AN ESTIMATION OF A CROSS-SECTION STRESS STATE IN A PRIMARY TUNNEL LINING FROM STEEL CONCRETE

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INTRODUCTION

The composite lining cross section built from shotcrete and steel elements is the most common structure to prop up the ground shortly after a work excavation. The shotcrete affiliates steel elements up with the ground. The steel elements provide an immediate response to the ground yielding. As shotcrete solidifies with time the cross section becomes stiffer and the lining response increases. A second shotcrete strata commonly sprayed later enhances further cross section stiffness. This composite cross section displays a time developing modulus of elasticity. A variable modulus of elasticity allows a relief of the primary ground stress round the work excavation at lower lining response. That way the ground yielding is allowed while ground doesn't collapse. The paper presents an application of a method based on the theory of cooperating rings and a computer program HOMO, both developed to determine the modulus of elasticity of composite cross sections. A following example of composite cross sections made from shotcrete and steel (Fig. 1) exhibits the method principle and its outputs.

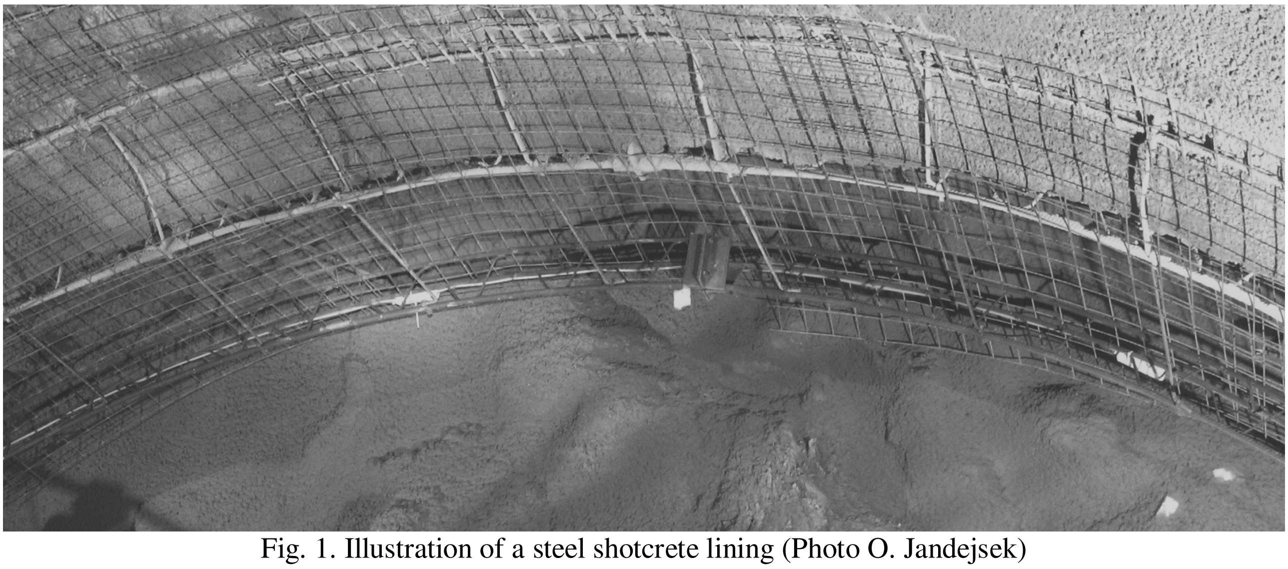


Fig. 1. Illustration of a steel shotcrete lining (Photo O. Jandejsek)

METHOD OF COOPERATING RINGS

This method is developed according to the analytical solution for calculating the stress-strain state in circular multi-layer ring compound that was formulated by prof. Bulytchev (Bulytchev, 1982). The layers are of two arts. The first one is homogeneous made up only from shotcrete. The second is heterogeneous and it combines two materials shotcrete and steel, or steel and free space in simple layer (Fig. 2).

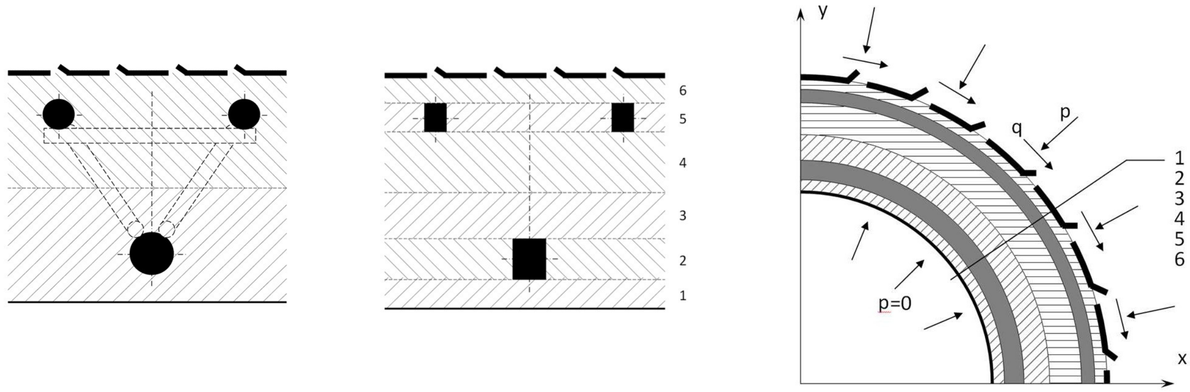


Fig. 2 The partition of a steel shotcrete cross-section for individual rings

A radial ground load on lining (p) is allotted among particular rings by radial stress transfer coefficients that are set up for each interface between adjacent rings in accordance with their stiffness parameters (Poisson's ratio, modulus of elasticity, ring thickness) while keeping the continuous radial deformation on interface between of two adjacent rings. The radial stress on lining inner surface equals zero. Procedure to calculate the elastic modulus of the multi-layer ring compound is divided into two sub-steps:

- single heterogeneous ring homogenization (shotcrete - steel, steel - free space)
- multi-layer ring compound homogenization (homogeneous rings). It starts on the inner ring. This and its adjacent ring are merged into new one. The merger process repeats until all rings are incorporated in only one ring.

The outputs of homogenization are the value of modulus of elasticity (E_{HOMO}) that stands up for deformation parameter of lining cross-section of the multi-layer ring compound and for each particular ring a set of redistribution coefficients of tangential stresses in shotcrete and steel). The tangential stress coefficients execute the conversion of stress state from homogenized cross-section to actual material of the particular rings. Full analysis of the method of cooperating rings and computational relations to determine radial stress transfer coefficients, modulus of elasticity (E_{HOMO}) and redistribution coefficients of tangential stresses of shotcrete and steel are on display in the journal TUNNEL 4/2010 (Vojtasik, Hrubesova, Mohyla, Stankova, 2010). A scheme of how the method is supposed to be in operation states the diagram on Fig. 3..

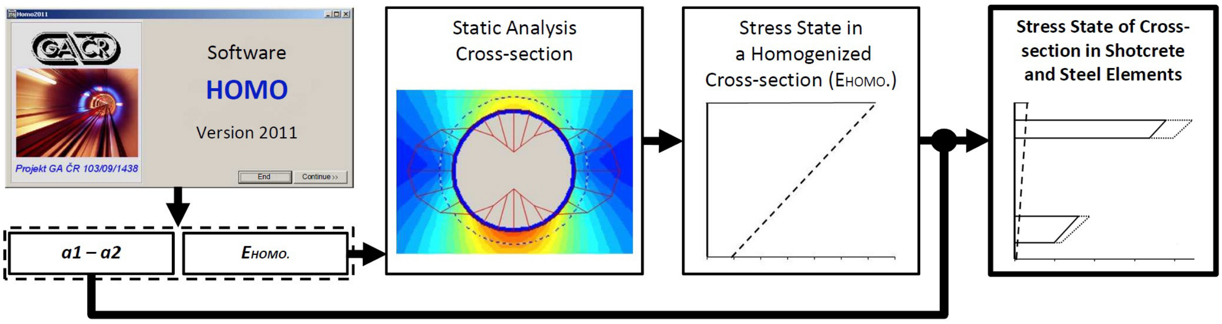
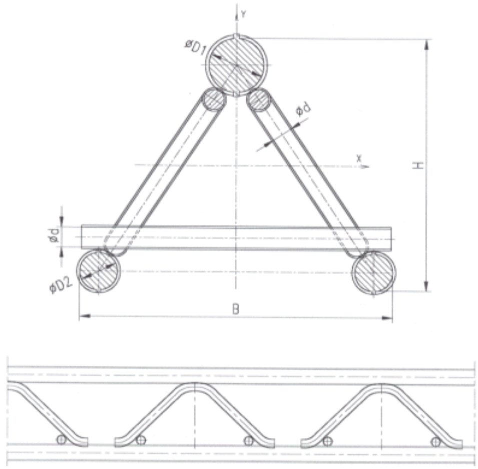


Fig. 3 An application scheme of the cooperating rings method for stress state estimation in the steel concrete cross section (E_{HOMO} – elasticity modulus of a homogenous cross-section; a_1, a_2 – redistribution coefficients of tangential stress for steel elements and shotcrete)

EXAMPLE

The example illustrates a calculation of stress state in the concrete and steel cross section built from the steel arch girder ASTA 95 (Fig. 4) embedded in shotcrete. The shotcrete is sprayed in two layers with the same thickness. There is a time shift of twelve hours between the execution of both layers. The total cross section thickness come to 0,20 m.



TYP	D1 [mm]	D2 [mm]	d [mm]	H [mm]	B [mm]	S $[cm^2]$	G [kg/m]	Ix $[cm^4]$	Wx $[cm^3]$	Iy $[cm^4]$	Wy $[cm^3]$
ASTA 95	32	22	12	149	182	15.65	16.42	591	79	493	54

Fig. 4 The steel arch girder ASTA 95

The calculation is carried out for three construction stages (Fig. 5). The first one states for the time of 12 hours after spraying the first layer and before spraying the second one. The modulus of elasticity of first shotcrete layer is 13600 MPa. The second stage displays the situation the 24 hours after spraying the first one. This time the modules of elasticity of shotcrete layers are 14600 MPa the first and 13600 MPa the second. The last stage represents the situation after 28 days when the shotcrete modules development in both layers terminate and the both retain the same value of 20300 MPa.

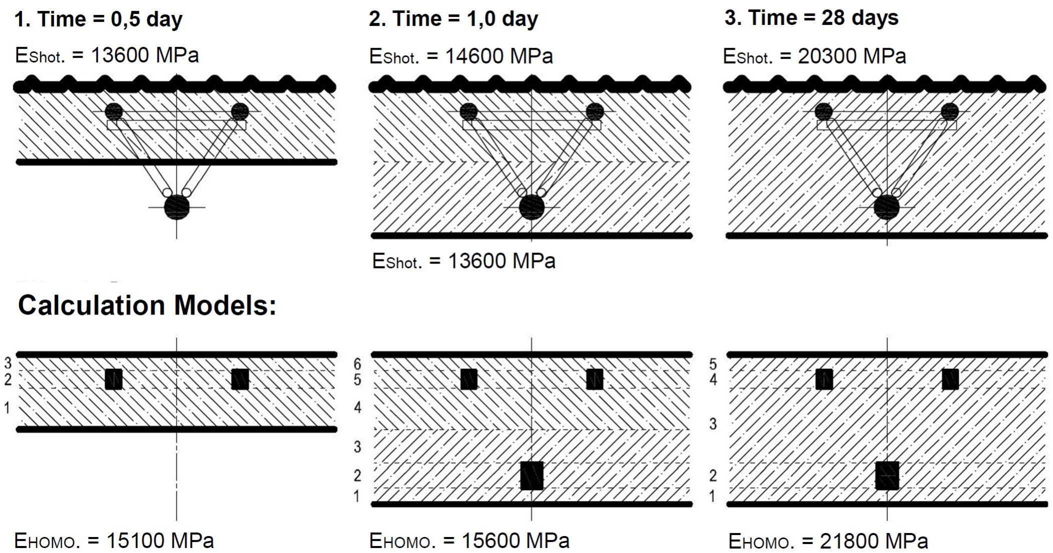


Fig. 5 The construction stages

RESULTS

For the three stages the program HOMO sets the respective values of modules (E_{HOMO}) of homogenized cross sections and a package of redistribution coefficients of tangential stresses for steel and shotcrete. The table No. 1 summarises all of the results. The elastic modules of the homogenized cross section (E_{HOMO}) are put in a FEM computational model of an underground work of the circular shape as deformation characteristics of steel concrete lining. In this example the lining structure is exposed to geo-static stress and each construction stage takes one third of it which doesn't likely match the real condition but way of lining load is chosen only for this method demonstration sake.

Table 1: E_{HOMO} and the redistribution coefficients of tangential stresses (a_1-inner ring surface, a_2-outer ring surface)

Construction Stage 1 (Time = 0,5 day)							
Ring	Thickness [m]	Eshot.	EHOMO.	Shotcrete		Steel	
				a1	a2	a1	a2
1	0,048	13600	15100	0,900	0,900	-	-
2	0,022			0,900	0,900	13,838	13,837
3	0,030			0,901	0,902	-	-

Construction Stage 2 (Time = 1,0 day)							
Ring	Thickness [m]	Eshot.	EHOMO.	Shotcrete		Steel	
				a1	a2	a1	a2
1	0,020	13600	15600	0,871	0,87	-	-
2	0,032			0,87	0,869	13,423	13,403
3	0,048			0,87	0,869	-	-
4	0,048	14600		0,931	0,932	-	-
5	0,022			0,932	0,932	13,216	13,218
6	0,030			0,933	0,935	-	-

Construction Stage 3 (Time = 28 days)							
Ring	Thickness [m]	Eshot.	EHOMO.	Shotcrete		Steel	
				a1	a2	a1	a2
1	0,020	20300	21800	0,931	0,930	-	-
2	0,032			0,930	0,929	9,611	9,597
3	0,096			0,930	0,930	-	-
4	0,022			0,930	0,931	9,468	9,470
5	0,030			0,931	0,933	-	-

The planar course of state tress in homogenized section is then converted by redistribution coefficients of tangential stresses (a_1, a_2) for actual materials. The graphs on figure 6 show conversion of the planar course of stress across the section to the stress state on the heterogeneous steel concrete section.

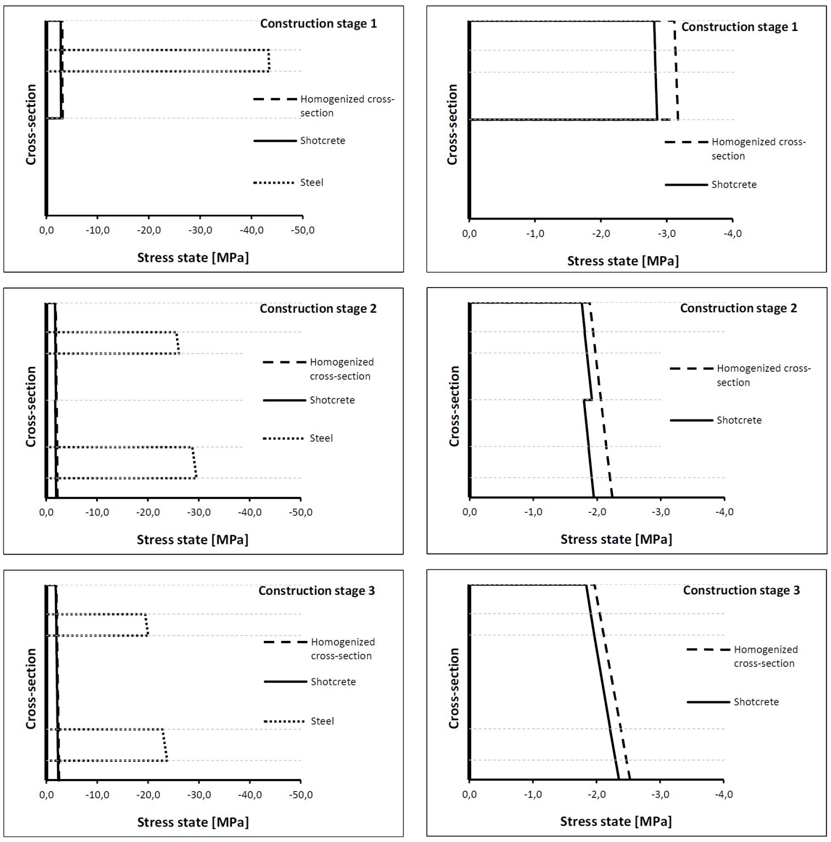


Fig. 6 The stress state development in section during the construction stages

CONCLUSIONS

The method of cooperating rings is suitable to state the transient yield of the heterogeneous steel concrete cross-section during the periods until it terminates after the lining construction completion.
The E_{HOMO} exemplifies the heterogeneous steel concrete cross-section of tunnel lining and the redistribution coefficients of tangential stresses provide stress calculation in this section.
This method should be considered as a simplified solution giving readily deformation parameters and stress state of a complex structure that all are possible to get more exactly but with much more effort.

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