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Influence of steel brackets supporting crane runway girders structure on the stress distribution in the brackets

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ABSTRACT: The paper presents a numerical analysis of steel brackets supporting a double-span crane runway girders. The purpose of the study was to assess the new structural solution based on the stress distribution in the brackets. In order to simplify the connection, the bottom flange of the crane runway girder is based directly on the upper flange of the bracket. As a result, the support reaction is no longer applied in the plane of the bracket web, but it is carried as ununiform pressure. Known analytical methods are not sufficient to assess the level of the bracket material effort due to the mechanism of the forces transmission. That is why the FE analysis was performed. Twisting of the bracket caused by eccentric load (in addition to the biaxial bending) was observed. What is more it occurred that transverse stiffeners in the bracket structure generate high stress.

1 INTRODUCTION

Designers and producers of up-to-date single storey industrial buildings are continually taking steps to make the structure more and more sufficient. One of the ways to achieve so is to simplify the structural solutions which leads to reduction of costs (materials, labor). The paper presents an example of such simplification: analysis of a new structure of the support of a crane runway girder on brackets fixed to columns.

The solutions of this kind of connection, used in practice, provide controlled transmission of the support reaction from the crane runway girder to the bracket (see Fig. 1a). Control of the force transmission is achieved due to the shape of the supporting element which directs crane runway girder reaction forces to the plane of the bracket web.

The new proposition of the connection is presented in Figure 1b. The example where both girder and brackets are made of I-beam is considered. The bottom flange of the crane runway girder is based directly on the upper flange of the bracket. As a result the structure is much simpler (no additional supporting elements). However this also means that the support reaction is no longer applied in the plane of the bracket web, but it is carried through the pressure of the bottom surface of the beam on the upper surface of the bracket. What is more, the pressure is not uniform on the whole surface due to the natural deformation of the simply supported beam (see Fig. 2). The bottom flange of the crane runway girder is connected to the upper flange of the bracket with two preloaded bolts, which provides transmission of the horizontal, longitudinal forces from the beam to the column.

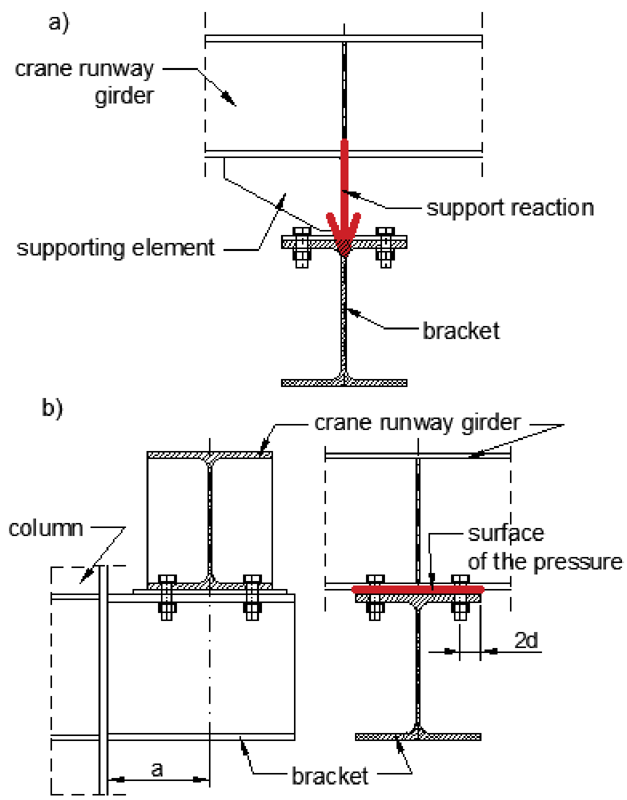

Figure 1. Construction of the crane runway girder connection with the column bracket: a) the example of the used one, b) the new one, analysed.

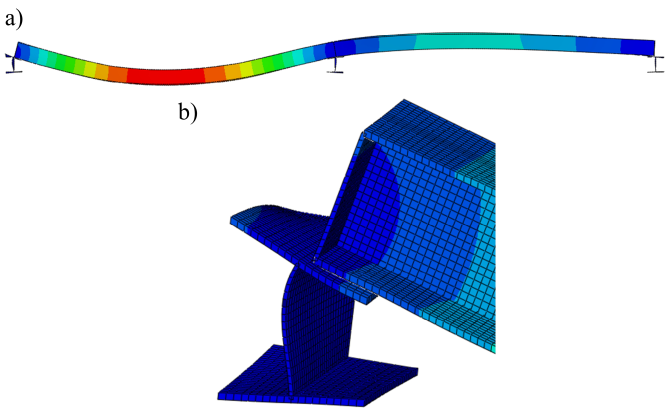

Figure 2. Deformation of the simply supported, double-span beam: a) view of the whole beam under single span loading; b) detail of the supporting area.

As far as the support reaction is applied in the plane of the bracket web, procedures of analytical calculations of the bracket and the welded connection of the bracket to the column are known (EN 1993-6, MacCrimmon 2009, Nussbaumer et al. 2018, Tooma 1980). However the established new construction of the connection does not allow for clear designing of the column bracket, especially the support cross-section, where the bracket is welded to the column. Known analytical methods are not sufficient to assess the level of the material effort, due to the mechanism of the forces transmission (horizontal and vertical forces transmission from the beam to the column).

The purpose of this study was to assess the correctness of the new structural solution of steel brackets supporting the crane runway girders based on the stress distribution in the brackets. Calculations were done using numerical models created in ABAQUS program (ABAQUS 2008).

2 MATERIALS & METHODS

2.1 *Data and calculation assumptions*

The extracted model consisted of four main parts: double-span crane runway girder made of I-beam (type HEA) supported on three brackets made of I-beam (type HEA or HEB) fixed to the columns. A static scheme and load cases of the crane runway girder chosen for the consideration are presented in Figure 3 and described in details in point 2.3.

There were three stiffeners in the beam: two stiffeners in the form of end plates at the external supports and one double-sided stiffener at the internal support of the beam. The connection of the crane runway girders with transverse stiffeners brackets is presented in Figures 4a, b respectively at the external and internal support. The maximum distance between the two ends of the crane runway girders supported on the bracket was assumed as equal to 40 mm, so the distance between the beam end and the bracket axis as 20 mm (see dimensions in Fig. 3).

The numerical models of the crane runway girder connection were analyzed for five values of vertical load Q per wheel: 33.0; 53.1; 86.5; 114.0 and 165.0 kN. It was assumed that these values comprise static and dynamic components of the vertical crane actions. The dimensions of the structural elements applied in the various connection models are listed in Table 1. Wheels track "e" (see Fig. 3) and the distance between the rail axis and the column side "a" (see Fig. 1b) was determined depending on vertical load Q per wheel. Moreover, the distance between the bolt axis and the edge of the beam or the bracket flange (see Fig. 1b) was assumed as the constant value equal to 2d (d – bolt diameter).

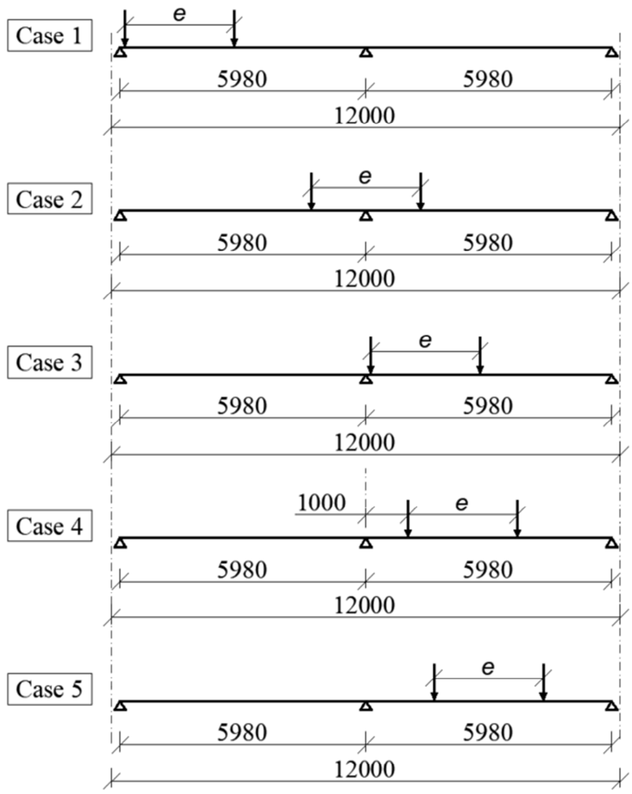

Figure 3. Static scheme and load cases of the crane runway girder.

Two types of brackets, with double-sided transverse stiffeners and without them, were computed for vertical load per wheel Q = 33.0; 53.1; 86.5 and 114.0 kN. Based on the computation results and conclusions of applying transverse stiffeners in column brackets (see point 4.2), calculations for brackets with these stiffeners for vertical load Q = 165.0 kN were not carried out.

Moreover, due to the high stress level at the bracket support cross-sections for every type of the crane, additional numerical models were elaborated. Instead of brackets made from HEA profiles, HEB sections were introduced in accordance with the specification in Table 1.

Table 1. Data specification for numerical models.

Maximum vertical load Q per wheel	kN	33.0	53.1	86.5	114.0	165.0
Wheels track “e” (Fig. 3)	mm	2.20	3.15	2.50	2.70	4.00
Wheel to rail pressure area	cm^2	55	55	55	78	78
Distance between rail axis and column side “a” (Fig. 1b)	mm	230	230	230	245	245
Connecting bolt	-	M20	M24	M24	M24	M24
Transverse stiffener thickness	mm	6	6	6	8	12
Crane runway girder	-	HEA 240	HEA 240	HEA 300	HEA 300	HEA 400
Original bracket	-	HEA 240	HEA 280	HEA 300	HEA 360	HEA 400
New bracket	-	HEB 300	HEB 320	HEB 360	HEB 360	HEB 400

2.2 *Key assumptions and scope of the FEA model*

A strength analysis was performed with an FE analysis in ABAQUS software. A static GNA (geometrically nonlinear analysis) was conducted. Shell finite elements S4R were applied to the numerical model.

The connection of the crane runway girders with transverse stiffeners brackets is presented in Figure 4a, b respectively at the external and internal support with visualization of sheets thickness.

Between the adjacent plane surfaces of the lower flange of the crane runway girder and the upper flange of the bracket, the contact mechanism (type: hard contact in normal direction) was implemented. The contact situation in normal direction maps the phenomenon of the pressure (or lack thereof) between the adjacent surfaces. The separation after contact was allowed.

The screw connection was mapped with "tie" elements that tie the bottom flange of the crane runway girder to the upper flange of the bracket at the one node (six degrees of freedom fixed). Such an approach resulted in local disturbances of the outcomes but had no effect on the results away from "tie" connection of the bracket to the column.

A linear-elastic material model with the following properties corresponding to the ordinary structural steel was adopted: Young's modulus $E = 2.1\times10^5$ MPa, Poisson's ratio $\nu = 0.3$, density $\rho = 7.8\times10^{-9}$ t/mm^3.

2.3 *Loads and boundary conditions*

Crane actions are induced on the crane runway beam by the wheels of the crane. They are usually divided into vertical actions caused by the self-weight of the crane and the hoist load, and horizontal actions caused by acceleration and deceleration, by skewing, and other dynamic effects. The horizontal actions (longitudinal and transverse) were not taken into consideration as it was assumed that they are carried out by other structure members, not being analyzed.

Vertical actions impact the crane runway girder as a pair of point forces in the "e" spacing (see Fig. 3). Point load induced by the crane wheel was applied to the crane runway girder as a uniformly distributed load on the pressure area of the wheel to rail (Fig. 4d). Values of the maximum vertical load Q per wheel considered in the analysis, “e” spacing of the forces and wheel to rail pressure area dimensions are given in Table 1.

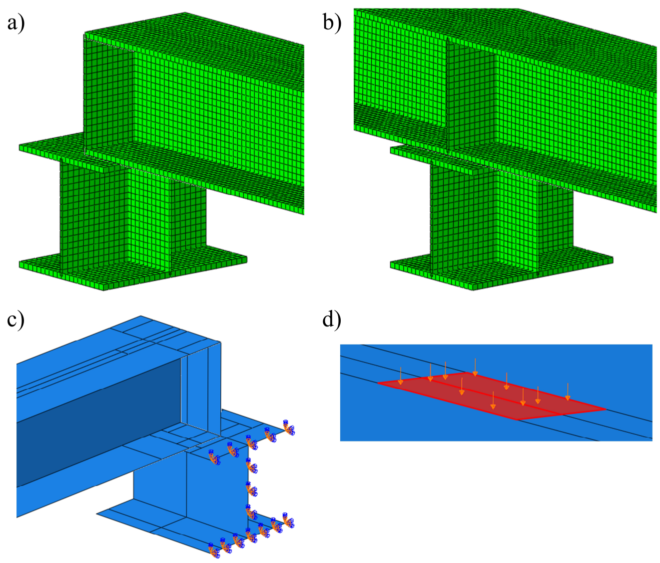

Figure 4. Numerical model details (Q = 86.5 kN): a) FEM mesh of the external bracket (the case with stiffeners), b) FEM mesh of the internal bracket (the case with stiffeners), c) bracket support (the case without stiffeners), d) wheel load applied on the upper flange of the crane runway girder.

The following load cases of crane runway girder, presented in Figure 3, were analyzed to find the unfavorable one (causing the maximum effort of the bracket support cross-section):

- Case 1 – eccentric load at the external support (force at the edge of the bracket flange),
- Case 2 – symmetrical load at the internal support,
- Case 3 – eccentric load at the internal support (force at the edge of the bracket flange),
- Case 4 – eccentric load at about 1.0 m from the internal support (depending on the type of crane),
- Case 5 – symmetrical load in the span.

In the case of a crane with a vertical load per wheel Q = 33.0 kN, the load Case 5 was equal to the load Case 4. The dead load of the adjacent beams was omitted.

To map the attachment of the brackets to columns, nodes of the bracket support cross-sections were set as rigid by fixing their translations and rotations (see Fig. 4c).

2.4 *Scheme of the analysis*

Summing up, the following numerical models of the double-span beam freely supported on brackets fixed to the columns were elaborated:

– five models (Q = 33.0; 53.1; 86.5; 114.0; 165.0 kN) without transverse stiffeners and supported on brackets made of HEA section,
– four models (Q = 33.0; 53.1; 86.5; 114.0 kN) with transverse stiffeners and supported on brackets made of HEA section,
– five models (Q = 33.0; 53.1; 86.5; 114.0; 165.0 kN) without transverse stiffeners but supported on the increased bracket profile (HEB section).

For every model, load cases 1÷5 were taken into consideration.

3 RESULTS OF THE PARTICULAR STEPS OF THE ANALYSIS

Maximum levels of equivalent stresses according to the HMH (Huber-Mises-Hencky) strength hypothesis in the brackets were computed and the stress distribution was observed. Due to the dynamic nature of the brackets' load, the level of allowable stresses from static loads were estimated at 220 MPa.

3.1 *HEA brackets without stiffeners*

First, calculations of the new structure without stiffeners for HEA section were performed. The size of brackets calculated as for typical constructional solution (when the reaction force is applied in the plane of the bracket web) were applied. The maximum stress values in particular support cross-sections of external or internal brackets are presented in Table 2. What is more, the selected results of the analysis are shown in graphic form – as stress absolute values maps determined on the basis of the envelope from all the layers of the shell element (Figs 5, 6). It can be noticed that the maximum stress level in brackets is higher than allowable stresses (estimated at 220 MPa).

Table 2. Maximum equivalent stresses for HEA brackets without transverse stiffeners [MPa]

Vertical load Q [kN]	Bracket	Load cases (Fig. 3)				
		1	2	3	4	5
33.0	external	252 [198]	--	--	--	293 [231]
	internal	--	75	215 [172]	--	299 [236]
53.1	external	313 [249]	--	--	--	359 [282]
	internal	--	92	294 [232]	--	357 [281]
86.5	external	225	--	--	--	--
	internal	--	136	215 [175]	280 [227]	292 [236]
114.0	external	226 [199]	--	--	--	--
	internal	230 [190]	134	249 [208]	--	328 [273]
165.0	external	299 [246]	--	--	--	317 [258]
	internal	--	138	--	--	300 [243]

Note: [ ] means value in the second finite element from the support (explanation in the text)

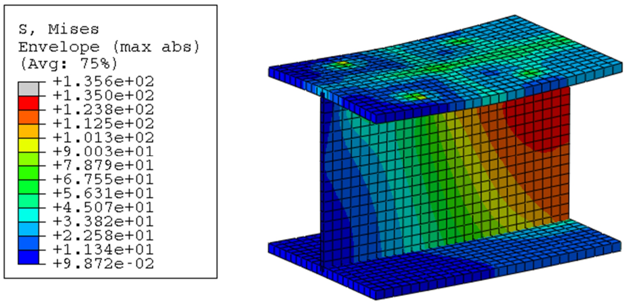

Figure 5. Stresses in bracket HEA300 without transverse stiffeners (Q = 86.5 kN, Case 2, scale of deformation 50).

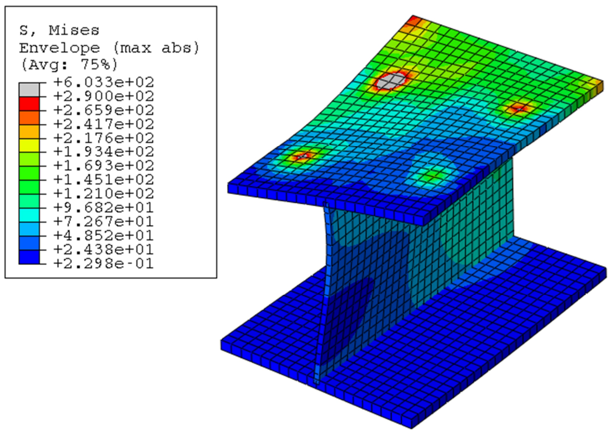

Figure 6. Stresses in bracket HEA300 without transverse stiffeners (Q = 86.5 kN, Case 5, scale of deformation 50).

3.2 *HEA brackets with stiffeners*

In the next analysis the same bracket profiles, but strengthened with transverse stiffeners were concerned. It occurred that the use of transverse stiffeners generates a high level of stresses in the stiffeners and at the bottom of the crane runway girder (Fig. 7).

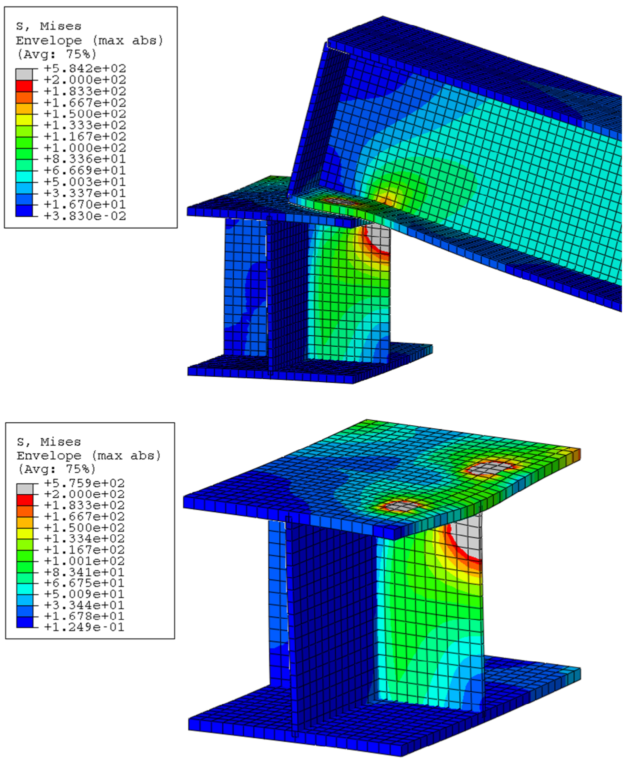

Figure 7. Stresses in the support bracket structure strengthened with transverse stiffeners (Q = 86.5 kN, Case 5).

3.3 *HEB brackets without stiffeners*

In the last step, the bracket profile was changed from HEA to HEB, thus increasing all the dimensions of I-section (according to Table 1). The results of the computational analyses are summarized in Table 3. In a few cases, the effort of the brackets at the support section is still too high (exceeds 220 MPa) despite the use of bigger profile.

The word of explanation is needed about the values of stresses in the second finite element from the support which are given in Tables 2 and 3 in square brackets. This is due to the fact that in FE solution local stress concentrations occur directly at the point of support of the element. This was visible in the corners of the upper flange of I-beams (areas of the higher stresses in the corners is visible in Figure 6. When FEM mesh was compacted (smaller elements), the maximum stress values increased because of the support applied to the construction nodes. However, the values given at a distance of about 2.25 cm from the support were similar for all the analysed FEM grids.

Table 3. Maximum equivalent stresses for HEB brackets without transverse stiffeners [MPa]

Vertical load Q [kN]	Bracket	Load cases (Fig. 3) 1	2	3	4	5
33.0	external	185 [149]	--	--	--	223 [178]
	Internal	--	42	162 [131]	--	217 [173]
53.1	external	251 [211]	--	--	--	291 [246]
	internal	--	63	234 [196]	--	280 [235]
86.5	external	150	--	--	--	187 [163]
	internal	--	80	157 [132]	206 [172]	216 [179]
114.0	external	196 [173]	--	--	220 [193]	245 [213]
	internal	--	100	213 [181]	273 [232]	281 [238]
165.0	external	254 [209]	--	--	--	276 [228]
	internal	--	109	--	--	269 [222]

Note: [ ] means value in the second finite element from the support (explanation in the text)

4 DISCUSSION

FE calculations and analyses were carried out to evaluate the new structure of steel bracket supporting the crane runway girder (see Fig. 1).

4.1 *HEA and HEB brackets without stiffeners*

The analysis of the stress values from Table 2 and 3 univocally indicates Case 5 of the load (symmetrical load in a single span of the crane runway girder – see Fig. 3) as a crucial load case for the bearing capacity of the support.

In all the analyzed types of cranes for Case 5 load, the values of maximum stresses obtained for HEA sections are too high (allowable stresses estimated at 220 MPa). It means that the profile which was sufficient in previous solution of the connection, in the new one is not enough.

Replacing HEA bracket profile with HEB reduced the stress level in the brackets (compare Table 2 and 3). However, in a few cases this effect is still not sufficient. It means that a new solution is definitely simpler (no additional element which direct reaction forces from the beam to the bracket), however bigger bracket profile is required.

What is more, the excessive stress increase in the support cross-section of the bracket construction was observed (see Fig. 6). The source of this increase is twisting produced by an eccentric load (in addition to the biaxial bending). The results of Case 2 calculations confirm this conclusion: it is a symmetrical load that does not cause twisting, only bending of the bracket (compare the stress distribution in brackets shown in Figs 5, 6).

Excessive torsion of the bracket results from the mechanism of the forces transmission from the beam to the column in the new simplify construction of the connection.

4.2 *HEA brackets with stiffeners*

The map of stresses for a bracket with transverse stiffeners (the example presented in Fig. 5) allows to observe arising deformations and concentration of stresses both in the stiffener and at the lower part of the crane runway girder (stresses in the crane runway girder were not analyzed). Transverse stiffeners are usually used to stiffen the web and increase torsional stiffness of I-sections. They fulfill their role when the load is applied in the plane of the web (see Fig. 1a). However, in the case of a load applied to the surface of the bracket flange (Fig. 1b), the stiffeners disturb uniform loads transmission and become even harmful elements. It can be said that internal force flow cannot be transferred fluently from one element to another. This phenomenon was confirmed by analyses carried out for brackets with and without the transverse stiffeners, for vertical loads Q = 33.0; 53.1; 86.5 and 114.0. Further analysis of the structural solution with transverse stiffeners was not carried out.

4.3 *Conclusions*

Results confirmed that known analytical methods, used in the case of controlled forces transmission from the beam directly to the plane of the bracket web, should not be used to assess the level of the material effort in the case of direct support of the bottom flange of the crane runway girder on the upper flange of the bracket. Excessive torsion of the bracket occurs, because the support reaction is no longer applied in the plane of the bracket web, but it is carried through the not uniform pressure of the bottom beam surface on the upper bracket surface. For that reason using a hollow section as the bracket structure could be taken into account, as it is very torsion resistant (this variant was not yet analyzed).

It was also observed that in the case of direct support of the bottom flange of the crane runway girder on the upper flange of the bracket, the use of transverse stiffeners (in the bracket structure) is not proper.

Outcomes highlighted the possible threats and warned about the effects of going away the simple static schemes. Simultaneously results helps to understand how the new structural solution works, what can be used in the future to establish simple analytical calculation methods (for instance based on the results of 1D-model).

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