

RIVET HEADING – THEORETICAL INVESTIGATION AND EXPERIMENTAL VERIFICATION

Kecman D., "Majevica - Poljooprema" Backa Palanka, Yugoslavia

Vilotić D., Plančak M., Faculty of Technical Sciences - University of Novi Sad, Yugoslavia

Stefanović M., Faculty of Mechanical Engineering, Kragujevac, Yugoslavia

ABSTRACT

Determination of stress-strain state in the technology of plasticity is essential as the knowledge of this state enables the determination of basic process parameters such as: deformation force, mean pressure and deformation work. Furthermore, it makes possible the analyse of the potential of material formability. In this paper theoretical and experimental investigation of rivet heading by spherical die is presented. Methods of the analysis: SLAB method and method of work of deformation. Experimental investigation has been carried out in order to verify the theoretical results. Reasonable agreement between theory and experiment has been obtained.

1 INTRODUCTION

Heading is a classical upsetting process, applied mostly in the screw, nuts, nails and bolt manufacturing.

It is a transient process, i.e. ,streamlines and flow lines do not coincide during the process [1]. This makes the theoretical analysis (stress analysis, velocity, material flow) of the process more difficult. On the other hand, knowledge of the stress state within the workpiece during deformation is unavoidable for determination of the basic process parameters such as load and work of deformation , formability potential, material flow, contact pressures.

This paper deals with the theoretical aspects of heading; stress distribution , using two theoretical methods, has been obtained. Predictions have been checked by experiment.

2 THEORETICAL ANALYSIS OF RIVET HEADING

2.1 SLAB METHOD

In the Fig.1. initial and intermediate stage of rivet heading process is presented. Also, the stress components as well as the geometry of the process are given. The cylindrical billet is compressed by spherical and flat die and appropriate equilibrium equation in ρ - direction is:

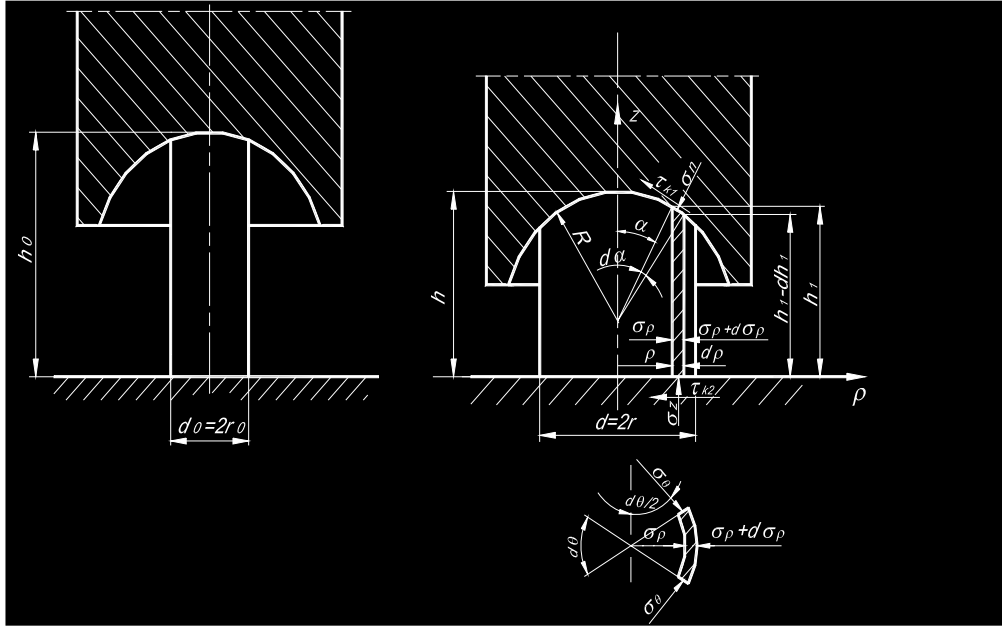


Fig.1. Stress scheme in upsetting of cylinder by spherical and flat dies

$$\begin{aligned} & \sigma_{\rho} \rho h_1 d\theta - (\sigma_{\rho} + d\sigma_{\rho})(\rho + d\rho)(h_1 - dh_1)d\theta - \sigma_n \sin \alpha \rho d\theta \frac{d\rho}{\cos \alpha} - \\ & - \tau_{k1} \cos \alpha \rho d\theta \frac{d\rho}{\cos \alpha} + 2\sigma_{\theta} h_1 \sin \frac{d\theta}{2} d\rho - \tau_{k2} \rho d\theta d\rho = 0 \end{aligned} \quad (1)$$

Equilibrium equation in z - direction is:

$$\sigma_z \rho d\theta d\rho - \sigma_n \cos \alpha \rho d\theta \frac{d\rho}{\cos \alpha} + \tau_{k1} \sin \alpha \rho d\theta \frac{d\rho}{\cos \alpha} = 0 \quad (2)$$

Geometrical relations, according to Fig.2, are:

$$\begin{aligned} h_1 &= h_0 - R(1 - \cos \alpha) \\ dh &= d\rho \tan \alpha \\ \rho &= R \sin \alpha \end{aligned} \quad (3)$$

or, after differentiating:

$$d\rho = R \cos \alpha d\alpha \quad (4)$$

The Tresca's yield criteria is:

$$\sigma_n - \sigma_\rho = k \quad \text{or} \quad \sigma_\rho = \sigma_n - k \quad (5)$$

After substitution of the yield criteria (5), geometrical relations (3) and (4) into the equations (1) and (2), following expression can be obtained:

$$\frac{d\sigma_\rho}{d\alpha} + \frac{\operatorname{tg}\alpha + 2\mu}{a + \cos\alpha} k \cos\alpha = 0 \quad (6)$$

Solution of the differential equation (6) for " σ_ρ " has been performed by numerical procedure (Runge-Kutha method). Boundary condition is: $\alpha = \alpha_{\max} \quad \sigma_\rho = 0$.

In the Fig.2 distribution of the normal contact stress σ_n (full line) and the radial stress σ_ρ (dashed line) for rivet head forming process is given as a function of stroke. Numbers above the stress curves indicate tool strokes values.

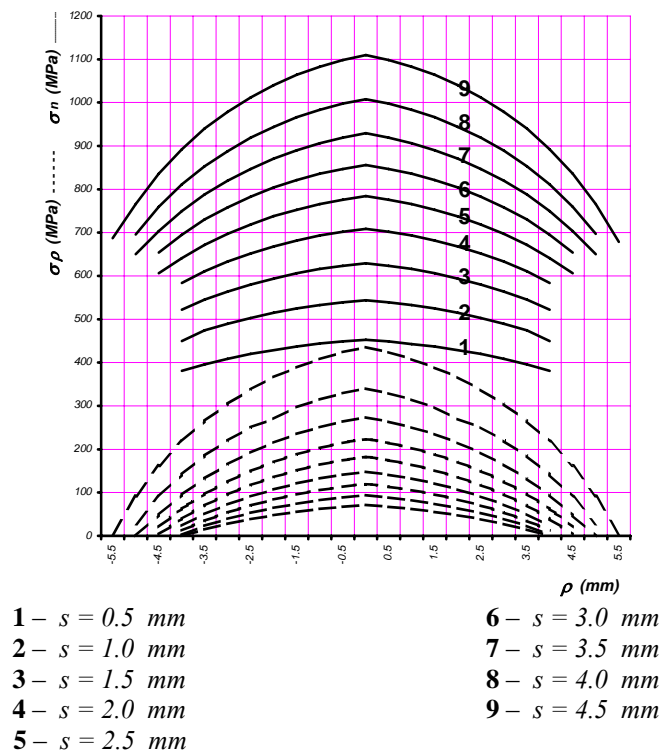


Fig.2 Distribution of stress components for rivet head forming process by spherical dies for different strokes

Forming load can be calculated by integration of the contact stress over the contact area:

$$F = \int_A \sigma dA = 2\pi R^2 \int_0^{\alpha_{\max}} (\sigma_n \cos \alpha \sin \alpha - \mu k \sin^2 \alpha) d\alpha \quad (7)$$

In the Fig.8 (curve "I") load - stroke diagram $[F - s]$ for the rivet head forming process, obtained by SLAB method is given.

2.2 METHOD OF WORK OF DEFORMATION

The heading is analyzed under the assumption of double action process, e.g. upper and lower die moves for the same amount of $\Delta h/2$ in opposite directions. Fig.3. shows initial and intermediate stage of the process, with the appropriate displacement distribution.

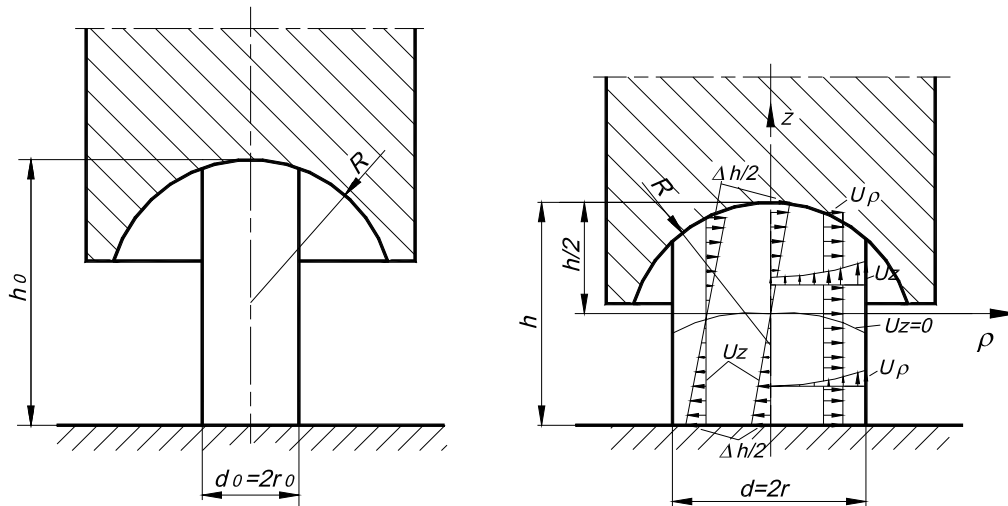


Fig.3 Upsetting of cylinder by the spherical and flat die – displacement distribution

By assuming linear relation between displacement U_z and the z coordinate, one obtains:

$$U_z = -\frac{\Delta h}{2} \left[\frac{2z + R - \sqrt{R^2 - \rho^2}}{h - R + \sqrt{R^2 - \rho^2}} \right] \quad (8)$$

The axial strain is:

$$\varepsilon_z = \frac{\partial U_z}{\partial z} = -\frac{\Delta h}{h - R + \sqrt{R^2 - \rho^2}} \quad (9)$$

From the strain tensor and volume constant law, and by using equation (9) and boundary condition: $\rho = 0$ $\sigma_\rho = 0$, displacement in radial direction is obtained:

$$U_\rho = \Delta h \left(\frac{R - \sqrt{R^2 - \rho^2}}{\rho} + \frac{R - h}{\rho} \ln \left(\frac{h}{h - R + \sqrt{R^2 - \rho^2}} \right) \right) \quad (10)$$

Appropriate strain components are:

$$\varepsilon_\theta = \frac{U_\rho}{\rho} = \Delta h \left(\frac{R - \sqrt{R^2 - \rho^2}}{\rho^2} + \frac{R - h}{\rho^2} \ln \left(\frac{h}{h - R + \sqrt{R^2 - \rho^2}} \right) \right) \quad (11)$$

$$\varepsilon_\rho = \Delta h \left(\frac{1}{h - R + \sqrt{R^2 - \rho^2}} - \frac{R - \sqrt{R^2 - \rho^2}}{\rho^2} - \frac{R - h}{\rho^2} \ln \left(\frac{h}{h - R + \sqrt{R^2 - \rho^2}} \right) \right) \quad (12)$$

Tangential strain components are:

$$\begin{aligned} \gamma_{\rho\theta} &= 0 \\ \gamma_{\theta z} &= 0 \end{aligned} \quad (13)$$

$$\gamma_{z\rho} = - \left(\frac{1}{2\sqrt{R^2 - \rho^2}} \right) \left(\frac{\rho}{h - R + \sqrt{R^2 - \rho^2}} \right) - \frac{(2z + R - \sqrt{R^2 - \rho^2})\rho}{2(h - R + \sqrt{R^2 - \rho^2})\sqrt{R^2 - \rho^2}}$$

The equivalent strain is:

$$\varepsilon_e = \frac{\sqrt{2}}{3} \sqrt{(\varepsilon_\rho - \varepsilon_\theta)^2 + (\varepsilon_\theta - \varepsilon_z)^2 + (\varepsilon_z - \varepsilon_\rho)^2 + \frac{2}{3}(\gamma_{\rho\theta}^2 + \gamma_{\theta z}^2 + \gamma_{z\rho}^2)} \quad (14)$$

The internal power of deformation is:

$$W_u = k \int_V \int \int \varepsilon_e dV = k \int_0^r \int_0^{2\pi} \int_{-\frac{h}{2}}^{\frac{h}{2} - R + \sqrt{R^2 - \rho^2}} \varepsilon_e \rho dz d\theta d\rho \quad (15)$$

The deformation work due to contact friction:

$$W_t = \int \int_{A_k} \tau_k U_k dA_k = W_{t1} + W_{t2} \quad (16)$$

The deformation work due the friction at the upper contact area is:

$$\begin{aligned} W_{t1} &= \mu k \int_0^r \int_0^{2\pi} (U_z \sin \alpha + U_\rho \cos \alpha) \rho d\theta \frac{d\rho}{\cos \alpha} \\ &= 2\pi \mu k R^2 \int_0^{\alpha_{\max}} \left(\frac{\Delta h}{2} \sin^2 \alpha + U_\rho \sin \alpha \cos \alpha \right) d\alpha \end{aligned} \quad (17)$$

The deformation work due to friction at the lower bottom area is:

$$\begin{aligned}
 W_{t2} &= \mu k \int_0^r \int_0^{2\pi} U_\rho \rho d\theta d\rho \\
 &= 2\pi \mu k \Delta h \int_0^r \left(\frac{R - \sqrt{R^2 - \rho^2}}{\rho} + \frac{R - h}{\rho} \ln \left(\frac{h}{h - R + \sqrt{R^2 - \rho^2}} \right) \right) \rho d\rho \quad (18)
 \end{aligned}$$

The forming load is:

$$F = \frac{1}{\Delta h} (W_U + W_{t1} + W_{t2}) \quad (19)$$

In the Fig.8 (*curve "2"*) load - stroke diagram $[F - s]$ for the rivet head forming process by spherical die, obtained by work of deformation method, is given.

2.3 EXPERIMENTAL INVESTIGATION

Experimental verification of the presented theoretical solution has been carried out by using specimens made out of Č.0247 (DIN St34-2). Flow curve for the given material has been obtained experimentally by Rastegaev test and following expression was determined:

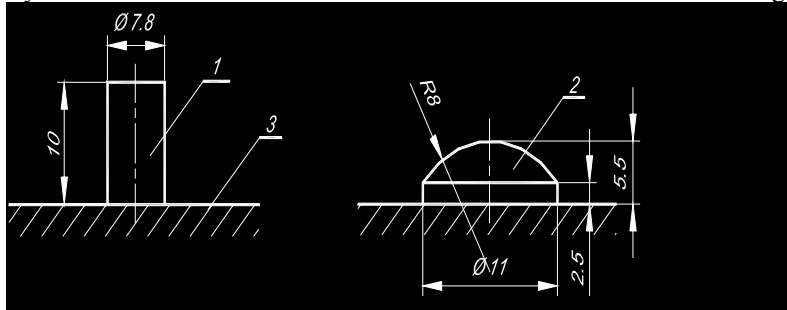
$$k = 303.85 + 375.203 \varphi_e^{0.405} \text{ [MPa]} \quad (20)$$

The surface of material was phosphatised and lubrication was performed by mineral oil ($\mu=0.12$). Upsetting was performed on the hydraulic press (Sack&Kiesselbach with 6.3 MN capacity) in Laboratory for Technology of Plasticity, University of Novi Sad (Fig. 4). The forming load versus stroke was plotted during the whole process.

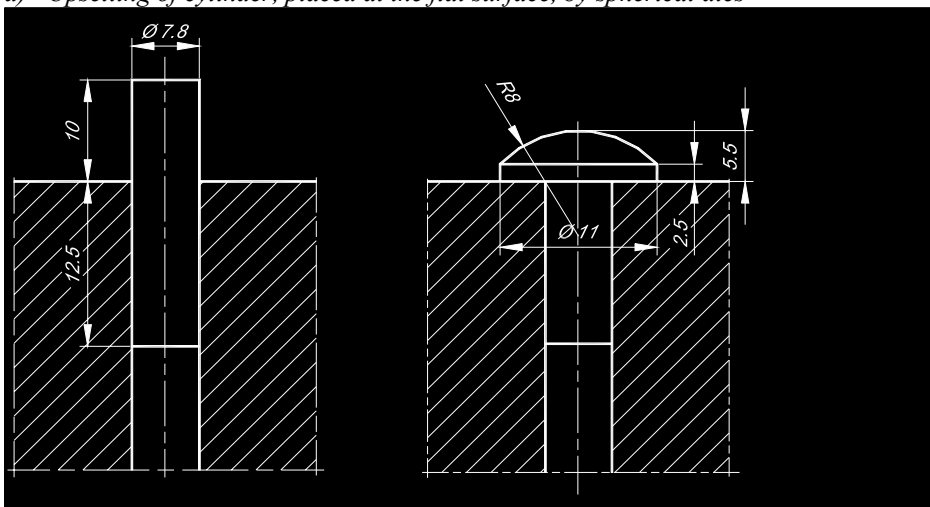


Fig.4 Machine tool and die set

Experimentally obtained relation load - stroke has been carried out for the following cases:



a) Upsetting of cylinder, placed at the flat surface, by spherical dies



b) Upsetting of cylinder, placed in the closed die, by spherical dies

Fig.5 Models of upsetting of cylinder by spherical dies

The tool for experimental investigation is shown on Fig.6.

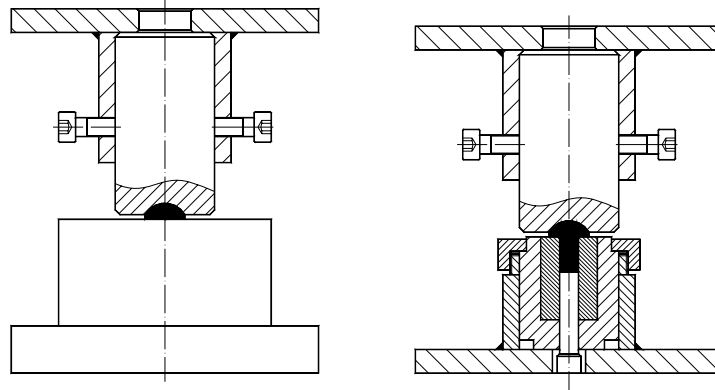


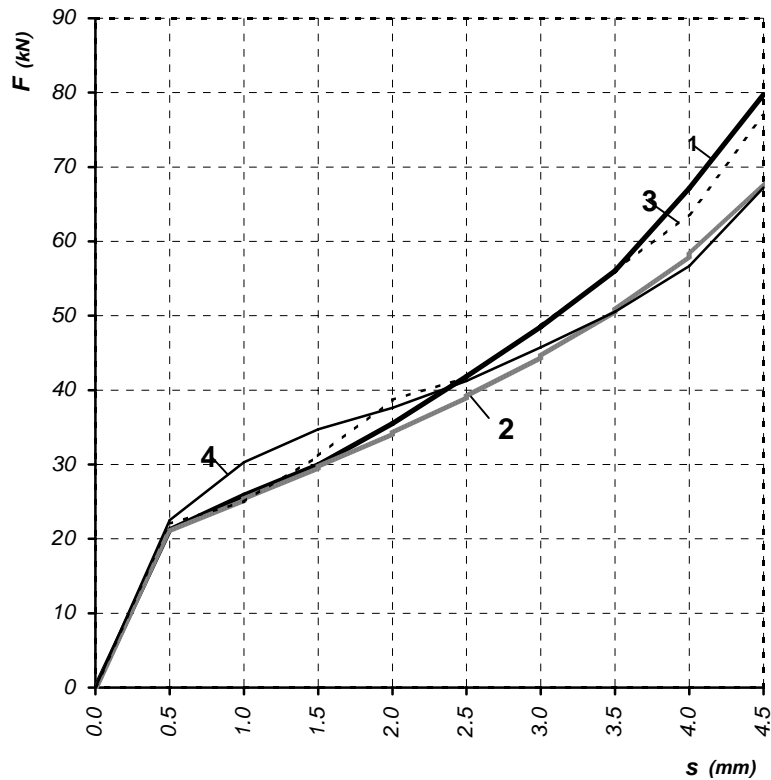
Fig.6 Tool set for rivet heading

In the Fig.7 photograph of deformed specimens are given.



Fig.7 Deformed specimens

In the Fig.8 load - stroke diagrams $[F - s]$ for the rivet heading, obtained theoretically and experimentally, are given.



- 1 (—) SLAB method
- 2 (—) work of deformation method
- 3 (.....) experiment Fig.5.a
- 4 (—) experimental Fig.5.b

Fig.8 Load stroke diagram in rivet heading

3 CONCLUSION

Process of rivet heading has been analyzed theoretically and experimentally. For the theoretical analysis two methods were applied: SLAB method and work of deformation method. Results in terms of load-stroke diagram show a satisfactory agreement between the two theoretical methods and experiment.

In the first stage of deformation steep rise of the force can be observed whereas in the further process development this rise is somewhat lower. Maximal force is obtained by SLAB method (80 kN), all other methods deliver the value of 66 kN as a maximal force.

In further work analysis of this process by FE method is planned. Also, simultaneous combination of heading and other forging operations such as backward extrusion, forward extrusion, radial extrusion will be investigated.

4 REFERENCES:

- [1] LANGE, K.: Handbook of Metalforming, McGraw-Hill Book Company, 1985.
- [2] VILOTIC D.: Steel Material Behavior in Different Working Systems of Bulk Cold Deformation processes (in Serbian), Faculty of Technical Sciences, Novi Sad, 1987.
- [3] PLANCAK M., VILOTIC D., VUJOVIĆ V.: Technology of Plasticity II (in Serbian), Faculty of Technical Sciences, Novi Sad, 1992.
- [4] VUJOVIC V.: Technology of Plasticity I (in Serbian), Faculty of Technical Sciences, Novi Sad, 1990.
- [5] KECCMAN D.: An contribution to the investigation of stress strain state, metal flow and process parameters in cold multi stage bulk forming of axis-symmetric workpieces (in Serbian), M.Sc.-work, Faculty of Technical Sciences, Novi Sad, 2002.
- [6] DEVEDZIC B.: Metal forming - third part (in Serbian), Naučna knjiga, Beograd, 1984.
- [7] DEVEDZIC B.: Metal forming- second part (in Serbian), Naučna knjiga, Beograd, 1981.
- [8] VUJOVIC V.: Formability, Monograph (in Serbian), Faculty of Technical Sciences, Novi Sad, 1992.
- [9] NAVROCKOGO G.A., Cold metal forming (in Russian), Masinstrojenje, Москва, 1973.
- [10] MUSAFIJA B.: Theory of Plasticity (in Serbian), University of Sarajevo, 1972.
- [11] SLJIVIC M.: Technology of Plasticity I (in Serbian), Faculty of Mechanical Engineering, Banja Luka, 1998.
- [12] KECCMAN D., VILOTIC D., PLANCAK M.: Design of Multistage Bulk Metal Forming Technology (in Serbian), 29 SPMJ, Beograd, 2002.

OBLIKOVANJE GLAVE ZAKOVICE – TEORETSKA I EKSPERIMENTALNA ISTRAŽIVANJA

Kecman D., Vilotić D., Plančak M, Stefanović M.

REZIME

Analiza naponsko-deformacionog stanja i parametara procesa kod zapreminskog oblikovanja veoma je složena zbog složenosti geometrije obratka i mnoštva uticajnih faktora. U ovom radu izvršena je analiza naponsko-deformacionog stanja kod oblikovanja sferične glave zabušene zakovice, uz pretpostavku da je moguće rezultat slobonog sabijanja sferičnim alatom primeniti i na slučaj sabijanja obratka postavljenog u matricu.

Oderđivanje naponsko-deformacionog stanja i parametara procesa izvršeno je primenom sledećih teorijskih metoda:

- metode ravnih preseka,
- metode deformacionog rada.

Eksperimentalna istraživanja sabijanja pomoću sferičnog alata izvršena za dva slučaja:

1. Sabijanje priprema postavljenog na ravnu ploču;
2. Sabijanje priprema postavljenog u matricu.

Potrebni uzorci izrađeni su od Č.0247 (DIN St34-2), prethodno su fosfatirani i podmazivani mineralnim uljem.

Na osnovu dobijenih rezultata može se zaključiti da primenjene metode analize naponsko-deformacionog stanja i uvedene pretpostavke, daju zadovoljavajuće rezultate, što je potvrđeno solidnim slaganjem dijagrama deformacione sile dobijenih teorijski i eksperimentalno.