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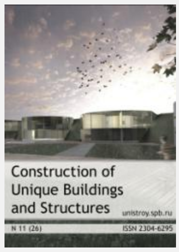

Concrete shrinkage effects in composite beams

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ABSTRACT

The text analyses stresses in composite beam, as a result of time - dependent concrete slab shrinkage, where in addition to analytical solution of stress distribution, numerical solution is given as well, using structural software SAP2000 v 16. For linear behavior of the headed stud anchors, whose stiffness for varying diameters is determined using separate finite element model, a comparison between numerical and analytical solutions of stress distribution is shown. Shrinkage strain is determined using EC2. For purposes of the finite element model, this strain is converted into equivalent temperature load.

Contents

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Introduction

Shrinkage is time - dependent irreversible deformation which causes the reduce in volume of unloaded concrete due to loss of water. Factors with the most influence on the value of shrinkage strain are the ambient humidity, the dimensions of the element and the composition and quality of concrete.

In composite beams, due to compatibility conditions, shrinkage of concrete part of the cross - section (concrete slab) results in an unfavourable redistribution of stresses. When losing water, concrete tends to shrink, in other words deformation of shortening tends to happen. However, steel part of the cross - section prevents concrete of deforming freely. As a result of restrained deformation, tensile stresses appear in concrete slab. Due to equilibrium, compressive stresses in the steel part of cross - section must appear as well [1].

The aim of this paper is to form a simple numerical model which will sufficiently accurate represent distribution of stresses in composite beam due to shrinkage of concrete slab. Regarding that, comparison between analytical and numerical obtained solution for a different points in time is shown [1-22].

Properties of composite beam

Cross - section of the composite beam consists of the steel part - IPE 400 and the 12 cm thick concrete slab. Based on the expressions given in EC2, creep coefficients which were used to determine the effective Young's modulus of elasticity are calculated [2].

Table 1. Properties of the concrete and the steel part of cross - section

Concrete		Steel	
C25/30; f_{ck}[N/mm^2]	25	S355; f_y [N/mm^2]	355
Young's modulus of elasticity E_{cm} [N/mm^2]	31 000	Young's modulus of elasticity E_a [N/mm^2]	21 000
Slab thickness h_c [cm]	12	Area A_a [cm^2]	84,50
Effective width b_{ef} [cm]	300	Moment of inertia I_a [cm^4]	23 130

Table 2. Properties of the composite beam cross - section in time "t"

Point in time t [days]	7	28	1000	∞
Creep coefficient φ	0	1,2	2,7	3,0
Effective Young's modulus of elasticity of concrete [N/mm^2]	31 000	14 091	8 378	7 750
$n=E_a/E_b$	6,77	14,90	25,07	27,10
Area A_i [cm^2]	615,93	326,06	228,12	217,36
Moment of inertia I_i [cm^4]	78 918	68 347	60 817	59 640

Table 3. Properties of the headed stud anchor

Tensile strenght	f_u=450 N/mm^2
Young's modulus of elasticity E [N/mm^2]	21 000
Diameter Φ [mm]	16 and 25
Height [mm]	100
Longitudinal spacing [cm]	14,6

Analytical solution

Shrinkage is unavoidable in material such as concrete. As it was said in introduction, because the deformation of concrete is restrained it results in tensile stresses in concrete slab and compressive stresses in the steel beam. In other words, composite beam is self - stressed and no external reactions are induced at the supports. The value of these stresses depend on the stiffness of the cross - section. Another time-dependant property of concrete is creep. Creep is time - dependent increase in deformation as a result of sustained stress. The effects of creep are being taken into account through effective Young's modulus of elasticity, in other words by reducing the stiffness of the cross - section. This reduction in stiffness leads to decrease in value of stresses caused by shrinkage.

In a relatively dry ambient the expected value of shrinkage strain of unrestrained concrete slab is 0.03% of the slabs length or higher. However, in composite beam the expected value of shrinkage strain is lower because concrete slab can't deform freely [3].

In Eurocode 2, the expression for determining the value of shrinkage strain are given as a function of the relative humidity (RH), the notional size of the cross - section (h_o), the concrete strenght class and the type of the cement. The total shrinkage strain is composed of the drying shrinkage strain and the autogenous shrinkage strain: [2]

$$\varepsilon_{cs} = \varepsilon_{cd} + \varepsilon_{ca} \quad (1)$$

Normal hardening cement CEM 32.5 for a concrete strength class C25/30, relative humidity RH=70% and the notional size of the cross - section h_0=11,54 cm the values of the shrinkage strain of concrete for which solidification process began after one day (according to Eurocode 4) are given in next table:

Table 4. Values of shrinkage strain

Point in time	ε_{cd} [10^{-6}]	ε_{ca} [10^{-6}]	ε_{cs} [10^{-6}]
t=7 days	15,41	40,56	55,97
t=28 days	24,49	132,55	157,04
t=1000 days	37,43	357,86	395,29
t=∞	37,50	375,51	413,01

After the values of the shrinkage strain have been determined, distrubution of stress along the cross - section height for selected points in time is calculated on the assumption of the full shear connection i.e. there is no slip between concrete slab and steel beam. For a given point in time, properties of idealised cross - section are calculated taking into account corresponding creep coefficient. Obtained stress distribution is shown in Figure 1.

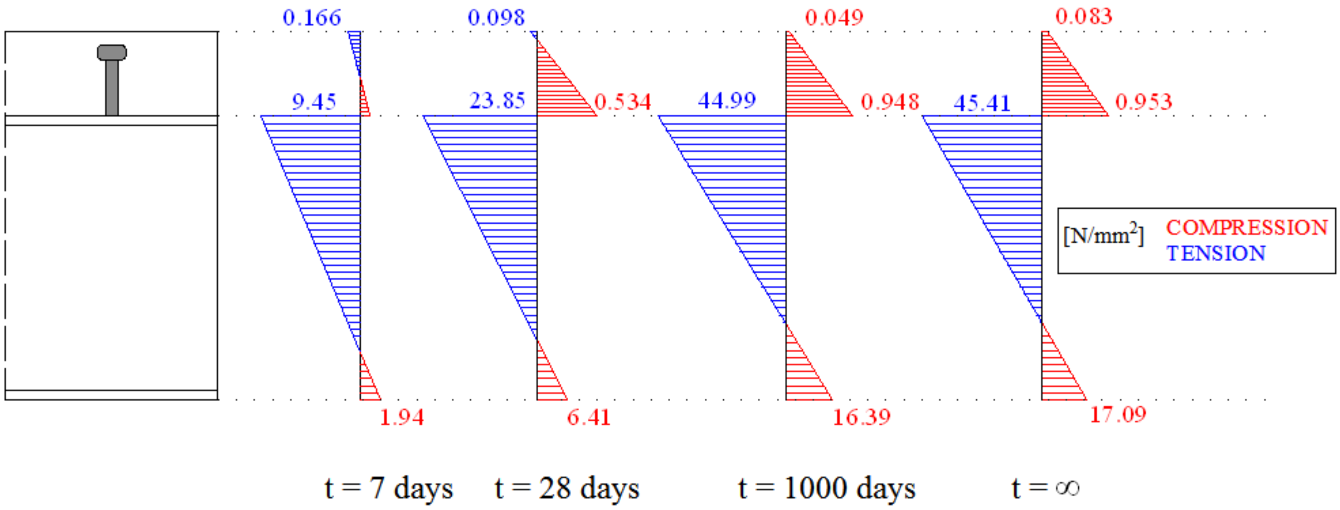

Figure 1. Distrubution of stresses σ_x [N/mm^2] along the cross - section height

It should be noted that these stresses are only important for serviceability limit state because they cause deflection which can be significant. [3] In ultimate limit state due to plastification, for classes of steel cross - section 1 and 2, the steel beam no longer offers resistance to concrete shrinkage. As a result, the stresses caused by shrinkage of concrete slab disappear.

Numerical model

Following elements were used for numerical model of composite beam:

- SHELL elements – rib and flange of steel beam,
- SHELL / SOLID elements – concrete slab,
- LINK elements – headed stud anchors.

Concrete slab can be modelled with SHELL elements whics have 4 nodes and 4 Gauss integration points or with SOLID elements which have 8 nodes and 8 Gauss integration points. [4] In general, for slabs with simple geometry and constant thickness, as in this model, it is more practical to use SHELL elements. SOLID elements can be used for slabs with complex geometry.

Along the *"x"* axis, the model is divided into 81 elements and in every node one LINK element which simulates headed stud anchor is associated. Calculation is conducted for linear elastic LINK elements with varying values of stiffness which depend on the diameter of the headed stud anchor. The stiffness of LINK elements for diameters Φ16 and Φ25 mm are determined on numerical model shown in 4.1. Models with finite element mesh are shown in Figures 2 and 3.

In this example because linear elastic behaviour is assumed, headed stud anchors could have been modelled with FRAME elements as well. However, LINK elements were used instead with which eventual nonlinear analysis could be conducted.

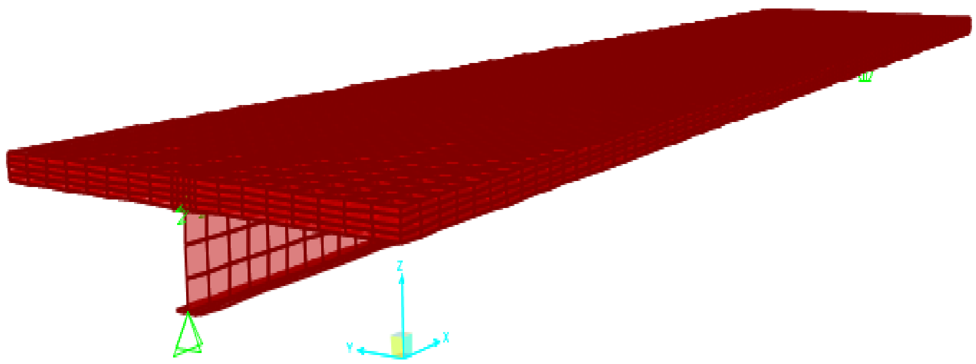

Figure 2. Numerical model – variant I (concrete slab modelled with SOLID elements)

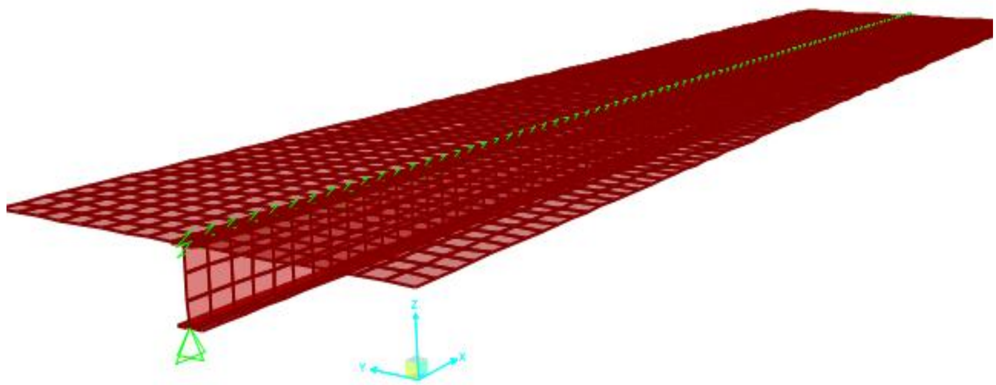

Figure 3. Numerical model – variant II (concrete slab modelled with SHELL elements)

Effects of shrinkage are simulated as a negative temperature load which is needed to cause the appropriate value of total shrinkage strain. Equivalent temperature load is shown in table 5.

Table 5. Equivalent temperature load

Point in time	Shrinkage strain ε_{cs} [10^{-6}]	Temperature [°C]
t=7 days	55,97	-5,60
t=28 days	157,04	-15,70
t=1000 days	395,29	-39,53
t=∞	413,01	-41,30

Stiffness of headed stud anchors

Equivalent stiffness of headed stud anchors is determined on numerical model shown in Figure 4. The length of the composite beam that is being modelled is equal to the longitudinal spacing of the headed stud anchors which is 146 mm. Concrete slab is modelled with SOLID elements while headed stud anchor is modelled with FRAME element. Finite element mesh 14x14x12 (X,Y,Z) is generated. Results are shown in table 6.

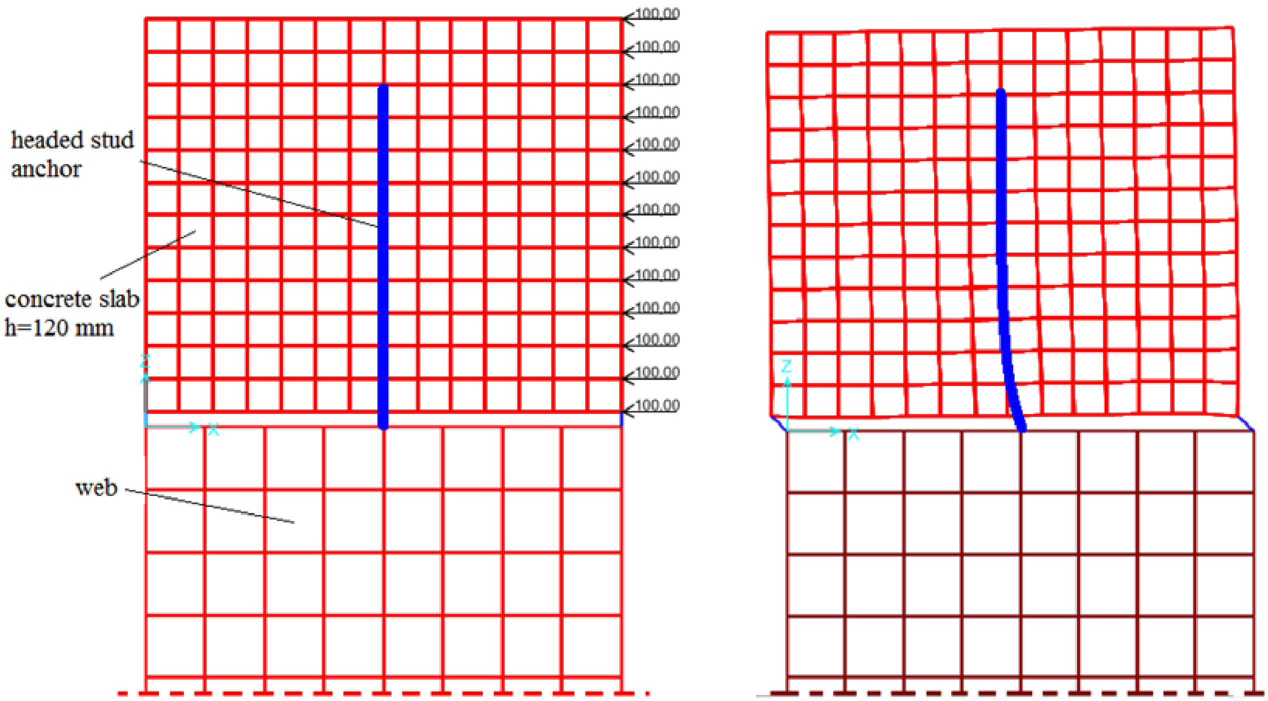

Figure 4. Numerical model for determining equivalent stiffness of headed stud anchor (left) and deformed configuration (right)

Table 6. Equivalent stiffness of headed stud anchor determined on numerical model

Headed stud anchors	Equivalent stiffness [kN/m]
Φ16mm	260 010
Φ25mm	336 500

Comparison of results

Below is given a comparison of analytical and numerical obtained stresses σ_x, for headed stud anchors of different stiffness and for different points in time. The comparison is given for the top and the bottom flange of steel beam and is shown on diagrams log t – $\sigma/\sigma_{analytical}$.

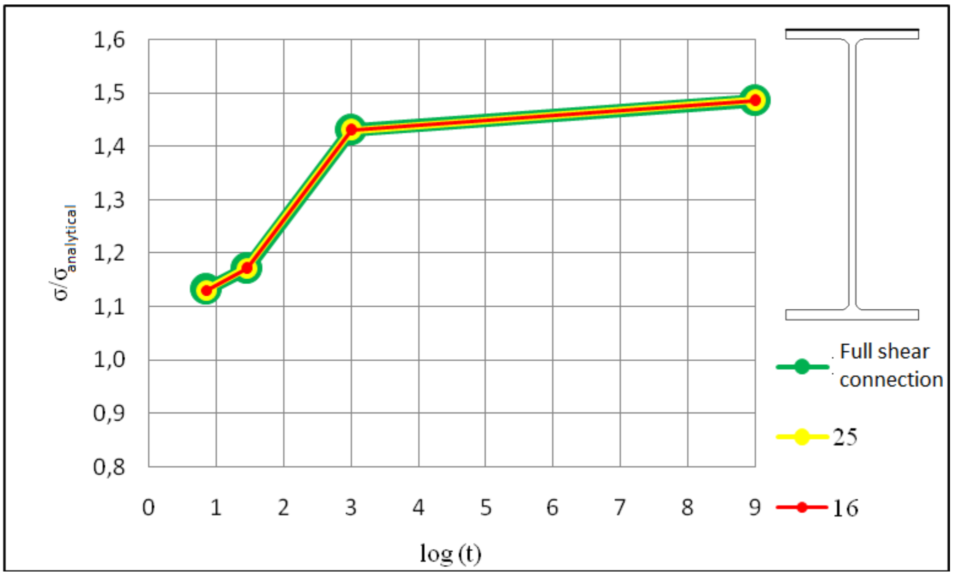

Figure 5. Comparison of numerical model with analyitical solution (top flange)

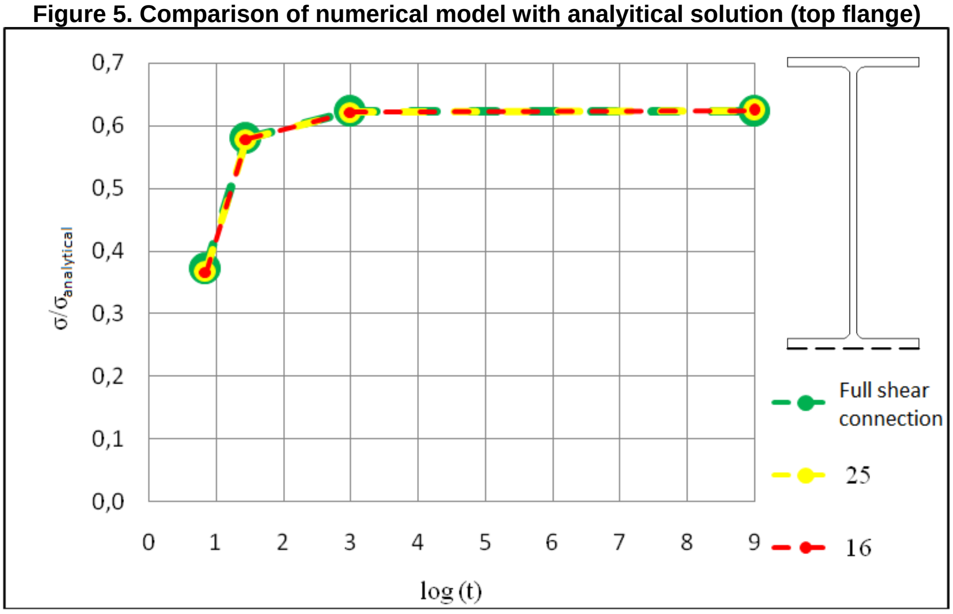

Figure 6. Comparison of numerical model with analyitical solution (bottom flange)

Conclusion

In this paper, a relatively simple numerical model of composite beam along with determining of equivalent stiffness of headed stud anchors of different diameters using commercial softwares like SAP 2000 is shown.

Effects of shrinkage of concrete slab on the state of stresses in composite beam is analysed analytically in order to test the numerical model. The results given in chapter 5. show that there is almost no difference in the value and distribution of stresses along the height of the cross - section whether the headed stud anchors are modelled as absolutely rigid or with stiffness determined in chapter 4.1. Absolutely rigid headed stud anchor were used to model composite beam with full shear connection in which the slip between concrete slab and steel beam is zero. By varying the diameter i.e. stiffness of headed stud anchor the known fact is confirmed: The diameter of headed stud anchor principally doesn't have an effect on the degree of the shear connection i.e. partial shear connection is very difficult to achieve by using cylindrical ductile headed stud anchor. For that purpose the transverse bracings are being used.

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Эффект усадки бетона в композитных балках

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АННОТАЦИЯ

В статье анализируется напряжение в составной балке, усадка бетонной плиты во временной зависимости. В дополнение к аналитическому решению напряжения опытных образцов, выполнено численное решение с помощью программного комплекса SAP2000 V 16. Для линейного поведения элементов различных диаметров, жесткость определяется с использованием конечно-элементной модели, сравнение численных и аналитических решений распределения напряжений показано. Деформация усадки определяется с помощью EC2. В целях модели из конечных элементов, этот штамм преобразуется в эквивалентную нагрузку температуры.

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