear keys
                                           $ (compressed mat area) [m^2]

let#A_ref_mat #b_mat*#dL  $ Reference area for the horizontal and vertical resistance
                          $ against disp. for the mat (area between each spring in the model) [m^2]

let#t_mat -25E-3      $ Thickness of the floating slab mat [m]


let#h_tot #h_deck+#t_mat+#h_slab $ Total height, deck cross section + mat thickness +
                                 $ track slab height [m]

let#CG_slab #h_deck+#t_mat+#h_slab/2 $ Center of gravity for the track  slab from the
                                     $ bottom of the deck cross section [m]


$----Elastic spring parameters----$
```

SOFiSTiK CADINP Input File
System

```
$ Floating slab mat, horizontal and vertical stiffness

let#bedding_module_v 5000  $ Static bedding module in the vertical direction for the mat
                           $ (varies with the thickness of the mat, manual input [kN/m^3]

let#bedding_module_h 1666.7 $ Static bedding module in the horizontal direction for the
                            $ mat (varies with the thickness of the mat, manual input) [kN/m^3]

let#k_mat_v #bedding_module_v*#b_mat $ Stiffness K against vertical disp. for the mat [kN/m^2]

let#k_mat_h #bedding_module_h*#b_mat $ Stiffness K against horizontal disp. for the mat [kN/m^2]

$ Extra stiffness for the springs before and after each shear key

let#k_mat_ve #bedding_module_v*#b_mat*#dL/2 $ Stiffness K against vertical disp. for the mat [kN/m^2]

let#k_mat_he #bedding_module_h*#b_mat*#dL/2 $ Stiffness K against horizontal disp. for the mat [kN/m^2]


$ Shear keys, horizontal and vertical stiffness. The mat is mounted all around the shear keys

let#k_sk_h #bedding_module_v*#A_ref_sk  $ Stiffness K against horizontal disp. for the mat [kN/m]

let#k_sk_v #bedding_module_v*#A_ref_mat $ Stiffness K against vertical disp. for the mat [kN/m]


$ Fixed support, horizontal stiffness

let#k_fixed 600000 $ Stiffness K against horizontal disp.[kN/m^2]



$----Non-linear spring parameters for the track----$

let#u0 0.5E-3      $ Displacement between the elastic and plastic zones [m]


$ Resistance against longitudinal disp. for the track

let#kp_loaded 60                        $ Plastic shear resistance for
                                        $ the loaded track [kN/m]

let#kep_loaded #kp_loaded/(#dL*#u0)     $ Elastic shear resistance for the
                                        $ loaded track [kN/m^2]
let#ket_loaded #kep_loaded

let#kp_unloaded 40                      $ Plastic shear resistance for
                                        $ the unloaded track [kN/m]

let#kep_unloaded #kp_unloaded/(#dL*#u0) $ Elastic shear resistance for
                                        $ the unloaded track [kN/m^2]
let#ket_unloaded #kp_unloaded

$-------------------------------------------------------------------------$


$$$-----------System----------------------------------------------------$$$


$----Supports----$
grp 5
$ Fixed support
```

SOFiSTiK CADINP Input File
System

```
node NO 1 X 0 Y 0 fix PY
spri NO 1 NA 1 DX -1 CP #k_fixed

$ Movable support
node NO 2 X #L Y 0 fix PY



$----Deck elements----$
grp 1
$ Creates 101 nodes with a distance of dL between each node
$ in the center of gravity for the deck cross section

node NO 1000 X 0 Y #CG_deck
node NO 1000 FIX KF NR1 1

node NO 1100 X #L Y #CG_deck
node NO 1100 FIX KF NR1 2

node NO (1001 1099 1) X (#dL #dL) Y #CG_deck

$ Creates 100 deck beam elements between node 1000-1100
beam NO fit NA 1000 NE 1100 NCS 1 DIV #divide

$ Top of the deck nodes - used to see the horizontal
$ displacement of the top of the deck
grp 6
node NO 10 X 0 Y #h_deck
node NO 10 FIX KF NR1 1000

node NO 11 X #L Y #h_deck
node NO 11 FIX KF NR1 1100



$----Track slab elements----$
grp 7
$ Creates 101 nodes with a distance of dL between each node
$ in the center of gravity for the track slab cross section

node NO (7000 7100 1) X (0 #dL) Y #CG_slab

$ Creates 100 track slab beam elements between node 7000-7100
beam NO fit NA 7000 NE 7100 NCS 3 DIV #divide



$----Rail elements----$

$ 499 rail elements to the left of the bridge:
$ Creates 500 nodes with a distance of 0.6 m between them
grp 2
node NO (2000 2499 1) X (-300 #dL) Y #h_tot
beam NO mesh NA 2000 NE 2499 NCS 2 DIV 499


$ 499 rail elements to the right of the bridge:
$ Creates 500 nodes with a distance of dL between them
grp 4
node NO (4000 4499 1) X (#L+#dL #dL) Y #h_tot
beam NO mesh NA 4000 NE 4499 NCS 2 DIV 499
```

SOFiSTiK CADINP Input File
System

```
$ 102 rail elements on top of the bridge:
$ Creates 102 nodes with a distance of dL between them
grp 3
node NO (3000 3100 1) X (0 #dL) Y #h_tot
beam NO mesh NA 2499 NE 4000 NCS 2 DIV #divide+2


$ Rail nodes - used to see the horizontal displacement
$ of the rail on top of the bridge
grp  6
node NO 12 X 0 Y #h_tot
node NO 12 FIX KF NR1 3000

node NO 13 X #L Y #h_tot
node NO 13 FIX KF NR1 3100




$----Spring elements---------------------$


$----Non-linear springs for different load positions----$

$ Direction of principal and lateral direction of the springs
let#d_x -1     $ X-component of direction
let#d_y 0     $ Y-component of direction


$ To use different load positions: Uncomment the desired position and
$ comment the undesired positions below.

$ Remember to change the position and load case for the different load
$ positions in the Loads section.

$ Remember to change the stiffness of the bridge deck in the Material section:
$ Rigid deck för braking and the real bridge deck stiffness for the vertical load
$ and temperature load


$$----Temperature variation load----$$

$ All springs are unloaded

$ Input of non-linear spring elements between node 2000-2499
$ to the left of the bridge. Embankment track.
grp 102
spri mesh NA 2000 NE 2499 DX #d_x CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded
spri NA 2499 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3


$ Input of non-linear spring elements between the track and the bridge deck
grp 103
spri NA 3000 NE 1000 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
spri mesh NA 3000 NE 3100 DX #d_x CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded NARE 1000 NERE 1100
spri NA 3100 NE 1100 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3


$ Input of non-linear spring elements between node 4000-4499
$ to the left of the bridge. Embankment track
```

SOFiSTiK CADINP Input File
System

```
grp 104
spri NA 4000 DX -#d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
spri mesh NA 4000 NE 4499 DX -#d_x CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded

$$----End of the temperature variation load----$$




$$----Different positions - braking and vertical load cases----$$

$$----Position 0 m from the movable support-----$$

$$ Input of non-linear spring elements between node 2000-2499
$$ to the left of the bridge. Embankment track.
$grp 102

$$ The track is loaded between node 2000-2499.
$spri mesh NA 2000 NE 2499 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded yiel #kp_loaded
$spri NA 2499 DX #d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3

$$ Input of non-linear spring elements between the track and the bridge deck
$grp 103

$$ The bridge track is unloaded between node 3000 - 3100
$spri mesh NA 3000 NE 3100 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded NARE 1000
$spri NA 3100 NE 1100 DX #d_x DY #d_y CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3



$$ Input of non-linear spring elements between node 4000-4499
$$ to the right of the bridge. Embankment track.
$grp 104

$$ The track is unloaded between node 4000-4499.
$spri NA 4000 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
$spri mesh NA 4000 NE 4499 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded

$$----End of position 0 m-----------------------$$





$$----Position 15 m from the movable support----$$


$$ Input of non-linear spring elements between node 2000-2499
$$ to the left of the bridge. Embankment track.
$grp 102

$$ The track is unloaded between node 2000-2025.
$spri mesh NA 2000 NE 2025 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded

$$ The track is loaded between node 2025-2499.
$spri mesh NA 2025 NE 2499 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded yiel #kp_loaded
$spri NA 2499 DX #d_x CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3


$$ Input of non-linear spring elements between the track and the bridge deck
$$ The bridge track is loaded between node 3000 - 3025
$grp 103
```

SOFiSTiK CADINP Input File
System

```
$spri NA 3000 NE 1000 DX #d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3
$spri mesh NA 3000 NE 3025 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded YIEL #kp_loaded NARE 1000 NERE 1

$$ The bridge track is unloaded between node 3025 - 3100
$grp 103
$spri mesh NA 3025 NE 3100 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded NARE 1025
$spri NA 3100 NE 1100 DX -#d_x DY #d_y CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3


$$ Input of non-linear spring elements between node 4000-4499
$$ to the left of the bridge. Embankment track.
$grp 104

$$ The track is unloaded between node 4000-4499.
$spri NA 4000 DX -#d_x CP #kep_unloaded CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
$spri mesh NA 4000 NE 4499 DX -#d_x DY #d_y CP #kep_unloaded ct #ket_unloaded yiel #kp_unloaded

$$----End of position 15 m---------------------------------------------------------------------------




$$----Position 30 m from the movable support----$$

$$ Input of non-linear spring elements between node 2000-2499
$$ to the left of the bridge. Embankment track.
$grp 102

$$ The track is unloaded between node 2000-2051.
$spri mesh NA 2000 NE 2051 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded

$$ The track is loaded between node 2051-2499.
$spri mesh NA 2051 NE 2499 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded yiel #kp_loaded
$spri NA 2499 DX #d_x CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3


$$ Input of non-linear spring elements between the track and the bridge deck
$$ The bridge track is loaded between node 3000 - 3050
$grp 103
$spri NA 3000 NE 1000 DX #d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3
$spri mesh NA 3000 NE 3050 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded YIEL #kp_loaded NARE 1000 NERE 1

$$ The bridge track is unloaded between node 3050 - 3100
$grp 103
$spri mesh NA 3050 NE 3100 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded NARE 1050
$spri NA 3100 NE 1100 DX -#d_x DY #d_y CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3


$$ Input of non-linear spring elements between node 4000-4499
$$ to the left of the bridge. Embankment track.
$grp 104

$$ The track is unloaded between node 4000-4499.
$spri NA 4000 DX -#d_x CP #kep_unloaded CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
$spri mesh NA 4000 NE 4499 DX -#d_x DY #d_y CP #kep_unloaded ct #ket_unloaded yiel #kp_unloaded

$$----End of position 30 m---------------------------------------------------------------------$$
```

SOFiSTiK CADINP Input File
System

```
$$----Position 45 m from the movable support----$$

$$ Input of non-linear spring elements between node 2000-2499
$$ to the left of the bridge. Embankment track.
$grp 102

$$ The track is unloaded between node 2000-2075.
$spri mesh NA 2000 NE 2075 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded

$$ The track is loaded between node 2075-2499.
$spri mesh NA 2075 NE 2499 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded yiel #kp_loaded
$spri NA 2499 DX #d_x CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3


$$ Input of non-linear spring elements between the track and the bridge deck
$$ The bridge track is loaded between node 3000 - 3075
$grp 103
$spri NA 3000 NE 1000 DX #d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3
$spri mesh NA 3000 NE 3075 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded YIEL #kp_loaded NARE 1000 NERE 1

$$ The bridge track is unloaded between node 3075 - 3100
$grp 103
$spri mesh NA 3075 NE 3100 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded NARE 1075
$spri NA 3100 NE 1100 DX -#d_x DY #d_y CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3


$$ Input of non-linear spring elements between node 4000-4499
$$ to the left of the bridge. Embankment track.
$grp 104

$$ The track is unloaded between node 4000-4499.
$spri NA 4000 DX -#d_x CP #kep_unloaded CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
$spri mesh NA 4000 NE 4499 DX -#d_x DY #d_y CP #kep_unloaded ct #ket_unloaded yiel #kp_unloaded

$$----End of position 45 m---------------------$$




$$----Position 60 m from the movable support----$$


$ Input of non-linear spring elements between node 2000-2499
$ to the left of the bridge. Embankment track.
grp 102

$ The track is unloaded between node 2000-2100.
spri mesh NA 2000 NE 2100 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded

$ The track is loaded between node 2100-2499.
spri mesh NA 2100 NE 2499 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded yiel #kp_loaded
spri NA 2499 DX #d_x CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3


$ Input of non-linear spring elements between the track and the bridge deck
$ The bridge track is loaded (between node 3000 - 3100)
grp 103
spri NA 3000 NE 1000 DX #d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3
spri mesh NA 3000 NE 3100 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded YIEL #kp_loaded NARE 1000 NERE 11
```

SOFiSTiK CADINP Input File
System

```
$ Input of non-linear spring elements between node 4000-4499
$ to the left of the bridge. Embankment track.
grp 104

$ The track is unloaded between node 3100-4499.
spri NA 3100 NE 1100 DX -#d_x DY #d_y CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
spri NA 4000 DX -#d_x CP #kep_unloaded CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
spri mesh NA 4000 NE 4499 DX -#d_x DY #d_y CP #kep_unloaded ct #ket_unloaded yiel #kp_unloaded

$$----End of position 60 m--------------------------$$



$----Elastic springs----$

$ Input of elastic spring elements between the slab and the deck (floating slab mat springs)
$ and shear key springs (one shear key spring every 3 meters, between them are the floating
$ slab mat springs placed)

grp 105

$ Slab mat springs
spri mesh NA 7000 NE 7004 CP #k_mat_v CT #k_mat_h NARE 1000 NERE 1004

spri NA 7004 NE 1004 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 3 m
spri NA 7005 NE 1005 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7006 NE 1006 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7006 NE 7009 CP #k_mat_v CT #k_mat_h NARE 1006 NERE 1009
spri NA 7009 NE 1009 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 6 m
spri NA 7010 NE 1010 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7011 NE 1011 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7011 NE 7014 CP #k_mat_v CT #k_mat_h NARE 1011 NERE 1014
spri NA 7014 NE 1014 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 9 m
spri NA 7015 NE 1015 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7016 NE 1016 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7016 NE 7019 CP #k_mat_v CT #k_mat_h NARE 1016 NERE 1019
spri NA 7019 NE 1019 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 12 m
spri NA 7020 NE 1020 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7021 NE 1021 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7021 NE 7024 CP #k_mat_v CT #k_mat_h NARE 1021 NERE 1024
spri NA 7024 NE 1024 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 15 m
spri NA 7025 NE 1025 CP #k_sk_v CT #k_sk_h
```

SOFiSTiK CADINP Input File
System

```
$ Slab mat springs
spri NA 7026 NE 1026 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7026 NE 7029 CP #k_mat_v CT #k_mat_h NARE 1026 NERE 1029
spri NA 7029 NE 1029 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 18 m
spri NA 7030 NE 1030 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7031 NE 1031 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7031 NE 7034 CP #k_mat_v CT #k_mat_h NARE 1031 NERE 1034
spri NA 7034 NE 1034 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 21 m
spri NA 7035 NE 1035 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7036 NE 1036 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7036 NE 7039 CP #k_mat_v CT #k_mat_h NARE 1036 NERE 1039
spri NA 7039 NE 1039 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 24 m
spri NA 7040 NE 1040 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7041 NE 1041 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7041 NE 7044 CP #k_mat_v CT #k_mat_h NARE 1041 NERE 1044
spri NA 7044 NE 1044 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 27 m
spri NA 7045 NE 1045 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7046 NE 1046 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7046 NE 7049 CP #k_mat_v CT #k_mat_h NARE 1046 NERE 1049
spri NA 7049 NE 1049 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 30 m
spri NA 7050 NE 1050 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7051 NE 1051 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7051 NE 7054 CP #k_mat_v CT #k_mat_h NARE 1051 NERE 1054
spri NA 7054 NE 1054 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 33 m
spri NA 7055 NE 1055 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7056 NE 1056 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7056 NE 7059 CP #k_mat_v CT #k_mat_h NARE 1056 NERE 1059
spri NA 7059 NE 1059 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 36 m
spri NA 7060 NE 1060 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7061 NE 1061 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7061 NE 7064 CP #k_mat_v CT #k_mat_h NARE 1061 NERE 1064
spri NA 7064 NE 1064 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 39 m
```

SOFiSTiK CADINP Input File
System

```
spri NA 7065 NE 1065 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7066 NE 1066 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7066 NE 7069 CP #k_mat_v CT #k_mat_h NARE 1066 NERE 1069
spri NA 7069 NE 1069 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 42 m
spri NA 7070 NE 1070 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7071 NE 1071 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7071 NE 7074 CP #k_mat_v CT #k_mat_h NARE 1071 NERE 1074
spri NA 7074 NE 1074 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 45 m
spri NA 7075 NE 1075 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7076 NE 1076 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7076 NE 7079 CP #k_mat_v CT #k_mat_h NARE 1076 NERE 1079
spri NA 7079 NE 1079 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 48 m
spri NA 7080 NE 1080 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7081 NE 1081 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7081 NE 7084 CP #k_mat_v CT #k_mat_h NARE 1081 NERE 1084
spri NA 7084 NE 1084 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 51 m
spri NA 7085 NE 1085 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7086 NE 1086 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7086 NE 7089 CP #k_mat_v CT #k_mat_h NARE 1086 NERE 1089
spri NA 7089 NE 1089 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 54 m
spri NA 7090 NE 1090 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7091 NE 1091 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7091 NE 7094 CP #k_mat_v CT #k_mat_h NARE 1091 NERE 1094
spri NA 7094 NE 1094 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 57 m
spri NA 7095 NE 1095 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7096 NE 1096 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7096 NE 7100 CP #k_mat_v CT #k_mat_h NARE 1096 NERE 1100


END
```

SOFiSTiK CADINP Input File Loads

5.3 Input code for SOFILOAD – Load cases and load positions

```
!#!chapter Loads

+PROG SOFILOAD urs:6.1 $ Text Interface for Loads
HEAD Text Interface for Loads
$ Actions
ACT G   $ dead load
ACT Q   $ variable load


$-------------Input data---------------------------------------------------------------

$ Temperature variation
LET#delta_T_deck 35  $ Thermal variation in the deck ['C]


$ Braking force

$ If the braking force acts from the movable support
$ towards the fixed support: -20 [kN/m]

$ If the braking force acts from the fixed support
$ towards the movable support: 20 [kN/m]

LET#F_braking 20 $ Horizontal braking force [kN/m]


$ Vertical load from the train
LET#F_vertical 80 $ Vertical train load [kN/m]




$--------------Loadcases and load positions---------------------------------------------

$ To use different load positions: Uncomment the desired position and
$ comment the undesired positions below.

$ Uncomment the desired position and load case below, comment all the
$ undesired positions and load cases below (temperature, braking or vertical load).

$ Remember to change the spring stiffnesses (unloaded or loaded) for the different load
$ positions for the braking load and vertical loac case in the System section.
$ For the temperature variation load should all springs be unloaded.

$ Remember to change the stiffness of the bridge deck in the Material section:
$ Rigid deck för braking and the real brdige deck stiffness for the vertical load



$$----Temperature variation load case----$$

LC 1 Q TITL 'Temperature variation - deck'
  BEAM FROM GRP 1 TYPE DT PA #delta_T_deck


$$----End of the temperature variation load----$$




$$----Different positions - braking and vertical load cases----$$
```

SOFiSTiK CADINP Input File
Loads

```
$$----Position 0 m from the fixed support----$$

$ The length of the train is 300 m, each element is
$ 0.6 m:

$ Uncomment the desired load case below (braking or vertical load)

$LC 1 Q TITL 'Braking force 0 m from the fixed support'
$  BEAM FROM 20001 TO 20499 TYPE PXX PA #F_braking
$  BEAM FROM 30001 TO 30001 TYPE PXX PA #F_braking


$$LC 1 Q TITL 'Vertical load 0 m from the fixed support'
$  BEAM FROM 20001 TO 20449 TYPE PG PA #F_vertical
$  BEAM FROM 30001 TO 30001 TYPE PG PA #F_vertical

$$----End of position 0 m----------------------$$





$$----Position 15 m from the fixed support----$$

$ The length of the train is 300 m, each element is
$ 0.6 m:

$ Uncomment the desired load case below (braking or vertical load)


$LC 1 Q TITL 'Braking force 15 m from the fixed support'
$  BEAM FROM 20026 TO 20499 TYPE PXX PA #F_braking
$  BEAM FROM 30001 TO 30025 TYPE PXX PA #F_braking

$LC 1 Q TITL 'Vertical load 15 m from the fixed support'
$  BEAM FROM 20026 TO 20499 TYPE PG PA #F_vertical
$  BEAM FROM 30001 TO 30025 TYPE PG PA #F_vertical

$$----End of position 15 m--------------------$$





$$----Position 30 m from the fixed support----$$

$$ The length of the train is 300 m, each element is
$$ 0.6 m:

$ Uncomment the desired load case below (braking or vertical load)

$LC 1 Q TITL 'Braking force 30 m from the fixed support'
$  BEAM FROM 20052 TO 20499 TYPE PXX PA #F_braking
$  BEAM FROM 30001 TO 30050 TYPE PXX PA #F_braking

$LC 1 Q TITL 'Vertical load 30 m from the fixed support'
$  BEAM FROM 20052 TO 20499 TYPE PG PA #F_vertical
$  BEAM FROM 30001 TO 30050 TYPE PG PA #F_vertical

$$----End of position 30 m----------------------$$
```

SOFiSTiK CADINP Input File
Loads

```
$$----Position 45 m from the fixed support----$$

$$ The length of the train is 300 m, each element is
$$ 0.6 m:

$ Uncomment the desired load case below (braking or vertical load)

$LC 1 Q TITL 'Braking force 45 m from the fixed support'
$  BEAM FROM 20076 TO 20499 TYPE PXX PA #F_braking
$  BEAM FROM 30001 TO 30075 TYPE PXX PA #F_braking

$LC 1 Q TITL 'Vertical load 45 m from the fixed support'
$  BEAM FROM 20076 TO 20499 TYPE PG PA #F_vertical
$  BEAM FROM 30001 TO 30075 TYPE PG PA #F_vertica

$$----End of position 45 m-------------------------$$




$$----Position 60 m from the fixed support----$$

$ The length of the train is 300 m, each element is
$ 0.6 m:

$ Uncomment the desired load case below (braking or vertical load)


$LC 1 Q TITL 'Braking force 60 m from the fixed support'
$  BEAM FROM 20101 TO 20499 TYPE PXX PA #F_braking
$  BEAM FROM 30001 TO 30101 TYPE PXX PA #F_braking

$LC 1 Q TITL 'Vertical load 60 m from the fixed support'
$  BEAM FROM 20101 TO 20499 TYPE PG PA #F_vertical
$  BEAM FROM 30001 TO 30101 TYPE PG PA #F_vertical

$$----End of position 60 m-------------------------$$

END
```

SOFiSTiK CADINP Input File
Calculation

5.4 Input code for ASE – Calculation

```
!#!chapter Calculation

+PROG ASE urs:20.1 $ Linear Analysis
HEAD Calculation of forces and moments
PAGE UNII 0
echo  OPT full yes
CTRL OPT SOLV VAL - $  Solution of the system
SYST prob NONL
LC 1

END
```

6 Slab track with a floating slab mat – test case F4-6

6.1 Input code for AQUA – Material and cross section properties

```
!#!chapter Material and cross section properties

+prog aqua urs:18.1

head Material and cross sections

$------------- Input parameters-------------------


$ To use different load positions and load cases: Uncomment the desired position and
$ comment the undesired positions in the System section and in the Loads section

$ Remember to change the stiffness of the bridge deck below:
$ Rigid deck for the braking force and the real bridge deck stiffness for the temperature and
$ vertical load

$ For the braking load case is the deck considered to be
$ rigid to be able to evaluate the effects of braking
$ forces alone. E*I for the deck -> infinity



LET#Alfa_deck 1.0E-5  $ Deck: Thermal expansion coefficient [1/K]
LET#Alfa_rail 1.2E-5  $ Rail: Thermal expansion coefficient [1/K]

LET#A_deck 0.74       $ The decks cross section area       [m^2]
LET#A_rail 0.007686   $ Cross section area for 1 rail      [m^2]
LET#A_slab 1.12       $ The track slabs cross section area [m^2]


LET#Iy_deck 1E16      $ Moment of inertia for the deck for the braking load case
                      $E*I for the deck -> infinity [m^4]

$LET#Iy_deck 2.59      $ Moment of inertia for the deck for the vertical load case [m^4]

LET#Iy_rail 30.383E-6 $ Moment of inertia for 1 rail      [m^4/rail]
LET#Iy_slab 0.0149    $ Moment of inertia for the track slab [m^4]

echo full
stee NO 1 TYPE S CLAS 355 ALFA #Alfa_deck  $ Deck material
stee NO 2 TYPE S CLAS 355 ALFA #Alfa_rail  $ Track material
conc NO 3 TYPE C FCN  30                   $ Track slab material

sval 1 MNO 1 A #A_deck IY #Iy_deck         $ Deck cross section
sval 2 MNO 2 A 2*#A_rail IY 2*#Iy_rail     $ 2 rail cross sections / track
                                           $ total track properties
sval 3 MNO 3 A #A_slab IY #Iy_slab         $ Track slab cross section

end
```

SOFiSTiK CADINP Input File System

6.2 Input code for SOFIMSHA – System / model properties

```
!#!chapter System

+PROG SOFIMSHA urs:5.1 $ Text Interface for Model Creation
HEAD System
SYST 2D


$$$---------Input data---------------------------------------------------------------$$$

$----Model geometry----$

$ If the span lenght is changed it is necessary to change the parameters in the System
$ input below to get the model to work for the new geometry.

let#L 60  $ Span length [m]

$ If the user want to change the element length /distance between each node
$ it is necessary to change the parameters in the System input below to get
$ the model to work for the new geometry.

let#divide 100       $ Choose divide so that the distance dL between each node/spring
                     $ is equal to L/divide = 0.6 m

let#dL #L/#divide    $ Distance between each node/spring
                     $ length of each beam element dL = 0.6 m

$----Bridge parameters----$

let#h_deck -6        $ Height of the deck cross section [m]

let#h_slab -0.4      $ Height of the track slab cross section [m]

let#b_slab 2.8       $ Breadth of the track slab cross section [m]

let#b_mat #b_slab    $ Breadth of the floating slab mat [m]

let#h_shear_key 0.1  $ Height of the shear key cross section [m]

let#b_shear_key 0.6  $ Breadth of the shear key cross section [m]

let#CG_deck -4.79    $ Center of gravity from the bottom of the deck cross section [m]


let#A_ref_sk #h_shear_key*#b_shear_key    $ Reference area for the horizontal resistance
                                          $ against disp. for the shear keys
                                          $ (compressed mat area) [m^2]

let#A_ref_mat #b_mat*#dL  $ Reference area for the horizontal and vertical resistance
                          $ against disp. for the mat (area between each spring in the model) [m^2]

let#t_mat -12E-3      $ Thickness of the floating slab mat [m]


let#h_tot #h_deck+#t_mat+#h_slab $ Total height, deck cross section + mat thickness +
                                 $ track slab height [m]

let#CG_slab #h_deck+#t_mat+#h_slab/2 $ Center of gravity for the track  slab from the
                                     $ bottom of the deck cross section [m]


$----Elastic spring parameters----$
```

SOFiSTiK CADINP Input File
System

```
$ Floating slab mat, horizontal and vertical stiffness

let#bedding_module_v 10000  $ Static bedding module in the vertical direction for the mat
                           $ (varies with the thickness of the mat, manual input [kN/m^3]

let#bedding_module_h 3333.3 $ Static bedding module in the horizontal direction for the
                            $ mat (varies with the thickness of the mat, manual input) [kN/m^3]

let#k_mat_v #bedding_module_v*#b_mat $ Stiffness K against vertical disp. for the mat [kN/m^2]

let#k_mat_h #bedding_module_h*#b_mat $ Stiffness K against horizontal disp. for the mat [kN/m^2]

$ Extra stiffness for the springs before and after each shear key

let#k_mat_ve #bedding_module_v*#b_mat*#dL/2 $ Stiffness K against vertical disp. for the mat [kN/m^2]

let#k_mat_he #bedding_module_h*#b_mat*#dL/2 $ Stiffness K against horizontal disp. for the mat [kN/m^2]


$ Shear keys, horizontal and vertical stiffness. The mat is mounted all around the shear keys

let#k_sk_h #bedding_module_v*#A_ref_sk  $ Stiffness K against horizontal disp. for the mat [kN/m]

let#k_sk_v #bedding_module_v*#A_ref_mat $ Stiffness K against vertical disp. for the mat [kN/m]


$ Fixed support, horizontal stiffness

let#k_fixed 120000 $ Stiffness K against horizontal disp.[kN/m^2]



$----Non-linear spring parameters for the track----$

let#u0 0.5E-3      $ Displacement between the elastic and plastic zones [m]


$ Resistance against longitudinal disp. for the track

let#kp_loaded 60                       $ Plastic shear resistance for
                                       $ the loaded track [kN/m]

let#kep_loaded #kp_loaded/(#dL*#u0)    $ Elastic shear resistance for the
                                       $ loaded track [kN/m^2]
let#ket_loaded #kep_loaded

let#kp_unloaded 40                     $ Plastic shear resistance for
                                       $ the unloaded track [kN/m]

let#kep_unloaded #kp_unloaded/(#dL*#u0) $ Elastic shear resistance for
                                       $ the unloaded track [kN/m^2]
let#ket_unloaded #kp_unloaded

$-------------------------------------------------------------------------$


$$$-----------System-----------------------------------------------------$$$


$----Supports----$
grp 5
$ Fixed support
```

SOFiSTiK CADINP Input File
System

```
node NO 1 X 0 Y 0 fix PY
spri NO 1 NA 1 DX -1 CP #k_fixed

$ Movable support
node NO 2 X #L Y 0 fix PY



$----Deck elements----$
grp 1
$ Creates 101 nodes with a distance of dL between each node
$ in the center of gravity for the deck cross section

node NO 1000 X 0 Y #CG_deck
node NO 1000 FIX KF NR1 1

node NO 1100 X #L Y #CG_deck
node NO 1100 FIX KF NR1 2

node NO (1001 1099 1) X (#dL #dL) Y #CG_deck

$ Creates 100 deck beam elements between node 1000-1100
beam NO fit NA 1000 NE 1100 NCS 1 DIV #divide

$ Top of the deck nodes - used to see the horizontal
$ displacement of the top of the deck
grp 6
node NO 10 X 0 Y #h_deck
node NO 10 FIX KF NR1 1000

node NO 11 X #L Y #h_deck
node NO 11 FIX KF NR1 1100



$----Track slab elements----$
grp 7
$ Creates 101 nodes with a distance of dL between each node
$ in the center of gravity for the track slab cross section

node NO (7000 7100 1) X (0 #dL) Y #CG_slab

$ Creates 100 track slab beam elements between node 7000-7100
beam NO fit NA 7000 NE 7100 NCS 3 DIV #divide



$----Rail elements----$

$ 499 rail elements to the left of the bridge:
$ Creates 500 nodes with a distance of 0.6 m between them
grp 2
node NO (2000 2499 1) X (-300 #dL) Y #h_tot
beam NO mesh NA 2000 NE 2499 NCS 2 DIV 499


$ 499 rail elements to the right of the bridge:
$ Creates 500 nodes with a distance of dL between them
grp 4
node NO (4000 4499 1) X (#L+#dL #dL) Y #h_tot
beam NO mesh NA 4000 NE 4499 NCS 2 DIV 499
```

SOFiSTiK CADINP Input File
System

```
$ 102 rail elements on top of the bridge:
$ Creates 102 nodes with a distance of dL between them
grp 3
node NO (3000 3100 1) X (0 #dL) Y #h_tot
beam NO mesh NA 2499 NE 4000 NCS 2 DIV #divide+2


$ Rail nodes - used to see the horizontal displacement
$ of the rail on top of the bridge
grp  6
node NO 12 X 0 Y #h_tot
node NO 12 FIX KF NR1 3000

node NO 13 X #L Y #h_tot
node NO 13 FIX KF NR1 3100




$----Spring elements---------------------$


$----Non-linear springs for different load positions----$

$ Direction of principal and lateral direction of the springs
let#d_x -1     $ X-component of direction
let#d_y 0     $ Y-component of direction


$ To use different load positions: Uncomment the desired position and
$ comment the undesired positions below.

$ Remember to change the position and load case for the different load
$ positions in the Loads section.

$ Remember to change the stiffness of the bridge deck in the Material section:
$ Rigid deck för braking and the real bridge deck stiffness for the vertical load
$ and temperature load


$$----Temperature variation load----$$

$$ All springs are unloaded

$$ Input of non-linear spring elements between node 2000-2499
$$ to the left of the bridge. Embankment track.
$grp 102
$spri mesh NA 2000 NE 2499 DX #d_x CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded
$spri NA 2499 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3


$$ Input of non-linear spring elements between the track and the bridge deck
$grp 103
$spri NA 3000 NE 1000 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
$spri mesh NA 3000 NE 3100 DX #d_x CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded NARE 1000 NERE 110
$spri NA 3100 NE 1100 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3


$$ Input of non-linear spring elements between node 4000-4499
$$ to the left of the bridge. Embankment track
```

SOFiSTiK CADINP Input File
System

```
$grp 104
$spri NA 4000 DX -#d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
$spri mesh NA 4000 NE 4499 DX -#d_x CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded

$$----End of the temperature variation load----$$




$$----Different positions - braking and vertical load cases----$$

$$----Position 0 m from the movable support-----$$

$$ Input of non-linear spring elements between node 2000-2499
$$ to the left of the bridge. Embankment track.
$grp 102

$$ The track is unloaded between node 2000-2499.
$spri mesh NA 2000 NE 2499 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded
$spri NA 2499 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3



$$ Input of non-linear spring elements between the track and the bridge deck
$grp 103

$$ The bridge track is unloaded between node 3000 - 3100
$spri mesh NA 3000 NE 3100 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded NARE 1000
$spri NA 3100 NE 1100 DX #d_x DY #d_y CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3



$$ Input of non-linear spring elements between node 4000-4499
$$ to the right of the bridge. Embankment track.
$grp 104

$$ The track is loaded between node 4000-4499.
$spri NA 4000 DX -#d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3
$spri mesh NA 4000 NE 4499 DX -#d_x DY #d_y CP #kep_loaded CT #ket_loaded yiel #kp_loaded

$$----End of position 0 m-----------------------$$





$$----Position 15 m from the movable support----$$

$$ Input of non-linear spring elements between node 2000-2499
$$ to the left of the bridge. Embankment track.
$grp 102

$$ The track is unloaded between node 2000-2499.
$spri mesh NA 2000 NE 2499 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded
$spri NA 2499 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3



$$ Input of non-linear spring elements between the track and the bridge deck
$grp 103

$$ The bridge track is unloaded between node 3000 - 3075
```

SOFiSTiK CADINP Input File
System

```
$spri NA 3000 NE 1000 DX #d_x DY #d_y CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
$spri mesh NA 3000 NE 3075 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded NARE 1000

$$ The bridge track is loaded between node 3075 - 3100
$spri mesh NA 3075 NE 3100 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded YIEL #kp_loaded NARE 1075 NERE 1
$spri NA 3100 NE 1100 DX #d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3



$$ Input of non-linear spring elements between node 4000-4499
$$ to the right of the bridge. Embankment track.
$grp 104

$$ The track is loaded between node 4000-4474.
$spri NA 4000 DX -#d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3
$spri mesh NA 4000 NE 4474 DX -#d_x DY #d_y CP #kep_loaded CT #ket_loaded yiel #kp_loaded

$$ The track is unloaded between node 4474-4499.
$spri mesh NA 4474 NE 4499  DX -#d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded

$$----End of position 15 m------------------------------------------------------------------------------




$$----Position 30 m from the movable support----$$

$$ Input of non-linear spring elements between node 2000-2499
$$ to the left of the bridge. Embankment track.
$grp 102

$$ The track is unloaded between node 2000-2499.
$spri mesh NA 2000 NE 2499 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded
$spri NA 2499 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3



$$ Input of non-linear spring elements between the track and the bridge deck
$grp 103

$$ The bridge track is unloaded between node 3000 - 3050
$spri NA 3000 NE 1000 DX #d_x DY #d_y CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
$spri mesh NA 3000 NE 3050 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded NARE 1000

$$ The bridge track is loaded between node 3050 - 3100
$spri mesh NA 3050 NE 3100 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded YIEL #kp_loaded NARE 1050 NERE 1
$spri NA 3100 NE 1100 DX #d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3



$$ Input of non-linear spring elements between node 4000-4499
$$ to the right of the bridge. Embankment track.
$grp 104

$$ The track is loaded between node 4000-4449.
$spri NA 4000 DX -#d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3
$spri mesh NA 4000 NE 4474 DX -#d_x DY #d_y CP #kep_loaded CT #ket_loaded yiel #kp_loaded

$$ The track is unloaded between node 4449-4499.
$spri mesh NA 4449 NE 4499  DX -#d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded
```

SOFiSTiK CADINP Input File
System

```
$$----End of position 30 m--------------------------------------------------------------------$$




$$----Position 45 m from the movable support----$$

$$ Input of non-linear spring elements between node 2000-2499
$$ to the left of the bridge. Embankment track.
$grp 102

$$ The track is unloaded between node 2000-2499.
$spri mesh NA 2000 NE 2499 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded
$spri NA 2499 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3



$$ Input of non-linear spring elements between the track and the bridge deck
$grp 103

$$ The bridge track is unloaded between node 3000 - 3025
$spri NA 3000 NE 1000 DX #d_x DY #d_y CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3
$spri mesh NA 3000 NE 3025 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded YIEL #kp_unloaded NARE 1000

$$ The bridge track is loaded between node 3025 - 3100
$spri mesh NA 3025 NE 3100 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded YIEL #kp_loaded NARE 1035 NERE 1
$spri NA 3100 NE 1100 DX #d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3



$$ Input of non-linear spring elements between node 4000-4499
$$ to the right of the bridge. Embankment track.
$grp 104

$$ The track is loaded between node 4000-4424.
$spri NA 4000 DX -#d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3
$spri mesh NA 4000 NE 4424 DX -#d_x DY #d_y CP #kep_loaded CT #ket_loaded yiel #kp_loaded

$$ The track is unloaded between node 4424-4499.
$spri mesh NA 4424 NE 4499  DX -#d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded

$$----End of position 45 m----------------------$$




$$----Position 60 m from the movable support----$$


$ Input of non-linear spring elements between node 2000-2499
$ to the left of the bridge. Embankment track.
grp 102

$ The track is unloaded between node 2000-2499.
spri mesh NA 2000 NE 2499 DX #d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded
spri NA 2499 DX #d_x CP #kep_unloaded*0.3 CT #ket_unloaded*0.3 YIEL #kp_unloaded*0.3



$ Input of non-linear spring elements between the track and the bridge deck
```

SOFiSTiK CADINP Input File
System

```
grp 103

$ The bridge track is loaded between node 3000 - 3100
spri NA 3000 NE 1000 DX #d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3
spri mesh NA 3000 NE 3100 DX #d_x DY #d_y CP #kep_loaded CT #ket_loaded YIEL #kp_loaded NARE 1000 NERE 11
spri NA 3100 NE 1100 DX #d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3



$ Input of non-linear spring elements between node 4000-4499
$ to the right of the bridge. Embankment track.
grp 104

$ The track is loaded between node 4000-4399.
spri NA 4000 DX -#d_x DY #d_y CP #kep_loaded*0.3 CT #ket_loaded*0.3 YIEL #kp_loaded*0.3
spri mesh NA 4000 NE 4399 DX -#d_x DY #d_y CP #kep_loaded CT #ket_loaded yiel #kp_loaded

$ The track is unloaded between node 4399-4499.
spri mesh NA 4399 NE 4499  DX -#d_x DY #d_y CP #kep_unloaded CT #ket_unloaded yiel #kp_unloaded

$$----End of position 60 m--------------------------$$


$----Elastic springs----$

$ Input of elastic spring elements between the slab and the deck (floating slab mat springs)
$ and shear key springs (one shear key spring every 3 meters, between them are the floating
$ slab mat springs placed)

grp 105

$ Slab mat springs
spri mesh NA 7000 NE 7004 CP #k_mat_v CT #k_mat_h NARE 1000 NERE 1004

spri NA 7004 NE 1004 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 3 m
spri NA 7005 NE 1005 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7006 NE 1006 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7006 NE 7009 CP #k_mat_v CT #k_mat_h NARE 1006 NERE 1009
spri NA 7009 NE 1009 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 6 m
spri NA 7010 NE 1010 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7011 NE 1011 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7011 NE 7014 CP #k_mat_v CT #k_mat_h NARE 1011 NERE 1014
spri NA 7014 NE 1014 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 9 m
spri NA 7015 NE 1015 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7016 NE 1016 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7016 NE 7019 CP #k_mat_v CT #k_mat_h NARE 1016 NERE 1019
spri NA 7019 NE 1019 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 12 m
spri NA 7020 NE 1020 CP #k_sk_v CT #k_sk_h
```

SOFiSTiK CADINP Input File
System

```
$ Slab mat springs
spri NA 7021 NE 1021 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7021 NE 7024 CP #k_mat_v CT #k_mat_h NARE 1021 NERE 1024
spri NA 7024 NE 1024 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 15 m
spri NA 7025 NE 1025 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7026 NE 1026 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7026 NE 7029 CP #k_mat_v CT #k_mat_h NARE 1026 NERE 1029
spri NA 7029 NE 1029 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 18 m
spri NA 7030 NE 1030 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7031 NE 1031 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7031 NE 7034 CP #k_mat_v CT #k_mat_h NARE 1031 NERE 1034
spri NA 7034 NE 1034 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 21 m
spri NA 7035 NE 1035 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7036 NE 1036 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7036 NE 7039 CP #k_mat_v CT #k_mat_h NARE 1036 NERE 1039
spri NA 7039 NE 1039 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 24 m
spri NA 7040 NE 1040 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7041 NE 1041 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7041 NE 7044 CP #k_mat_v CT #k_mat_h NARE 1041 NERE 1044
spri NA 7044 NE 1044 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 27 m
spri NA 7045 NE 1045 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7046 NE 1046 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7046 NE 7049 CP #k_mat_v CT #k_mat_h NARE 1046 NERE 1049
spri NA 7049 NE 1049 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 30 m
spri NA 7050 NE 1050 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7051 NE 1051 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7051 NE 7054 CP #k_mat_v CT #k_mat_h NARE 1051 NERE 1054
spri NA 7054 NE 1054 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 33 m
spri NA 7055 NE 1055 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7056 NE 1056 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7056 NE 7059 CP #k_mat_v CT #k_mat_h NARE 1056 NERE 1059
spri NA 7059 NE 1059 CP #k_mat_ve CT #k_mat_he
```

SOFiSTiK CADINP Input File
System

```
$ Shear key spring - 36 m
spri NA 7060 NE 1060 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7061 NE 1061 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7061 NE 7064 CP #k_mat_v CT #k_mat_h NARE 1061 NERE 1064
spri NA 7064 NE 1064 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 39 m
spri NA 7065 NE 1065 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7066 NE 1066 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7066 NE 7069 CP #k_mat_v CT #k_mat_h NARE 1066 NERE 1069
spri NA 7069 NE 1069 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 42 m
spri NA 7070 NE 1070 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7071 NE 1071 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7071 NE 7074 CP #k_mat_v CT #k_mat_h NARE 1071 NERE 1074
spri NA 7074 NE 1074 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 45 m
spri NA 7075 NE 1075 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7076 NE 1076 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7076 NE 7079 CP #k_mat_v CT #k_mat_h NARE 1076 NERE 1079
spri NA 7079 NE 1079 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 48 m
spri NA 7080 NE 1080 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7081 NE 1081 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7081 NE 7084 CP #k_mat_v CT #k_mat_h NARE 1081 NERE 1084
spri NA 7084 NE 1084 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 51 m
spri NA 7085 NE 1085 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7086 NE 1086 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7086 NE 7089 CP #k_mat_v CT #k_mat_h NARE 1086 NERE 1089
spri NA 7089 NE 1089 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 54 m
spri NA 7090 NE 1090 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7091 NE 1091 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7091 NE 7094 CP #k_mat_v CT #k_mat_h NARE 1091 NERE 1094
spri NA 7094 NE 1094 CP #k_mat_ve CT #k_mat_he

$ Shear key spring - 57 m
spri NA 7095 NE 1095 CP #k_sk_v CT #k_sk_h

$ Slab mat springs
spri NA 7096 NE 1096 CP #k_mat_ve CT #k_mat_he
spri mesh NA 7096 NE 7100 CP #k_mat_v CT #k_mat_h NARE 1096 NERE 1100
```

SOFiSTiK CADINP Input File
System

```
END
```

SOFiSTiK CADINP Input File Loads

6.3 Input code for SOFILOAD – Load cases and load positions

```
!#!chapter Loads

+PROG SOFILOAD urs:6.1 $ Text Interface for Loads
HEAD Text Interface for Loads
$ Actions
ACT G   $ dead load
ACT Q   $ variable load


$-------------Input data---------------------------------------------------------------

$ Temperature variation
LET#delta_T_deck 35  $ Thermal variation in the deck ['C]


$ Braking force

$ If the braking force acts from the movable support
$ towards the fixed support: -20 [kN/m]

$ If the braking force acts from the fixed support
$ towards the movable support: 20 [kN/m]

LET#F_braking -20 $ Horizontal braking force [kN/m]

$ Vertical load from the train
LET#F_vertical 80 $ Vertical train load [kN/m]




$--------------Loadcases and load positions---------------------------------------------

$ To use different load positions: Uncomment the desired position and
$ comment the undesired positions below.

$ Uncomment the desired position and load case below, comment all the
$ undesired positions and load cases below (temperature, braking or vertical load).

$ Remember to change the spring stiffnesses (unloaded or loaded) for the different load
$ positions for the braking load and vertical loac case in the System section.
$ For the temperature variation load should all springs be unloaded.

$ Remember to change the stiffness of the bridge deck in the Material section:
$ Rigid deck for braking and the real bridge deck stiffness for the vertical load



$$----Temperature variation load case----$$

$LC 1 Q TITL 'Temperature variation - deck'
$  BEAM FROM GRP 1 TYPE DT PA #delta_T_deck


$$----End of the temperature variation load----$$




$$----Different positions - braking and vertical load cases----$$

$$----Position 0 m from the movable support----$$
```

SOFiSTiK CADINP Input File
Loads

```
$ The length of the train is 300 m, each element is
$ 0.6 m:

$ Uncomment the desired load case below (braking or vertical load)

$LC 1 Q TITL 'Braking force 0 m from the movable support'
$  BEAM FROM 40001 TO 40449 TYPE PXX PA #F_braking

$$LC 1 Q TITL 'Vertical load 0 m from the movable support'
$  BEAM FROM 40001 TO 40449 TYPE PG PA #F_vertical

$$----End of position 0 m----------------------$$




$$----Position 15 m from the movable support----$$

$ The length of the train is 300 m, each element is
$ 0.6 m:

$ Uncomment the desired load case below (braking or vertical load)


$LC 1 Q TITL 'Braking force 15 m from the movable support'
$  BEAM FROM 30077 TO 30102 TYPE PXX PA #F_braking
$  BEAM FROM 40001 TO 40474 TYPE PXX PA #F_braking

$LC 1 Q TITL 'Vertical load 15 m from the movable support'
$  BEAM FROM 30077 TO 30102 TYPE PG PA #F_vertical
$  BEAM FROM 40001 TO 40474 TYPE PG PA #F_vertical

$$----End of position 15 m--------------------$$




$$----Position 30 m from the movable support----$$

$$ The length of the train is 300 m, each element is
$$ 0.6 m:

$ Uncomment the desired load case below (braking or vertical load)

$LC 1 Q TITL 'Braking force 30 m from the movable support'
$  BEAM FROM 30052 TO 30102 TYPE PXX PA #F_braking
$  BEAM FROM 40001 TO 40449 TYPE PXX PA #F_braking

$LC 1 Q TITL 'Vertical load 30 m from the movable support'
$  BEAM FROM 30052 TO 30102 TYPE PG PA #F_vertical
$  BEAM FROM 40001 TO 40449 TYPE PG PA #F_vertical

$$----End of position 30 m----------------------$$




$$----Position 45 m from the movable support----$$
```

SOFiSTiK CADINP Input File
Loads

```
$$ The length of the train is 300 m, each element is
$$ 0.6 m:

$ Uncomment the desired load case below (braking or vertical load)

$LC 1 Q TITL 'Braking force 45 m from the movable support'
$  BEAM FROM 30027 TO 30102 TYPE PXX PA #F_braking
$  BEAM FROM 40001 TO 40424 TYPE PXX PA #F_braking

$LC 1 Q TITL 'Vertical load 45 m from the movable support'
$  BEAM FROM 30027 TO 30102 TYPE PG PA #F_vertical
$  BEAM FROM 40001 TO 40424 TYPE PG PA #F_vertical

$$----End of position 45 m--------------------------$$




$$----Position 60 m from the movable support----$$

$ The length of the train is 300 m, each element is
$ 0.6 m:

$ Uncomment the desired load case below (braking or vertical load)

LC 1 Q TITL 'Braking force 60 m from the movable support'
  BEAM FROM 30002 TO 30102 TYPE PXX PA #F_braking
  BEAM FROM 40001 TO 40399 TYPE PXX PA #F_braking

$LC 1 Q TITL 'Vertical load 60 m from the movable support'
$  BEAM FROM 30002 TO 30102 TYPE PG PA #F_vertical
$  BEAM FROM 40001 TO 40399 TYPE PG PA #F_vertical

$$----End of position 60 m--------------------------$$


END
```

SOFiSTiK CADINP Input File
Calculation

6.4 Input code for ASE – Calculation

```
!#!chapter Calculation

+PROG ASE urs:20.1 $ Linear Analysis
HEAD Calculation of forces and moments
PAGE UNII 0
echo  OPT full yes
CTRL OPT SOLV VAL - $  Solution of the system
SYST prob NONL
LC 1

END
```

Appendix 6

Derivation of the floating slab mats horizontal stiffness

The parameters have the following units:

***Mat thickness, t_{mat}*:** [m]

***Poisson's ratio - shear strain, ν_{mat}*:** [-]

***Shear stress, τ*:** [N/m^2], [Pa]

***Shear modulus, G*:** [N/m^2]

***Modulus of elasticity (Young's modulus), E*:** [N/m^2]

***Vertical mat stiffness, $k_{bm,mat,v}$*:** [N/m^3]

***Horizontal mat stiffness, $k_{bm,mat,h}$*:** [N/m^3]

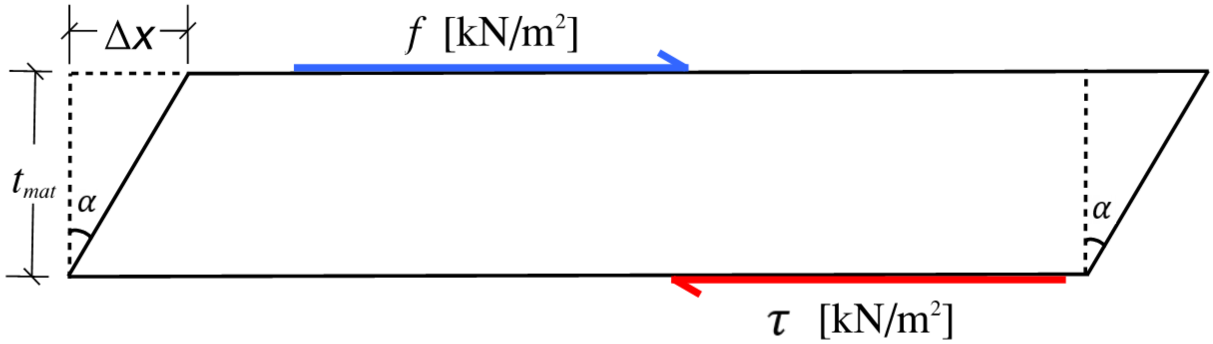

Figure 1 Shear stress acting on the floating slab mat.

Equilibrium: $f - \tau = 0 \implies \tau = f$ (1)

Shear strain: $\nu_{mat} = \tan\alpha = \frac{\Delta x}{t_{mat}} \implies small\ angle \implies \nu_{mat} = \alpha = \frac{\Delta x}{t_{mat}}$ (2)

Equation (2) gives: $\Delta x = \nu_{mat} \times t_{mat}$ (3)

Hooke's law for shear stress and shear strain: $\tau = G \times \nu_{mat} \implies \nu_{mat} = \frac{\tau}{G}$ (4)

Equation (3) and (4) gives: $\Delta x = \nu_{mat} \times t_{mat} = \frac{\tau}{G} \times t_{mat} \Rightarrow \tau = \frac{G}{t_{mat}} \times \Delta x$ (5)

The horizontal mat stiffness in equation (5) is: $k_{bm,mat,h} = \frac{G}{t_{mat}}$ (6)

The relation between the shear modulus G and the Young's modulus E for an isotropic material is:

$G = \frac{E}{2(1+\nu_{mat})}$ (7)

Modulus of elasticity (Young's modulus): $E = k_{bm,mat,v} \times t_{mat}$ (8)

Equation (6), (7) and (8) gives the relation between the vertical and horizontal stiffness of the mat:

$$k_{bm,mat,h} = \frac{k_{bm,mat,v}}{2(1+\nu_{mat})} \qquad (9)$$

Appendix 7 – About the author

Daniel Kostet was born in Kiruna, Sweden, on August 26th, 1988. He attended primary and secondary school in Kiruna and attended a building technology programme with specialization in carpentry.

He worked with construction for two years and then attended a one-year Preparatory Programme at Chalmers University of Technology in Gothenburg.

From 2010 he worked two and a half years with construction and mining and then started in a Master Programme in Civil Engineering with specialization in Structural Engineering at Luleå University of Technology in Luleå.