

Saimaa University of Applied Sciences

The Faculty of Technology, Lappeenranta

Double Degree Programme in Construction and Civil Engineering

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Design of steel-concrete composite beam of the floor structure

Bachelor's Thesis 2015

CONTENTS

1. INTRODUCTION.....	4
2. BUILDING CODE REQUIREMENTS FOR FLOOR SYSTEM OF RESIDENTIAL BUILDING.....	6
2.1. Fire safety of buildings.....	6
2.2. Corrosion protection	10
3. DESIGN OF STEEL AND CONCRETE COMPOSITE BEAM.....	11
3.1. Load estimation.....	14
3.2. I stage Steel Beam calculation.....	16
3.2.1. Beam Section	17
3.2.2. Strength verification.....	18
3.2.3. Serviceability limit state	19
3.2.4. Overall stability	20
3.2.5. Flange local stability	21
3.2.6. Fillet weld strength verification.....	22
3.3. II stage Composite beam calculation	24
3.3.1. Static Calculation.....	24
3.3.2. Composite beam section.....	24
3.3.3. Strength verification.....	26
3.3.4. Serviceability limit state	27
3.3.5. Anchor shift verification	28
3.3.6. Local concrete crumbling verification	30
4. COMPARISON OF THE CREATED ALGORITHM WITH EXPERIENCE AND COMPUTER-AIDED CALCULATION.....	31
4.1. Computer-aided calculation of the steel beam	31
4.2. Computer-aided calculation of the composite beam	33
4.3. Ruukki test	40
5. CONCLUSION.....	42
Figures	43
Tables	44
Charts	44
REFERENCES	45
APPENDICES	46
APPENDIX 1 Automatized design of the composite beam “Calculation program”	46

Abstract

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The purpose of the thesis was to design a steel-concrete composite beam of the floor structure for a multi-storey residential building according to the Building Codes. The work was commissioned by the company Ruukki Rus, specialized in steel construction.

The thesis should be of interest to Ruukki, any customer, design engineers and other construction companies dealing with civil engineering especially residential building. Data for this study were collected by Russian and European building codes, books of construction disciplines and Ruukki specifications and reports.

The first part of the thesis contains general guidance, requirements and restrictions for the floor system in a residential building that takes place in Building Codes.

The second part includes calculation points. It contains load estimation, I stage steel beam design and II stage composite beam design.

The last part is a comparison of the results obtained by the created program with experience and computer-aided calculation accomplished by means of SolidWorks.

As a result of this project, the guidance for a designer with calculation algorithm of steel and concrete composite beam was made as soon as the program of the composite beam calculation was made in Microsoft Excel Software.

Keywords: Steel-concrete composite beam, design of composite structures, calculations, program.

1. INTRODUCTION

Recently the application of steel frame and light-weight envelope structures is developed in residential construction in Russia. Frame structural system provides a free building space division that can be changed during building operation. Both light-weight building envelope and internal vertical partition structures are already widespread in the construction. Thus, in order to achieve a minimum of dead load of the building designers have worked up composite light-weight flooring systems. Composite floors using profiled sheet decking have become very popular for non-residential multi-storey buildings. Its success is due to the strength and stiffness that can be achieved, with a minimum use of materials.

Steel-concrete composite structure has already been used in the XIX century. In the end of the century scientists noticed that steel beam with concrete cover made for increasing a fire proof has more strength and stiffness than it was required. And in 1923 it was approved by the experiments in England. The typical steel beam with concrete cover can be seen in figure 1.1. Based on the discovery they decided to divide functions between concrete that is a brittle material and steel that is an elastic material. Concrete is good to resist compression while steel has good tensile strength. Thus, this was a reason to apply a composite structure, one part of which resists on tensile forces, another one is in compression.

The purpose of the project is to design a steel-concrete composite beam with light-weight concrete as a part of a composite floor structure that is more efficient than a common reinforced concrete floor structure with heavy-weight concrete. Application of light-weight concrete reduces permanent load acting on the floor and the frame of the building. As a result of the work, an algorithm of the composite beam calculation was created in compliance with the requirements and limitations from Building Codes and also the calculation program was made in Microsoft Excel Software. It is simple in use with a small instruction. The program provides a design of the composite beam.

As it was told earlier, the composite flooring system has been designed at first for non-residential building. A widespread composite flooring system is a concrete slab resting upon downstand steel I-beams (see figure 1.2). Collaboration of steel and concrete parts of the structure is provided by anchors welded on the upper flange of the I-beam. In order to apply a composite flooring structure in residential building it is important to minimize the thickness of the floor for effective space usage. Therefore the designed floor structure was developed to provide a minimum depth. A downstand beam is replaced by partially encased into a concrete slab steel beam.

Along the letter notation axis the flooring system is presented by a continuous monolithic ribbed slab. It is poured by means of retained formwork as steel profiled sheet. As a reinforcement of the slab bar mat reinforcement and reinforcing mesh are used.

In another direction it is a steel-concrete composite beam with I-section. The steel beams are partially encased in the slab that eliminates the fire protection costs and

improve the flexibility of layout. The usage of light-weight concrete and T-section of steel beam leads to reducing the overall dead weight.

The flooring system that is designed will be applied in the residential 11-storey building. The total height of the building is about 33 m. The frame system is one of the modern mixed systems called Column-slab with rigid core. The durability of the designed building is 50 years as large-scale housing construction according to GOST 54257-2010.

Building Code requirements to the floor structure are mainly referred to fire-resistance and corrosion protection as soon as strength, stiffness and stability.

The flooring system reduces loads on the building frame, the overall costs of the load-bearing structure in comparison with a typical reinforced concrete floor, has less thickness of the floor, weight of steel and concrete mass than a composite floor with I-section steel beams. If we take the following unit price of structural materials: 1 t of steel – 30 000 rubles; 1 m³ of steel – 230 000 rubles, 1 m³ of concrete - 2500 rubles; we will save as a minimum 1000 rubles per 1 m of steel beam by using the designed flooring system.

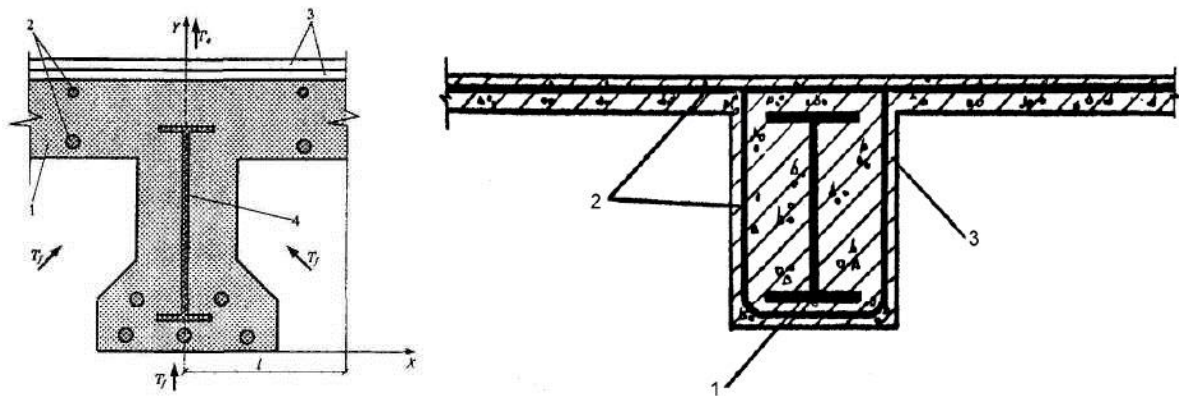


Figure 1.1 Steel beam with the concrete cover

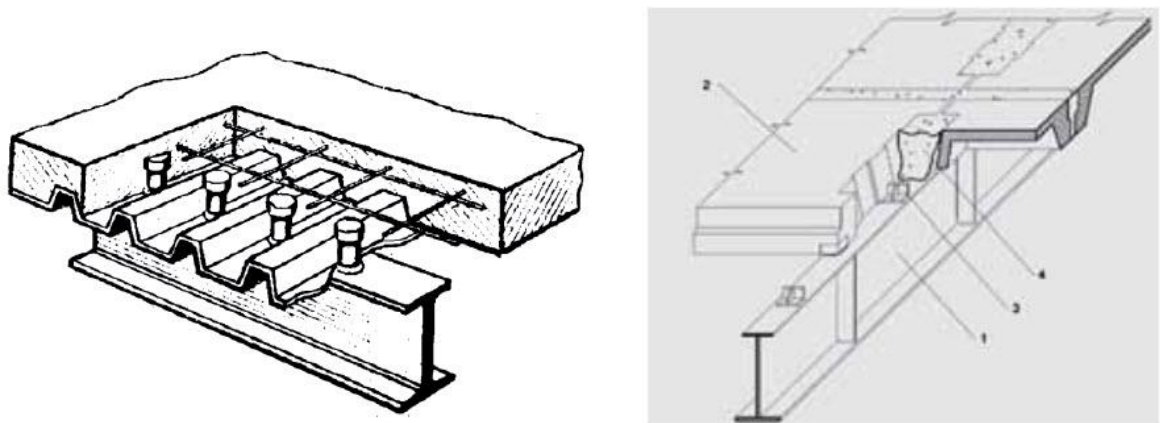


Figure 1.2 Widespread composite flooring: concrete slab resting upon downstand steel beams.

2. BUILDING CODE REQUIREMENTS FOR FLOOR SYSTEM OF RESIDENTIAL BUILDING

2.1. Fire safety of buildings

The fire class of a building should be known in order to define the required fire class for its load-bearing structures. In this case we are taking the residential 11-storey building.

The fire class of the building is P1 defined by National Building Code of Finland E1, fire load is less than 600 MJ/m². In according to National Building Code of Finland E1 a required fire class for load-bearing structures is R120 that means the load-bearing structure carries 120 minutes under the fire.

The fire class of the designed building is II defined by the building height in SP 54.13330.2011. According to SNiP 21.01-97 "Fire Safety of buildings and works" a required fire class for load-bearing structures is R90. Load-bearing structure is a structure that takes part of providing the overall stability and geometric invariability of a building. For building envelope integrity and insulation should be guaranteed at the same time. Flooring system is both load-bearing structure and building envelope. So it should be REI 90.

Steel structure has low limit of fire-resistance that is increased by enclosure steel surface from the fire by a layer like suspended ceiling, fireproof coating. According to Manual 2013 Steel T-section beam fire-resistance limit is R 9 as the given metal thickness is $t_{red} = 4,9$ mm. As told in SP 54.13330.2011 "Multicompartiment residential building", essential level of load-bearing structure fire-resistance must be provided only by structural fire protection like flame retardants of ROCKWOOL, Technonicol.

The given thickness is defined by the following formula:

$$t_{red} = \frac{A_{st}}{u} \quad (2.1)$$

$u = 2 * D + 2 * B$ – perimeter of the section, see figure 2.1.

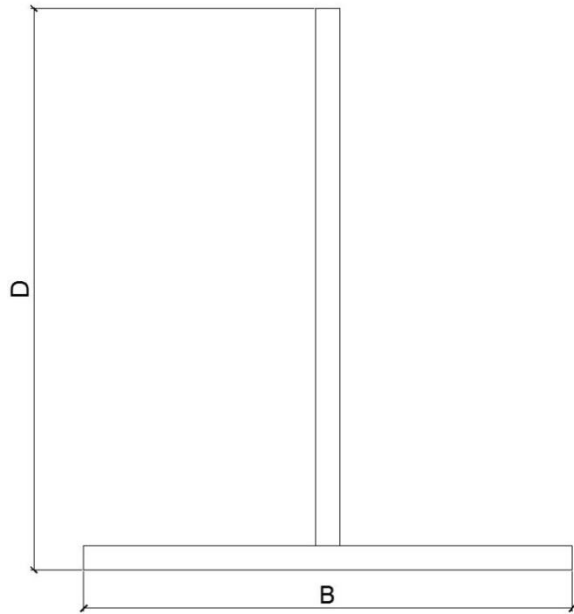


Figure 2.1 Beam parameters for given thickness t_{red} calculation

Mainly there are three ways for fire protection of building structures in the contemporary construction: fireproof plaster on reinforcing mesh, fireproof thermally intumescent paint and facing with fireproof plate materials. A fireproof plate may be gypsum board, vermiculite slab and magnesite board. Fire-protective plaster SOSCH1 increases the fire-resistance of a structure up to REI 150.

It is obvious that the most appropriate way of fire protection of the composite beams is facing with fireproof plate materials. Suspended ceiling is foamed by fireproof plates. In addition, application of thermally intumescent paint for steel beam may be realized as an extra fire protection.

Design of appropriate device (structure) of the fire protection depends on properties of used materials that are mainly thermal conductivity and thermal capacity. Firstly limit of heat flow rating is provided by the material with low thermal conductivity. The next layer is made of high thermal capacity material that is slowly heated during the conflagration.

Essential thicknesses of each layer are defined depending on the device of the fire protection and properties of the layers. It may be accomplished by the program SolidWorks. Heat flow rating is a design load in the fire resistance calculation. The value of the fire load equals $P = 1000 \text{ W/m}^2$. The value of heat flow of normal conditions is about $P = 8 \text{ W/m}^2$.

There are material parameters in Table 2.1 that are used in the fire resistance analysis realized by the Solidworks.

Table 2.1 Material parameters

№	Material	Thermal conductivity $\lambda, \frac{W}{m \cdot C}$	Thermal capacity $c, \frac{J}{kg \cdot K}$	Class of inflammability
1	Magnesite plate	0,216	750	KM0
2	Conlit 150 (Rockwool)	0,05	1090	KM1
3	Air*	0,16	1000	-
4	Concrete D1200	0,31	840	KM0

*- thermal conductivity of air is taken greater as correction due to convection. The actual air value of thermal conductivity is $= 0,025 \frac{W}{m \cdot C}$. Classification of inflammability according to Chapter 3 Asset 13 Federal Law published 22.07.2008 № 123-FL

One of the versions of the flooring system is shown in figure 2.2.

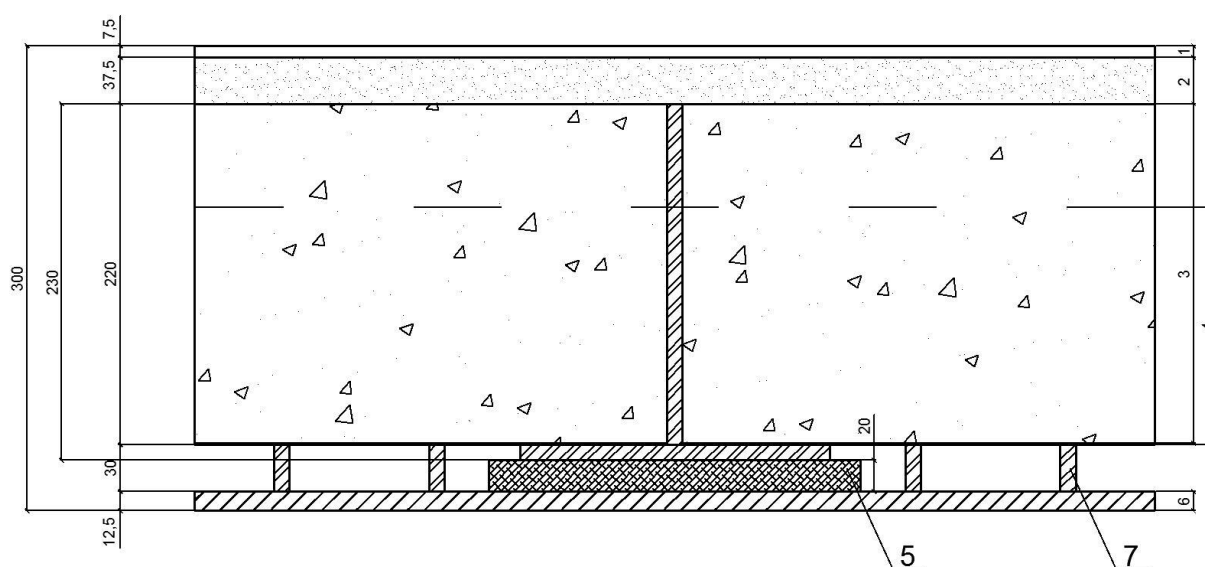


Figure 2.2 Section of the composite flooring system

The specification of the structure is listed in table 2.2.

Table 2.2 Specification of the flooring structure

№	Name	Vertical size	Function of the layer
1	Floor covering	7,5 mm	Cover
2	Cap	30 mm	Slab protection, leveling
3	Concrete slab	220 mm	Load-bearing and envelope
4	Steel profiled sheet	153 mm	Load-bearing and formwork
5	Conlit 150 (Rockwool)	20 mm	Beam fire protection
6	Magnesite plates	12,5 mm	Floor fire resistance
7	Steel fasteners (cold-formed members)	-	Fastening, air layer – floor fire resistant component.

The structure shown in figure 2.2 is a preliminary version to provide the fire resistance of the flooring system that is confirmed by the model thermal analysis realized by the program Solidworks. The model is an approximate slab structure that consists of magnesite plate 12,5 mm, air layer, concrete D1200 and steel bar. The model for thermal analysis is shown in figure 2.3.

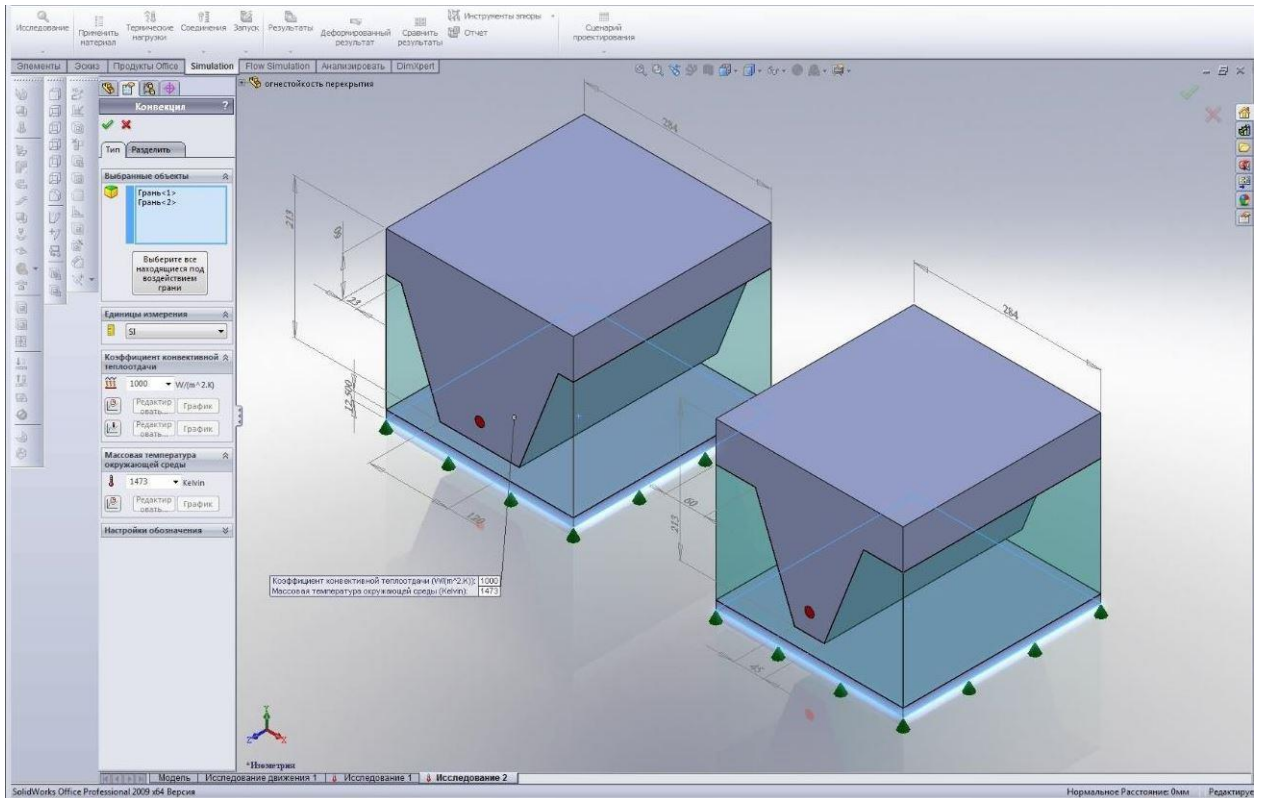


Figure 2.3 Model for thermal analysis

The result of the analysis is presented in figure 2.4.

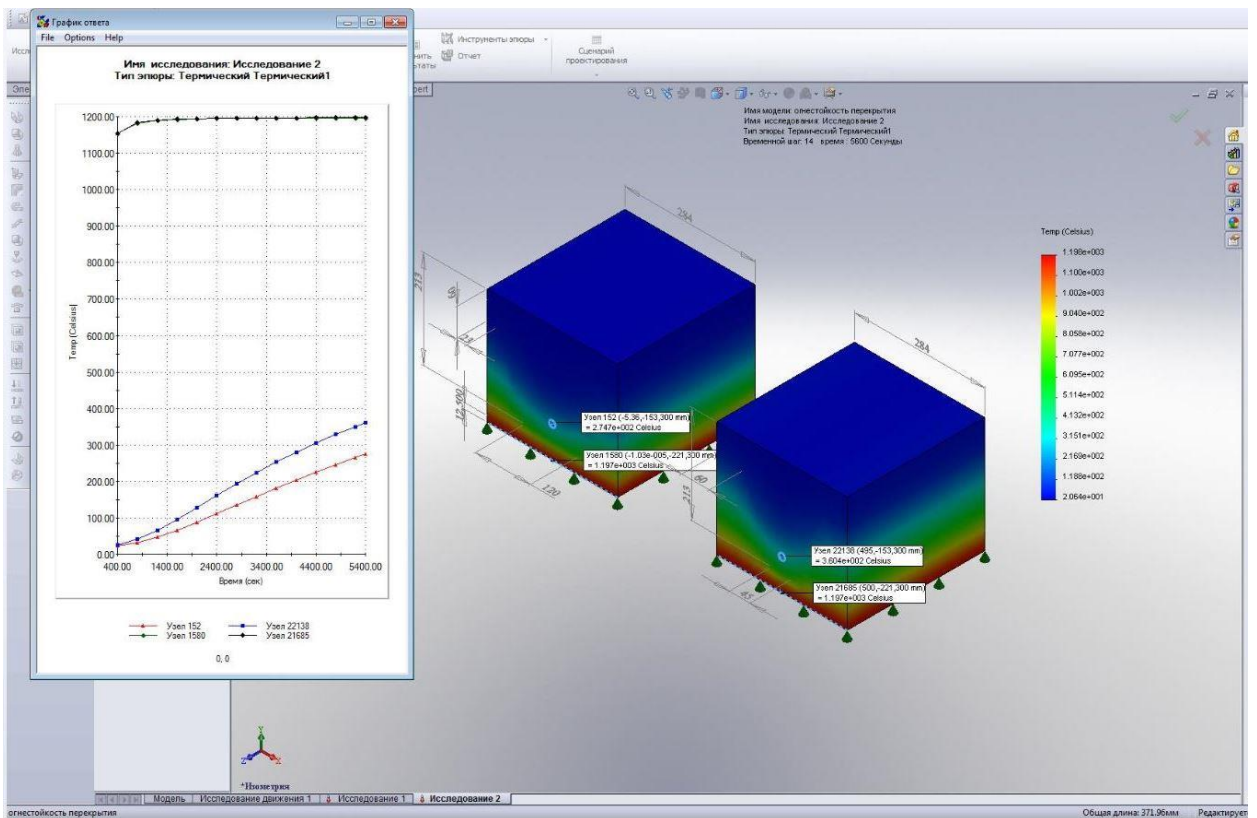


Figure 2.4 Thermal analysis result made in SolidWorks

In order to accept the final decision of the envelope structure additional tests are necessary to approve the design proposal. It contains a fire-resistance limit of the structure that is determined in compliance with GOST 30247 and a fire hazard class of a structure that is set in compliance with GOST 30403.

2.2. Corrosion protection

The flooring system serves in two zones: non-aggressive and slightly aggressive. The tee section steel structures can be designed in non-aggressive and slightly aggressive zones. Steel beams are protected on the factory by paint coating. The protective layer consists of ground coat and varnish. A manufacturing process is automatized in the Ruukki factory.

There are no special requirements on reinforcement protection in the zones in Building codes.

3. DESIGN OF STEEL AND CONCRETE COMPOSITE BEAM

The composite beam shown in figure 3.1 is a steel beam and a reinforced concrete slab that take up the load together. The joint between steel and concrete parts is provided by steel anchors. The brace is steel bars that are placed along the beam by essential step. The bracing is necessary in order to ensure integrity of the structure. The steel beam has tee cross section. A design section of the composite beam is a steel part and effective slab section. A floor surface consists of a cap with a required thickness and floor covering represented by laminated plastic. A ceiling structure is a gypsum cardboard layer attached to steel cold-foamed bars that are parallel to the composite beam. A layer that is set under the steel beam flange provides required fire-resistance of the structure.

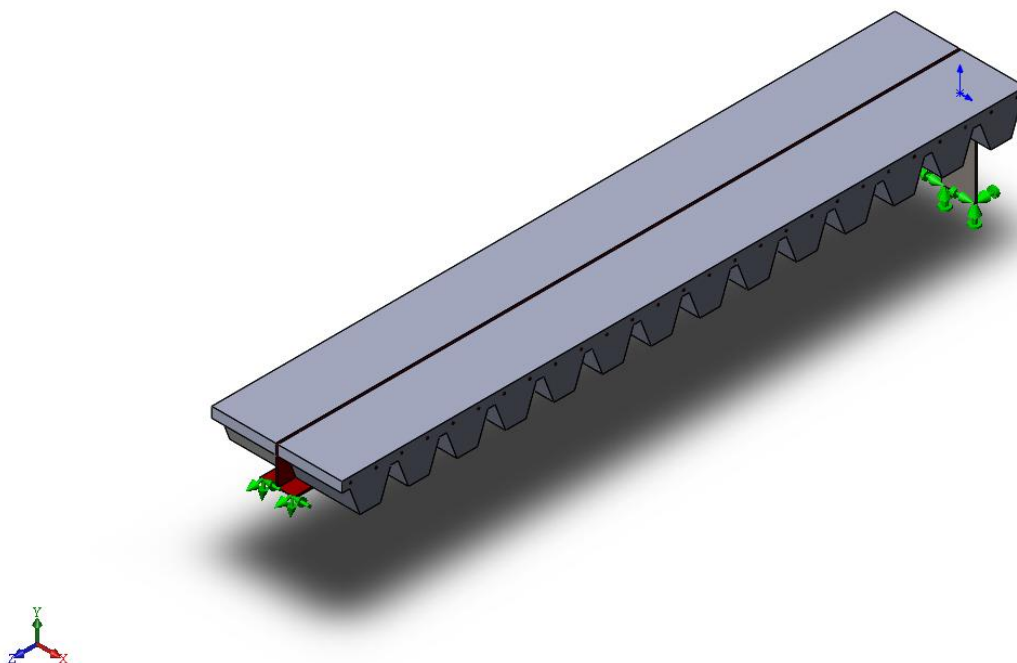


Figure 3.1 Steel and concrete composite beam

The calculation is complicated by two stages: construction and operation. On the first stage the steel beam is calculated in compliance with SP 16.13330.2011 and SP 20.13330.2011. On the second stage the steel and concrete composite beam is calculated in compliance with SNiP 52-01-2003, SP 63.13330.2012, EuroCode 1994. The total deflection of the composite beam is a sum of the steel beam of the I stage and the composite beam of the II stage deflections. The total state of stress is also formed by construction and operation stage stresses. There are no district requirements for supporting the beam during casting. Steel beam is designed in such a way as a real deflection of the steel beam is less than limit deflection, I stage load is taken. But this implementation is appropriate only for the composite beam as the part of steel-concrete composite flooring system. Usually steel studs are used as an additional supporting of steel sheet.

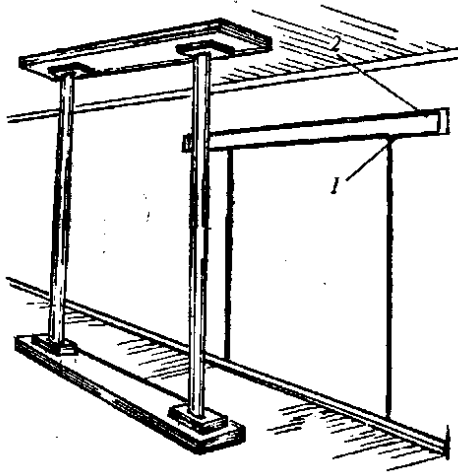


Figure 3.2 steel studs as an additional supporting of steel sheet

There are different stress situations in I and II stages. Stress distribution is being changed since a concrete slab begins to harden. The neutral axis is changing its position because of modification of the beam section. When upper concrete flange of the composite beam hardens, it will take most part of the compressive stress.

Stress diagram changes by the following way, see figure 3.3 and 3.4:

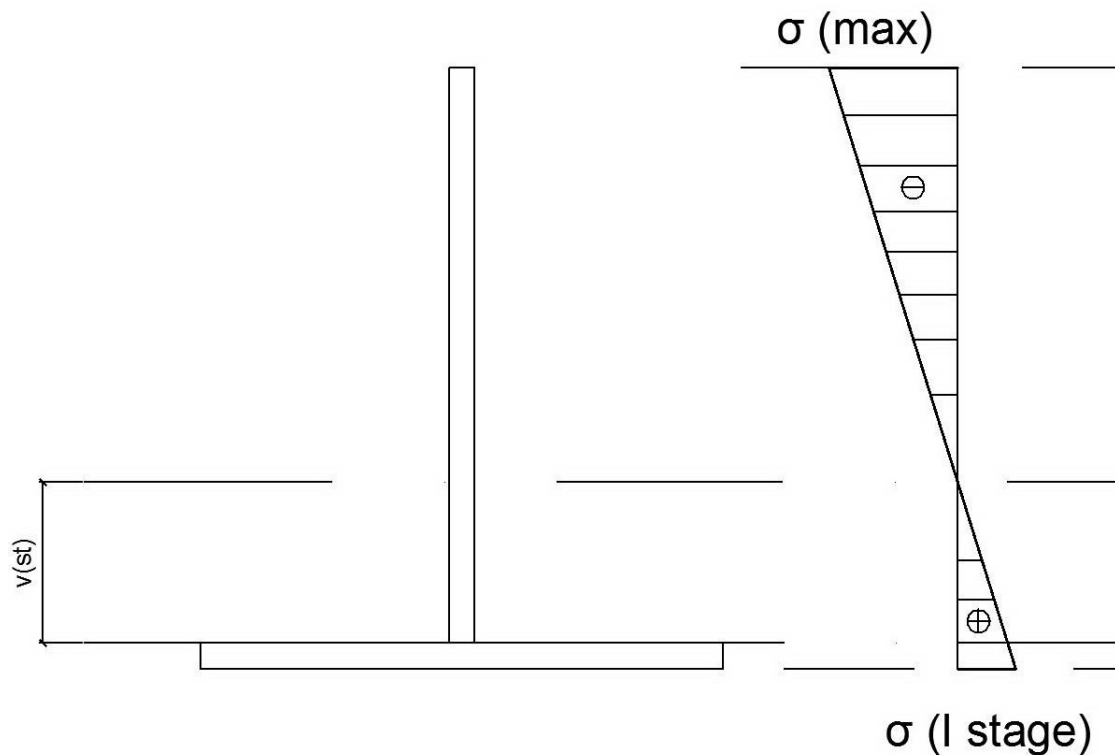


Figure 3.3 Steel and concrete composite beam

Steel beam resists a bend. There are bending moment and shear force action in the sections of the beam. A lower part of the steel beam that is mainly a flange resists tension. An upper part – it is only steel web – is under the compression.

Steel beam should be enough strong, stiff and stable to provide good conditions for concrete slab foaming. At the time as a concrete slab hardened, concrete and steel parts of the composite beam start bearing together. See figure 3.4.

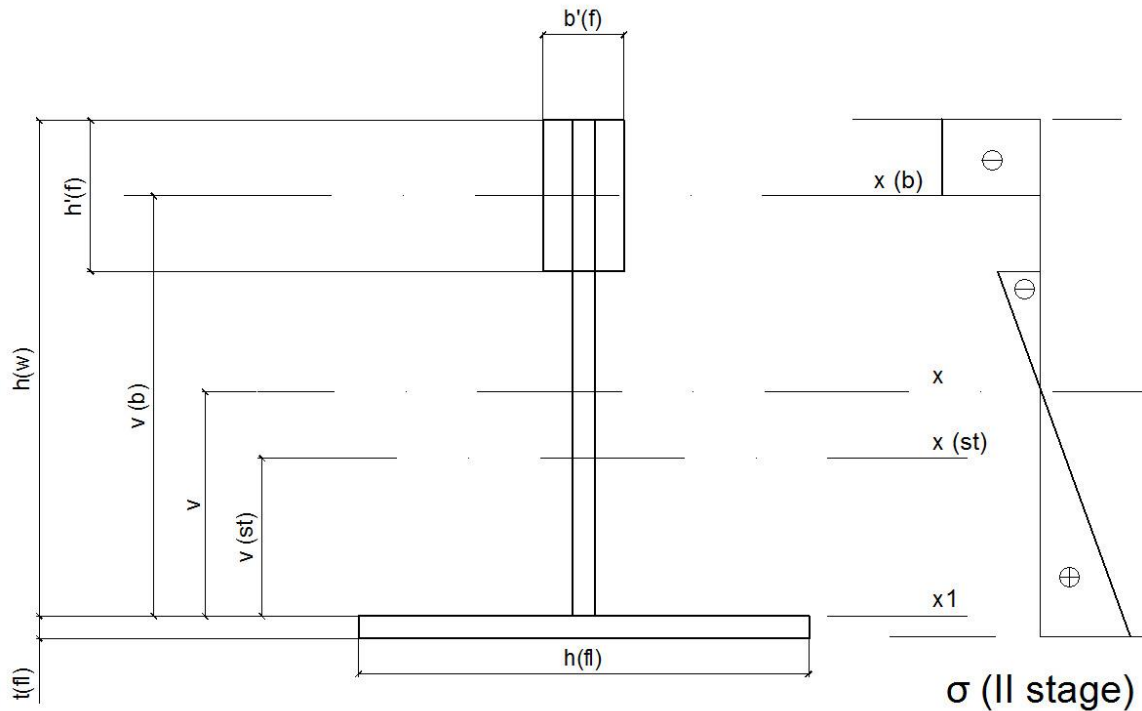


Figure 3.4 Steel and concrete composite beam

Concrete slab represents an upper flange of the composite beam that resists the compression. Thus, the whole section of the beam is I-section. Stress distribution is presented in figure 3.4.

In order to realize the benefits of the composite structures at the maximum level there should be a strong and stiff joint between steel and concrete structures. The joint is provided by steel anchors. The brace is steel bars that are placed along the beam by essential step. The bracing is necessary in order to ensure integrity of the structure.

3.1. Load estimation

There are two stages in load estimation. The first stage is a steel beam deflection under the first group of loads: dead weight of steel beam, profiled sheet, reinforced concrete as soon as sustained load of additional reinforcement and assemblage load. The second group of loads that makes a composite beam deflection contains floor covering, temporary useful and temporary partition load.

According to SP 20.13330.2011 Safety factor for each group of loads is the following:

- Temporary working (useful) and temporary partition loads - $\gamma_t = 1,3$
- Dead weight of steel structures and additional bars $\gamma_t = 1,05$
Dead weight of steel structures and floor covering, cap $\gamma_t = 1,3$
Dead weight of gypsum cardboard $\gamma_t = 1,2$
- Load of assemblage $\gamma_t = 1,2$

It is presented in table 3.1.

Table 3.1 Safety factor in compliance with SP 20.13330.2011

No	Load type	Safety factor γ_t	Comment
1	Dead weight of steel structure	1,05	table 7.1 SP 20.13330.2011
2	Dead weight of reinforced concrete structure	1,3	
3	Dead weight of structure component made on site	1,3	
4	Dead weight of structure component made on factory	1,2	
5	Load of assemblage	1,2	Table 8.2 of SP 20.13330.2011
6	Temporary working (useful) and temporary partition loads	1,3	8.2.2 of SP 20.13330.2011

According to TKP 45-5.03-16-2005 the following loads are considered in the construction stage:

- Dead weight of steel beam;
- Dead weight of steel sheet
Profiled sheet T153-120L-850-1,0: $q_{sh}^n = 0,14$ kPa as in technical specification;
- Dead weight of light-weight concrete mix: $\rho_{cm}^n = 12 \frac{kN}{m^3}$;
- Additional bars $\rho_{adb}^n = 1 \frac{kN}{m^3}$ per m^3 of concrete mix as in STO 0047-2005
- Load of assemblage $q_{as}^n = 0,5$ kPa

The algorithm of load estimation on the I stage is shown in table 3.2. The final result is load per unit of length *Sum of q, kN/m*.

Table 3.2 Load estimation on the I stage

Load type	№	Name	Normative value, kPa	Safety factor γ_t	$q_n, kN/m$	$q, kN/m$	Comment
Constant load - dead weight	1	Steel beam	-	1,05	0,33	0,35	Safety coefficient is considered.
	2	Steel profiled sheet	0,12	1,05	0,38	0,40	
	3	Reinforced concrete	1,97	1,3	6,50	8,46	
Temporary load	4	Sustained load of additional reinforcement	0,10	1,05	0,33	0,34	
	5	Assemblage load	0,5	1,2	1,65	1,98	
Sum					8,86	11,52	

According to TKP 45-5.03-16-2005 the following loads are considered in the operation stage:

- Temporary working (useful) load $q_{tw}^n = 1,5$ kPa
- Temporary partition load $q_{tp}^n = 0,5$ kPa as in the 3.6 of SNiP 2.01.07-85*
- Dead weight of the floor covering and suspended ceiling were taken from the preliminary design, see MS Excel file.

The algorithm of load estimation on the II stage is shown in table 3.3.

Table 3.3 Load estimation on the II stage

Load type	№	Load	Normative value, kPa	Safety factor γ_t	$q_n, kN/m$	$q, kN/m$	Comment
Constant load - dead weight	1	Floor covering	0,00675	1,3	0,022275	0,03	
	2	Cap	0,66	1,3	2,178	2,83	
	3	Gypsum cardboard	0,20	1,2	0,66	0,79	
Temporary load	4	Temporary working (useful) load	1,50	1,3	4,95	6,44	
	5	Temporary partition load	0,50	1,3	1,65	2,15	
Sum					9,46	12,23	

Preliminary values of unit weight of the flooring system elements and some factors that are considered in the load estimation are listed in table 3.4.

Table 3.4 Unit loads of material, structure and factor

No	Load	Value	Comment
1	Sustained load of additional reinforcement,	5	% of concrete weight
2	Assemblage load, kPa	0,5	
3	Floor covering kN/m^3	0,9	Unit weight of the element
	Width of the layer, mm	7,5	
4	Cap kN/m^3	22	Unit weight of the element
	Width of the layer, mm	30	
5	Gypsum cardboard kN/m^2	0,1	Unit weight of the element
	Amount of layers	2	
6	Temporary working (useful) load	1,50	According to SP 20.13330.2011
7	Temporary partition load	0,50	According to STO 0047-2005

3.2. I stage Steel Beam calculation

Static analysis is accomplished based on Structural mechanics. The main task is to determine the maximum values of shear force and bending moment. A scheme for static calculation is a beam with the span of $l = 4$ m and uniformly distributed load $q_{design} = 11,46$ kN/m as shown on the figure 3.5.

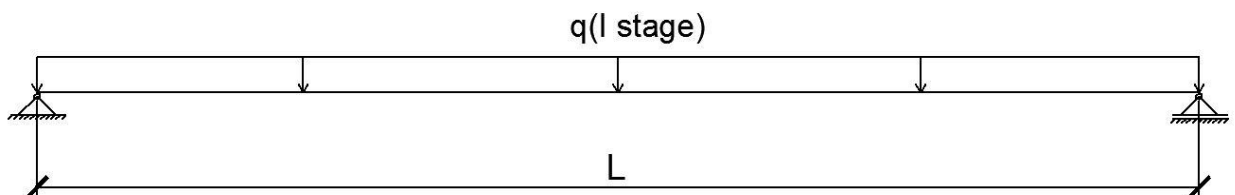
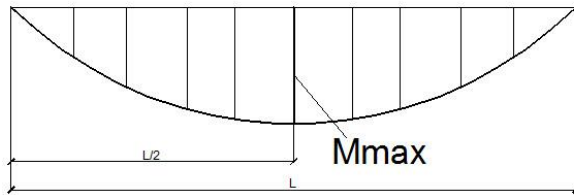


Figure 3.5 The scheme for static analysis of steel beam

Static calculation was done by means of SCAD Soft. The final result is bending moment and shear force diagrams that are shown in figure 3.6.

M, kNm diagram



Q, kN diagram

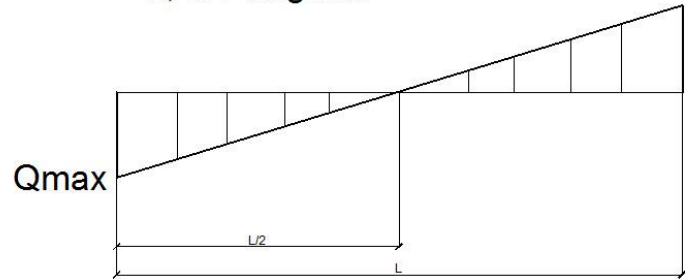


Figure 3.6 Bending moment and shear force diagram

The maximum value of bending moment and shear force: $M = 22,9 \text{ kNm}$; $Q = 22,9 \text{ kN}$

In further calculations it is only the maximum values of bending moment and shear force that are necessary. Therefore the values are determined automatically in MS Excel program.

In the program the bending moment and shear force values are defined by the following formulas (1) and (2):

$$M = \frac{q \cdot L^2}{8}, \text{ kNm} \quad (3.1)$$

$$Q = \frac{q \cdot L}{2}, \text{ kN} \quad (3.2)$$

3.2.1. Beam Section

The section shown in figure 3.7 is a tee formed by welding two steel sheets. The figure and specification are obtained by means of "Section design" program of Scad Soft. Actually the program is used only for getting a vertical coordinate of center of mass v_{st} .

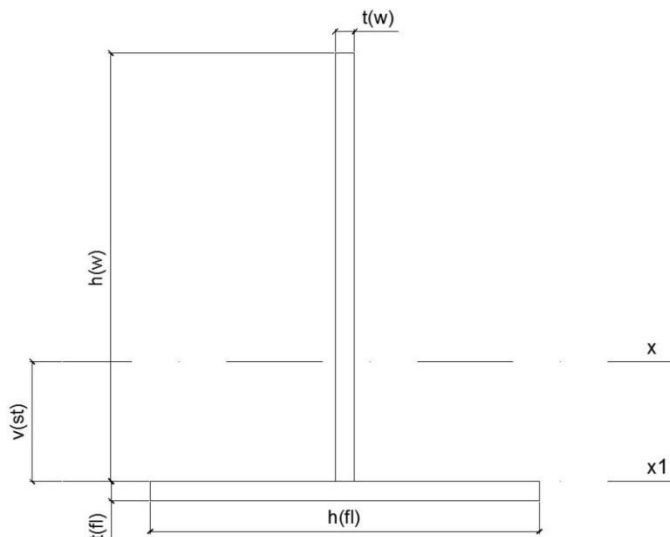


Figure 3.7 Steel beam section

The main section characteristics are determined automatically based on linear dimensions of two steel sheets and vertical coordinate of center of mass in the MS Excel program. It is presented in table 3.5.

Table 3.5 Geometrical characteristics of steel beam

№	Parameter	Symbol	Value	Comment
1	Web height	h_w, mm	220	Add the value according to preliminary design.
2	Web thickness	t_w, mm	10	Add the value according to preliminary design.
3	Flange height	h_f, mm	200	Add the value according to preliminary design.
4	Flange thickness	t_f, mm	10	Add the value according to preliminary design.
5	Cross-sectional area	A_{st}, sm^2	42,0	It is calculated automatically.
7	Moment of Section	S_{st}^{cut}, sm^3	136,1	It is used to determine max shear stress.
6	Moment of inertia	I_{st}, sm^4	2 274,5	It is calculated automatically.
7	Moment of resistance	W_{st}, sm^3	137,8	It is calculated automatically.
8	Vertical coordinate of centre of mass	v_{st}, sm	5,50	Add from the Tee section characteristics

Steel sheet dimensions are got from a preliminary design of the floor structure. The easiest way to get a value of vertical coordinate of center of mass z_m is to use the program “Section design” of Scad Soft. The vertical coordinate also may be obtained by the further shown way based on the theory of material resistance.

$$v_{st} = \frac{S_{x1}}{A_{st}} \quad (3.3)$$

$S_{x1} = S_{x1}^1 + S_{x1}^2 = A_{st}^1 * z_{x1}^1 + A_{st}^2 * z_{x1}^2$ – static moment of section related to axis X1.

A_{st}, sm^2 – cross-sectional area of steel beam.

3.2.2. Strength verification

The strength of a steel beam is verified in the way expressed in SP16.13330.2011. This method is based on Euler-Bernoulli hypothesis that plane sections remain plane and normal to the axis after deformation, the so-called plane-sections hypothesis.

Strength analysis of the steel beam must be realized by formulas:

$$\sigma_I = \sigma_{max} = \frac{M_I}{W_{st}} \leq R_y * \gamma_c \quad (3.4)$$

$$\tau_I = \tau_{max} = \frac{Q_I * S_{st}^{cut}}{I_{st} * t_w} \leq R_s * \gamma_c \quad (3.5)$$

M_I, Q_I – Maximum values of bending moment and shear force on the I stage;

t_w, sm – Web thickness;

W_{st}, sm^3 – Moment of resistance of steel beam;

I_{st}, sm^4 – Moment of inertia of steel beam cross-section;

S_{st}^{cut}, sm^3 – Static moment of section;

$R_y, kN/sm^2$ – Design yield strength determined by SP16.13330.2011.

$R_s, kN/sm^2$ – Design shear strength determined by SP16.13330.2011.

$\gamma_c = 1$ – Coefficient of working condition according to SP16.13330.2011.

Stress distribution in the T-section is illustrated in figure 3.8.

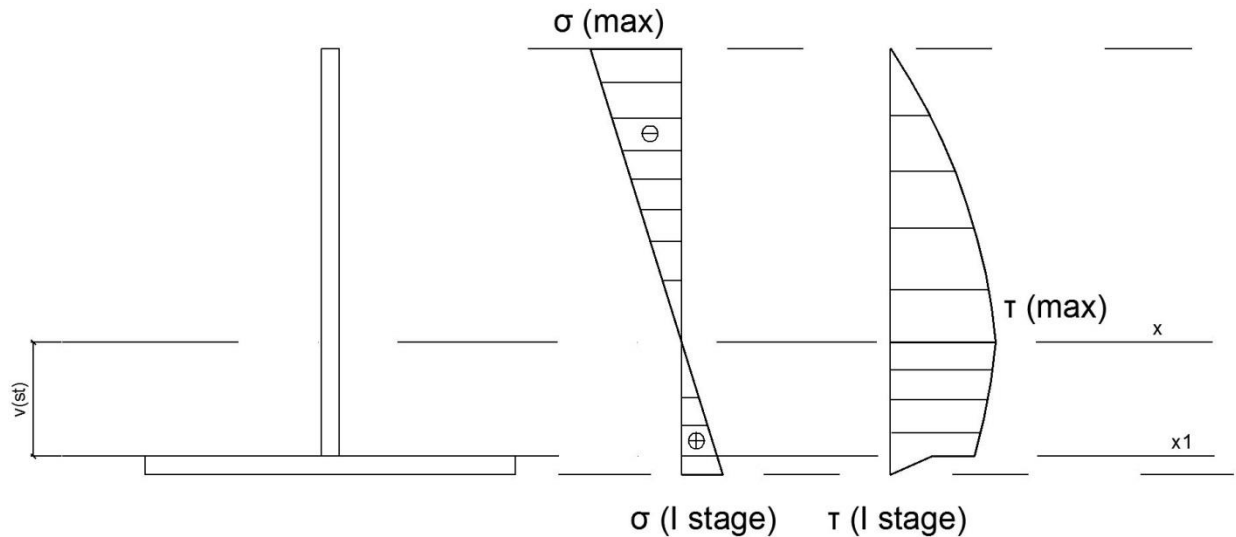


Figure 3.8 Stress diagram of steel beam

3.2.3. Serviceability limit state

The aim is to prove that structural behavior does not exceed serviceability limit state (SLS) design criteria values. In this instance SLS design criteria is a limit value of beam deflection. If it is based on SP 20.13330.2011, a limit deflection should be $[\frac{f}{L}] = \frac{l}{150}$ as for a beam with elements subjected to cracking. If we referred to STO 0047-2005, the limit deflection of composite beam would be $[\frac{f}{L}] = \frac{l}{250}$ and for II stage loading - $[\frac{f}{L}] = \frac{L}{300}$.

The verification of beam stiffness is performed by formula:

$$f \leq f_u \quad (3.6)$$

Or

$$\frac{f}{L} \leq [\frac{f}{L}] \quad (3.7)$$

f, mm – deflection of a beam determined by formulas of “Resistance of materials”;

f_u, mm – limit value of deflection.

As told in SP 20.13330.2011, a deflection is determined by normative value of estimated load.

The maximum value of beam deflection is defined by formula:

$$f_I = f_{max} = \frac{5}{384} * \frac{q_n^I * L^4}{E_{st} * I_{st}} \quad (3.8)$$

$q_n^I, kN/m$ – normative value of estimated load on the I stage;

L, m – span of a beam;

E_{st}, MPa – Elastic modulus of steel;

The relative deflection of steel beam must satisfy the following expression:

$$\frac{f_I}{L} \leq \left[\frac{f}{L} \right] = \frac{L}{300} \quad (3.9)$$

The less value of beam deflection the less the floor structure cost. It is caused by decreasing of surface of floor and ceiling that defines the essential amount of facing materials.

3.2.4. Overall stability

The overall stability of a steel beam must be provided as told in SP 16.13330.2011. But there is not enough information to check the overall stability of T-section beam in SP 16.13330.2011. The overall instability of steel beam is shown in figure 3.9.

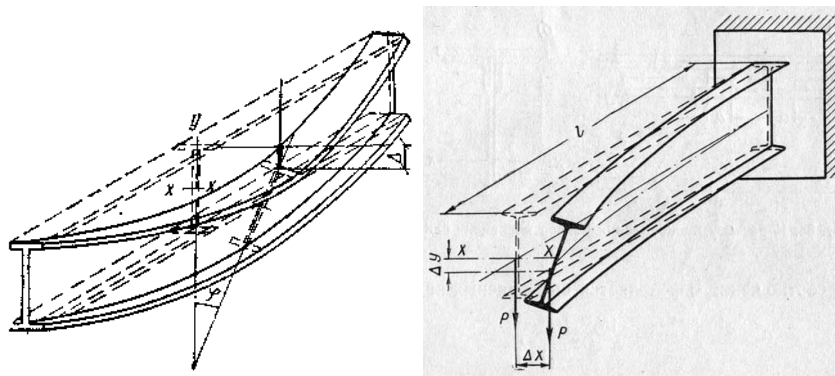


Figure 3.9 Overall instability of steel beam

According to SP 16.13330.2011 T-section beam must not be designed. So, the overall stability verification of T-section beam is impossible to be accomplished by means of Russian Building Codes.

Ruukki Rus has realized a test of the steel beam. Therefore the overall stability of the beam would be provided by known limit value of load. So, based on the test results presented in 4.1 of the thesis, the following expression must be satisfied:

$$q_l \leq 2 * \frac{F_{cr}}{L_{test}} \quad (3.10)$$

$q_l, \frac{kN}{m}$ – design value of the load on the I stage;

F_{cr}, kN – critical load taken from the paragraph 4.1 of the thesis; critical load is a load that causes overall instability of the beam.

L_{test}, m – length of the beam that was tested.

3.2.5. Flange local stability

There is no note about the local stability of tensile flange in Russian building codes. In this paragraph steel beam is verified on the following form of local instability of flange as illustrated in figure 3.10.

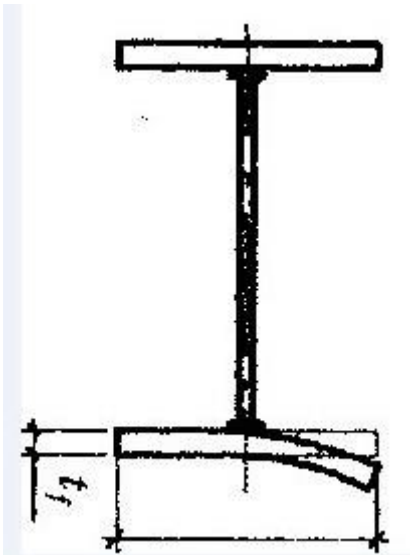


Figure 3.10 Flange local instability

So the local stability of down flange is checked by formula of SP16.13330.2011.

The formula that is used is the following:

$$\sigma_{flange} = \sigma_{max} = \frac{M_{fl}}{W_{fl}} \leq R_y * \gamma_c \quad (3.11)$$

M_{fl}, kNm – maximum value of bending moment that is determined by formula:

$$M_{fl} = \frac{0,5 * q * (0,5 * (h_f - t_w))^2}{2} \quad (3.12)$$

W_{fl}, sm^3 – moment of resistance of the flange width of which is 100 sm.

3.2.6. Fillet weld strength verification

Steel T-section beam is made by welded two steel sheets. Fillet weld is usually used for the sheet connection as shown in figure 3.8.

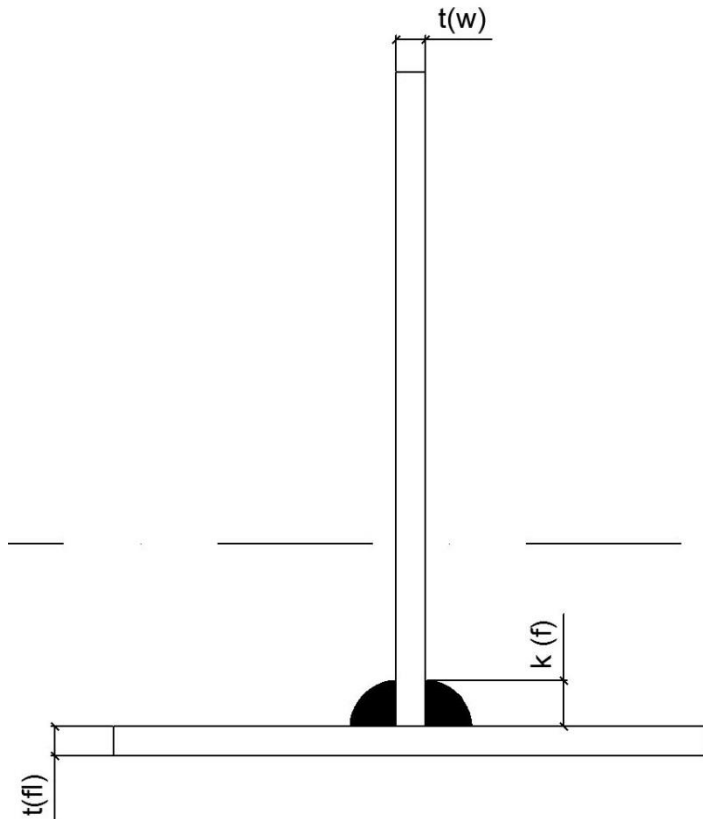


Figure 3.11 Welded belt connection of tee steel beam

Welded belt connection is designed according to SP 16.13330.2011:

$$\frac{T}{n \cdot k_f \cdot \beta_f} \leq R_{wf} \cdot \gamma_c \quad (3.13)$$

$$\frac{T}{n \cdot k_f \cdot \beta_z} \leq R_{wz} \cdot \gamma_c \quad (3.14)$$

n – amount of fillet welds: one-sided or two-sided.

k_f, mm – weld leg the minimum value of which is defined according to SP 16.13330.2011 depending on type of connection, type of welding, thickness of welded elements and yield strength of steel. $k_f \leq 1,2t, t$ – thickness of thinner one of welded elements.

β_f, β_z – coefficients that are defined according to SP 16.13330.2011 depending on weld procedure and weld leg. Semiautomatic and machine welding is used with electrode wire $d=1,2$ mm, SV 08 G2S.

$\gamma_c = 1$ – coefficient of work condition according to SP 16.13330.2011.

R_{wf}, R_{wz} – parameters of weld material. For steel of welded elements with yield strength more than 285 MPa the following expression must be satisfied: $R_{wz} \leq R_{wf} \leq \frac{\beta_z}{\beta_f} * R_{wz}$

Design resistance of weld connection defined by weld steel that is determined according to SP 16.13330.2011:

$$R_{wf} = \frac{0,55 * R_{wun}}{\gamma_{wn}} \quad (3.15)$$

R_{wun} – normative resistance of weld material that is taken from SP16.13330.2011.

$\gamma_{wn} = 1,25$ – safety coefficient defined by weld steel according to SP 16.13330.2011.

The value of R_{wf} may be taken in SP 16.13330.2011.

Design resistance of weld connection defined by steel of fusion border that is determined according to SP 16.13330.2011:

$$R_{wz} = 0,45 R_{un} \quad (3.16)$$

$R_{un} = 470 \text{ MPa}$ – normative resistance of steel of welded elements (C345) as in SP 16.13330.2011.

Shift force per meter is determined by formula, kN/m:

$$T = \frac{Q_{max}^I S_{st}^{cut}}{I_{st}} \quad (3.17)$$

As a result of the verification there will be assigned weld material, weld leg in the report in compliance with the type of connection, weld procedure, loads, thickness of welded elements.

3.3. II stage Composite beam calculation

3.3.1. Static Calculation

Static analysis is accomplished based on Structural mechanics. The main task is to determine the maximum values of shear force and bending moment in the composite beam.

A scheme for static calculation is a beam with the span of $l=4\text{m}$ and uniformly distributed load $q_{design} = 12,23 \text{ kN/m}$. Static calculation was done by means of SCAD Soft.

The maximum value of bending moment and shear force: $M = 24,5 \text{ kNm}$; $Q = 24,5 \text{ kN}$. In further calculations it is only maximum values of bending moment and shear force that are necessary. Therefore the values are determined automatically in MS Excel program.

3.3.2. Composite beam section

The design section of a composite beam is a double tee with reinforced concrete compressed flange. How linear dimensions of the upper flange are set is described below.

The effective width of the slab taken into design section is determined according to SP 63.13330.2012, EuroCode 4 and Ruukki comparative analysis. Effective width of slab is a design section of slab that significantly contributes to the bending resistance of beam. The composite beam section is illustrated in figure 3.12.

Ruukki comparative analysis contains comparison of the maximum stresses of four versions of composite beam section that is obtained by means of the finite element method and strip method. The difference between the versions is the effective width: 300, 500, 1000 and 1500 mm. Appropriate slab section with such an effective width that the value of stresses is the most equal. The result of the analysis shows that conformity of tensile stresses is in the section with 1500 mm width and the conformity of compression stresses – 500 mm of width. Thus the most optimal decision of effective width is in the range from 500 to 1500 mm:

$$500 \text{ mm} \leq b'_f \leq 1500 \text{ mm} \quad (3.18)$$

Two limits are formed for this instance from 8.1.11 in SP 63.13330.2012:

$$b'_f \leq 2 * \frac{L}{6} + t_w = 1343 \text{ mm} \quad (3.19)$$

$$b'_f \leq \frac{l}{2} = 1500 \text{ mm} \quad (3.20)$$

L, mm – beam span;

l, mm – beam step;

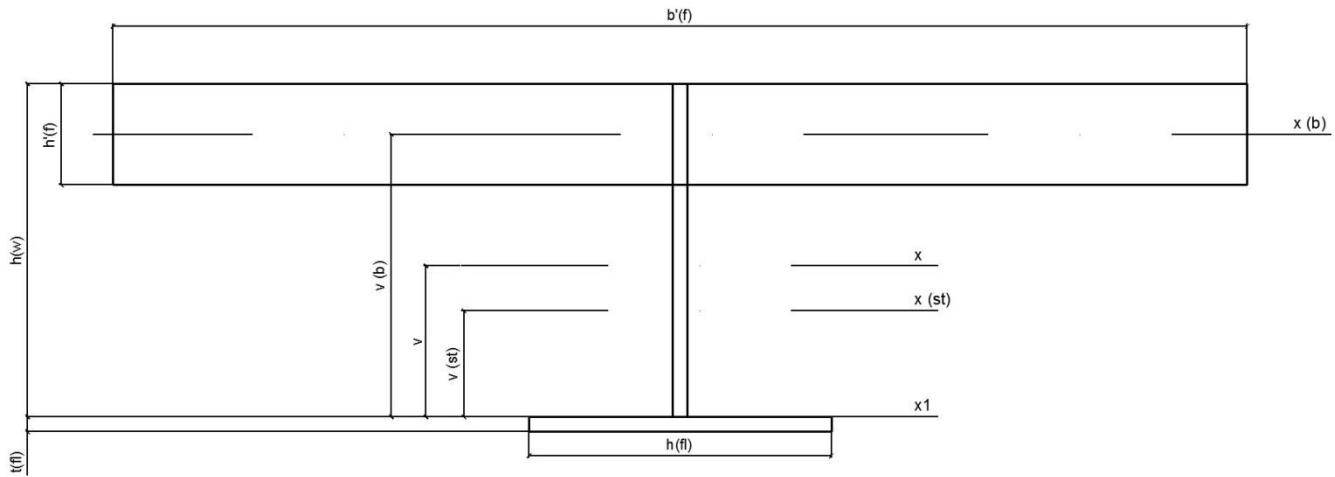


Figure 3.12 Section of steel and concrete composite beam

STO 0047-2005 recommends to define effective width by formula:

$$b'_f = \frac{l}{4} = 750 \text{ mm} \quad (3.21)$$

Thus, the effective width of the slab that is used in calculation is 750 mm.

The effective thickness of slab h'_f equals the distance between upper surface of slab and the upper plane of steel profiled sheet.

3.3.3. Strength verification

Strength is checked according to SP 16.13330.2011 by using reduction coefficient and characteristics. Reduction coefficient $n = \frac{E_{st}}{E_b}$ is used to transform the composite section into homogeneous section shown in figure 3.13.

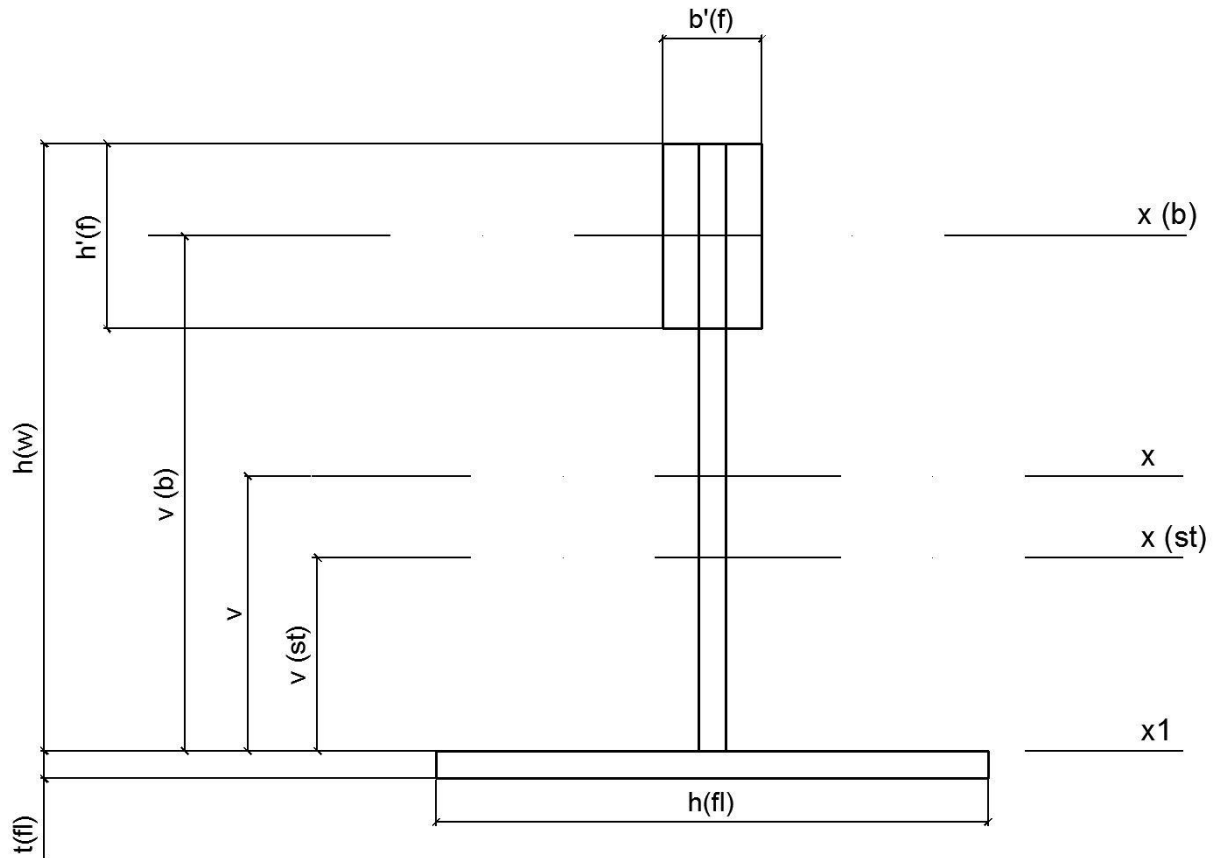


Figure 3.13 Equivalent Section of the composite beam

Strength verification is accomplished by formulas:

$$\sigma_{II} = \sigma_{max} = \frac{M_{II} * (h_w - v)}{I_{eq}} \leq R_y * \gamma_c \quad (3.22)$$

$$\tau_{II} = \tau_{max} = \frac{Q_{II} * S_{eq}^{cut}}{I_{eq} * t_w} \leq R_s * \gamma_c \quad (3.23)$$

M_{II}, Q_{II} – Maximum values of bending moment and shear force on the II stage;

h_w, sm – Web height;

v, sm – coordinate of center of mass of the composite beam;

S_{eq}^{cut}, sm^3 – Equivalent static moment of cut part of section that is defined by the following formula:

$$S_{eq}^{cut} = A_{st}^{fl} * (0,5t_{fl} + v) + v * t_w * (0,5 * v) \quad (3.24)$$

I_{eq}, sm^4 – Equivalent moment of inertia of composite beam cross-section that is determined by the formula:

$$I_{eq} = I_{st} + A_{st} * (v - v_{st})^2 + \frac{1}{n} * (I_b + A_b * (v_b - v)^2) \quad (3.25)$$

$n = \frac{E_{st}}{E_b}$ – reduction material coefficient;

STO 0047-2005 offers to consider load type by means of different reduction factors:

$n = 18$ – for constant load;

$n = 6$ – for temporary load.

Strength analysis of the steel beam may be accomplished by formula:

$$\sigma_{II} = \sigma_{max} = \frac{q(G_3)*L^2}{8*\frac{I_{eq}^{n=18}}{z_{max}^{n=18}}} + \frac{q(Q)*L^2}{8*\frac{I_{eq}^{n=6}}{z_{max}^{n=6}}} \leq R_y * \gamma_c \quad (3.26)$$

$q(G_3), kN/sm$ – design load of temporary partition;

$q(Q), kN/sm$ – design load of temporary useful load;

$I_{eq}^{n=6}, sm^4$ – equivalent moment of inertia by reduction factor $n=6$;

$z_{max}^{n=6}, sm$ – distance between the outermost tensile or compressed fibre and centre of mass of reduced section by reduction factor $n=6$.

$I_{eq}^{n=18}, sm^4$ – equivalent moment of inertia by reduction factor $n=18$;

$z_{max}^{n=18}, sm$ – distance between the outermost tensile or compressed fibre and centre of mass of steel beam section.

There are almost the same results in calculations of STO method and method based on “Resistance of material”.

3.3.4. Serviceability limit state

Deflection has to be calculated according to the basics of strength of materials. Manual of Scientific Research Institute of Concrete and Reinforced concrete offers to determine a deformation by using common methods like method of Maxwell-Mohr. If we referred to STO 0047-2005, the limit deflection of composite beam would be $[\frac{f}{l}] = \frac{l}{250}$ and for II stage loading - $[\frac{f}{l}] = \frac{l}{300}$. The stiffness of the composite beam may be checked according to RSN 64-88. There is only another value of deflection limit compared to STO and SP 20.13330.2011.

The verification of beam stiffness is performed by formula:

$$\frac{f}{L} \leq \left[\frac{f}{L} \right] \quad (3.27)$$

f, mm – deflection of a beam determined by formulas of “Resistance of materials”;

$\left[\frac{f}{L} \right]$ – limit value of beam deflection.

The maximum value of beam deflection of the II stage load is defined by formula:

$$f_{II} = f_{max} = \frac{5}{384} * \frac{q_n^{II} * L^4}{E_{st} * I_{eq}} \quad (3.28)$$

$q_n^{II}, kN/m$ – normative value of estimated load on the II stage;

The relative deflection of composite beam of the II stage must satisfy the following expression:

$$\frac{f_{II}}{L} \leq \left[\frac{f}{L} \right] = \frac{L}{300} \quad (3.29)$$

The total deflection of the composite beam of floor structure equals:

$$f_{total} = f_I + f_{II} \quad (3.30)$$

The relative deflection of composite beam should be:

$$\frac{f_{total}}{L} \leq \left[\frac{f}{L} \right] = \frac{L}{250} \quad (3.31)$$

STO 2005 offers to consider load type by using different reduction coefficients:

$n = 18$ – for constant load;

$n = 6$ – for temporary load.

$$f_{II} = f_{max} = \frac{5}{384} * \left(\frac{q_n^{II}(Q) * L^4}{E_{st} * I_{eq}^{n=6}} + \frac{q_n^{II}(G_3) * L^4}{E_{st} * I_{eq}^{n=18}} \right) \quad (3.32)$$

There are almost the same results in calculations of STO method and method based on “Resistance of material”.

3.3.5. Anchor shift verification

Anchor diameter and its amount are defined by design crumbling resistance of tee web steel. The length of the anchors is assigned according to SP 63.13330.2012.

Anchors must be set such as the following equation would be satisfied:

$$\sigma_{shift} \leq R_s^{crumb} \quad (3.33)$$

$\sigma_{shift}, \frac{kN}{sm^2}$ – local stress that appears in the hole of web as a result of crumbling by anchor;

$R_s^{crumb}, \frac{kN}{sm^2}$ – design crumbling resistance of tee web steel calculated according to SP 16.13330.2011.

The maximum acceptable anchor's step near support is determined by formula:

$$a_{max}^{support} = \frac{T_R^{anch}}{t} \quad (3.34)$$

The anchor resistance is limited not so much by the shear anchor's steel resistance as the crumbling resistance of web steel. The maximum value of shift force that can be resisted by one double anchor, kN:

$$T_R^{anch} = R_s^{crumb} * d * t_w \quad (3.35)$$

d, mm – diameter of anchor;

t_w, mm – web thickness;

The shift force per meter is defined by formula based on a concept of complementary shear stress, kN:

$$t = \frac{Q_{max}^{II} * S_{eq}^{cut}}{I_{eq}} \quad (3.36)$$

The maximum acceptable anchor's step in the span is determined by formula:

$$a_{max}^{span} = 2 * a_{max}^{support} \quad (3.37)$$

Near support (1/4 span) the anchor step is two times less than in the middle part of beam (2/4 span) as the shear force has the opposite relation. The anchors are located such as in figure 3.11.

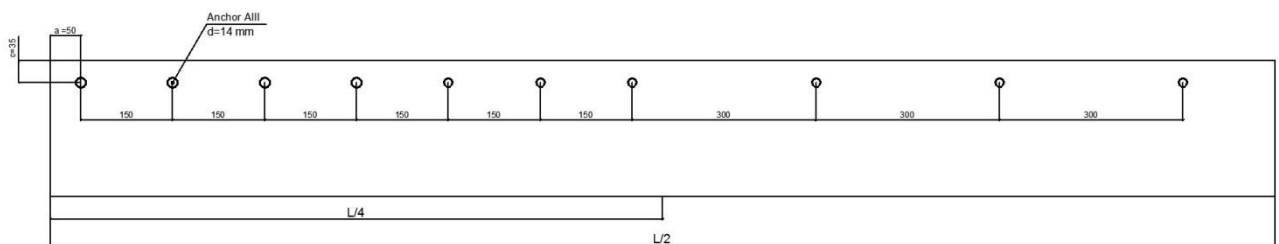


Figure 3.14 Scheme of anchor installation

After choosing an anchor's step below the limit the shift verification is accomplished:

The real shift force acting on one double anchor is defined by formula:

$$T_{anch}^{support} = t * a^{support} \quad (3.38)$$

And the following expression must be satisfied:

$$T_{anch}^{support} \leq T_R^{anch} \quad (3.39)$$

It represents the main expression of anchor shift verification $\sigma_{shift} \leq R_s^{crumb}$. If these expressions are true it means that anchor's parameters and its step are assigned properly.

3.3.6. Local concrete crumbling verification

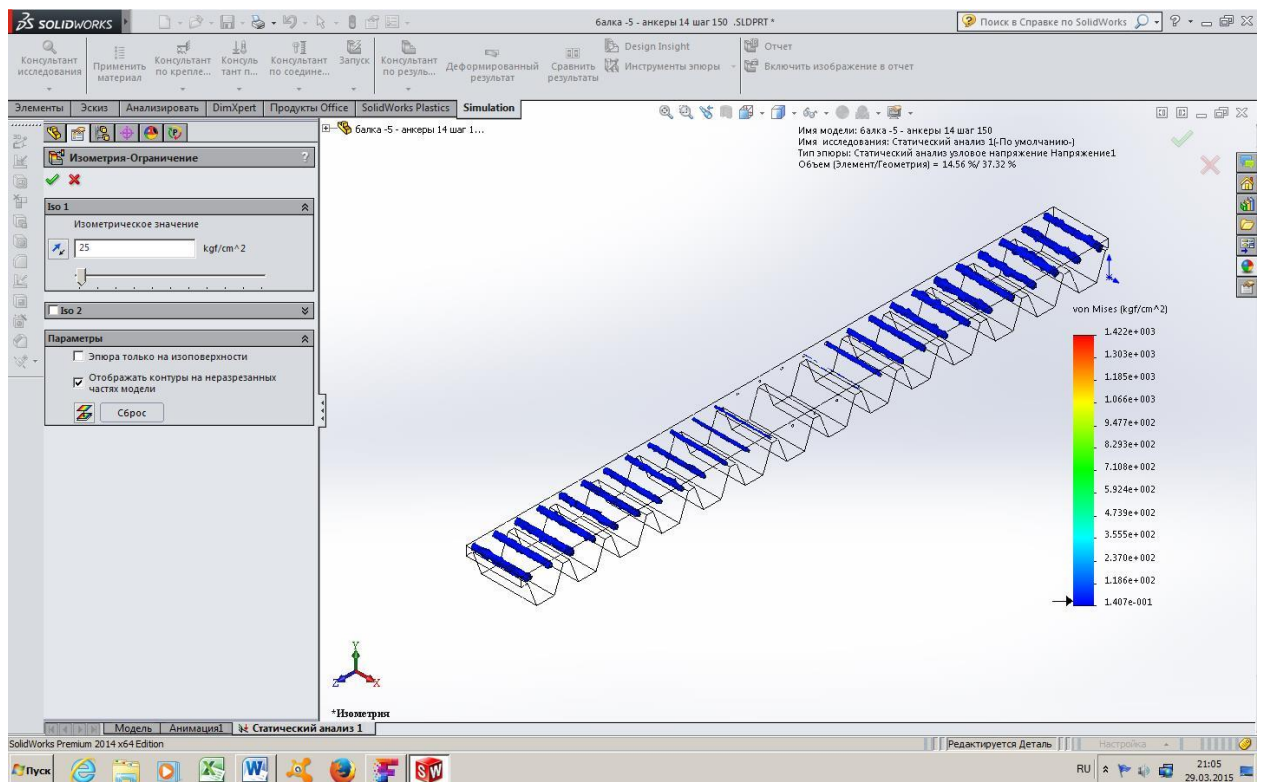
Local crumbling concrete strength is compared with a design stress that is expressed according to SP 63.13330.2012:

$$\sigma_t \leq R_{loc,c} \quad (3.40)$$

$R_{loc,c} = R_b, kN/sm^2$ – local crumbling concrete resistance equals concrete resistance in compression.

$\sigma_t, \frac{kN}{sm^2}$ – design stress that is determined in the elastic concrete massive by uniformly distributed load acting on the area of anchor's longitudinal section in compliance with law of linear stress distribution in a ground. The design stress is taken from the formula:

$$\sigma_t = \frac{T_{anch}^{support}}{2*(l_d*d)} \quad (3.41)$$



. Such value of the design anchor length is taken based on the stresses given in the digital model of the structure. So that allows us use the formula (3.41) and design stress σ_t as a design criteria.

4. COMPARISON OF THE CREATED ALGORITHM WITH EXPERIENCE AND COMPUTER-AIDED CALCULATION

4.1. Computer-aided calculation of the steel beam

The deflection of steel beam is illustrated in figure 4.1.

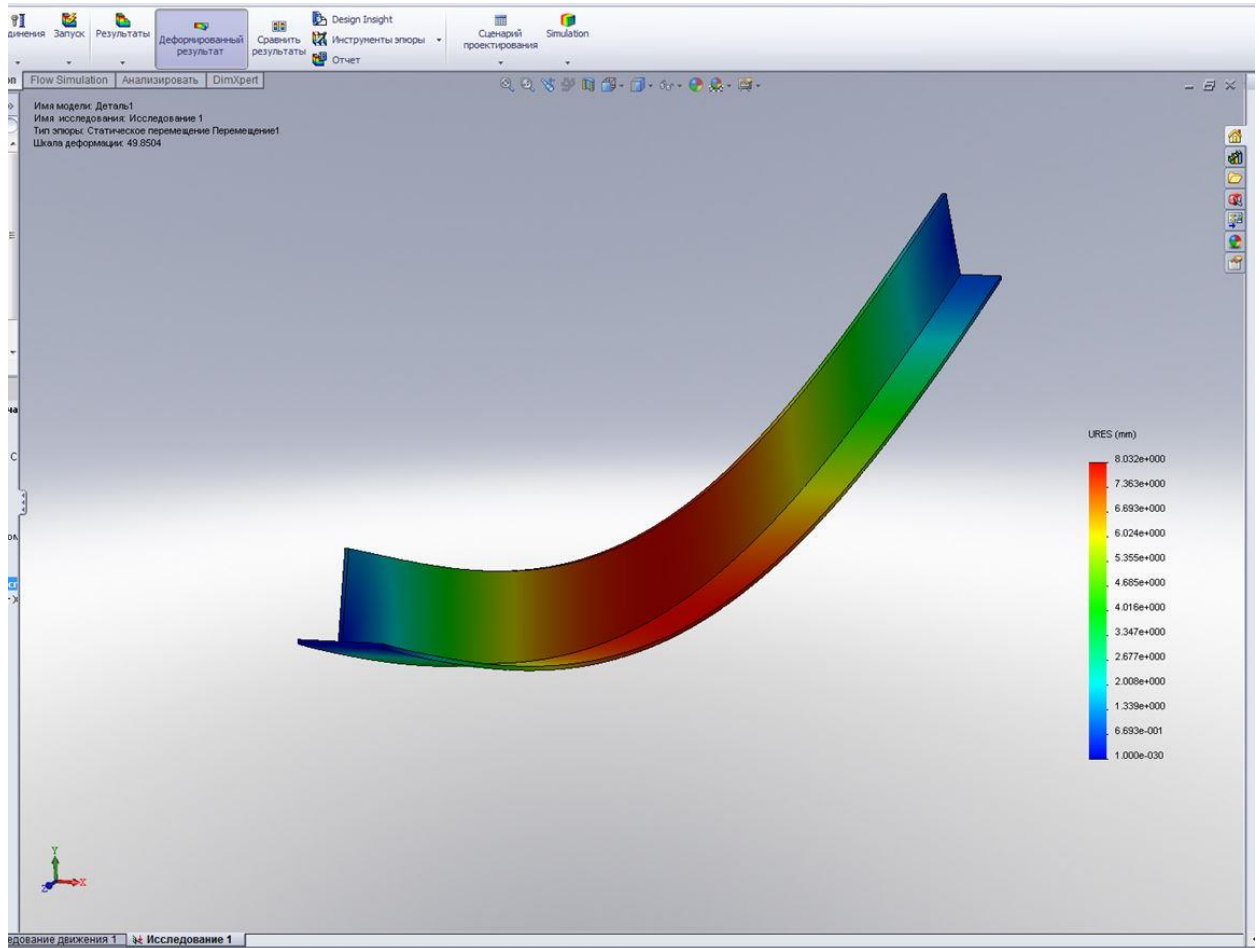


Figure 4.1 Deflection of steel beam

The results of the steel beam calculations are listed in table 4.1.

Table 4.1 Comparison of steel beam calculations

No	Parameter	Symbol/unit	Strip method	Method of finite element
1	Deflection	f_l, mm	6,18	7,8
2	Compression stress	$\sigma_l, kN/sm^2$	16,72	13,29
3	Shear stress	$\tau_l, kN/sm^2$	1,38	1,25

Deflection and stress values are similar taken by two different methods.

You can figure out how the plate thickness affects the beam capacity if you analyze chart 4.1. There is a function between the total strength of composite beam and the thickness of used steel sheets. According to one of the requirements of fillet weld both thicknesses of steel sheets have to be the same that guarantees a high quality of automatized welding.

Table 4.2 Dependence between composite beam strength and plate thickness

No	Thickness, mm	Main stress, N/mm ²	Limit stress, N/mm ²
1	6	351,2	320
2	8	273	
3	10	225	
4	12	192,2	

Strength of composite beam

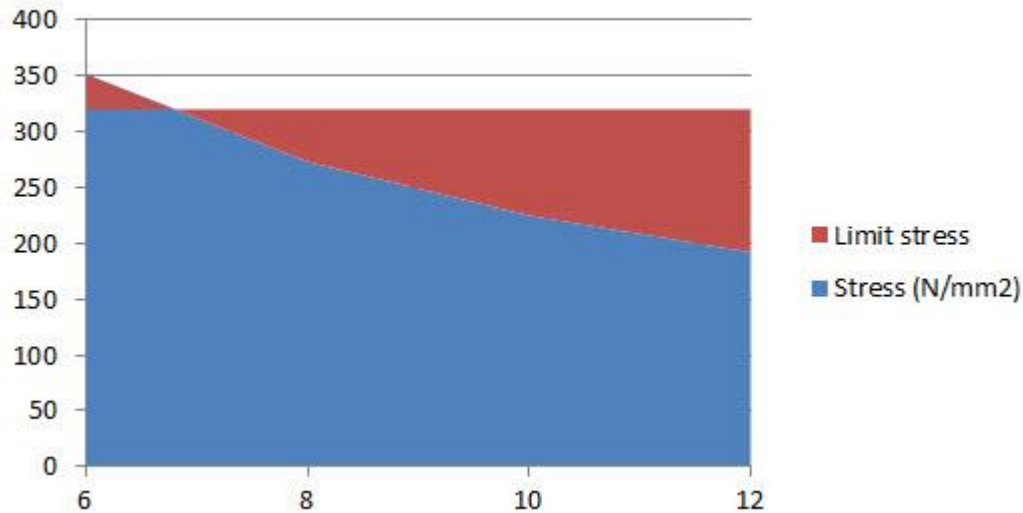


Chart 4.1 Strength of composite beam

As you can see in the chart, there is not enough strength of composite beam with 6 mm steel sheets. The actual stress is $351,2 \text{ N/mm}^2$ that is higher than the limit stress – 320 N/mm^2 . The choice is 10 mm steel sheets that provide safety factor about 30% for the composite beam in comparison with 8 mm sheets with safety factor of 8%. The sheet thickness also affects the limit value of anchor step. More thickness of steel sheets more efficient design due to less amount of anchors is needed.

Table 4.3 Dependence between anchor step and plate thickness

No	Thickness, mm	$a_{max}^{support}$, mm	a_{max}^{span} , mm
1	6	147	295
2	8	196	392
3	10	244	489
4	12	291	583

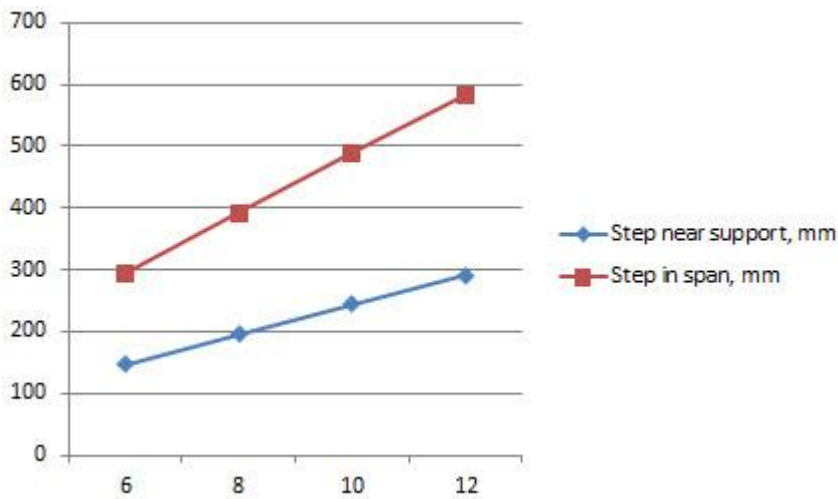


Chart 4.2 Anchor step

4.2. Computer-aided calculation of the composite beam

The digital three-dimensional model shown in figure 4.2 was created by means of SolidWorks that is a program of Dassault Systèmes SOLIDWORKS Corp.

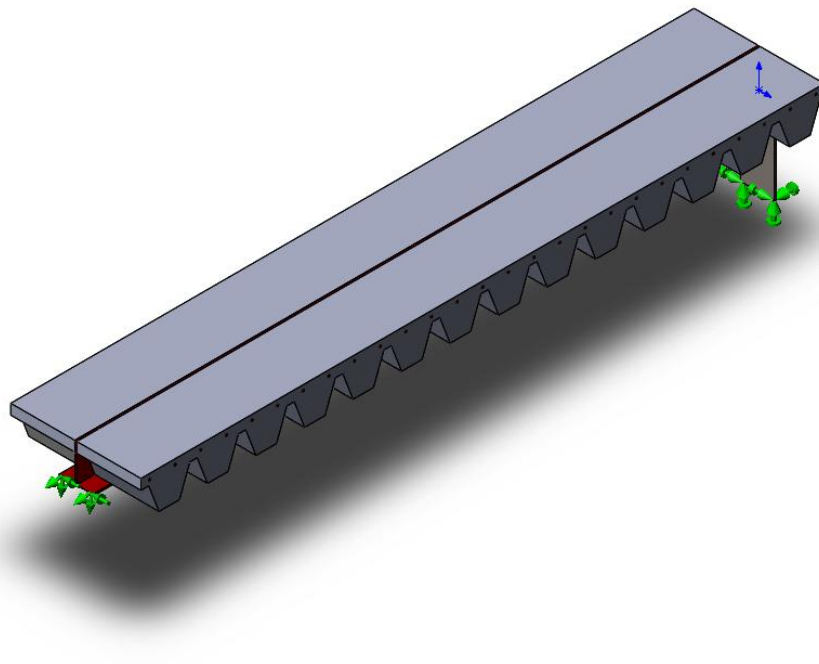


Figure 4.2 Digital model of the composite beam

It let us to accomplish stress and deformation analysis and consider little things in the created algorithm of the composite beam calculation. The main task of the model analysis is to calibrate the algorithm and confirm the results of the program made in MS Excel.

The work does not consider reinforcement of design part of slab in calculation by means of Solidworks as it serves mainly for spreading stresses along the concrete mass and avoiding stress concentration in the middle of the composite beam. The upper reinforcement contributes a little part of capacity in comparison with concrete mass. The reduction strongly simplifies grid creation process and reduces the total time of calculation.

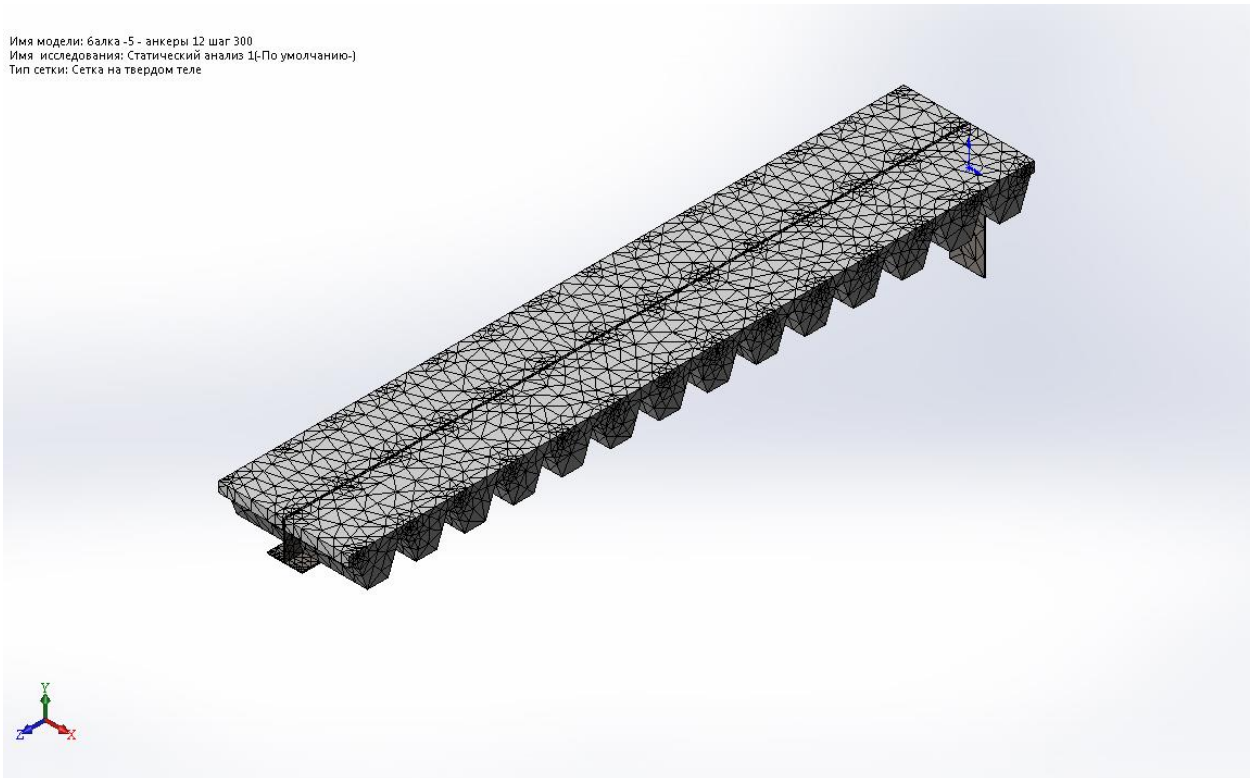


Figure 4.3 Digital model grid of finite element

There is a method of finite element used in the program. The automatized process of creation of finite element grid significantly simplifies the calculation. The digital model grid of the finite element is illustrated in figure 4.3.

A design load is assigned as the load estimated on the II stage $q_{II} = 14,48 \text{ kN/m}$. So the appeared stresses and deformation of the model will be compared with the ones calculated on the II stage in the program. Comparison of maximum compression and tension stresses, maximum deformation of composite beam and crumbling stresses in the concrete mass that is located around the anchor are going to be accomplished.

The strip method is used in the created program. The maximum value of compression stress is $\sigma_{II} = 70,8 \text{ N/mm}^2$. The shear stress is $\tau_{II} = 15,4 \text{ N/mm}^2$. The value of vertical deformation is $f_{II} = 3,62 \text{ mm}$. The crumbling stress in the concrete mass is $\sigma_t = 2,6 \text{ N/mm}^2$.

The corresponding values of parameters obtained by the method of finite element are illustrated in the following figures. The value of vertical deformation is $f_{II} = 4,09 \text{ mm}$ in figure 4.4.

Имя модели: балка -5 - анкеры 14 шаг 150
 Имя исследования: Статический анализ 1(По умолчанию)
 Тип эпюры: Статическое перемещение Перемещение1
 Шкала деформации: 235.621

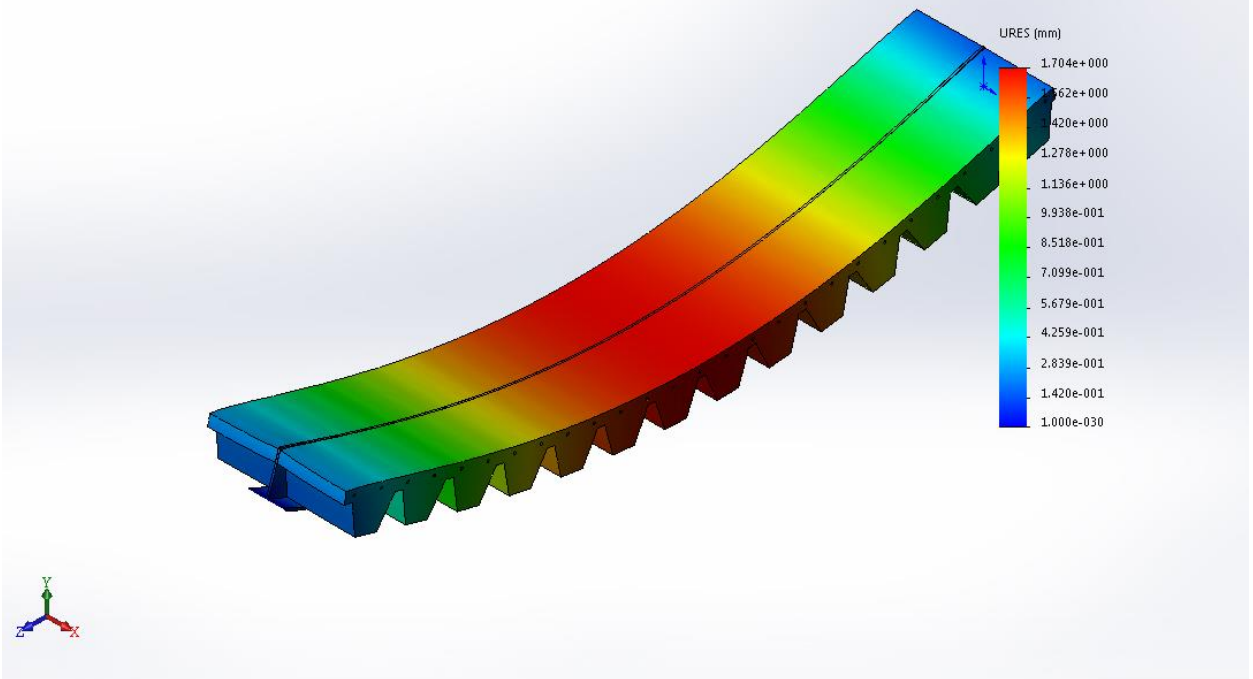


Figure 4.4 Deformation of the composite beam (model version 1)

There are crumbling stresses in figure 4.5.

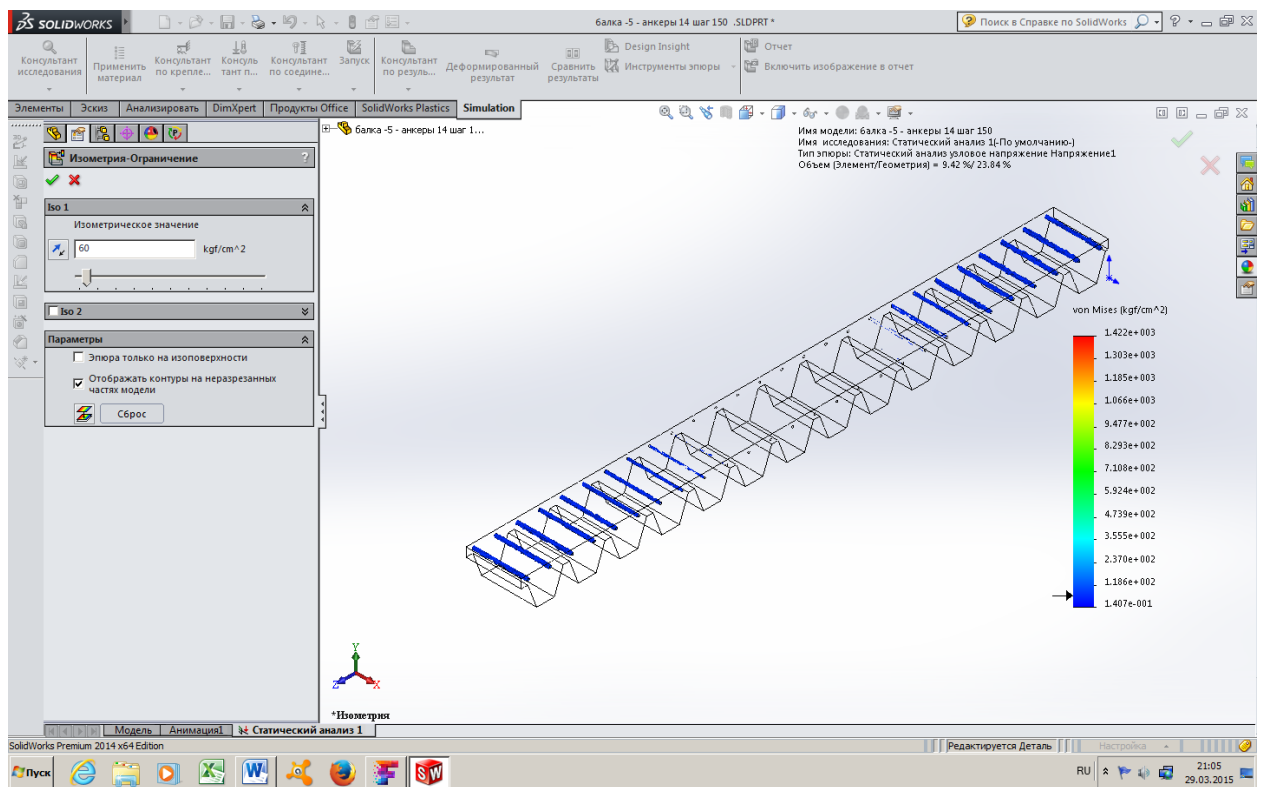


Figure 4.5 Crumbling stress in the concrete mass

The values of stress in the steel beam are presented in figure 4.6.

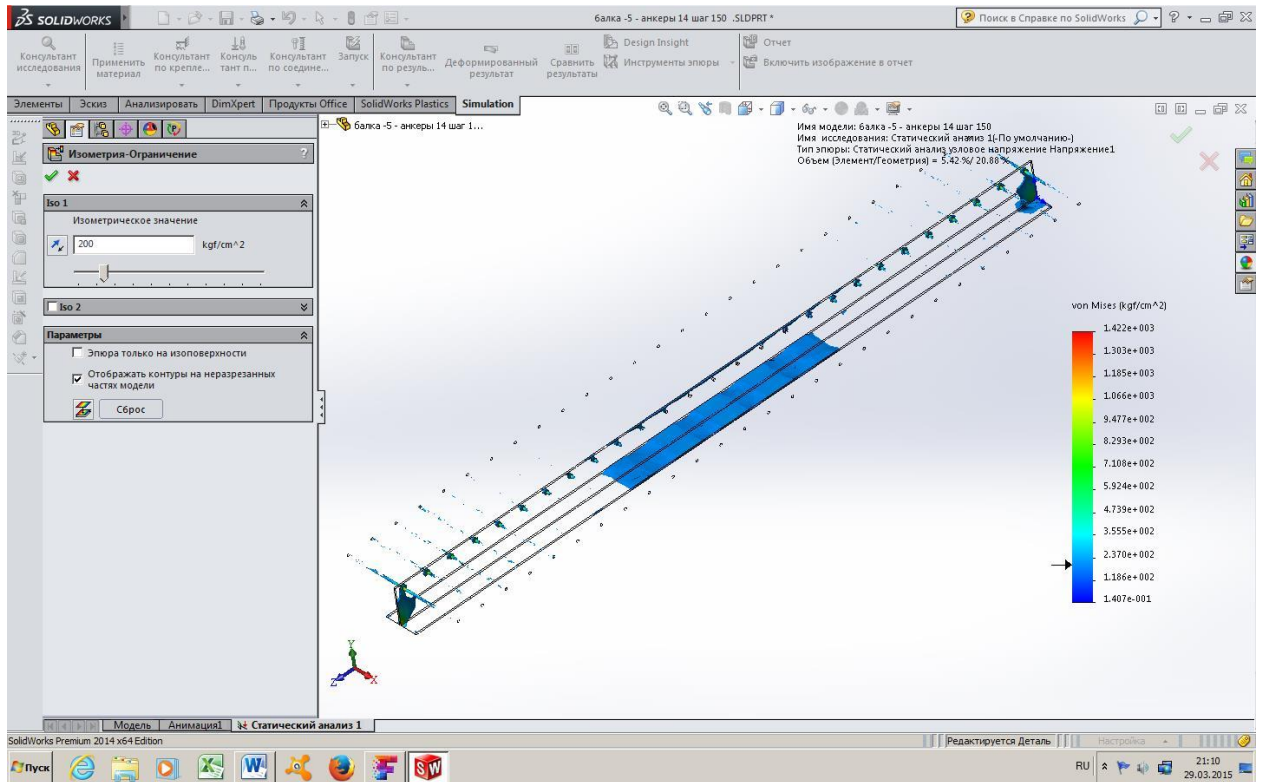


Figure 4.6 Stresses in the steel part of composite beam

The stresses in the concrete mass are illustrated in figure 4.7.

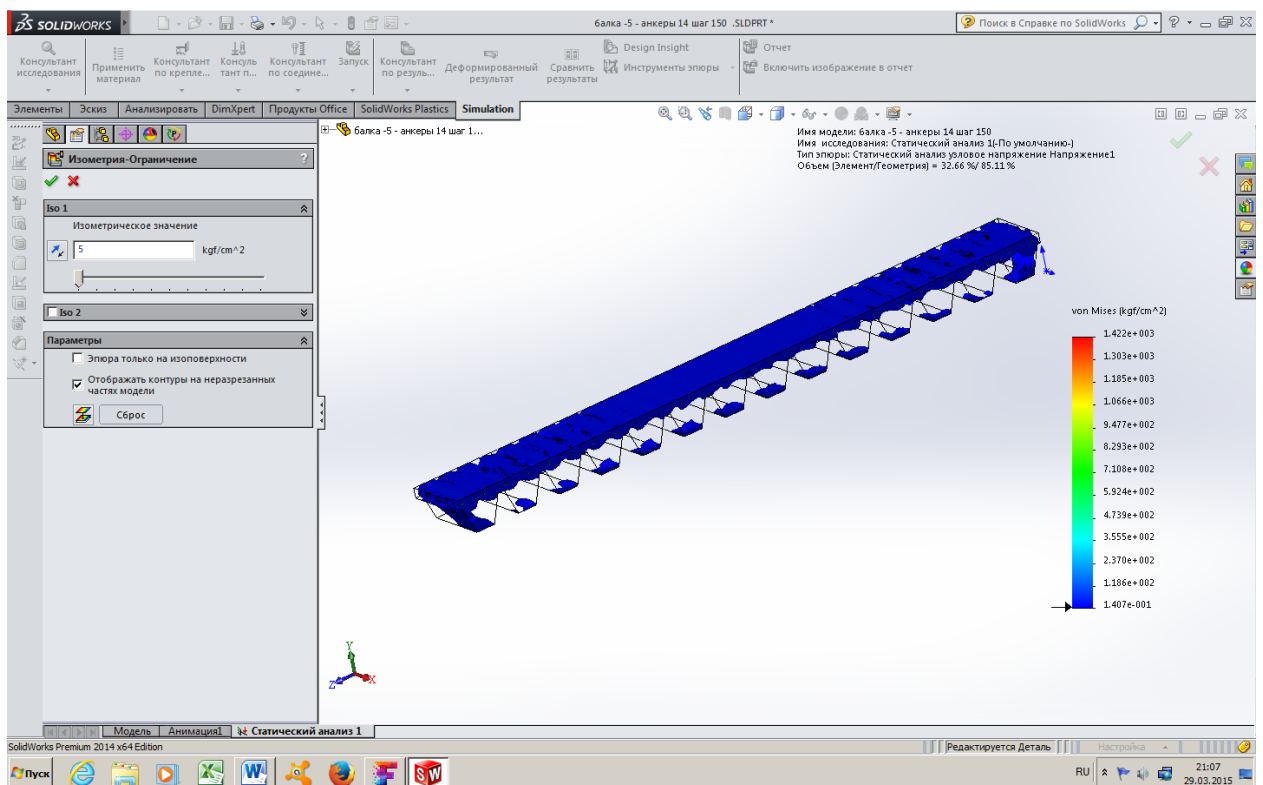


Figure 4.7 Stresses in the concrete part of composite beam

The results obtained by the Strip method and method of finite element are different by two times. It is presented in table 4.2.

Table 4.4 The comparison of results obtained by created Excel program and Solidworks model analysis (model version 1)

No	Parameter	Symbol/unit	Strip method	Method of finite element
1	Deflection	f_{II}, mm	3,62	1,9
2	Compression stress	$\sigma_{II}, N/mm^2$	70,8	23,8
3	Crumbing stress	$\sigma_t, N/mm^2$	2,6	3,5 - 10,4

It is explained by the distribution of the stresses that takes place because of the stress concentrator presented by anchors. It is not important how the load is applied on the slab (model version 1) or on the steel flange (model version 2). The results of 2 versions of calculation are shown in table 4.3.

Table 4.5 The comparison of results obtained by created Excel program and Solidworks model analysis (model version 2)

No	Parameter	Symbol/unit	Strip method	Method of finite element
1	Deflection	f_{II}, mm	3,62	1,8
2	Compression stress	$\sigma_{II}, N/mm^2$	70,8	25,0
3	Crumbing stress	$\sigma_t, N/mm^2$	2,6	3,5 – 10,4

The difference in three times between the values of crumbing stress shows that elastic supports that reduce a length of the anchor are not considered. It was decided to take a value of the design anchor length 0,25 of an actual anchor's length in order to get the similar stress value in the program as in the digital model. The anchor significant influence on the stress distribution is confirmed by the composite beam analysis where connection between concrete and steel parts is direct (model version 3). It was decided to create a model that is the most similar to Strip method model. The contact between concrete and steel part of the composite beam is a contact face between them. The deflection of the model is illustrated in figure 4.8.

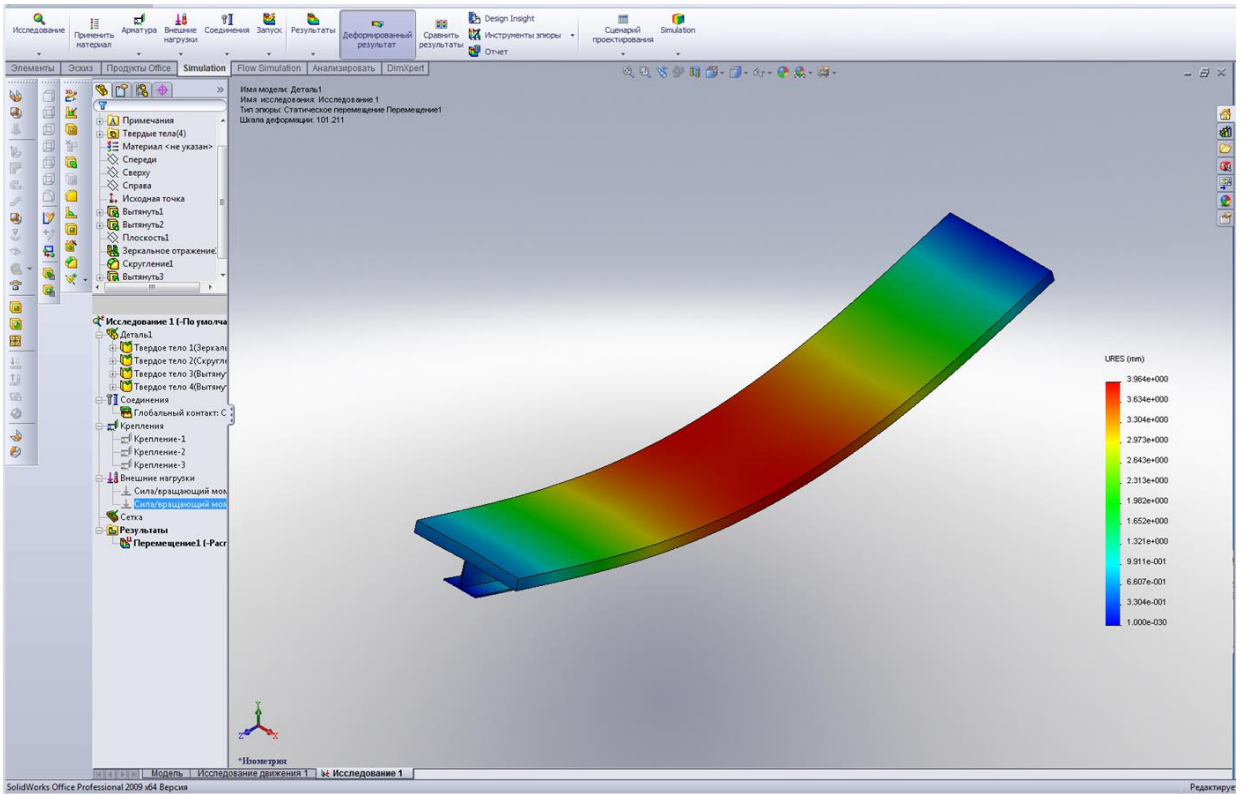


Figure 4.8 Deformation of the composite beam (model version 3)

There is the maximum value of compression and tensile stresses in the steel part of composite beam presented in figure 4.9 and shear stresses in the section near support – in figure 4.10.

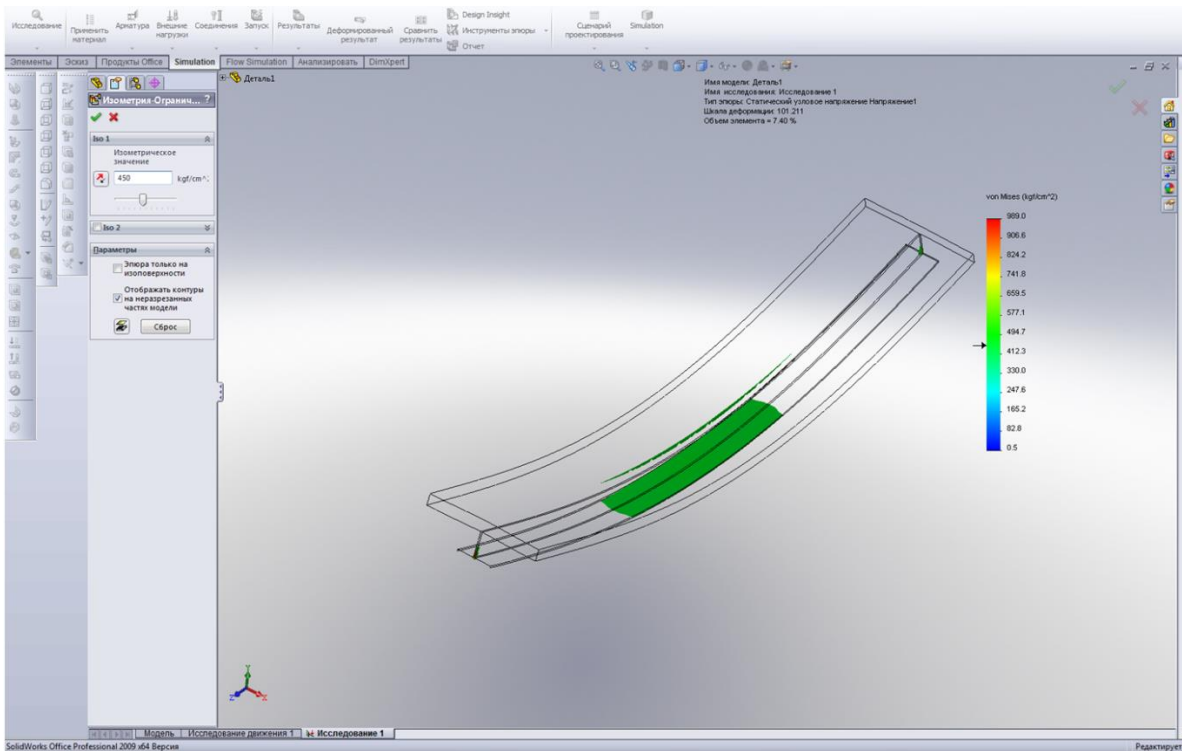


Figure 4.9 Compression and tensile stresses in the steel part of composite beam

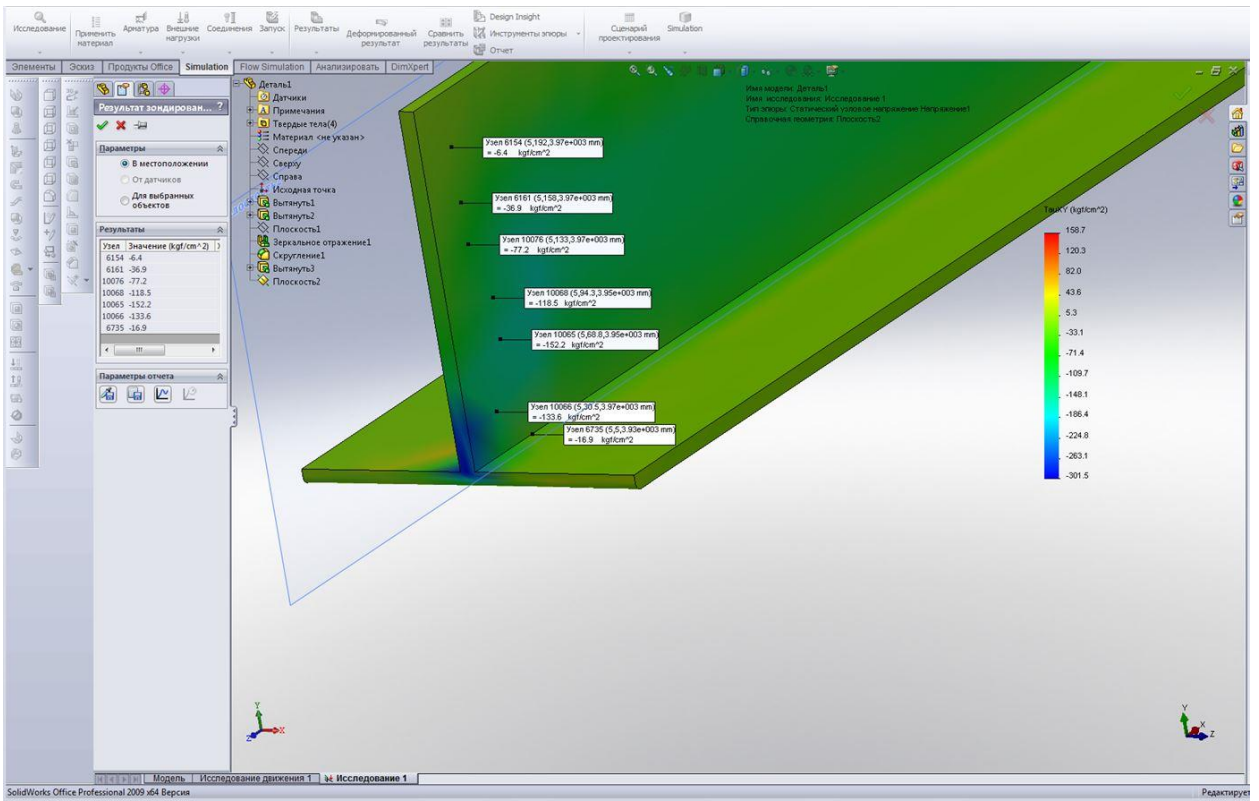


Figure 4.10 Shear stresses in the section near support

Stresses that equal to design resistance of the light-weight concrete D1200 are illustrated in figure 4.11.

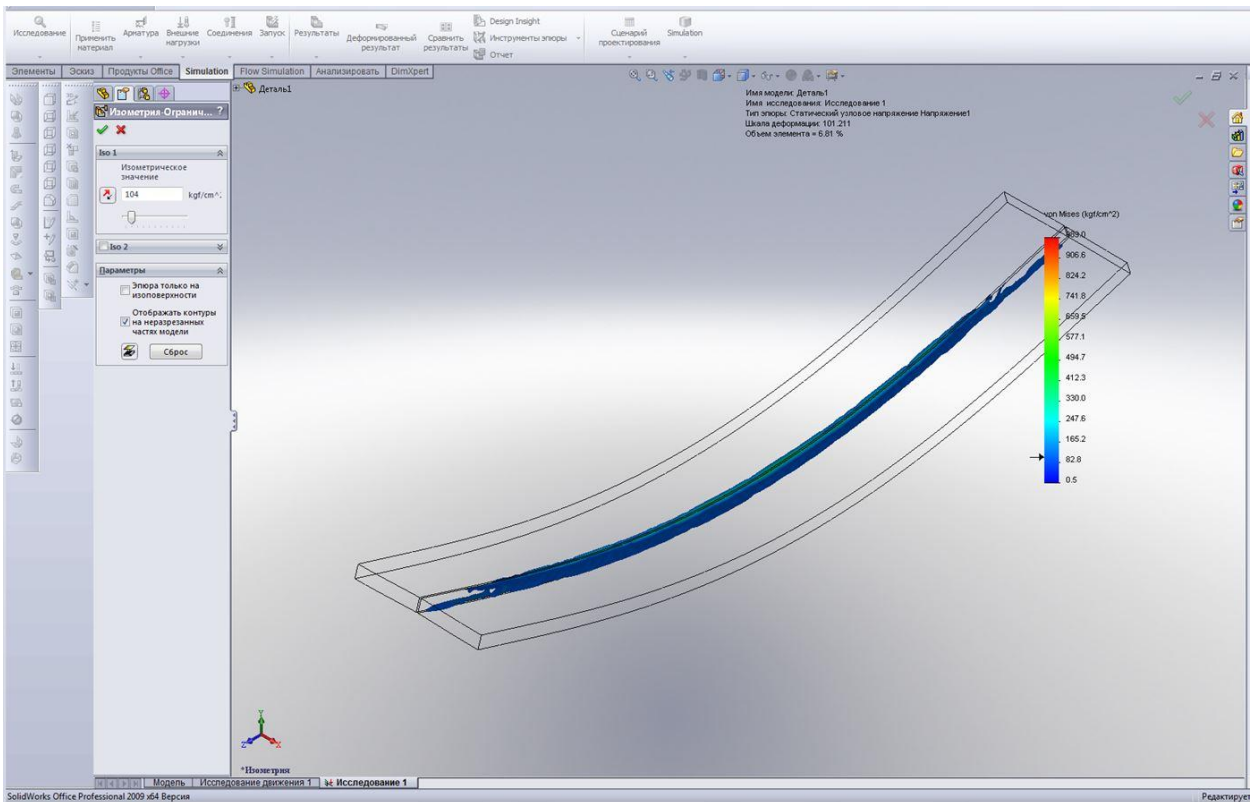


Figure 4.11 Critical stresses in the concrete mass

It is an area along the connection plane between steel and concrete parts of composite beam that means the concrete slab does not have a contact with the web of steel beam that confirms anchors are essential part to provide collaborative resistance of the structure.

The value of stresses and deformation of the composite beam model version 3 are similar with the Strip method. The results are presented in table 4.4.

Table 4.6 Comparison of results obtained by created Excel program and Solidworks model analysis (model version 3)

No	Parameter	Symbol/unit	Strip method	Method of finite element
1	Deflection	f_{II}, mm	3,62	3,96
2	Compression stress	$\sigma_{II}, N/mm^2$	70,8	49,0
3	Shear stress	$\tau_{II}, N/mm^2$	15,4	15,2

4.3. Ruukki test

The purpose of the test of T-section beam is to get an empirical value of load that causes the overall instability of the beam and the local instability of the web. The result is used in the design of the beam.

The length of the beam is $L_{test} = 4,2 m$. Steel C245 flange 10*200 mm and web 8*220 mm made of the same material as the flange. Welded seam has 6 mm leg according to GOST8713 and GOST14771.

The scheme of the test is presented in figure 4.12.

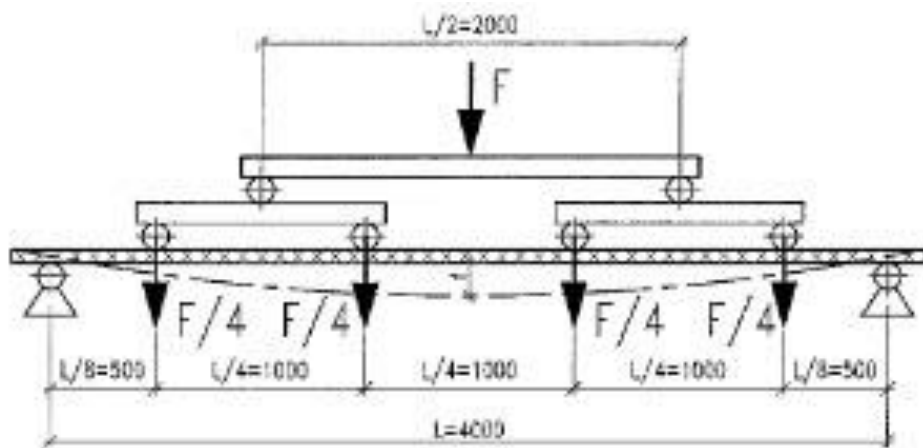


Figure 4.12 Scheme of the Ruukki test of steel beam

A critical load of the overall instability of the beam was obtained by loading pattern as in figure 4.13, b. the critical load $F_{cr} = 39,3 kN$ of the overall instability. In the case shown in figure 4.13, a. critical load of the local instability of the web was obtained. It is $F_{cr} = 78 kN$.



Figure 4.13 Load application: a. Web local instability. b. Overall beam instability.

Thus, in a construction stage there should be a load less than $F_{cr} = 39,3 \text{ kN}$ and $F_{cr} = 78 \text{ kN}$ on a beam in order to provide stability of the beam. See the application of the test result in 3.2.4 of the thesis.

5. CONCLUSION

As a result of this work the calculation program for steel and concrete composite beam calculation with the guidance for a designer was made. The program includes load estimation, static analysis of the structure on two stages, strength, stiffness and stability verification, design of welded connection of steel beam and verification of the connection between steel and concrete parts of the structure. Also the work comprises general guidance, requirements and restrictions for floor system in residential building that take place in Russian and European Building Codes. The consideration of requirements of Russian and European norms showed some difference between them related to building classification, safety factors, load estimation and fire safety of buildings.

There are definite steps in the algorithm of the flooring structure design. It is essential to provide enough level of fire protection, corrosion protection and, of course, strength, stiffness and stability. Design of appropriate device (structure) of the fire protection of a structure may be accomplished by means of thermal analysis in the program SolidWorks. Anyway, additional tests are necessary to approve the design proposal in order to accept the final decision of the envelope structure. According to norms, T-section steel beam can serve in non-aggressive and slightly aggressive zones. Corrosion protection of a beam is automatized in the Ruukki factory. It is presented by paint coating manufacturing process.

The calculation is complicated by two stages: construction and operation. On the first stage the steel beam is designed. On the second stage the steel and concrete composite beam is calculated. The total deflection of the composite beam is a sum of the steel beam of I stage and the composite beam of the II stage deflections. The total state of stress is also formed by construction and operation stage stresses.

The most critical thing, in my opinion, was to provide enough strong and stiff connection between steel beam and concrete slab. The weakest point is an interaction of anchor and foamed concrete. It was particularly checked on local crumbling of the concrete. The easier but more expensive technical decision is to apply I-beam instead of T-beam that provides guaranteed strength of the composite beam.

The created calculation algorithm was calibrated and confirmed by the computer-aided model analysis. Comparison of the created algorithm with computer-aided calculation is based on the parameters such as deflection, compression stress, crumbling stress and shear stress.

Finally, it should be noticed that Russian building codes need to be modified in compliance with contemporary construction. Building Codes have to be convenient for designers. The created composite beam calculation program is an example of improving work-conditions for the designers.

Figures

Figure 1.1 Steel beam with the concrete cover	5
Figure 1.2 Widespread composite flooring: concrete slab resting upon downstand steel beams.	5
Figure 2.1 Beam parameters for given thickness <i>tred</i> calculation.....	7
Figure 2.2 Section of the composite flooring system	8
Figure 2.3 Model for thermal analysis	9
Figure 2.4 Thermal analysis result made in SolidWorks.....	10
Figure 3.1 Steel and concrete composite beam.....	11
Figure 3.2 steel studs as an additional supporting of steel sheet.....	12
Figure 3.3 Steel and concrete composite beam.....	12
Figure 3.4 Steel and concrete composite beam.....	13
Figure 3.5 The scheme for static analysis of steel beam.....	16
Figure 3.6 Bending moment and shear force diagram	17
Figure 3.7 Steel beam section	17
Figure 3.8 Stress diagram of steel beam	19
Figure 3.9 Overall instability of steel beam	20
Figure 3.10 Flange local instability	21
Figure 3.11 Welded belt connection of tee steel beam.....	22
Figure 3.12 Section of steel and concrete composite beam.....	25
Figure 3.13 Equivalent Section of the composite beam	26
Figure 3.14 Scheme of anchor installation	29
Figure 4.1 Deflection of steel beam	31
Figure 4.2 Digital model of the composite beam.....	33
Figure 4.3 Digital model grid of finite element.....	34
Figure 4.4 Deformation of the composite beam (model version 1)	35
Figure 4.5 Crumbling stress in the concrete mass.....	35
Figure 4.6 Stresses in the steel part of composite beam.....	36
Figure 4.7 Stresses in the concrete part of composite beam	36
Figure 4.8 Deformation of the composite beam (model version 3)	38
Figure 4.9 Compression and tensile stresses in the steel part of composite beam	38
Figure 4.10 Shear stresses in the section near support	39
Figure 4.11 Critical stresses in the concrete mass	39
Figure 4.12 Scheme of the Ruukki test of steel beam	40
Figure 4.13 Load application: a. Web local instability. b. Overall beam instability.	41

Tables

Table 2.1 Material parameters	8
Table 2.2 Specification of the flooring structure	8
Table 3.1 Safety factor in compliance with SP 20.13330.2011	14
Table 3.2 Load estimation on the I stage	15
Table 3.3 Load estimation on the II stage	15
Table 3.4 Unit loads of material, structure and factor	16
Table 3.5 Geometrical characteristics of steel beam	18
Table 4.1 Comparison of steel beam calculations	31
Table 4.2 Dependence between composite beam strength and plate thickness	32
Table 4.3 Dependence between anchor step and plate thickness	32
Table 4.4 The comparison of results obtained by created Excel program and Solidworks model analysis (model version 1)	37
Table 4.5 The comparison of results obtained by created Excel program and Solidworks model analysis (model version 2)	37
Table 4.6 Comparison of results obtained by created Excel program and Solidworks model analysis (model version 3)	40

Charts

- Chart 4.1 Strength of composite beam
- Chart 4.2 Anchor step

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APPENDICES

APPENDIX 1 Automatized design of the composite beam “Calculation program”

Instruction of the program

Program for composite beam calculation	Guideline to use the program
<p>The program was created with compliance with following building codes, manuals and guidelines:</p> <ol style="list-style-type: none"> 1. EN 1994: Design of composite steel and concrete structures – Part 1-1: General rules and rules for buildings. 2004. 2. EN 1994: Design of composite steel and concrete structures – Part 1-2: General rules – structural fire design. 2004. 3. E1 The National building code of Finland “Fire safety of buildings”. Refutation and guidelines. 2002. Helsinki. 4. STO 0047-2005 Steel and concrete composite floor structure with monolithic slab and steel profiled sheet. 2005. Moscow. 5. Manual of Scientific Research Institute of Concrete and Reinforced concrete “Steel and concrete composite floor structure with monolithic slab and steel profiled sheet”. 1987. Moscow. 6. RCN 64-88: Design of composite steel and concrete structures. 1988. Belorussia. 7. SP 20.13330.2011 Loads and factors. 2011. Moscow. 8. SP 16.13330.2011 Steel Structures. 2011. Moscow. 9. SP 63.13330.2012 Concrete and reinforced concrete structures. 2012. Moscow. 10. SP 54.13330.2011 Multi-compartment residential buildings. 2011. Moscow. 11. SNiP 21.01.97 Fire safety of buildings and works. 1989. Moscow. 12. Strength and deformability of steel and concrete composite structures, Zamalev F.S. 2013. Kazan. 13. Technical specification of steel profiled sheet T153-120L-850. Ruukki Rus. 14. GOST 380-94 Common quality carbon steel. 1998. Moscow. 15. GOST 19281-82 Rolled steel with improved strength. 1989. Moscow. 16. Unified specification of metal-roll. 2011. Ruukki Rus. 17. Preliminary specification of concrete 18. TKP 45-5.03-16-2005 Steel and concrete structures. General rules 19. Manual to design steel anchors for reinforced concrete structure made by Scientific Research Institute of Concrete and Reinforced concrete 1984 	<p>I. Initial data</p> <ol style="list-style-type: none"> 1. Enter structure parameters, material characteristics, preliminary steel beam and composite beam cross-sectional parameters, anchor parameters, weld connection parameters and steel profiled sheet characteristics. Initially parameters of profiled sheet T153 has already been added. 2. Specific information like coefficients that are necessary only for steel beam or composite beam calculation is added in corresponding section. 3. In the structure parameters graph the design values of bending moment and shear force of the I and II stage are automatically defined. <p>II. Calculation</p> <ol style="list-style-type: none"> 1. Load estimation is accomplished based on preliminary design, Ruukki specification and Russian building codes. Although structure of the flooring system varies from case to case, average version of the flooring system is taken for the load estimation. As a result, normative and design value of load per unit of length is obtained for I and II stage calculation. 2. On the I stage Steel beam is checked on strength, stiffness, overall stability, local stability of flange, weld connection. The overall stability is accomplished based on the Ruukki test of steel beam. As a result parameters of the beam, weld materials and procedure are designed. 3. On the II stage Composite beam is checked on strength, stiffness, anchor shift, local concrete crumbling. Overall stability of the composite beam is provided by the reinforced concrete slab with steel profiled sheet. As a result, anchor parameters and its disposition are obtained that are essential in order to provide II. Report <p>Report presents material characteristics, composite beam parameters, weld characteristics and procedure and anchor parameters that are designed.</p> <p>The program was made by Aleksel Pashko with Ruukki Rus assistance in 2015.</p>

Initial data

Initial Data				
I. Structure parameters				
Nº	Parameter	Symbol	Value	Comment
1	Beam span	L, m	4,0	The maximum beam span.
2	Beam interval	l, m	3,0	The step range is between 3 m and 3,6 m.
3	Width of load area	B_{load}, m	3,3	Include a half of the beam step from each side.
4	Design Bending moment	M, kNm	23,0	I stage; the value is calculated automatically depending on load.
5	Design Shear force	Q, kN	23,0	I stage; the value is calculated automatically depending on load.
6	Design Bending moment	M, kNm	24	II stage; the value is calculated automatically depending on load.
7	Design Shear force	Q, kN	24	II stage; the value is calculated automatically depending on load.
II. Material characteristics				
Nº	Parameter	Symbol	Value	Comment
1	Steel Elastic modulus	E_{st}, MPa	210 000	According to the table 63 in SNiP II-23-81; steel elastic modulus
2	Design resistance of steel	R_{st}, MPa	320	According to the table 51* in SNiP II-23-81; steel C345
3	Design resistance of steel	R_{st}, MPa	470	According to the table B.5 in SP 16.13330.2011; steel C345
4	Material safety coefficient	γ_m	1,025	According to the table 3 in SP 16.13330.2011; steel C345
5	Density of steel	$\rho_{st}, kg/m^3$	7 850	According to the table 63 in SNiP II-23-81; steel density
6	Concrete Elastic modulus	E_{bc}, MPa	10 000	According to the table 6.11 in SP 63.13330.2012; light-weight concrete, D=1200, B12.5
7	Design resistance of concrete	R_{bc}, MPa	10,2	According to Experience Report; foamed concrete D1200
8	Density of concrete	$\rho_{bc}, kg/m^3$	1 200	According to technical specification
IV. Steel cross-section				
Nº	Parameter	Symbol	Value	Comment
1	Web height	h_w, mm	220	Add the value according to preliminary design.
2	Web thickness	t_w, mm	10	Add the value according to preliminary design.
3	Flange height	h_f, mm	200	Add the value according to preliminary design.
4	Flange thickness	t_f, mm	10	Add the value according to preliminary design.
5	Cross-sectional area	A_{st}, cm^2	42,0	It is calculated automatically.
7	Moment of Section	S_{st}, cm^3	136,1	It is used to determine max shear stress.
6	Moment of inertia	I_{st}, cm^4	2 274,5	It is calculated automatically.
7	Moment of resistance	W_{st}, cm^3	137,8	It is calculated automatically.
8	Vertical coordinate of centre of mass	v_{st}, cm	5,50	Add from the Tee section characteristics
V. Composite cross-section				
Nº	Parameter	Symbol	Value	Comment
1	Design slab thickness	h_f, m	0,067	The slab thickness above the steel profiled sheet.
2	Slab average thickness	h_f, m	0,164	The value is used to calculate the slab weight.
3	Design slab width	b, m	0,75	Determine in compliance with 8.1.11 in SP 63.13330.2012 and Ruukki experience analysis.
4	Cross-sectional area	A_{bc}, cm^2	496	It is calculated automatically.
5	Moment of inertia	I_{bc}, cm^4	1 855	It is calculated automatically.
6	Vertical coordinate of	v_{bc}, cm	16,2	Distance depends on reduction coefficient and calculated

Load estimation

I. Safety factor			
Nr	Load type	Safety factor γ_t	Comment
1	Dead weight of steel structure	1,05	
2	Dead weight of reinforced concrete structure	1,3	table 7.1 SP 20.13330.2011
3	Dead weight of structure component made on site	1,3	
4	Dead weight of structure component made on factory	1,2	
5	Load of assemblage	1,2	Table 8.2 of SP 20.13330.2011
6	Temporary working (useful) and temporary partition loads	1,3	8.2.2 of SP 20.13330.2011

II. Material, Structure and factor unit load			
Nr	Load	Value	Comment
1	Sustained load of additional reinforcement.	5	% of concrete weight
2	Assemblage load, kPa	0,5	
3	Floor covering kN/m^2	0,9	Unit weight of the element
	Width of the layer, mm	7,5	
4	Cap kN/m^2	22	Unit weight of the element
	Width of the layer, mm	30	
5	Gypsum cardboard kN/m^2	0,1	Unit weight of the element
	Amount of layers	2	
6	Temporary working (useful) load	1,50	According to SP 20.13330.2011
7	Temporary partition load	0,50	According to STO 0047-2005

I stage Load								
Load type	Nr	Name	Normative value, kPa	Safety factor γ_t	$q_w, kN/m$	$q, kN/m$	Comment	
Constant load - dead weight	1	Steel beam	-	1,05	0,33	0,35	Safety coefficient is considered.	
	2	Steel profiled sheet	0,12	1,05	0,38	0,40		
	3	Reinforced concrete	1,97	1,3	6,50	8,46		
Temporary load	4	Sustained load of additional reinforcement	0,10	1,05	0,33	0,34		
	5	Assemblage load	0,5	1,2	1,65	1,98		
					Sum	8,86	11,52	

II stage Load								
Load type	Nr	Load	Normative value, kPa	Safety factor γ_t	$q_w, kN/m$	$q, kN/m$	Comment	
Constant load - dead weight	1	Floor covering	0,0675	1,3	0,022275	0,03		
	2	Cap	0,66	1,3	2,178	2,83		
	3	Gypsum cardboard	0,20	1,2	0,66	0,79		
Temporary load	4	Temporary working (useful) load	1,50	1,3	4,95	6,44		
	5	Temporary partition load	0,50	1,3	1,65	2,15		
					Sum	9,46	12,23	

I stage – Steel beam design

I stage. Steel beam calculation						
1. Strength verification - SP 16.13330.2011 p.8.2						
$\sigma_I = \sigma_{max}$	=	16,72	<	$R_y * \gamma_s$	=	32 kN/sm^2
$\tau_I = \tau_{max}$	=	1,38	<	$R_s * \gamma_s$	=	18,56 kN/sm^2
2. Stiffness verification (Service ability limit state)						
$f_I = f_{max}$	=	6,18	<	f_{pos}	=	13,33333333 mm
3. Verification of Local stability of flange						
$\sigma_{flange} = \sigma_{max}$	=	0,16	<	$R_y * \gamma_s$	=	32 kN/sm^2
M_{fl}	=	0,026				kNm
$W_x f^l$	=	16,67				sm^3
4. Verification of weld						
$R_{wz} \leq R_{wf} \leq R_{wz} * \frac{\beta_z}{\beta_f}$						
R_{wz}	=	212	<	R_{wf}	216	< $R_{wz} * \frac{\beta_z}{\beta_f} = 302,14$
$\frac{T}{n * k_f * \beta_f}$	=	24,63	<	$R_{wf} * \gamma_c$	=	215,6 MPa
$\frac{T}{n * k_f * \beta_z}$	=	17,24	<	$R_{wz} * \gamma_c$	=	212 MPa



II stage – Composite beam design

II stage. Composite beam calculation					
1. Strength verification					
$\sigma_{II} = \sigma_{max}$	=	5,79	<	$R_y * \gamma_s$	= 32 kN/sm^2
$\sigma_{total} = \sigma_I + \sigma_{II}$	=	22,50	<	$R_y * \gamma_s$	= 32 kN/sm^2
$\tau_{II} = \tau_{max}$	=	1,31	<	$R_s * \gamma_s$	= 18,56 kN/sm^2
$\tau_{total} = \tau_I + \tau_{II}$	=	2,69	<	$R_s * \gamma_s$	= 18,56 kN/sm^2
2. Stiffness verification (Service ability limit state)					
f_{II}	=	3,02	<	f_{pos}	= 13,333333 mm
$f_{total} = f_I + f_{II}$	=	9,20	<	f_{pos}	= 16 mm
3. Anchor shift verification $\sigma_{shift} < R_s^{crumbling}$					
$a_{max}^{support}, mm$	=	244,54		a_{max}^{span}, mm	= 489,07863
$a^{support}, mm$	=	150		a^{span}, mm	= 300
Check the decision:					
$T_{anch}^{support}, kN$	=	19,69	<	T_R^{anch}, kN	= 32,1
T_{anch}^{span}, kN	=	19,69	<	T_R^{anch}, kN	= 32,1
Comment:					
Near support (1/4 span) the anchor step is two times less than in the middle part of beam (2/4 span) is a force that acts on the double anchor because web crumbling is checked.					

4. Local Concrete crumbling verification SP 63.13330.2012 p.8.1.43-44

$$\sigma_c, \frac{kN}{sm^2} = 0,76 < R_{loc,c} \frac{kN}{sm^2} = 1,02$$

Report

Report					
I. Structure characteristics					
№	Parameter	Symbol	Value	Comment	
1	Beam span	l, m	4,0	The maximum beam span.	
2	Beam interval	l, m	3,0	The step range is between 3 m and 3,6 m.	
II. Steel parameters					
3	Web height	h_w, mm	220	Fill in all gaps in according to steel beam calculation.	
4	Web thickness	t_w, mm	10		
5	Flange height	h_f, mm	200		
6	Flange thickness	t_f, mm	10		
7	Design resistance of steel	R_s, MPa	320	According to the table 51* in SNIP II-23-81; steel C345	
8	Density of steel	$\rho_{st}, kg/m^3$	7 850	According to the table 63 in SNIP II-23-81; steel density	
III. Concrete parameters					
9	Concrete Elastic modulus	E_c, MPa	10 000	According to the table 18 in SNIP 2.03.01-84; light-weight concrete, D=1200, B12.5	
10	Design resistance of concrete	R_b, MPa	10,2	According to Experience Report; foamed concrete D1200	
11	Density of concrete	$\rho_{m}, kg/m^3$	1 200		
IV. Anchor parameters					
12	Diameter	d, mm	14		
13	Anchor length	l, mm	370	in according to 5.13-5.14 in SNIP	
14	Design resistance of steel	R_s, MPa	365	Steel A III	
15	Step near support	a^{near}, mm	150		
16	Step in span	a^{in}, mm	300		
 (Ctrl) ▾					
CR-2939.01 ТП					
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