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NON-HOMOGENEOUS FINITE STRIP METHOD APPLICATION

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Summary: *Non-homogeneous finite strip method is applied to material nonlinear analysis of simply supported 20m long reinforced concrete folded plate structure. Finite strips are divided into cells along their length and layered throughout the thickness. The viscoelastoplastic constitutive matrix is developed using the rheological-dynamical theory. The results of analysis are compared with the results of linear analysis. The types of non-homogeneous finite strip method convergence of the stresses by the number of strips and by number of series terms are shown.*

Keywords: *Non-homogeneous finite strip method, rheological-dynamical theory, reinforced concrete, folded plate structure*

1. INTRODUCTION

Reinforced concrete folded plate structures (RCFPS) have significant nonlinear behaviour. In earlier work [1] the authors showed how the geometric nonlinear analysis of these structures can be performed using the harmonic coupled finite strip method (HCFSM) [2]. Also, the impact regarding the neglecting of these effects on the results of RCFPS with various lengths is presented in Ref. [3].

This paper describes a numerical analysis of a feasible RCFPS, based on inelastic relationship between stress and strain of the constituent materials. The influence of the effects of material nonlinearity on RCFPS is shown through comparison with the results of the linear analysis on the same structure.

Performed analysis ilustrates the application of non-homogeneous finite strip method (NHFSM) with viscoelastoplastic constitutive matrix for one- and two-dimensional state of stress in concrete and rebar developed using the rheological-dynamical theory. The

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NHFSM, which is described in the previous paper of this Proceedings[4], is programmed in Wolfram Mathematica.

2. DESCRIPTION OF THE RCFPS AND METHODS OF ANALYSIS

The application is performed on the simply supported 20m long RCFPS under a vertical uniformly distributed load. The structure is made of concrete C35/45 and steel B400. The RCFPS geometry, finite strip mesh, and zones with different layer pattern for material nonlinear analysis are shown in Fig. 1.

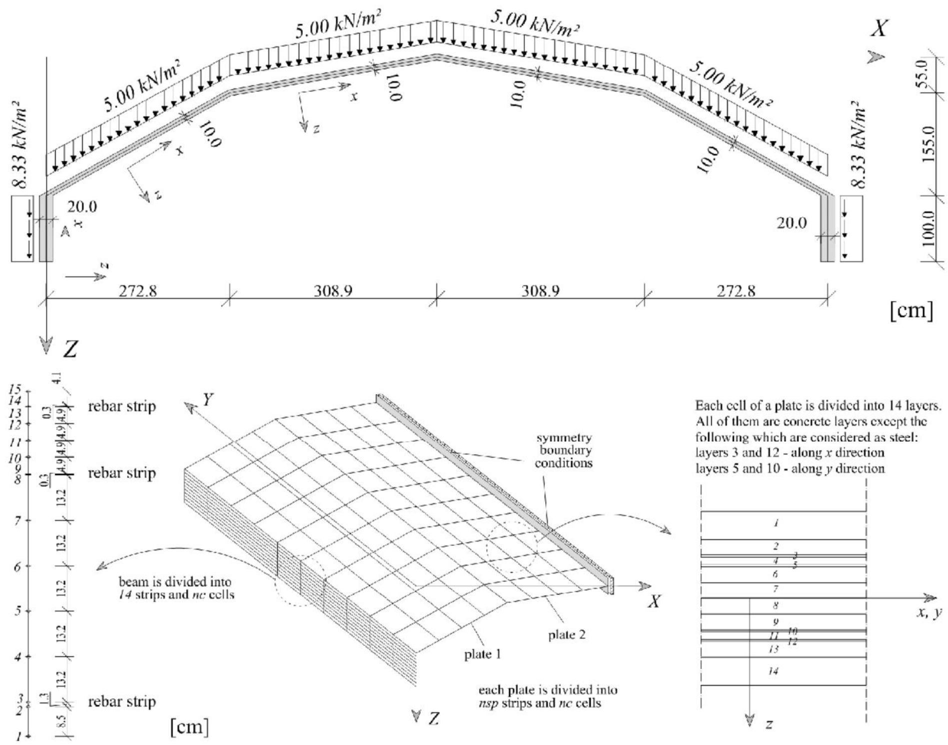


Figure 1. Cross-section, load and discretization scheme of analysed RCFPS

Structure is designed according to linear homogenous FSM solution. The properties of the concrete and steel are specified in Table 1. The rebar characteristics are summarized in Table 2 and Table 3.

The load in Fig. 1 is multiplied by factor 1.8 in order to reach the limit state of structure. This load intensity causes yield stress in the bottom steel layer of the beam's central cross-section, which is furter considered as rebar failure. All presented results are shown for this load level. The tension stiffening effects of concrete (after the cracking at 2.3 MPa) are not included in the computation, but they should be taken into account when geometrically nonlinear problems are investigated.

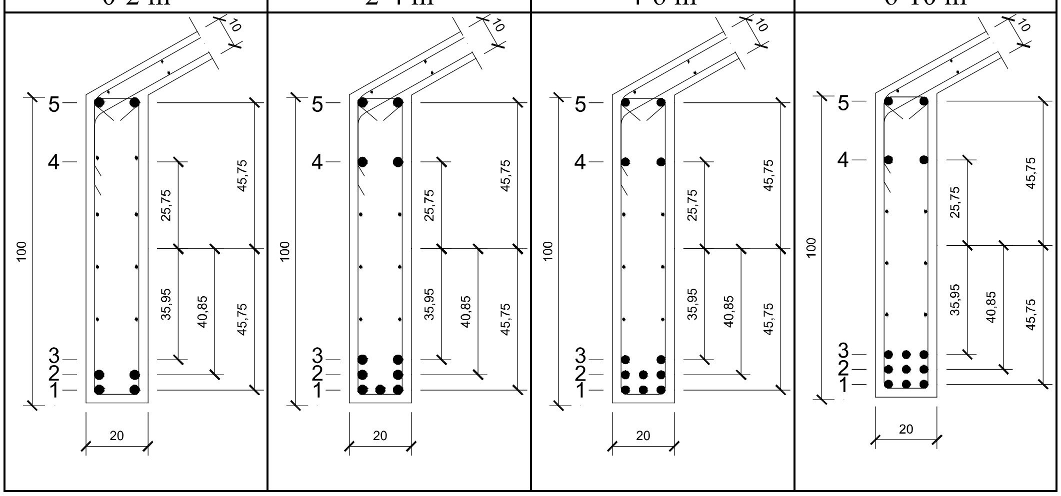
[4] Milašinović, D.D., Borković, A., Goleš, D.: Rheological-dynamical approach in non homogeneous finite strip method

Table 1. Problem parameters for the RCFPS

Concrete C35/45	**Steel B400**
Mechanical material properties	
Secant modulus, E_{cm}=34000 MPa (ε_E =0.3 ‰) Poisson's ratio, μ=0.18 Elasticity stress, σ_E=13.2 MPa Ult. comp. strength, f_{cm}=43 MPa (ε_{c1}=2.25 ‰) Ult. tens. strength, f_{tk}=2.3 MPa	Design modulus, E_S=210000 MPa (ε_E =1‰) Poisson's ratio, μ=0.33 Elasticity stress, σ_E=187 MPa Characteristic yield stress, f_{yk}=400 MPa Ult. tens. strength, f_{tk}=500 MPa
Rheological-dynamical material properties	
Initial modulus of elasticity, E_H=52000 MPa Constant of the column, K_φ=0.0402	Initial modulus of elasticity, E_H=629000 MPa Constant of the column, K_φ=0.01068
RDA modulus: $E_R = \dfrac{E_H}{1+\sigma_{RDA}K_\varphi}$, RDA working diagram: $\sigma_{RDA} = \dfrac{1}{2K_\varphi}\left(\sqrt{1+4K_\varphi E_H \varepsilon}-1\right)$, Creep coefficient: $\varphi = \sigma_{RDA}K_\varphi$, Poisson's ratio: $\mu(\varphi) = \left[1-\dfrac{1}{\sqrt[4]{0.0006\left(\dfrac{\varphi}{1+\varphi}\right)+1}}\right]\cdot 1000$.	

Table 2. Concrete and rebar details for the RCFPS's beam

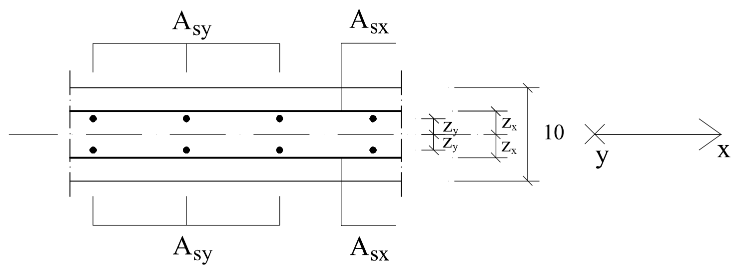
0-2 m	2-4 m	4-6 m	6-10 m



After exhaustive convergence tests, the following discretization is adopted: beam is divided into 14 and each plate into *nsp*=12 strips. Five series terms and *nc*=10 cells are used. Cross-section of plates has ten concrete and four steel layers numbered as shown in Fig. 1. In the beam, strips 8 and 13 represent rows 4 and 5 of rebar, while strip 2 represents sum of rows 1, 2, and 3 of rebar that are illustrated in Table 2 and Fig. 1. Norm of residual strains is set to be less or equal to δ=0.001.

Table 3. Rebar details for the RCFPS's plates

	Longitudinal direction							
	0-4 m				4-10 m			
Transverse direction	A_{sx} (cm^2/m)	z_x (cm)	A_{sy} (cm^2/m)	z_y (cm)	A_{sx} (cm^2/m)	z_x (cm)	A_{sy} (cm^2/m)	z_y (cm)
1st plate	2.8	2.5	2.8	1.9	1.4	2.5	1.4	1.9
1st, 2nd and 3rd quarter of 2nd plate	1.4	2.5	1.4	1.9	1.4	2.5	1.4	1.9
4th quarter of 2nd plate	3.9	2.44	1.4	1.9	3.9	2.44	1.4	1.9



3. RESULTS OF ANALYSIS

The crack pattern of the RCFPS's beam reflects the pure flexural failure of concrete with cracks opening only in longitudinal direction. In contrast to this the NHFSM plates model leads to crack patterns shown in Fig. 2 simultaneous in both directions. It is obvious that all crack patterns are realistic.

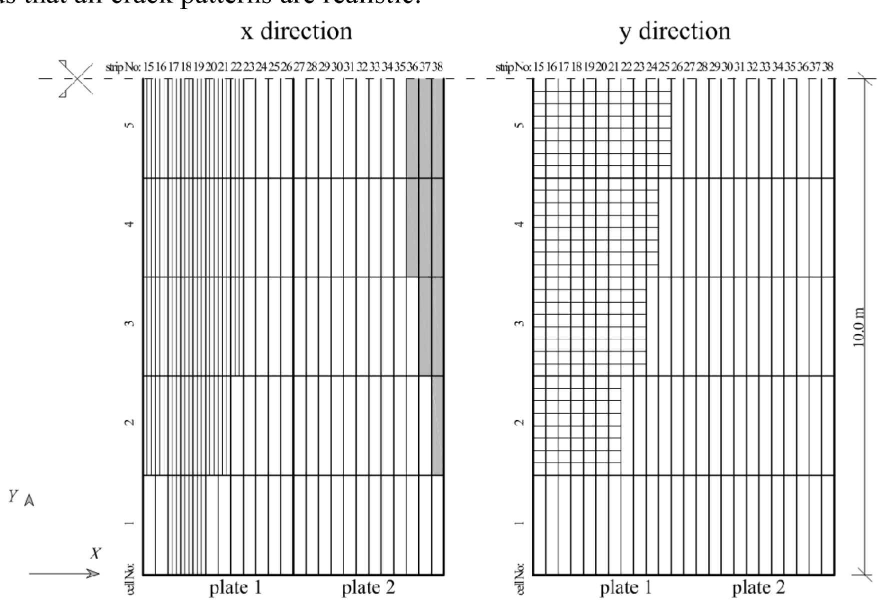


Figure 2. Plan view of bottom layer of plates: Numerically computed crack pattern (white-elastic; hatched-cracked; gray-plastic)

Fig. 3 illustrates the variation in the moments M_x and forces N_x along the transverse central line for material linear and nonlinear approach. Prominent influence of material nonlinear effects is obvious.

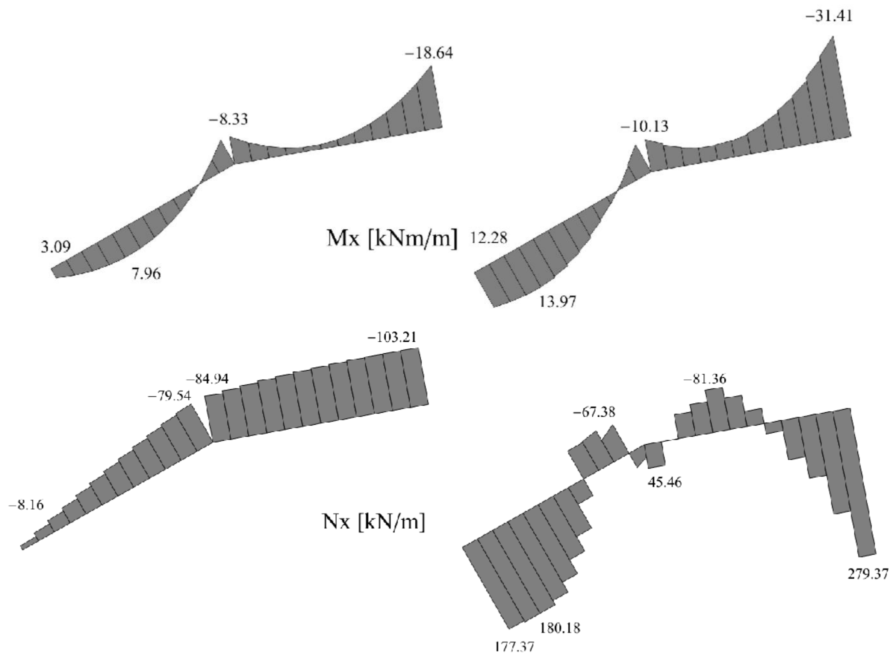


Figure 3. Variation of moment M_x and force N_x along the transverse central line: left - elastic solution; right - last iteration solution

Fig. 4 illustrates the types of NHFSM convergence of the stresses by number of strips in plates. It is apparent that forty strips in plates are required for the stress in steel layer to converge to the exact answer. On the other hand the stress value in concrete in this case converges at a slower rate.

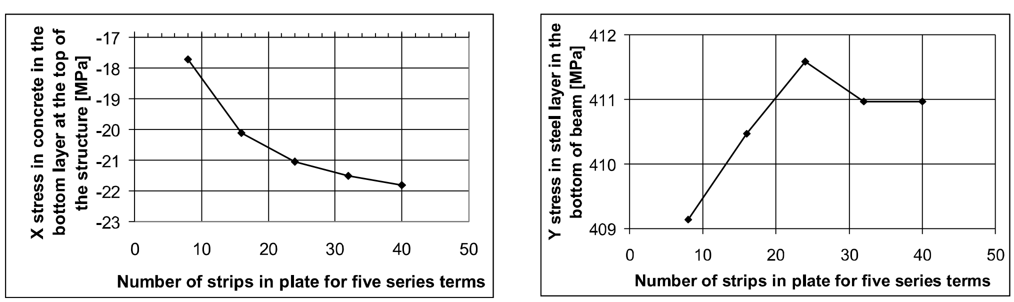


Figure 4. Types of NHFSM convergence by number of strips in plates: left – compression stress σ_x in titled concrete layer; right – tension stress σ_y in titled steel layer

The rate of convergence for stresses by number of series terms was also analyzed. As it is shown in Fig. 5, although nonlinear behaviour is very prominent, only seven terms are required for the stresses to converge to the exact answer.

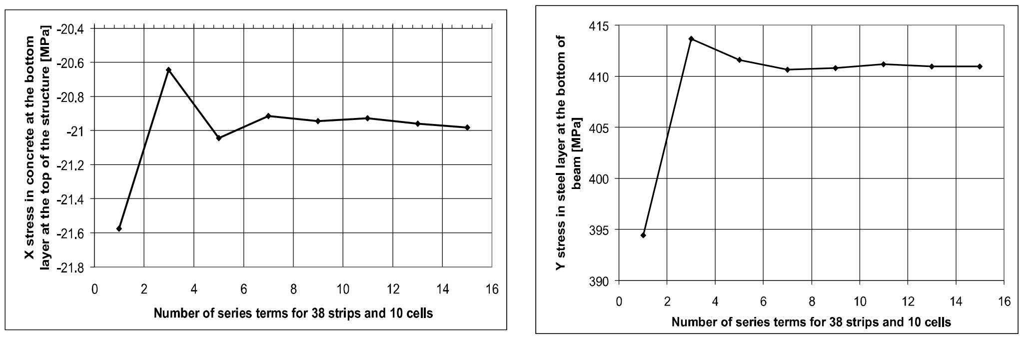


Figure 5. Types of NHFSM convergence by number of series terms: left – compression stress σ_x in marked concrete layer; right – tension stress σ_y in marked steel layer

4. CONCLUSIONS

The non-homogeneous finite strip method is successfully applied to material nonlinear analysis of reinforced concrete folded plate structure. The RDA modulus iterative method proves to be very useful for tracing the structural response after cracking. The results obtained from the NHFSM algorithm implemented in Wolfram Mathematica show very good convergence properties by number of series terms and number of strips.

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ПРИМЕНА НЕХОМОГЕНОГ МЕТОДА КОНАЧНИХ ТРАКА

Резиме: *Нехомоген метод коначних трака примењен је на материјално нелинеарну анализу слободно ослоњене армиранобетонске полиедарске љуске распона 20м. Коначне траке су по дужини подељене у ћелије и услојене по дебљини. Вискоеластопластична конститутивна матрица је одређена применом реолошко-динамичке теорије. Резултати анализе су упоређени са резултатима линеарне анализе. Приказани су типови конвергенције напона у нехомогеном методу коначних трака у функцији броја трака и броја чланова реда.*

Кључне речи: *Нехомогени метод коначних трака, реолошко-динамичка теорија, армирани бетон, полиедарска љуска*