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Mathematical modeling in the calculation of flexible circular plates

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Abstract

In this paper, we consider the bends of flexible circular plates in a geometric nonlinear formulation under the action of axisymmetric loads in the Kirchhoff-Love fo Abstract: In this paper, we consider the bends of flexible circular plates in a geometric nonlinear formulation under the action of axisymmetric loads in the Kirchhoff-Love formulation and obtained systems of quasilinear differential equations. To solve systems of differential equations, central finite-difference formulas approximating derivatives are applied up to the second order. The convergence of the finite difference method using the table is shown.

Keywords: Flexible, round, nonlinear, difference schemes, quasilinear, differential equation, convergence, system.

1. Introduction

In the present paper, we consider the bending of circular plates under the action of axisymmetric loads.

General equilibrium equations for plates and shells, taking into account geometric nonlinearity in the Love's form [1], have the form:

$$\begin{aligned}
&\frac{\partial}{\partial\alpha}\left(B\overline{T}_1\right)-\frac{\partial}{\partial\beta}\left(A\overline{S}_2\right)-\left(r_1B\overline{S}_1+r_2A\overline{T}_2\right)+\left(q_1B\overline{Q}_1+q_2A\overline{Q}_2\right)+ABX=0,\\
&\frac{\partial}{\partial\alpha}\left(B\overline{S}_1\right)+\frac{\partial}{\partial\beta}\left(A\overline{T}_2\right)-\left(p_1B\overline{Q}_1+p_2A\overline{Q}_2\right)+\left(r_1B\overline{T}_1-r_2A\overline{S}_2\right)+ABY=0,\\
&\frac{\partial}{\partial\alpha}\left(B\overline{Q}_1\right)+\frac{\partial}{\partial\beta}\left(A\overline{Q}_2\right)-\left(q_1B\overline{T}_1-q_2A\overline{S}_2\right)+\left(p_1B\overline{S}_1+p_2A\overline{T}_2\right)+ABZ=0
\end{aligned}\tag{1}$$

where α,β,γ are curvilinear coordinates, A,B are coefficients of the first quadratic form, $\overline{T}_1,\overline{T}_2,\overline{S}_1,\overline{S}_2$ are components of the membrane forces, $\overline{Q}_1,\overline{Q}_2$ are the cutting forces, r_1,r_2,q_1,q_2,p_1,p_2 are surface curvatures, X,Y,Z are volume forces.

Expressions for $A,B,r_1,r_2,q_1,q_2,p_1,p_2$ have the following form:

$$A=\left[h_1\left(1-\frac{\gamma}{R_1}\right)\right]^{-1},\ B=\left[h_2\left(1-\frac{\gamma}{R_2}\right)\right]^{-1},\tag{2}$$

$$\begin{aligned}
p_1&=\frac{\partial}{\partial\alpha}\left(\frac{1}{B}\frac{\partial\overline{w}}{\partial\beta}+\frac{\overline{v}}{R_2}\right)-\frac{1}{B}\frac{\partial A}{\partial\beta}\left(\frac{1}{A}\frac{\partial\overline{w}}{\partial\alpha}+\frac{\overline{u}}{R_1}\right)-\frac{1}{R_1}\left(\frac{\partial\overline{v}}{\partial\alpha}-\frac{\overline{u}}{B}\frac{\partial A}{\partial\beta}\right);\\
q_1&=-\frac{A}{R_1}-\frac{\partial}{\partial\alpha}\left(\frac{1}{A}\frac{\partial\overline{w}}{\partial\alpha}+\frac{\overline{u}}{R_1}\right)-\frac{1}{B}\frac{\partial A}{\partial\beta}\left(\frac{1}{B}\frac{\partial\overline{w}}{\partial\beta}+\frac{\overline{v}}{R_2}\right);\\
r_1&=-\frac{1}{B}\frac{\partial A}{\partial\beta}+\frac{\partial}{\partial\alpha}\left(\frac{1}{A}\frac{\partial\overline{u}}{\partial\alpha}-\frac{\overline{v}}{AB}\frac{\partial A}{\partial\beta}\right)+\frac{A}{R_1}\left(\frac{1}{B}\frac{\partial\overline{w}}{\partial\beta}+\frac{\overline{v}}{R_2}\right);
\end{aligned}\tag{3}$$

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$$r_2 = \frac{1}{A}\frac{\partial B}{\partial \alpha} + \frac{\partial}{\partial \alpha}\left(\frac{1}{A}\frac{\partial \bar{v}}{\partial \alpha} - \frac{\bar{u}}{AB}\frac{\partial A}{\partial \beta}\right) - \frac{B}{R_2}\left(\frac{1}{A}\frac{\partial \bar{w}}{\partial \alpha} + \frac{\bar{u}}{R_1}\right);$$

$$p_2 = \frac{B}{R_2} + \frac{\partial}{\partial \beta}\left(\frac{1}{B}\frac{\partial \bar{w}}{\partial \beta} + \frac{\bar{v}}{R_2}\right) + \frac{1}{A}\frac{\partial B}{\partial \alpha}\left(\frac{1}{A}\frac{\partial \bar{w}}{\partial \alpha} + \frac{\bar{u}}{R_1}\right);$$

$$q_2 = -\frac{\partial}{\partial \beta}\left(\frac{1}{A}\frac{\partial \bar{w}}{\partial \alpha} - \frac{\bar{u}}{R_1}\right) + \frac{1}{A}\frac{\partial B}{\partial \alpha}\left(\frac{1}{B}\frac{\partial \bar{w}}{\partial \beta} + \frac{\bar{v}}{R_2}\right) - \frac{B}{AR_2}\left(\frac{\partial \bar{v}}{\partial \alpha} - \frac{\bar{u}}{B}\frac{\partial A}{\partial \beta}\right),$$

here $\bar{u}, \bar{v}, \bar{w}$ are the displacement components of the middle surface along the axes OX, OY, OZ; R_1, R_2 are the curvature radii of the main normal sections of the surface by the planes passing through the axes OX, OY, OZ; h_1, h_2 are functions of α, β, γ.

Expressions (2) and (3) for circular plates have the form:

$$\begin{aligned} & h_1 = 1, h_2 = \frac{1}{\bar{r}}, A = 1, B = \bar{r}, p_1 = 0, p_2 = \frac{d\bar{w}}{d\bar{r}}, \\ & q_1 = -\frac{d^2\bar{w}}{d\bar{r}^2}, r_1 = \frac{d^2\bar{v}}{d\bar{r}^2}, q_2 = 0, r_2 = 1, s_1 = s_2 = s = 0, \\ & \bar{Q}_2 = 0, X = 0, Y = 0, Z = \bar{q} \end{aligned} \tag{4}$$

Substituting expressions (4) into system (1), we obtain the following system of equilibrium for flexible circular plates under the action of uniformly distributed loads:

$$\left.\begin{aligned} & \frac{d}{d\bar{r}}\left(\bar{T}_1\bar{r}\right) - \bar{T}_2 - \bar{r}\bar{Q}\frac{d^2\bar{w}}{d\bar{r}^2} = 0, \\ & \frac{d}{dr}\left(\bar{Q}\bar{r}\right) + \bar{r}\bar{T}\frac{d^2\bar{w}}{d\bar{r}^2} + \bar{T}_2\frac{d\bar{w}}{d\bar{r}} + \bar{r}\bar{q} = 0 \end{aligned}\right\} \tag{5}$$

where

$$\left.\begin{aligned} & \bar{T}_1 = \frac{12}{h^2}D\left(\bar{\varepsilon}_{11} + \mu\bar{\varepsilon}_{22}\right), \bar{T}_2 = \frac{12}{h^2}D\left(\bar{\varepsilon}_{22} + \mu\bar{\varepsilon}_{11}\right) \\ & \bar{Q} = -D\left(\frac{d^3\bar{w}}{d\bar{r}^3} + \frac{1}{\bar{r}}\frac{d^2\bar{w}}{d\bar{r}^2} - \frac{1}{\bar{r}^2}\frac{d\bar{w}}{d\bar{r}}\right), \varepsilon_{11} = \frac{d\bar{u}}{d\bar{r}} + \frac{1}{2}\left(\frac{d\bar{w}}{d\bar{r}}\right)^2, \varepsilon_{22} = \frac{\bar{u}}{\bar{r}} \end{aligned}\right\} \tag{6}$$

Now substituting (6) into (5) and introducing the following dimensionless quantities

$$r = \frac{\bar{r}}{a}, u = \frac{\bar{u}}{n}, w = \frac{\bar{w}}{n}, \delta = \frac{a}{n}, \tag{7}$$

we reduce system (5) to the following quasilinear system of differential equations:

$$\left.\begin{aligned} & -a_1\frac{d^2u}{dr^2} - a_2\frac{du}{dr} + a_3u - a_4\frac{d^2w}{dr^2} - a_5\frac{dw}{dr} = 0, \\ & b_1\frac{d^4w}{dr^4} + b_2\frac{d^2w}{dr^3} + b_3\frac{d^2w}{dr^2} + b_4\frac{dw}{dr} = \beta \end{aligned}\right\} \tag{8}$$

where $a_1 = 12\delta^2, a_2 = \dfrac{12\delta^2}{r}, a_3 = \dfrac{12\delta^2}{r^2}, a_4 = \dfrac{1}{\delta}\dfrac{d^3w}{dr^3} + \dfrac{1}{r\delta}\dfrac{d^2w}{dr^2} + \left(12\delta - \dfrac{1}{r^2\delta}\right)\dfrac{dw}{dr}$

$$a_5 = \frac{6(1-\mu)}{r}\delta\frac{dw}{dr}, b_1 = 1, b_2 = \frac{2}{r}, b_3 = \frac{1}{r^2} + 12\delta\left[\frac{du}{dr} + \frac{1}{2\delta}\left(\frac{dw}{dr}\right)^2 + \mu\frac{u}{r}\right],$$

$$b_4 = \frac{1}{r^3} - \frac{12}{r}\delta\left[\frac{u}{r} + \mu\frac{du}{dr} + \mu\frac{1}{2\delta}\left(\frac{dw}{dr}\right)^2\right], \beta = qq_0, q_0 = \frac{12(1-\mu^2)}{E}\delta^4, q = q(r).$$

System of equations (8) is solved in the domain

$$\omega = \begin{cases} 0 \le r \le 1 \ (\text{solid circular plate}) \\ r_0 \le r \le 1 \ (\text{circular ring plate}) \end{cases}$$

with the boundary conditions:

$$T_\nu \delta u_\nu\big|_\Gamma = 0,\ \mu_\nu \delta \frac{\partial w}{\partial \nu}\bigg|_\Gamma = 0,\ R_\nu \delta\omega\big|_\Gamma = 0 \qquad (9)$$

Equations (8) for given boundary conditions are solved by the grid method.

Introduce the grid:

$$\omega_h = \begin{cases} r_i = ih \ \text{ for the solid circular plate,} \\ r_i = r_0 + ih(1-r_0) \ \text{ for the circular ring plate} \end{cases}$$

with the step $h = \dfrac{1}{N}$ on the segment $0 \le r_i \le 1$ or $r_0 \le r_i \le 1$.

$X_i = \{u_i, w_i\}$ is the grid function in the domain ω_n.

Using central difference formulas approximating derivatives with second-order accuracy [4], instead of equations (8), we obtain the following system of quasilinear algebraic equations [3]:

$$A_i X_{i-2} + B_i X_{i-1} + C_i X_i + D_i X_{i+1} + E_i X_{i+2} = g_i \qquad (10)$$

where $A_i = \begin{pmatrix} 0 & 0 \\ 0 & a_{22} \end{pmatrix}, B_i = \begin{pmatrix} b_{11} & b_{12} \\ 0 & b_{22} \end{pmatrix}, C_i = \begin{pmatrix} c_{11} & c_{12} \\ 0 & c_{22} \end{pmatrix},$

$$D_i = \begin{pmatrix} d_{11} & d_{12} \\ 0 & d_{22} \end{pmatrix}, E_i = \begin{pmatrix} 0 & 0 \\ 0 & e_{22} \end{pmatrix}, g_i = \begin{pmatrix} 0 \\ \beta \end{pmatrix},$$

$$b_{11} = a_1 N^2 - a_2\frac{N}{2}, b_{12} = a_4 N^2 - a_5\frac{N}{2}, c_{11} = 2a_1 N^2 + a_3,$$

$$c_{12} = 2a_4 N^2, d_{11} = a_1 N^2 + a_2\frac{N}{2}, d_{12} = a_4 N^2 + a_5\frac{N}{2},$$

$$a_{22} = b_1 N^4 - b_2\frac{N^3}{2}, e_{22} = b_1 N^4 + b_2\frac{N^3}{2}, c_{22} = 6b_1 N^4 + 2b_3 N^2,$$

$$b_{22}=4b_1N^4-b_2N^3+b_3N^2+b_4\frac{N}{2},\ d_{22}=4b_1N^4+b_2N^3+b_3N^2-b_4\frac{N}{2},\ a_1=12\delta^2, a_2=\frac{12\delta^2}{r_i},$$

$$a_3=12\frac{\delta^2}{r_i^2},\ a_4=\frac{N^3}{2\delta}\left(w_{i+2}-2w_{i+1}+2w_{i-1}+w_{i-2}\right)+$$

$$+\frac{N^2}{r_i\delta}\left(w_{i+1}-2w_i+w_{i-1}\right)+\left(12\delta-\frac{1}{r_i^2\delta}\right)\left(w_{i+1}-w_{i-1}\right)\frac{N}{2},$$

$$b_1=1, b_2=\frac{2}{r_i}, b_3=\frac{1}{r_i^2}+12\delta\left[\frac{N}{2}\left(u_{i+1}-u_{i-1}\right)+\frac{N^2}{8\delta}\left(w_{i+1}-w_{i-1}\right)^2+\mu\frac{u_i}{r_i}\right],$$

$$b_4=\frac{1}{r_i^3}-\frac{12\delta}{r_i}\left[\frac{u_i}{r_i}+\mu\frac{N}{2}\left(u_{i+1}-u_{i-1}\right)+\mu\frac{N^2}{8\delta}\left(w_{i+1}-w_{i-1}\right)^2\right],$$

2. Theoretical and experimental research

Let us consider some difference boundary conditions for flexible round plates under statistical loading.

1. For a solid round plate, contaminated

$$\left.\begin{array}{l} u(0)=0, w'(0)=0, w'''(0)=0 \text{ at } r=0; \\ u(1)=0, w(1)=0, w'(1)=0 \text{ at } r=1. \end{array}\right\} \quad (11)$$

From the first, fourth and fifth conditions (11) we obtain

$$u_0=0, u_N=0, w_N=0 \quad (12)$$

Applying the central difference formulas with the second order of approximation [3] to the second, third and sixth conditions (11), we find [2].

$$\left.\begin{array}{l} w_0=\frac{4}{3}w_1-\frac{1}{3}w_2,\ w_{-1}=\frac{4}{9}w_1+\frac{8}{9}w_2-\frac{1}{3}w_3, \\ w_{N+1}=w_{N-1} \end{array}\right\} \quad (13)$$

In vector form, conditions (12) and (13) have the following form:

$$EX_0=A_0X_1+B_0X_2,\ E_{-1}X_{-1}=A_{-1}X_1+B_{-1}X_2+C_{-1}X_3 \quad (14)$$

and

$$X_N=0,\ EX_{N+1}=EX_{N-1} \quad (15)$$

Substituting (14) and (15) into the system of difference equations (10), we obtain a system of quasilinear algebraic equations

$$NX=b \quad (16)$$

where

$$N=\begin{cases}\overline{C}_1\overline{D}_1\overline{E}_1\\ \overline{B}_2\overline{C}_2D_2E_2\\ A_3B_3C_3D_3E_3\\ \cdots\cdots\cdots\cdots\cdots\\ A_{N-3}B_{N-3}C_{N-3}D_{N-3}E_{N-3}\\ \quad A_{N-2}B_{N-2}C_{N-2}D_{N-2}\\ \quad\quad A_{N-1}B_{N-1}\overline{C}_{N-1}\end{cases}$$

where

$$\overline{c}_1=c_1+A_1A_0+B_1B_0$$

$$\overline{D}_1=D_1+A_1B_{-1}+B_1B_0,\ \overline{E}_1=E_1+A_1C_{-1},\ \overline{B}_2=A_2A_0+B_2,\ \overline{C}_2=C_2+A_2B_0,\ \overline{C}_{N-1}=C_{N-1}+E_{N-1}E_N,$$

$$A_0=\begin{pmatrix}0&0\\0&4/3\end{pmatrix},B_0=\begin{pmatrix}0&0\\0&-1/3\end{pmatrix}=C_{-1},E_N=\begin{pmatrix}0&0\\0&1\end{pmatrix},A_{-1}=\begin{pmatrix}0&0\\0&4/9\end{pmatrix},B_{-1}=\begin{pmatrix}0&0\\0&8/9\end{pmatrix}$$

2. For a continuous circular annular plate articulated along the contour.

$$\left.\begin{aligned}&u(0)=0,w'(0)=0,w''(0)=0\ at\ r=0;\\&u(1)=0,w(1)=0,w'(1)=0\ at\ r=1.\end{aligned}\right\}\qquad(17)$$

The difference conditions on the circuit in vector form will take the form:

$$X_N=0,\ E_NX_{N+1}=\overline{E}X_{N-1}\qquad(18)$$

Substituting conditions (14) and (18) into the system of difference equations in (10), we obtain a system of quasilinear algebraic equations in the form (16), where

$$\overline{C}_{N-1}=C_{N-1}+E_{N-1}\overline{E}_N,\overline{E}_N=\begin{pmatrix}0&0\\0&H_1\end{pmatrix},H_1=\frac{1-2\mu}{\mu+2N}.$$

To solve the system of equations (16), an implicit iterative process is used in combination with the Gauss elimination method [4].

As a result of the i th equation (16) we find

$$X_{i-1}=\alpha_iX_{i+1}+\beta_iX_{i+2}+\gamma_i\qquad(19)$$

where

$$\begin{aligned}&\alpha_i=\left[D_i+\overline{Q}_i\beta_{i-1}\right]Q_i^{-1},\ \beta_i=Q_i^{-1}E_i,\ \gamma_i=\left(b_i^2-\left(\overline{Q}_i+A_i\gamma_{i-2}\right)\right)Q_i,\\&Q_i=c_i+A_i\beta_{i-2}+\overline{Q}_i\alpha_{i-1};Q_i=A_i\alpha_{i-2}+B_i.\end{aligned}\qquad(20)$$

Using formulas (20), we find the values of the last value of the unknown vector X_N and X_{N-1} (if the edge is free (X_N) in the case of other boundary conditions (X_{N-1})), we determine the values of the grid function $X_i\left(i=\overline{1,N-2}\right)$.

When calculating (19), the iterative process continues until the condition

$$\left|X_i^{(j+1)}-X_i^{(j)}\right|\le\varepsilon\qquad(21)$$

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After determining the desired functions by the finite difference X_i method, calculated values are calculated.
Thus, a mathematical model was compiled to obtain a numerical result.

3. Methodology

In this paper, we present the results of a study of the convergence of the finite difference method and the method for solving nonlinear algebraic equations depending on the intensity of the external load β and the ratio of the radius to the plate $\delta = 40$ thickness.

Tables 1-3 for values of a continuous round plate clamped along the contour show the values β, $w_\lambda(0)$, $w_{H\lambda}(0)$, $M_{1\lambda}(0)$, $M_{1H\lambda}(0)$, $\delta_1(0)$ - at $N = 10, 20, 40$ –step of the grid $\varepsilon = 10^{-4}$ of convergence accuracy.

It can be seen from the tables that, for $N = 10$ and $N = 20$, the values, $w_\lambda(0)$, $w_{H\lambda}(0)$, $M_{1H\lambda}(0)$ –are two and $M_{1\lambda}(0)$ –one decimal places, the values $\sigma_i(0)$ at $\beta < 100$ do not coincide, and two decimal places $100 \le \beta \le 200$ coincide in the interval.

When $N = 20$ and $N = 40$ the value $w_\lambda(0)$ matches three decimal places, and $w_{H\lambda}(0)$ two. If we take into account that $w_\lambda(0)$ when $N = 20$- differ from the exact value $w_\lambda(0)$- only by 0.002%, then for a rough calculation you can use the values of $w_\lambda(0)$ at $N = 20$.

The value $M_{1\lambda}(0)$ matches two decimal places, and y $M_{1H\lambda}(0)$ - two in the interval $25 \le \beta \le 100$.

The value $\sigma_1'(0)$ in the interval $25 \le \beta \le 150$ does not match, but in the interval $150 \le \beta \le 200$ matches two decimal places.

For all, N the number of iterations is constant.

4. Finding

The compiled algorithm allows you to get the necessary results at any grid pitch and load intensity.

λ - in the linear statement of the problem, $H\lambda$ - in the nonlinear statement of the problem, w - deflection of the plate, M_1 - radial moments, σ_1 - radial stress.

№	β	$w_\lambda(0)$	$w_{H\lambda}(0)$	$M_{1\lambda}(0)\cdot 10^{-3}$	$M_{1H\lambda}(0)\cdot 10^{-3}$	$\sigma_1'(0)\cdot 10^{-3}$
1	12,5	0,19581762	0,191478	0,346445	0,453684	0,241034
2	25	0,391635525	0,365690	0,930252	0,654487	0,378930
3	37,5	0,58745287	0,516298	1,39451	1,18455	0,694914
4	50	0,78327049	0,645557	1,85818	1,45247	0,886161
5	62,5	0,97908812	0,7572070	2,32128	1,67058	1,05458
6	75	1,17490574	0,855182	2,78380	1,85140	1,20458
7	87,5	1,37007233	0,942533	3,24574	2,00449	1,34020
8	100	1,56654098	1,021158	3,70701	2,13534	1,46349
9	125	1,9581762	1,158715	4,62807	2,34969	1,68276
10	150	2,34981148	1,276296	5,54673	2,51814	1,87386
11	175	2,7414467	1,379709	6,46307	2,65655	2,04529
12	200	3,13308197	1,472415	7,37709	2,77408	2,20248

TABLE 1. At $\delta = 40,\ N = 10,\ \varepsilon = 10^{-4}$

№	β	$w_\lambda(0)$	$w_{H\lambda}(0)$	$M_{1\lambda}(0)\cdot 10^{-3}$	$M_{1H\lambda}(0)\cdot 10^{-3}$	$\sigma_1'(0)\cdot 10^{-3}$
1	12,5	0,1953747	0,1907875	0,480732	0,467727	0,246999
2	25	0,3907494	0,3654287	0,960858	0,877379	0,493488
3	37,5	0,5861240	0,5116917	1,440381	1,210690	0,713587

4	50	0,7814987	0,6388544	1,919293	1,478613	0,907084
5	62,5	0,9768734	0,7473702	2,397603	1,694665	1,076493
6	75	1,1722480	0,842843	2,875304	1,872566	1,226895
7	87,5	1,3676227	0,9278838	3,352412	2,022491	1,322437
8	100	1,5629974	1,0043476	3,82889	2,14994	1,48544
9	125	1,9537467	1,138057	4,78006	2,35773	1,70389
10	150	2,344461	1,2517449	5,72889	2,51796	1,82266
11	175	2,7352543	1,3528125	6,67519	2,65293	2,506443
12	200	3,1259948	1,4429474	7,61902	2,76563	2,92076

TABLE 2. At $\delta = 40,\ N = 20,\ \varepsilon = 10^{-4}$

№	β	$w_\lambda(0)$	$w_{H\lambda}(0)$	$M_{1\lambda}(0)\cdot 10^{-3}$	$M_{1H\lambda}(0)\cdot 10^{-3}$	$\sigma_1^{'}(0)\cdot 10^{-3}$
1	12,5	0,19530867	0,19107834	0,485725	0,472984	0,251815
2	25	0,39061735	0,36550100	0,970885	0,888274	0,500117
3	37,5	0,58592605	0,51666869	1,455332	1,225217	0,721178
4	50	0,78123470	0,6459896	1,939214	1,491382	0,912696
5	62,5	0,97654338	0,7583067	2,422471	1,705786	1,062491
6	75	1,17185203	0,85585956	2,905123	1,876603	1,243470
7	87,5	1,36716073	0,9425701	3,387152	2,018304	1,379510
8	100	1,56246940	1,01986810	3,688570	2,135591	1,501753
9	125	1,95308676	1,15407524	4,829563	2,322790	1,718991
10	150	2,24370411	1,26641023	5,788091	2,462441	1,905951
11	175	2,73432146	1,3627218	6,74416	2,57073	2,07100
12	200	3,1249388	1,4497568	7,697770	2,667366	2,227210

TABLE 3. At $\delta = 40,\ N = 40,\ \varepsilon = 10^{-4}$

Table (4) shows the percentage change

$$K = 100\%\left(\frac{1}{H\lambda} - 1\right).$$

And the number of iterations Θ at $\delta = 20$ and 40 with increasing parameter β.
It can be seen from table (4) that, for a fixed interval δ, the calculation is $0,25 \le w_\lambda \le 100$ Θ almost proportional β, i.e. curves $w_{H\lambda}$ □ β and Θ □ β almost coincide. The results of table (4) allow us to conclude that with a fixed β increase δ increases Θ.

β	k	Θ	β	k	Θ
At $\delta = 20$			At $\delta = 40$		
16	3	3	25	6,9	5
32	9,5	5	50	19,2	8
48	18,1	6	100	53,1	12
64	27,6	7	125	70	14
96	47	9	150	85,1	14
112	56	9	175	100	14
128	64,6	9	200	115,6	17

TABLE 4. At $N = 40,\ \varepsilon = 10^{-5}$

δ	$w_\lambda(0)$	$w_{H\lambda}(0)$	$M_{1\lambda}(0)\cdot 10^{-2}$	$M_{1H\lambda}(0)\cdot 10^{-2}$
10	1,6005093	1,01098	1,58692104	0,878604
20	1,6005093	1,016144	1,58692104	0,874455
30	1,600509	1,017638	1,586921	0,874547

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40	1,600509	1,01824	1,586621	0,874693
50	1,600509	1,018622	1,586921	0,874869
60	1,600509	1,01997	1,586921	0,875159

TABLE 5. At $\beta = 102,4;\ \varepsilon = 10^{-6};\ \mu = 0,3;\ N = 20$

5. Conclusion

It can be seen from table (5) that, with a constant β with an increase δ in the linear statement of the problem w and M , they do not change in the nonlinear w and M coincide in three decimal places.

6. References

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