10.1515/tvsb-2016-0002

Transactions of the VŠB – Technical University of Ostrava

Civil Engineering Series, Vol. 16, No. 1, 2016

paper #2

Temuri R. KIKAVA[1]

THE ANALYSIS OF THE TUNNEL WITH THE MIDDLE SOIL-BASED WALL

Abstract

The methods for analysis of the ferroconcrete construction for a particular case are proposed in the present work. The underground construction is considered and analyzed as a double-drift frame situated on linearly-deformed basis. The formulas of analysis are given herein.

Keywords

Frame, ground pressure, underground structure, reinforced concrete, linearly-deformed basis.

1 INTRODUCTION

The underground constructions like tunnels are commonly used in construction practice. They may be intended for different types of transport as well as for laying gas, petrol and water pipelines. Many of these constructions serve the purposes of the frame constructions while vary sufficiently in outline and complexity. The purpose of this paper is to consider joint action of the frame's lower girder and the soil basis, the analysis of a beam separately on the basis of the linearly-deformed basis (lower girder) and the frame regardless of this and thereafter the consideration of joint deformation of the lower girder and the frame's upper part.

Let us first consider the transverse section of a double-drift tunnel in the form of a ferroconcrete frame (Figure 1a).

Let us analyze mentioned frame in two versions (Figure 1b). The analysis shall be made per unit of the tunnel's length, i.e. b = 1 m.

The tunnel is affected by equally distributed over ground load and the soil's specific weight from above and by soil's pressure from the side surfaces.

2 THE FIRST VERSION OF THE ANALYSIS

We divide the frame (tunnel) cutout per unit of the frame (tunnel)'s length in separate parts and consider each of them separately (Figure 1).

From conditions of statics, in the result of symmetry and load of the construction:

$$|M_c| = |M_D| \quad Y_c = Y_D = 0.5(q^{(cp)} \cdot L - Y_E) \tag{1}$$

[1] Temuri T. Kikava, Professor, MSc, PhD., Engineering and Construction Department, Faculty of Technologies, Batumi Shota Rustaveli State University, 35 Ninoshvili, 6010 Batumi, Georgia, phone: +995 (422) 271 780, e-mail: temurikikava@yahoo.com.

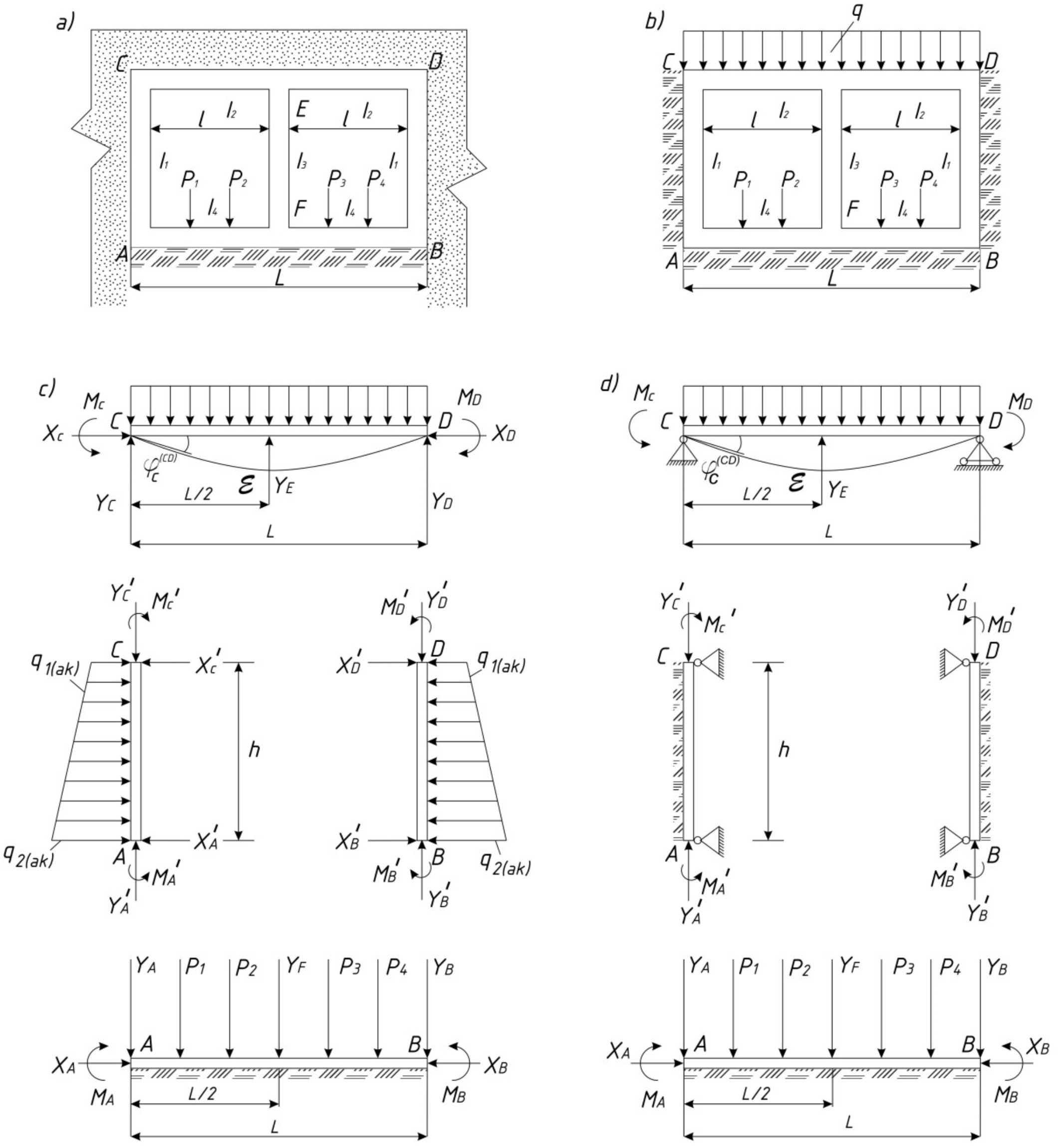

Figure 1

By using universal formula of the beam's elastic curve we find turning angle $\varphi_c^{(CD)}$ of the upper girder CD in C node point:

$$\varphi_C^{(CD)} = \frac{M_C \cdot L}{2E_2 \cdot I_2} + \frac{L^2}{8E_2 \cdot I_2} \cdot \left(\frac{Y_E}{2} - \frac{q^{(CD)} \cdot L}{3}\right), \tag{2}$$

where У_E - independent longtitutional force in the middle wall EF;

$q^{(CD)}$ _ equally distributed load on the upper girder (own mass of land and over ground load).

We find turning angles $\varphi_C^{(AC)}$ and $\varphi_A^{(AC)}$ of the left hand column being under action of the land's side pressure.

We receive the side pressure of the land in the form of trapezium (Figure 1) and by using the universal formula of the beam's elastic curve we receive:

$$\left.\begin{aligned} \varphi_A^{(AC)} &= \frac{1}{E_1 \cdot I_1}\left[\frac{h}{6}(2M'_A + M'_C) - \frac{h^3}{360}(8q_{2a} + 7q_{1a})\right] \\ \varphi_C^{(AC)} &= \frac{1}{E_1 \cdot I_1}\left[-\frac{h}{6}(M'_A + 2M'_C) + \frac{h^3}{360}(7q_{2a} + 8q_{1a})\right]. \end{aligned}\right\} \quad (3)$$

By using the universal formula of the beam's elastic curve we find bilge of the upper girder CD in point E:

$$f_E^{(CD)} = \frac{L^2}{384 \cdot E_2 \cdot I_2}\left(48M_c + 8Y_E \cdot L - 5q^{(CD)} \cdot L^2\right). \quad (4)$$

We find turning curve of the lower girder AB:

$$\varphi_A^{(AB)} = \frac{1}{\pi E_0 b L^2}\left\{-\overline{\varphi}_{2A}^{(A)} \cdot M_A + \overline{\varphi}_{2B}^{(A)} \cdot M_B + L\left[\overline{\varphi}_{3A}^{(A)} \cdot Y_A + \overline{\varphi}_{3F}^{(A)} \cdot Y_F + \overline{\varphi}_{3(B)}^{(A)} \cdot Y_B + \right.\right.$$
$$\left.\left. + \sum \overline{\varphi}_{3i}^{(A)} \cdot P_i\right]\right\}. \quad (5)$$

It is supposed that the forces $P_1 = P_2 = P_3 = P_4 = P$ and they are placed symmetrically on the lower girder.

We find deflection $f_F^{(AB)}$ in the middle of the lower girder:

$$f_F^{(AB)} = \frac{1}{\pi \cdot E_0 \cdot b \cdot L}\left\{-\overline{y}_{2A}^{(F)} \cdot M_A + \overline{y}_{2B}^{(F)} \cdot M_B + L\left[\begin{array}{c}\overline{y}_{3A}^{(F)} \cdot Y_A + \overline{y}_{3F}^{(F)} \cdot Y_F + \overline{y}_{3B}^{(F)} \cdot Y_B + \\ + \sum \overline{y}_{3i}^{(F)} \cdot P_i\end{array}\right]\right\}. \quad (6)$$

For the case under review:

$$|M_c| = |M_D|; \quad |M_A| = |M_B|; \quad Y_A = Y_B; \quad Y_E = Y_F; \quad Y_C = Y_D;$$

$$\left.\begin{aligned} X'_A &= \frac{M'_A - M'_C}{h} + \frac{h}{6}(q_{1a} + 2q_{2a}) \\ X'_C &= \frac{M'_A - M'_C}{h} + \frac{h}{6}(2q_{1a} + q_{2a}) \end{aligned}\right\} \quad (7)$$

From conditions $\varphi_C^{(CD)} = \varphi_C^{(AC)}$; $\varphi_A^{(AC)} = \varphi_A^{(AB)}$ and $f_E^{(CD)} = f_F^{(AB)}$ we receive equation for defining the unknown quantities M_A, M_c, Y_A and Y_F :

$$\frac{M_C \cdot L}{2E_2 \cdot I_2} + \frac{L^2}{48E_2 \cdot I_2}\left(3Y_E - 2q^{(CD)} \cdot L\right) = \frac{1}{E_1 I_1}\left[-\frac{h}{6}(M_A + 2M_C) + \frac{h^3}{360}(7q_{2A} + 8q_{1A})\right] \quad (8)$$

$$-\frac{1}{\pi \cdot E_0 \cdot b \cdot L^2}\left\{-\overline{\varphi}_{2A}^{(A)} M_A + \overline{\varphi}_{2B}^{(A)} M_B + L\left(\overline{\varphi}_{3A}^{(A)} \cdot Y_A + \overline{\varphi}_{3F}^{(A)} \cdot Y_F + \overline{\varphi}_{3B}^{(A)} \cdot Y_B + \sum \overline{\varphi}_{3i}^{(A)} \cdot P_i\right)\right\} = \frac{1}{E_1 \cdot I_1}\left[\frac{h}{6}(2M_A + M_C) - \frac{h^3}{360}(8q_{2A} + 7q_{1A})\right] \quad (9)$$

$$\frac{L^2}{384E_2 \cdot I_2}\left(48M_C + 8Y_E \cdot L - 5Q^{(CD)} \cdot L^2\right) = \frac{1}{\Pi \cdot E_0 \cdot BL}\left\{-\overline{Y}_{2A}^{(F)} \cdot M_A + \overline{Y}_{2B}^{(F)} \cdot M_B + L\left[\overline{Y}_{3A}^{(F)} \cdot Y_A + \overline{Y}_{3F}^{(F)} \cdot Y_F + \overline{Y}_{3B}^{(F)} Y_B + \sum \overline{Y}_{3I}^{(F)} \cdot P_I\right]\right\} \quad (10)$$

We solve these equations together with the equations of statics, find unknown M_A, M_C, Y_A and Y_F. After defining the unknown quantities for the given frame according to table (3) it shall be possible to construct the epures of reactive pressure of soil p, intersecting forces Q and bending moments, M.

3 THE SECOND VERSION OF THE ANALYSIS

Let us consider the closed frame allocated to transverse direction (Figure 1b) and the same frame divided into separate elements (Figure 1d).

Formulas (2) and (4) are true for defining the turning angle of the upper girder $\varphi_C^{(CD)}$ in node point C and deflection $f_E^{(CD)}$ in the middle of the upper girder CD in section E.

By accepting approximately module of soil's deformation by depth as constant, we consider the side walls AC and BD as the beams on the linearly-deformed basis relied on the rigid bearers at the same time (wall AC relies on the points A and C and wall BD – on the points B and D) (Kikava, T. 2007.)

We use the following formulas for defining the turning angles $\varphi_C^{(AC)}$ and $\varphi_A^{(AC)}$:

$$\varphi_C^{(AC)} = \frac{1}{\pi \cdot E_0 b h^2}\left\{-\overline{\varphi}_{2C}^{(C)} \cdot M_C + \varphi_{2A}^{(C)} \cdot M_A + h\left[\overline{\varphi}_{3C}^{(C)} \cdot X_C + \overline{\varphi}_{3A}^{(C)} \cdot X_A\right]\right\} \quad (11)$$

$$\varphi_A^{(AC)} = \frac{1}{\pi \cdot E_0 b h^2}\left\{-\overline{\varphi}_{2C}^{(A)} \cdot M_C + \varphi_{2A}^{(A)} \cdot M_A + h\left[\overline{\varphi}_{3C}^{(A)} \cdot X_C + \overline{\varphi}_{3A}^{(A)} \cdot X_A\right]\right\} \quad (12)$$

The lower girder works as a beam on the linearly-deformed basis (Simvulidi, I. Kikava, T. Bulatov, V. 1986.) and formulas (5) and (6) are true for defining the turning angle $\varphi_A^{(AB)}$ and deflection $f_F^{(AB)}$.

Therefore, by using conditions:

$$\varphi_C^{(CD)} = \varphi_C^{(AC)}; \ \varphi_A^{(AC)} = \varphi_A^{(AB)}; \ f_E^{(CD)} = f_F^{(AB)}$$

as well the conditions of statics (1) and by solving the received equations related to the unknown quantities M_A, M_C, Y_A and Y_F jointly, we receive possibility to construct the epures p, Q and M for the whole frame (Simvulidi, I. 1987).

Let us consider concrete example for the beam calculation (lower cross bar) on the linearly-deformed basis loaded with the concentrated forces (Fig. 2).

It is required to determinate values of curving moments M and reaction pressures of the ground ρ, if : $P_1=P_2=P_3=P_4=100kN$; $P_F=200kN$; $M_A=14kNm$; the width b=2m; the index of flexibility α=200 the module of deformation $E_0=320\cdot10^2 kN/m^2$.

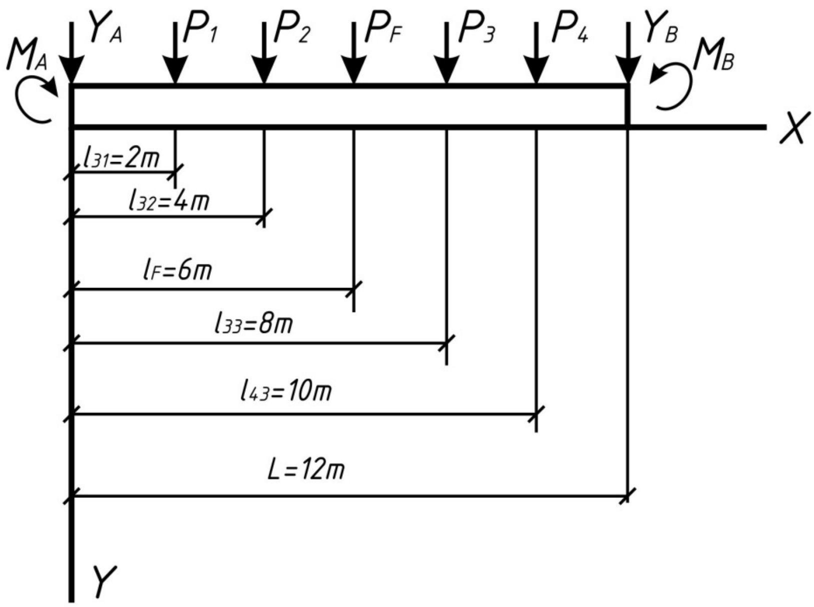

Figure 2

Solution. According to the condition of the problem:

$$\beta_1 = \frac{l_{31}}{L} = 0.17;$$

$$\beta_2 = \frac{l_{32}}{L} = 0.33;$$

$$\beta_F = \frac{l_{F_3}}{L} = 0.5;$$

$$\beta_3 = \frac{l_{33}}{L} = 0.67;$$

$$\beta_4 = \frac{l_{43}}{L} = 0.83;$$

According to conditions of symmetry $|M_A| = |M_B|$

According to conditions of statics: $Y_A = Y_B = Y_C = Y_D = 0$

For the determination of ordinate ρ_1; ρ_2; ρ_F; ρ_3; ρ_4; from force P_1; P_2; P_F; P_3 and P_4; we use the values of $\bar{\rho}_1$; $\bar{\rho}_2$; $\bar{\rho}_1$; $\bar{\rho}_F$; $\bar{\rho}_3$; $\bar{\rho}_4$; corresponding α=200 and $\beta_1 = 0.17; \beta_2 = 0.33; \beta_F = 0.5; \beta_{13} = 0.67; \beta_4 = 0.83$; for all values $\bar{\rho}_1$; $\bar{\rho}_2$; $\bar{\rho}_1$; $\bar{\rho}_F$; $\bar{\rho}_3$; and $\bar{\rho}_4$; from ξ=0 till ξ=1, where ξ is considered cross-section (Simvulidi, I.1987). Having multiplied each ordinate according to the formula:

$$\rho = \bar{\rho} \cdot P/b \cdot L \tag{13}$$

where $P/bL = 100/2 \cdot 12 = 4.2\ \mathrm{kN/m^2}$ $P_F/bL = 200/2\,4 = 8.4\ \mathrm{kN/m^2}$we'll get values ρ in various points.

Then we'll get values $\bar{\rho}_{M_A}$ and $\bar{\rho}_{M_B}$ for α=200; $\beta_{21} = 0$ and $\beta_{22} = 1.0$ multiplied each ordinate to $M_A/bL^2 = 14/2 \cdot 12^2 = 0.05\ \mathrm{kN/m^2}$ and $M_B/bL^2 = 0.05\ \mathrm{kN/m^2}$

Table 1:

ξ	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
$\bar{\rho}_1$	3.845	2.793	1.988	1.388	0.956	0.648	0.424	0.246	0.068	-0.145	-0.437
ρ_1	16.149	11.731	8.35	5.83	4.02	2.72	1.781	1.033	0.29	-0.61	-1.84
$\bar{\rho}_2$	2.386	2.05	1.736	1.434	1.157	0.901	0.669	0.464	0.28	0.132	0.01
ρ_2	10.02	8.61	7.29	6.023	4.86	3.784	2.81	1.95	1.18	0.55	0.04
$\bar{\rho}_F$	0.666	0.846	0.987	1.087	1.147	1.167	1.147	1.087	0.987	0.846	0.666
ρ_F	5.594	7.106	8.29	9.13	9.64	9.802	9.64	9.13	8.29	7.106	5.594
$\bar{\rho}_3$	0.01	0.132	0.28	0.464	0.669	0.901	1.157	1.434	1.736	2.05	2.386
ρ_3	0.04	0.55	1.18	1.95	2.81	3.784	4.86	6.023	7.29	8.61	10.02
$\bar{\rho}_4$	-0.437	-0.145	0.068	0.246	0.424	0.648	0.956	1.388	1.988	2.793	3.845
ρ_4	-1.84	-0.61	0.29	1.033	1.781	2.723	4.02	5.83	8.35	11.731	16.149
$\bar{\rho}_{M_A}$	15.323	7.758	2.572	-0.655	-2.343	-2.911	-2.781	-2.373	-2.106	-2.402	-3.679
$\bar{\rho}_{M_B}$	-3.679	-2.402	-2.106	-2.373	-2.781	-2.911	-2.343	-0.655	-2.572	-7.758	-15.323
$\bar{\rho}_{M_A} + \bar{\rho}_{M_B}$	11.644	5.356	0.466	-3.028	-5.124	-5.822	-5.124	-3.028	0.466	5.356	11.644
$\rho_{M_A} + \rho_{M_B}$	0.582	0.268	0.023	-0.151	-0.256	-0.291	-0.256	-0.151	0.023	0.268	0.582
ρ	30.545	27.655	25.423	23.815	22.355	22.519	22.355	23.815	25.423	27.655	30.545

The values ρ give in $\mathrm{kN/m^2}$; M-kN·m. Using the independence principle of force activity for getting values ρ we take algebraic sum: $\rho = \rho_1 + \rho_{2+}\ \rho_{F+}\ \rho_{3+}\ \rho_{4+}\ \rho_{MA+}\ \rho_{MB}$

For the determination of ordinates curving moment M from the forces P_1; P_2; P_F; P_3; P_4; and from moments M_A and M_B , we use the values of $\bar{M}_1$; $\bar{M}_2$; $\bar{M}_F$; $\bar{M}_3$; $\bar{M}_4$; $\bar{M}_{M_A}$and $\bar{M}_{M_B}$for α=200 and $\beta_1 = 0.17$; $\beta_2 = 0.33$; $\beta_F = 0.5$; $\beta_3 = 0.67$; $\beta_4 = 0.83$; $\beta_{M_A} = 0$ and $\beta_{M_B} = 1.0$ for all values $\bar{M}$ from ξ=0 till ξ=1 (Simvulidi, I.1987). Having multiplied each ordinate to:

$$M_P = \overline{M}_P \cdot P \cdot L \quad (14)$$

$$\left.\begin{aligned} M_{M_A} &= \overline{M}_{M_A} \cdot M_A \\ M_{M_B} &= \overline{M}_{M_B} \cdot M_B \end{aligned}\right\} \quad (15)$$

where P·L=100·12=1200 kN·m ; P_F·L=200·112=2400 kN·m

Using the independence principle of force activity for getting values M we take algebraic sum:

$$M = M_{P_1} + M_{P_2} + M_{P_F} + M_{P_3} + M_{P_4} + M_A + M_B$$

Table 2:

ξ	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
$\overline{M}_{P_1}$	0	0.018	0.063	0.029	0.008	-0.003	-0.007	-0.007	-0.005	-0.001	0
M_{P_1}	0	21.6	75.6	34.8	9.6	-3.6	-8.4	-8.4	-6	-1.2	0
$\overline{M}_{P_2}$	0	0.012	0.044	0.093	0.057	0.032	0.016	0.007	0.003	0.001	0
M_{P_2}	0	14.4	52.8	111.6	68.4	38.4	19.2	8.4	3.6	1.2	0
$\overline{M}_{P_F}$	0	0.004	0.015	0.037	0.07	0.114	0.07	0.037	0.015	0.004	0
M_{P_F}	0	9.6	36	88.8	168	273.6	168	88.8	36	9.6	0
$\overline{M}_{P_3}$	0	0.001	0.003	0.007	0.016	0.032	0.057	0.093	0.044	0.012	0
M_{P_3}	0	1.2	3.6	8.4	19.2	38.4	68.4	111.6	52.8	14.4	0
$\overline{M}_{P_4}$	0	-0.001	-0.005	-0.007	-0.007	-0.003	0.008	0.029	0.063	0.018	0
M_{P_4}	0	1.2	-6	-8.4	-8.4	3.6	9.6	34.8	75.6	21.6	0
$\overline{M}_A$	-1	-0.937	-0.796	-0.625	-0.460	-0.318	-0.204	-0.119	-0.054	-0.015	0
$\overline{M}_B$	0	-0.015	-0.054	-0.119	-0.204	-0.318	-0.460	-0.625	-0.796	-0.937	-1
$\overline{M}_{M_A} + \overline{M}_{M_B}$	-1	-0.952	-0.85	-0.744	-0.664	-0.636	-0.664	-0.744	-0.85	-0.952	-1
$M_{M_A} + M_{M_B}$	-14	-13.33	-11.9	-10.42	-9.3	-8.9	-9.3	-10.42	-11.9	-13.33	-14
M	-14	-34.67	-150.1	224.8	247.5	341.5	247.5	224.8	-150.1	-34.67	-14

4 CONCLUSIONS

The methods for analysis of the ferroconcrete construction for a particular case are proposed in the present work. The underground construction is considered and analyzed as a double-drift frame situated on linearly-deformed basis. The formulas of analysis are given herein. Example of calculation is given.

REFERENCES

[1] SIMVULIDI, I. KIKAVA, T. BULATOV, V. 1986. Approximate method for analysis of a beam on elastic foundation. Moscow., VINITI 2341-86. p.1-7.

[2] SIMVULIDI, I. 1987. Analysis of the engineering constructions on elastic foundation. Moscow., Higher school. p.79-99.

[3] KIKAVA, T. 2007. The analysis of the rectangular closed rigid frame supported by trestle bents. Tbilisi., Gournal“Energy” №1. p. 109-111.