報　　文

円壔殻に関する2つの研究

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TWO STUDIES ON THE CIRCULAR CYLINDRICAL SHELLS.

(JSCE July 1953)

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Synopsis　This paper deals with two problems about the stresses in the circular cylindrical shells. In the first part, eight tables are given for calculating the stress resultants in a portion of a shell supported simply along the circular edges and arbitraly along other two streight edges. According to the Finsterwalders method of approximation for the stress analysis in the shell, the bending moments M_θ are afforded by the expression (1) and α satifies the equation (2).When the thickness of the shell is very small in comparison with its diameter, the roots of the equation (2) can be put in (3) approximately and the stress resultants and the deformations are given in the form (4) (5) & (6), and the coefficient in these equations are numerically calculated and tablated for shells, whose dimentions are radious/length $=0.3\sim2.0$ radious/thickness$=100\sim700$. In the second part, the bending moments at the fixed end of the circular cylindrical tank are calculated whose lower end is fixed and the upper end is free and the horizontal uniform lords are acting on it. If we consider the membrane stresses only, the slope of the wall of the tank at the bottom is given in (7) and as this is fixed, the slope must be canceled by the deformations due to bending stresses. Putting the deformations due to the bending stresses as (9), α must satisfy the algebraic equation (10) and when the thickness of the wall of he tank is very much small in comparison with its diameter, α can be expressed as (12) approximately and the maximum bending moment at the bottom of the wall is given by (13).

要旨　円壔殻に関する2つの研究を集めたものである。第1部は両円弧端を単純に支持された薄肉円壔殻の近似解法に必要なる一数表と題し，特に貯油槽に用いられるごとき寸法をもつ円壔殻に Finsterwalder の近似解法を適用する際に必要な数表を示したものである。第2部は水平等分布荷重をうける円壔形タンク側壁底部の曲げモーメントの近似計算と題し，地震時に下端を埋込まれたタンクの側壁底部に生ずる曲げモーメントを膜応力論を補正する形で近似的に求めたものである。

第1部　両円弧端を単純に支持された薄肉円壔殻の近似解法に必要なる一数表

1. 基礎方程式

表面からは外力をうけていない円壔殻の基礎方程式は次のごとくである。ただし式中の諸記号は図—1 に示してある。平衡方程式は

$$a\frac{\partial N_x}{\partial x}+\frac{\partial N_{\theta x}}{\partial \theta}=0$$

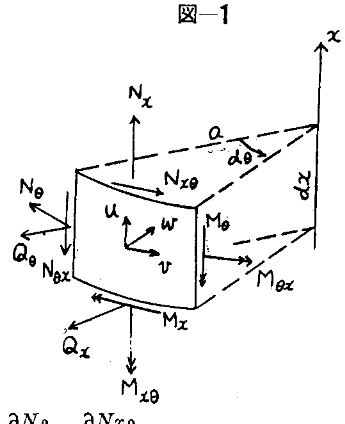
$$\frac{\partial N_\theta}{\partial \theta}+a\frac{\partial N_{x\theta}}{\partial x}-Q_\theta=0$$

$$a\frac{\partial Q_x}{\partial x}+\frac{\partial Q_\theta}{\partial \theta}+N_\theta=0$$

$$a\frac{\partial M_{x\theta}}{\partial x}-\frac{\partial M_\theta}{\partial \theta}+aQ_\theta=0$$

$$\frac{\partial M_{\theta x}}{\partial \theta}+a\frac{\partial M_x}{\partial x}-aQ_x=0$$

図—1



変位と部材力との関係式は $N_x, N_{x\theta}, N_\theta$ に及ぼす曲

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げの影響を無視するとき

$$N_x=\frac{Et}{1-\nu^2}\left\{\frac{\partial u}{\partial x}+\frac{\nu}{a}\left(\frac{\partial v}{\partial \theta}-w\right)\right\}$$

$$N_\theta=\frac{Et}{1-\nu^2}\left\{\frac{1}{a}\left(\frac{\partial v}{\partial \theta}-w\right)+\nu\frac{\partial u}{\partial x}\right\}$$

$$M_x=-D\left\{\frac{\partial^2 w}{\partial x^2}+\frac{\nu}{a^2}\left(\frac{\partial v}{\partial \theta}+\frac{\partial^2 w}{\partial \theta^2}\right)\right\}$$

$$M_\theta=-D\left\{\frac{1}{a^2}\left(\frac{\partial v}{\partial \theta}+\frac{\partial^2 w}{\partial \theta^2}\right)+\nu\frac{\partial^2 w}{\partial x^2}\right\}$$

$$N_{\theta x}=N_{x\theta}=\frac{Et}{2(1+\nu)}\left(\frac{1}{a}\frac{\partial u}{\partial \theta}+\frac{\partial v}{\partial x}\right)$$

$$M_{x\theta}=-M_{\theta x}=\frac{D(1-\nu)}{a}\left(\frac{\partial v}{\partial x}+\frac{\partial^2 w}{\partial x\partial \theta}\right)$$

ここに t は壁厚, uvw はそれぞれ円壔の母線方向, 円周方向, 内向法線方向の変位を表わす。また E はヤング係数, ν はポアソン比, D は次式である。

$$D=\frac{Et^3}{12(1-\nu^2)}$$

2. 近似解法

円壔殻が図—2 のごとく両円弧端AB, 及び CD にそつて単純に支持されている場合には次のごとき近似解法がある[1]。すなわちこのような殻では実験によると M_x と Q_x は小であるから

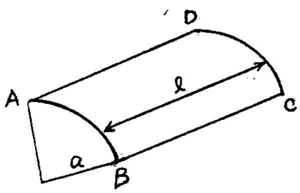
$$M_x=Q_x=0$$

とおきかつ,

$$M_{x\theta}=0$$

と仮定する。しからば

図—2



$$Q_\theta=\frac{1}{a}\frac{\partial M_\theta}{\partial \theta}$$

$$N_\theta=-\frac{1}{a}\frac{\partial^2 M_\theta}{\partial \theta^2}$$

$$\frac{\partial N_{x\theta}}{\partial x}=\frac{1}{a^2}\left(\frac{\partial M_\theta}{\partial \theta}+\frac{\partial^3 M_\theta}{\partial \theta^3}\right)$$

$$\frac{\partial^2 N_x}{\partial x^2}=-\frac{1}{a^3}\left(\frac{\partial^2 M_\theta}{\partial \theta^2}+\frac{\partial^4 M_\theta}{\partial \theta^4}\right)$$

となり M_θ は次の微分方程式を満足する。

$$\frac{\partial^8 M_\theta}{\partial \theta^8}+(2+\nu)a^2\frac{\partial^8 M_\theta}{\partial x^2\partial \theta^6}+2\frac{\partial^6 M_\theta}{\partial \theta^6}+(1+2\nu)a^4\frac{\partial^8 M_\theta}{\partial x^4\partial \theta^4}+2(2+\nu)a^2\frac{\partial^6 M_\theta}{\partial x^2\partial \theta^4}+\frac{\partial^4 M_\theta}{\partial \theta^4}+\nu a^6\frac{\partial^8 M_\theta}{\partial x^6\partial \theta^2}$$
$$+(1+\nu)^2a^4\frac{\partial^6 M_\theta}{\partial x^4\partial \theta^2}+(2+\nu)a^2\frac{\partial^4 M_\theta}{\partial x^2\partial \theta^2}+\frac{12(1-\nu^2)a^6}{t^2}\frac{\partial^4 M_\theta}{\partial x^4}=0$$

いま

$$M_\theta=fe^{\alpha\theta}\sin\frac{m\pi x}{l},$$

(m: 整数, f: 常係数)………………(1)

とおいて前の微分方程式に代入すれば α は次式を満足せねばならない。

$$\alpha^8+4b\alpha^6+6c\alpha^4+4d\alpha^2+\frac{ea^2}{t^2}=0 \quad \cdots\cdots\cdots(2)$$

ただし

$$\lambda=\frac{m\pi a}{l},$$

$$b=\frac{1}{4}\{2-(2+\nu)\lambda^2\},$$

$$c=\frac{1}{6}\{1+2\nu)\lambda^4-2(2+\nu)^2+1\}$$

$$d=\frac{1}{4}\{(1+\nu)^2\lambda^4-\nu\lambda^6-(2+\nu)\lambda^2\}$$

$$e=12(1-\nu^2)\lambda^4$$

なおこの場合変位は次式によつて求められる。

$$Et\frac{\partial u}{\partial x}=N_x-\nu N_\theta$$

$$Et\frac{\partial^2 v}{\partial x^2}=2\frac{\partial N_{x\theta}}{\partial x}-\frac{1}{a}\frac{\partial N_x}{\partial \theta}+\nu\left(2\frac{\partial N_{x\theta}}{\partial x}+\frac{1}{a}\frac{\partial N_\theta}{\partial \theta}\right)$$

$$Et\frac{\partial^2 w}{\partial x^2}=2\frac{\partial^2 N_{x\theta}}{\partial x\partial \theta}-a\frac{\partial^2 N_\theta}{\partial x^2}-\frac{1}{a}\frac{\partial^2 N_x}{\partial \theta^2}+\nu\left(a\frac{\partial^2 N_x}{\partial x^2}+2\frac{\partial^2 N_{x\theta}}{\partial x\partial \theta}+\frac{1}{a}\frac{\partial^2 N_\theta}{\partial \theta^2}\right)$$

3. 厚さの薄い円壔殻への応用

鋼製水槽のごとき構造物では直径に比し壁厚が薄く,

$$a/l=0.3\sim 2.0 \qquad a/t=100\sim 700$$

である。この範囲について上記8次方程式の係数を $\nu=0.3$ として求めれば係数 ea^2/t^2 は他の係数に比し格段に大なることが認められる。よつて近似的に

$$\alpha^8=-12(1-\nu^2)\lambda^4\frac{a^2}{t^2}$$

上式を満足する8個の α のうち $e^{\alpha\theta}$ が θ とともに減衰するごとき α は次の4個である。

$$\left.\begin{aligned}\alpha_{1,2}&=-\sqrt{\lambda}B\left(\cos\frac{\pi}{8}\pm i\sin\frac{\pi}{8}\right)\\ \alpha_{3,4}&=-\sqrt{\lambda}B\left(\sin\frac{\pi}{8}\pm i\cos\frac{\pi}{8}\right)\end{aligned}\right\}\cdots\cdots(3)$$

ただし

$$B=\sqrt[8]{12(1-\nu^2)\frac{a^2}{t^2}}$$

よつて

$$M_\theta=\sin\frac{m\pi x}{l}\{f_1e^{-\gamma\theta}\cos\beta\theta+f_2e^{-\gamma\theta}\sin\beta\theta+g_1e^{-\beta\theta}\cos\gamma\theta+g_2e^{-\beta\theta}\sin\gamma\theta\}\quad\cdots\cdots\cdots(4)$$

ただし

1) S. Timoshenco: Theory of platesand shells. 1940, p.446

$$\gamma=\sqrt{\lambda}\,B\cos\frac{\pi}{8}\qquad\beta=\sqrt{\lambda}\,B\sin\frac{\pi}{8}$$

でその値は表―1 のごとくである。f_1, f_2, g_1, g_2 は係数である。これで問題は解けたわけであるが同時に部材力 Q_θ, $N_{x\theta}$, N_θ, N_x 変位 u, v, w を与えておくと計算に便利である。すなわち,

$$\left.\begin{aligned}
Q_\theta&=-\frac{1}{a}\sin\frac{m\pi x}{l}\{(\gamma f_1-\beta f_2)e^{-\gamma\theta}\cos\beta\theta+(\beta f_1+\gamma f_2)e^{-\gamma\theta}\sin\beta\theta\\
&\qquad+(\beta g_1-\gamma g_2)e^{-\beta\theta}\cos\gamma\theta+(\gamma g_1+\beta g_2)e^{-\beta\theta}\sin\gamma\theta\}\\
N_{x\theta}&=\frac{1}{a}\cos\frac{m\pi x}{l}\{(T_1f_1-T_2f_2)e^{-\gamma\theta}\cos\beta\theta+(T_2f_1+T_1f_2)e^{-\gamma\theta}\sin\beta\theta\\
&\qquad+(T_1'g_1-T_2'g_2)e^{-\beta\theta}\cos\gamma\theta+(T_2'g_1+T_1'g_2)e^{-\beta\theta}\sin\gamma\theta\}\\
N_\theta&=-\frac{\Theta}{a}\sin\frac{m\pi x}{l}\{(f_1-f_2)e^{-\gamma\theta}\cos\beta\theta+(f_1+f_2)e^{-\gamma\theta}\sin\beta\theta\\
&\qquad-(g_1+g_2)e^{-\beta\theta}\cos\gamma\theta+(g_1-g_2)e^{-\beta\theta}\sin\gamma\theta\}\\
N_x&=\frac{1}{a}\sin\frac{m\pi x}{l}\{(X_1f_1-X_2f_2)e^{-\gamma\theta}\cos\beta\theta+(X_2f_1+X_1f_2)e^{-\gamma\theta}\sin\beta\theta\\
&\qquad-(X_1g_1+X_2'g_2)e^{-\beta\theta}\cos\gamma\theta+(X_2'g_1-X_1g_2)e^{-\beta\theta}\sin\gamma\theta\}
\end{aligned}\right\}\cdots\cdots\cdots(5)$$

$$\left.\begin{aligned}
Etu&=-\cos\frac{m\pi x}{l}\{(U_1f_1-U_2f_2)e^{-\gamma\theta}\cos\beta\theta+(U_2f_1+U_1f_2)e^{-\gamma\theta}\sin\beta\theta\\
&\qquad-(U_1g_1+U_2'g_2)e^{-\beta\theta}\cos\gamma\theta+(U_2'g_1-U_1g_2)e^{-\beta\theta}\sin\gamma\theta\}\\
Etv&=\sin\frac{m\pi x}{l}\{(V_1f_1-V_2f_2)e^{-\gamma\theta}\cos\beta\theta+(V_2f_1+V_1f_2)e^{-\gamma\theta}\sin\beta\theta\\
&\qquad+(V_1'g_1-V_2'g_2)e^{-\beta\theta}\cos\gamma\theta+(V_2'g_1+V_1'g_2)e^{-\beta\theta}\sin\gamma\theta\}\\
Etw&=\sin\frac{m\pi x}{l}\{(W_1f_1-W_2f_2)e^{-\gamma\theta}\cos\beta\theta+(W_2f_1+W_1f_2)e^{-\gamma\theta}\sin\beta\theta\\
&\qquad-(W_1g_1+W_2'g_2)e^{-\beta\theta}\cos\gamma\theta+(W_2'g_1-W_1g_2)e^{-\beta\theta}\sin\gamma\theta\}
\end{aligned}\right\}\cdots\cdots\cdots(6)$$

ここに

$$T_1=\frac{B}{\sqrt{\lambda}}\{1+(\sqrt{2}-1)\lambda B^2\}\cos\frac{\pi}{8}$$

$$T_2=\frac{B}{\sqrt{\lambda}}\{1+(\sqrt{2}+1)\lambda B^2\}\sin\frac{\pi}{8}$$

$$T_1'=\frac{B}{\sqrt{\lambda}}\{1-(\sqrt{2}+1)\lambda B^2\}\sin\frac{\pi}{8}$$

表―1

m	a/l \ a/t	β							γ						
		100	200	300	400	500	600	700	100	200	300	400	500	600	700
1	0.3	1.584	1.884	2.085	2.240	2.369	2.479	2.577	3.823	4.547	5.033	5.408	5.719	5.986	6.221
	0.4	1.828	2.174	2.407	2.586	2.735	2.862	2.975	4.414	5.249	5.811	6.243	6.602	6.910	7.181
	0.6	2.240	2.666	2.948	3.168	3.350	3.506	3.644	5.407	6.431	7.118	7.648	8.087	8.465	8.798
	0.8	2.586	3.076	3.404	3.658	3.868	4.049	4.208	6.243	7.425	8.219	8.831	9.338	9.774	10.158
	1.0	2.891	3.438	3.806	4.090	4.324	4.526	4.704	6.980	8.301	9.189	9.873	10.439	10.927	11.36
	1.2	3.167	3.767	4.169	4.480	4.737	4.958	5.153	7.646	9.093	10.065	10.815	11.44	11.97	12.44
	1.4	3.421	4.069	4.504	4.839	5.117	5.356	5.566	8.259	9.823	10.873	11.68	12.35	12.93	13.44
	1.6	3.657	4.350	4.814	5.173	5.470	5.726	5.950	8.829	10.501	11.62	12.49	13.21	13.82	14.37
	1.8	3.879	4.613	5.107	5.487	5.802	6.073	6.311	9.365	11.14	12.33	13.25	14.01	14.66	15.24
	2.0	4.089	4.863	5.383	5.784	6.016	6.402	6.653	9.872	11.74	13.00	13.96	14.77	15.46	16.06
2	0.3	2.240	2.666	2.948	3.168	3.350	3.506	3.644	5.407	6.431	7.118	7.648	8.087	8.465	8.798
	0.4	2.586	3.076	3.404	3.658	3.868	4.049	4.208	6.243	7.425	8.219	8.831	9.338	9.774	10.158
	0.6	3.167	3.767	4.169	4.480	4.737	4.958	5.153	7.646	9.093	10.065	10.815	11.44	11.97	12.44
	0.8	3.657	4.350	4.814	5.173	5.470	5.726	5.950	8.829	10.501	11.62	12.49	13.21	13.82	14.37
	1.0	4.089	4.863	5.383	5.784	6.016	6.402	6.653	9.872	11.74	13.00	13.96	14.77	15.46	16.61
	1.2	4.479	5.327	5.897	6.336	6.700	7.012	7.288	10.814	12.86	14.24	15.30	16.17	16.93	17.59
	1.4	4.838	5.754	6.369	6.844	7.237	7.575	7.872	11.68	13.89	15.38	16.52	17.47	18.29	19.00
	1.6	5.172	6.152	6.801	7.316	7.736	8.098	8.416	12.49	14.85	16.44	17.66	18.68	19.55	20.32
	1.8	5.486	6.525	7.222	7.760	8.205	8.589	8.926	13.24	15.75	17.44	18.74	19.81	20.74	21.55
	2.0	5.783	6.878	7.613	8.180	8.649	9.053	9.409	13.96	16.60	18.38	19.75	20.88	21.86	22.72
3	0.3	2.743	3.262	3.611	3.880	4.102	4.294	4.463	6.622	7.876	8.718	9.367	9.904	10.367	10.774
	0.4	3.167	3.767	4.169	4.480	4.737	4.958	5.153	7.646	9.093	10.065	10.815	11.44	11.97	12.44
	0.6	3.879	4.613	5.107	5.487	5.802	6.073	6.311	9.365	11.14	12.33	13.25	14.01	14.66	15.24
	0.8	4.479	5.327	5.897	6.336	6.700	7.013	7.288	10.816	12.86	14.24	15.30	16.17	16.93	17.59
	1.0	5.008	5.956	6.593	7.084	7.490	7.840	8.148	12.09	14.38	15.92	17.10	18.08	18.93	19.67
	1.2	5.486	6.525	7.222	7.760	8.205	8.589	8.926	13.24	15.75	17.44	18.74	19.81	20.74	21.55
	1.4	5.926	7.048	7.801	8.382	8.863	9.277	9.641	14.31	17.01	18.83	20.24	21.40	22.40	23.28
	1.6	6.335	7.534	8.340	8.961	9.475	9.918	10.307	15.29	18.19	20.13	21.63	22.88	23.94	24.88
	1.8	6.719	7.991	8.846	9.505	10.050	10.519	10.933	16.22	19.29	21.36	22.95	24.26	25.40	26.39
	2.0	7.082	8.424	9.324	10.019	10.594	11.09	11.52	17.10	20.34	22.51	24.19	25.58	26.77	27.82

$$T_2'=\frac{B}{\sqrt{\lambda}}\{1-(\sqrt{2}-1)\lambda B^2\}\cos\frac{\pi}{8}$$

$$\Theta=\frac{\lambda B^2}{\sqrt{2}}$$

$$X_1=\frac{B^2}{\sqrt{2}\lambda}$$

$$X_2=\frac{B^2}{\sqrt{2}\lambda}(1+\sqrt{2}\lambda B^2)$$

$$X_2'=\frac{B^2}{\sqrt{2}\lambda}(1-\sqrt{2}\lambda B^2)$$

$$U_1=\frac{(1+\nu\lambda^2)B^2}{\sqrt{2}\lambda^2}$$

$$U_2=\frac{B^2}{\sqrt{2}\lambda^2}(1+\nu\lambda^2+\sqrt{2}\lambda B^2)$$

$$U_2'=\frac{B^2}{\sqrt{2}\lambda^2}(1+\nu\lambda^2-\sqrt{2}\lambda B^2)$$

$$V_1=\left[2+B^2(\sqrt{2}-1)\left(B^2+2\lambda-\frac{1}{\lambda}\right)+\nu\{2+(\sqrt{2}-1)\lambda B^2\}\right]\frac{B}{\sqrt{\lambda^3}}\cos\frac{\pi}{8}$$

$$V_2=\left[2-B^2(\sqrt{2}+1)\left(B^2-2\lambda+\frac{1}{\lambda}\right)+\nu\{2+(\sqrt{2}+1)\lambda B^2\}\right]\frac{B}{\sqrt{\lambda^3}}\sin\frac{\pi}{8}$$

$$V_1'=\left[2-B^2(\sqrt{2}+1)\left(B^2+2\lambda-\frac{1}{\lambda}\right)\right.$$

$$+\nu\{2-(\sqrt{2}+1)\lambda B^2\}\Big]\frac{B}{\sqrt{\lambda^3}}\sin\frac{\pi}{8}$$

$$V_2'=\Big[2+B^2(\sqrt{2}-1)\Big(B^2-2\lambda-\frac{1}{\lambda}\Big)$$

$$+\nu\{2-(\sqrt{2}-1)\lambda B^2\}\Big]\frac{B}{\sqrt{\lambda^3}}\cos\frac{\pi}{8}$$

$$W_1=-\Big(\frac{B^4}{\sqrt{2}}+\frac{\lambda^2}{\sqrt{2}}+\sqrt{2}+\frac{\nu}{\sqrt{2}}\Big)\frac{B^2}{\lambda}$$

$$W_2=\Big\{\frac{B^4}{\sqrt{2}}-\Big(2\lambda+\frac{1}{\lambda}\Big)B^2-\Big(\frac{\lambda^2}{\sqrt{2}}+\sqrt{2}+\frac{\nu}{\sqrt{2}}\Big)\Big\}\frac{B^2}{\lambda}$$

$$W_2'=\Big\{\frac{B^4}{\sqrt{2}}+\Big(2\lambda-\frac{1}{\lambda}\Big)B^2-\Big(\frac{\lambda^2}{\sqrt{2}}-\sqrt{2}+\frac{\nu}{\sqrt{2}}\Big)\Big\}\frac{B^2}{\lambda}$$

4. 数 表

前記諸係数を $a/l=0.3\sim2.0$, $a/t=100\sim700$ の範囲について計算すれば表—2~8のごとくなる。

5. 結 語

両円弧端を単純に支持され他の2辺が任意の状態に支持されている部分円壔殻の問題，たとえば円壔形屋根の問題，補剛支柱を有する貯油槽の問題等はこの表を用いることによつて比較的簡単に取扱うことができる。本表の作製には東大生産技術研究所上林敏子氏があたられた。ここに感謝の意を表する次第である。

第2部 水平等分布荷重をうける円壔形タンク側壁底部の曲げモーメントの近似計算

1. 計算方針

一様なる水平等分布荷重をうける円壔形タンクの側壁底部には局部的に曲げモーメントを生ずるがそれは次のごとく考えて近似的に求められる。

1. 底部を除いては応力は膜応力（membrane stress）の状態にある。

2. 膜応力により側壁は底部にて傾斜することになるが，側壁がここで埋込端である場合にはここに曲げ応力を生じその大きさは前記の傾斜を打消すごときものである。

3. 曲げ応力の影響は局部的のものである。

2. 膜応力の算定

膜応力に関する平衡方程式は

$$a\frac{\partial N_x}{\partial x}+\frac{\partial N_{\theta x}}{\partial\theta}=0$$

$$a\frac{\partial N_{\theta x}}{\partial x}+\frac{\partial N_\theta}{\partial\theta}+aY=0$$

$$N_\theta+aZ=0$$

ここに Z は壁面に直交して内向に，Y は壁面に切して水平方向に働らく外力の強度である。また歪と変位及び応力との関係は

$$\varepsilon_x=\frac{\partial u}{\partial x}=\frac{1}{Et}(N_x-\nu N_\theta)$$

$$\varepsilon_\theta=\frac{1}{a}\Big(\frac{\partial v}{\partial\theta}-w\Big)=\frac{1}{Et}(N_\theta-\nu N_x)$$

$$\gamma_{\theta x}=\frac{\partial v}{\partial x}+\frac{1}{a}\frac{\partial u}{\partial\theta}=\frac{2(1+\nu)}{Et}N_{\theta x}$$

いま外力を Y_1, Z_1 を常数として

$$Y=Y_1\sin\theta \qquad Z=Z_1\cos\theta$$

なる水平力と考える，これは地震力，地震時動水圧をうける状態を推測したものである。このとき応力と変位についても

$$N_\theta=n_\theta\cos\theta \quad N_x=n_x\cos\theta \quad N_{\theta x}=n_{\theta x}\sin\theta$$

$$v=V\sin\theta \qquad u=U\cos\theta \qquad w=W\cos\theta$$

のごとく x の函数と θ の函数にわけて表わしうるものとする。しからば，

$$\frac{dU}{dx}=\frac{1}{Et}(n_x-\nu n_\theta)$$

$$\frac{1}{a}(V+W)=\frac{1}{Et}(n_\theta-\nu n_x)$$

$$\frac{dV}{dx}-\frac{U}{a}=\frac{2(1+\nu)}{Et}n_{\theta x}$$

及び

$$a\frac{dn_x}{dx}+n_{\theta x}=0 \qquad a\frac{dn_{\theta x}}{dx}-n_\theta+aY_1=0$$

$$n_\theta+aZ_1=0$$

上式を $x=l$ にて $n_x=n_{\theta x}=0$ のもとに解くと

$$n_\theta=-aZ_1 \qquad n_{\theta x}=(Z_1+Y_1)(l-x)$$

$$n_x=\frac{1}{2a}(Z_1+Y_1)(l-x)^2$$

$$\therefore\ EtU=C_1-\frac{1}{6a}(Z_1+Y_1)(l-x)^3+\nu aZ_1x$$

$$EtV=C_2+C_1\frac{x}{a}+\frac{1}{24a^2}(Z_1+Y_1)(l-x)^4+\frac{\nu}{2}Z_1x^2-(1+\nu)(Z_1+Y_1)(l-x)^2$$

$$EtW=-EtV-a^2Z_1-\frac{\nu}{2}(Z_1+Y_1)(l-x)^2$$

積分常数 C_1C_2 は $x=0$ にて $U=0$, $V=W$ なるごとくすればタンク全体に適当なる大いさの一様なる水平移動を与えることによりタンク底端の各点の変位を0ならしめることができる。このとき側壁底部の傾斜角を求めると

$$\Big(\frac{\partial w}{\partial x}\Big)_{x=0}=-\frac{(2+\nu)}{Et}(Z_1+Y_1)l\cos\theta \quad\cdots\cdots(7)$$

3. 側壁底部に生ずる曲げ応力の計算

(7) の側斜を打消すべき局部的曲げ応力の正確な算出は煩雑で実際的でないので近似解を行う。側壁面上に外力が働らいていない円壔では次の関係が成立つ。

$$\left.\begin{aligned}
&\frac{\partial^2 u}{\partial x^2}+\frac{1-\nu}{2a^2}\frac{\partial^2 u}{\partial\theta^2}+\frac{1+\nu}{2a}\frac{\partial^2 v}{\partial x\partial\theta}-\frac{\nu}{a}\frac{\partial w}{\partial x}=0\\
&\frac{1+\nu}{2}\frac{\partial^2 u}{\partial x\partial\theta}+\frac{a(1-\nu)}{2}\frac{\partial^2 v}{\partial x^2}+\frac{1}{a}\frac{\partial^2 v}{\partial\theta^2}-\frac{1}{a}\frac{\partial w}{\partial\theta}+h\left(a\frac{\partial^3 w}{\partial x^2\partial\theta}+\frac{1}{a}\frac{\partial^3 w}{\partial\theta^3}\right)\\
&\qquad+h\left\{(1-\nu)a\frac{\partial^2 v}{\partial x^2}+\frac{1}{a}\frac{\partial^2 v}{\partial\theta^2}\right\}=0\\
&\nu\frac{\partial u}{\partial x}+\frac{1}{a}\frac{\partial v}{\partial\theta}-\frac{w}{a}-h\left(a^3\frac{\partial^4 w}{\partial x^4}+2a\frac{\partial^4 w}{\partial x^2\partial\theta^2}+\frac{1}{a}\frac{\partial^4 w}{\partial\theta^2}\right)\\
&\qquad-h\left\{(2-\nu)a\frac{\partial^3 v}{\partial x^2\partial\theta}+\frac{1}{a}\frac{\partial^3 v}{\partial\theta^3}\right\}=0
\end{aligned}\right\}\cdots\cdots(8)$$

ここに

$$h=\frac{t^2}{12a^2}$$

である。いま n を 整数, ABC を任意常数として

$$u=A\cos n\theta e^{\alpha x/a}\qquad v=B\sin n\theta e^{\alpha x/a}$$

$$w=C\cos n\theta e^{\alpha x/a}\quad\cdots\cdots(9)$$

とおいて (8) に代入して得られる係数行列式を 0 とおくと

$$\left(\frac{h}{2}+h^2\right)\alpha^8-2n^2\left(h+\frac{3-\nu}{4}h^2\right)\alpha^6+\frac{(1-\nu)}{2}\left[1+\nu+h\left\{2+(2-n^2)\nu+\frac{6n^2(n^2-1)}{1-\nu}\right\}+n^4h^2\right]$$

$$\alpha^4+\frac{hn^2(n^2-1)}{2}(3+\nu-4n^2)\alpha^2+\frac{hn^4(n^2-1)^2}{2}=0\cdots\cdots(10)$$

を得る。特に $n=1$ なる場合は

$$\left[\left(\frac{h}{2}+h^2\right)\alpha^4-2\left(h+\frac{3-\nu}{4}h^2\right)\alpha^2+\frac{(1-\nu)}{2}\{1+\nu+(2+\nu)h+h^2\}\right]\alpha^4=0\cdots\cdots(11)$$

解 $\alpha=0$ は問題の目的に副わぬから除外し他の解を求めると h が微少なる場合には近似的に

$$\alpha^4=-12(1-\nu^2)\frac{a^2}{t^2}$$

である。よつて底部の曲げモーメントの影響は局部的なることを考慮して

$$\alpha=k(-1\pm i)\cdots\cdots(12)$$

とおく。ここに

$$k=\sqrt[4]{3(1-\nu^2)\frac{a^2}{t^2}}\quad(\text{正根のみとる})$$

である。よつて

$$w=e^{-\frac{kx}{a}}\left(C_1\sin\frac{kx}{a}+C_2\cos\frac{kx}{a}\right)\cos\theta$$

$$u=e^{-\frac{kx}{a}}\left(A_1\sin\frac{kx}{a}+A_2\cos\frac{kx}{a}\right)\cos\theta$$

$$v=e^{-\frac{kx}{a}}\left(B_1\sin\frac{kx}{a}+B_2\cos\frac{kx}{a}\right)\sin\theta$$

$\frac{A_1}{C_1}$, $\frac{B_1}{C_1}$ 等の比はそれぞれ α の2個の値に対して (11) より定められる。常数 C_1C_2 を $x=0$ にて $u=v=w=0$ 及び $\frac{\partial w}{\partial x}$ が (7) の値を打消すごとく定めれば,

$$C_1=\frac{la(2+\nu)}{kEt}(Z_1-Y_1)\qquad C_2=0$$

である。側壁底端における曲げモーメントは

$$(M_x)_{x=0}=-D\left\{\frac{\partial^2 w}{\partial x^2}+\frac{\nu}{a^2}\left(\frac{\partial v}{\partial\theta}+\frac{\partial^2 w}{\partial\theta^2}\right)\right\}_{x=0}$$

$$=-D\left(\frac{\partial^2 w}{\partial x^2}\right)_{x=0}$$

によつて与えられるから最大曲げモーメントは

$$(M_x)_{\max}=\frac{(2+\nu)kt^2l}{6(1-\nu^2)a}(Z_1+Y_1)\quad\cdots\cdots(13)$$

となる。

4. 結語

地震時にタンクに働らく主たる地震力はタンク自身の慣性力と貯水の動水圧とであり，これらは多くの場合水平方向に働らく一様なる大いさ（高さの方向には変らないとの意）の分布荷重とみなして差支えない。したがつて上記の計算はこの種構造物の地震時応力の算定に応用することができると思う。

表—2~4

$\frac{a}{\ell}=100$

m	a/ℓ	T_1	T_2	T_1'	T_2'	Ⓗ	X_1	X_2	X_2'	U_1	U_2	U_2'	V_1	V_2	V_1'	V_2'	W_1	W_2	W_2'
1	0.3	32.84	71.19	-67.82	-24.73	12.11	13.64	344.1	-316.8	18.73	368.9	-332.3	636.2	-1231	-1504	514.5	-455.0	543.0	475.2
	0.4	36.75	81.71	-78.80	-29.73	16.15	10.234	340.7	-320.2	12.00	275.1	-251.1	434.6	-815.5	-1027	346.3	-342.2	247.2	379.4
	0.6	43.58	99.47	-97.09	-37.84	24.23	6.819	337.3	-323.6	7.474	182.8	-167.8	255.9	-396.0	-606.6	168.7	-229.3	146.0	278.1
	0.8	49.50	114.5	-112.5	-44.50	32.30	5.115	335.6	-325.3	5.892	137.4	-125.6	178.0	-228.9	-422.3	97.82	-173.4	93.29	225.5
	1.0	54.85	127.8	-126.0	-50.35	40.38	4.092	334.6	-326.4	5.160	110.4	-100.05	135.1	-144.2	-321.9	62.31	-140.7	60.80	193.0
	1.2	59.63	139.9	-138.2	-55.57	48.46	3.410	333.9	-327.0	4.762	92.44	-82.92	109.15	-95.65	-259.5	41.01	-118.3	38.64	170.8
	1.4	64.07	150.9	-149.4	-60.32	56.53	2.923	333.4	-327.5	4.520	79.66	-70.62	91.35	-63.89	-217.4	27.76	-107.90	22.45	154.6
	1.6	68.24	161.2	-159.8	-64.73	64.61	2.557	333.0	-327.9	4.365	70.11	-61.38	78.65	-42.93	-187.3	18.85	-91.56	10.060	142.2
	1.8	72.17	170.9	-169.5	-68.86	72.69	2.273	332.7	-328.2	4.259	62.70	-54.19	69.15	-28.17	-164.8	12.56	-82.92	2.019	132.4
	2.0	75.70	180.1	-178.8	-72.76	80.76	2.046	332.5	-328.4	4.182	56.77	-48.41	61.80	-17.40	-147.3	7.970	-76.15	-7.268	124.3
2	0.3	43.58	99.47	-97.09	-37.84	24.23	6.819	337.3	-323.6	7.474	182.8	-167.8	255.9	-396.0	-606.6	168.7	-229.3	146.0	278.1
	0.4	49.50	114.5	-112.5	-44.54	32.30	5.115	335.6	-325.3	5.892	137.4	-125.6	128.0	-228.9	-422.3	97.82	-173.4	93.29	225.5
	0.6	59.63	139.9	-138.2	-55.57	48.46	3.410	333.9	-327.0	4.762	92.44	-82.92	109.15	-95.05	-259.5	41.01	-118.3	38.64	170.8
	0.8	68.24	161.2	-159.8	-64.73	64.61	2.557	332.0	-327.9	4.365	70.11	-61.38	78.65	-42.93	-187.3	18.85	-91.56	100.60	142.2
	1.0	75.90	180.1	-178.8	-72.76	80.76	2.046	332.5	-328.4	4.182	56.77	-48.41	61.80	-17.40	-147.3	7.770	-76.15	-78.68	124.3
	1.2	82.86	197.2	-196.0	-79.99	96.91	1.705	332.2	-328.8	4.082	47.91	-39.75	51.17	-3.150	-122.2	1.884	-664.2	-204.2	111.8
	1.4	89.27	212.8	-211.7	-86.65	113.1	1.461	331.9	-329.0	4.022	41.59	-33.54	43.91	5.484	-104.93	-1.811	-597.3	-278.7	102.31
	1.6	95.26	227.5	-226.4	-92.77	129.2	1.279	331.7	-329.2	3.983	36.75	-28.89	38.67	10.805	-92.39	-4.381	-554.7	-373.8	948.0
	1.8	100.90	241.3	-240.3	-98.55	145.4	1.136	331.6	-329.3	3.956	33.17	-25.26	34.64	14.51	-82.86	-6.180	-523.5	-435.8	885.8
	2.0	106.23	254.3	-253.3	-104.01	161.5	1.0228	331.5	-329.4	3.937	30.23	-22.86	31.51	17.05	-75.42	-7.208	-501.8	-488.2	832.8
3	0.3	52.22	121.4	-119.4	-47.53	36.34	4.547	335.0	-325.9	5.465	122.4	-111.4	153.9	-180.3	-365.5	77.21	-154.9	75.34	207.5
	0.4	59.63	139.9	-138.2	-55.57	48.46	3.410	333.9	-327.0	4.762	92.44	-82.92	109.15	-95.05	-259.5	41.01	-118.3	38.64	170.8
	0.6	72.17	170.9	-169.5	-68.86	72.69	2.273	332.7	-328.2	4.259	62.70	-54.19	69.15	-28.17	-163.8	12.56	-82.92	2.019	132.4
	0.8	82.86	197.2	-196.0	-79.99	96.91	1.705	332.2	-328.8	4.082	47.91	-39.75	51.17	-3.150	-122.2	1.524	-664.2	-204.2	111.8
	1.0	92.32	220.3	-219.3	-89.75	121.1	1.364	331.8	-329.1	4.001	39.07	-31.06	41.09	8.313	-98.21	-3.666	-575.0	-398.2	983.6
	1.2	100.90	241.3	-240.3	-98.55	145.4	1.130	331.6	-329.3	3.956	33.17	-25.26	34.63	14.51	-82.86	-6.180	-523.5	-435.8	885.8
	1.4	108.82	260.6	-259.7	-106.65	169.6	0.9742	331.4	-329.5	3.930	28.98	-21.12	30.16	18.01	-72.27	-7.595	-493.8	-512.7	809.1
	1.6	116.7	278.4	-277.6	-114.1	193.8	0.8523	331.3	-329.6	3.912	25.83	-18.00	26.89	20.05	-64.46	-8.411	-477.4	-576.4	745.3
	1.8	123.1	295.3	-294.5	-121.2	218.1	0.7377	331.2	-329.7	3.901	23.38	-15.58	24.37	21.25	-58.47	-8.888	-470.2	-631.5	670.4
	2.0	129.6	311.2	-310.4	-127.8	242.3	0.6819	331.1	-329.8	3.892	21.42	-13.64	22.39	21.93	-53.69	-9.166	-469.7	-680.3	641.4

$\frac{a}{\ell}=200$

m	a/ℓ	T_1	T_2	T_1'	T_2'	Ⓗ	X_1	X_2	X_2'	U_1	U_2	U_2'	V_1	V_2	V_1'	V_2'	W_1	W_2	W_2'
1	0.3	53.24	118.9	-114.9	-43.59	17.13	19.29	680.2	-641.6	25.92	727.2	-675.3	1474	-3232	-3823	1352	-1281×10	10620	1326×10
	0.4	60.09	136.7	-133.2	-51.73	22.84	14.47	675.4	-646.5	16.97	543.2	-509.2	994.4	-2018	-2376	845.9	-962.1	726.8	1041×10
	0.6	71.88	165.7	-163.9	-65.06	34.26	9.643	670.6	-651.3	10.569	361.2	-340.1	573.5	-1017.2	-1371	426.9	-643.0	480.9	745.3
	0.8	82.04	192.2	-189.7	-76.13	45.68	7.233	668.2	-653.7	8.332	271.3	-254.7	392.3	-613.1	-938.5	257.6	-484.3	327.2	593.5
	1.0	91.07	214.6	-212.4	-85.78	57.10	5.787	666.7	-655.1	7.296	217.7	-203.1	294.4	-405.8	-704.6	170.7	-389.5	230.5	522.9
	1.2	99.28	234.9	-232.9	-94.46	68.53	4.823	665.7	-656.1	6.734	182.1	-168.6	234.2	-284.0	-560.6	119.6	-326.7	173.9	438.3
	1.4	106.84	253.5	-251.6	-102.37	79.95	4.133	665.1	-656.8	6.393	156.7	-143.9	193.8	-206.0	-464.1	80.86	-282.1	128.6	393.0
	1.6	113.9	270.8	-269.1	-109.73	91.37	3.617	664.5	-657.3	6.173	137.7	-125.3	166.4	-152.8	-395.5	64.59	-245.9	94.26	358.6
	1.8	120.6	287.2	-285.5	-116.6	102.79	3.215	664.1	-657.7	6.022	122.9	-110.87	143.2	-115.0	-344.8	48.68	-223.5	67.20	331.6
	2.0	126.9	302.6	-301.1	-123.2	114.0	2.904	663.8	-658.0	5.936	111.1	-99.25	127.4	-86.98	-305.5	36.92	-204.1	45.44	310.8
2	0.3	71.88	166.7	-163.9	-65.06	34.26	9.643	670.6	-651.3	10.569	361.2	-340.1	573.5	-1017.2	-1371.0	426.4	-643.0	480.9	745.3
	0.4	82.04	192.2	-189.7	-76.13	45.68	7.233	668.2	-653.7	8.332	271.3	-254.7	392.3	-613.1	-938.5	257.6	-484.3	329.2	573.5
	0.6	99.28	234.9	-232.9	-94.46	68.53	4.823	665.7	-656.1	6.734	182.1	-168.6	234.2	-284.0	-560.6	119.6	-326.7	173.9	438.3
	0.8	113.9	270.8	-269.1	-109.73	91.37	3.617	664.5	-657.3	6.173	137.7	-125.3	166.4	-152.8	-395.5	64.59	-245.9	94.26	358.6
	1.0	126.9	302.6	-301.1	-123.2	114.0	2.904	663.8	-658.0	5.936	111.1	-99.25	127.4	-86.98	-305.5	36.92	-204.8	45.44	310.8
	1.2	138.7	331.3	-329.9	-135.2	137.1	2.411	663.3	-658.5	5.773	93.44	-81.89	103.96	-49.19	-249.3	21.06	-173.6	117.5	276.1
	1.4	149.5	357.8	-356.5	-146.3	159.9	2.066	663.0	-658.9	5.688	80.82	-69.44	88.06	-25.59	-211.1	11.15	-133.0	-129.1	251.4
	1.6	159.6	382.4	-381.1	-156.6	182.7	1.808	662.7	-659.1	5.633	71.37	-60.11	76.61	-9.982	-183.7	4.585	-138.2	-320.1	232.3
	1.8	169.1	405.5	-404.4	-166.3	205.6	1.607	662.5	-659.3	5.595	64.03	-52.84	68.00	0.8098	-163.1	0.0390	-127.1	-473.8	216.9
	2.0	178.1	427.4	-426.3	-175.5	228.4	1.446	662.4	-659.5	5.568	58.16	-47.02	61.30	8.518	-147.1	-3.211	-108.8	-601.5	204.2
3	0.3	86.68	203.7	-201.8	-81.10	51.40	6.430	667.4	-654.5	7.728	241.5	-226.1	336.8	-494.5	-806.0	207.8	-431.6	277.9	542.3
	0.4	99.28	234.9	-232.9	-94.46	68.53	4.823	665.7	-656.1	6.734	182.1	-168.6	234.2	-284.0	-560.6	119.6	-326.7	173.9	438.3
	0.6	120.6	287.2	-285.5	-116.6	102.79	3.215	664.1	-657.7	6.022	122.9	-110.87	143.2	-115.0	-344.8	48.68	-223.5	67.20	331.6
	0.8	138.7	331.3	-329.9	-135.2	137.1	2.411	663.3	-658.5	5.773	93.44	-81.89	103.96	-49.19	-249.3	21.06	-173.6	117.5	276.1
	1.0	154.6	370.3	-369.9	-151.6	171.3	1.929	662.9	-659.0	5.658	75.79	-64.47	[illegible]	-17.04	-196.4	7.551	-145.1	-230.2	241.3
	1.2	169.1	405.5	-404.4	-166.3	205.6	1.607	662.5	-659.3	5.595	64.03	-52.84	68.00	2.8098	-163.0	0.0390	-127.1	-473.8	216.9
	1.4	182.5	438.0	-436.9	-179.9	239.8	1.378	662.3	-659.5	5.558	55.65	-44.53	58.49	11.54	-140.3	-4.883	-111.5	-658.0	198.5
	1.6	194.9	468.1	-467.1	-192.5	274.1	1.205	662.1	-659.7	5.533	49.36	-38.79	51.53	18.38	-123.8	-7.090	-107.35	-804.8	183.8
	1.8	206.6	496.4	-495.5	-204.3	308.4	1.0716	662.0	-659.9	5.517	44.48	-33.44	45.95	21.99	-110.2	-9.190	-101.91	-926.7	169.7
	2.0	217.6	523.2	-522.3	-215.4	342.6	0.9643	662.0	-660.0	5.504	40.57	-29.56	42.11	25.94	-101.44	-10.775	-982.2	-1034.0	161.2

$\frac{a}{\ell}=300$

m	a/ℓ	T_1	T_2	T_1'	T_2'	Ⓗ	X_1	X_2	X_2'	U_1	U_2	U_2'	V_1	V_2	V_1'	V_2'	W_1	W_2	W_2'
1	0.3	70.98	168.7	-166.3	-60.26	20.98	23.62	1015.0	-967.8	31.74	1083.6	-1020.1	2425	-5414	-5802	2260	-2349×10	2226×10	2421×10
	0.4	80.39	184.9	-181.1	-71.14	27.98	17.73	1009.2	-973.7	20.79	810.1	-768.5	1626	-3407	-3893	1422	-1760×10	1439×10	1886×10
	0.6	96.56	225.7	-222.6	-89.01	41.97	11.81	1003.2	-979.6	12.95	538.9	-513.0	927.3	-1744	-2226	728.5	-1178×10	937.7	1334×10
	0.8	110.4	260.2	-257.5	-103.89	55.96	8.859	1000.2	-982.5	10.205	404.7	-394.3	627.1	-1068.3	-1549	446.4	-835.9	656.7	1053.3
	1.0	122.7	290.6	-288.2	-116.9	69.94	7.088	998.5	-984.3	8.937	324.6	-306.7	463.8	-719.8	-1125	301.0	-711.3	485.7	882.3
	1.2	133.9	318.2	-315.9	-128.6	83.93	5.907	997.3	-985.5	8.248	271.3	-254.8	370.5	-514.2	-889.2	215.1	-595.4	370.6	767.2
	1.4	144.2	343.4	-341.6	-139.3	97.92	5.062	996.4	-986.3	7.830	233.2	-217.6	304.8	-381.6	-731.6	158.8	-512.8	287.5	684.0
	1.6	153.8	367.0	-365.0	-149.2	111.9	4.430	995.8	-987.0	7.561	204.8	-189.7	258.3	-291.1	-620.3	122.0	-451.3	224.7	621.3
	1.8	162.9	387.8	-387.3	-158.5	125.9	3.938	996.3	-987.4	7.376	182.7	-168.0	223.9	-226.1	-537.6	94.83	-403.9	175.5	572.1
	2.0	171.5	410.1	-408.4	-167.3	139.9	3.543	994.9	-987.8	7.243	165.0	-150.5	187.4	-177.9	-474.3	74.68	-366.1	135.7	532.2
2	0.3	96.56	225.7	-222.6	-89.01	41.97	11.81	1003.2	-979.6	12.95	538.9	-513.0	927.3	-1744	-2224	728.5	-1178×10	937.7	1334×10
	0.4	110.4	260.2	-257.5	-103.89	55.96	8.859	1000.2	-982.5	10.205	404.7	-394.3	627.1	-1068.3	-1509	446.4	-835.9	656.7	1053.3
	0.6	133.9	318.2	-315.9	-128.6	83.93	5.907	997.3	-985.5	8.248	271.3	-254.8	370.5	-514.2	-889.2	215.1	-595.4	370.6	767.2
	0.8	153.3	367.0	-365.0	-149.2	111.9	4.430	995.8	-987.0	7.561	204.8	-189.7	258.3	-291.1	-620.3	122.0	-451.3	224.7	621.3
	1.0	171.5	410.1	-408.4	-167.3	139.9	3.543	994.9	-987.8	7.243	165.0	-150.5	187.4	-177.9	-474.3	74.68	-366.1	135.7	532.2
	1.2	187.5	449.0	-447.5	-183.7	167.9	2.953	994.3	-988.4	7.071	138.6	-124.4	159.7	-112.3	-383.6	46.78	-310.2	75.26	471.8
	1.4	202.2	484.9	-483.4	-198.7	195.8	2.531	993.9	-988.8	6.967	119.7	-105.73	134.2	-70.90	-322.6	29.58	-271.1	31.20	427.7
	1.6	215.9	518.2	-516.9	-212.6	223.8	2.215	993.6	-989.2	6.899	105.51	-91.71	116.0	-43.32	-279.1	18.38	-242.4	-259.3	393.9
	1.8	228.8	549.6	-548.4	-225.7	251.8	1.968	993.3	-989.4	6.853	94.50	-80.80	102.32	-23.70	-246.0	10.238	-220.8	-295.2	367.0
	2.0	241.0	579.3	-578.1	-238.1	279.8	1.772	993.2	-989.6	6.820	85.70	-72.06	91.77	-7.633	-220.8	4.345	-200.0	-318.4	344.9
3	0.3	116.3	275.8	-273.3	-110.6	62.95	7.875	997.3	-983.5	9.466	360.1	-341.2	538.7	-869.0	-1294	363.3	-728.9	561.9	958.5
	0.4	133.9	318.2	-315.9	-128.6	83.93	5.907	997.3	-985.5	8.248	271.3	-254.8	370.5	-514.2	-889.2	215.1	-595.4	370.6	767.2
	0.6	162.9	387.8	-387.3	-158.5	125.9	3.938	995.3	-987.4	7.376	182.7	-168.0	223.9	-226.1	-537.6	94.83	-403.9	125.5	572.1
	0.8	187.5	449.0	-447.5	-183.7	167.9	2.763	994.3	-988.4	7.071	138.6	-124.4	159.7	-112.3	-383.6	46.78	-310.2	75.26	471.8
	1.0	209.2	501.8	-500.4	-205.8	209.8	2.362	993.7	-989.0	6.930	112.1	-98.27	124.5	-53.73	-299.1	23.64	-255.7	132.7	409.8
	1.2	228.8	549.6	-548.4	-225.7	251.8	1.968	993.3	-989.4	6.853	94.50	-80.80	102.32	-23.70	-246.0	10.238	-220.8	-295.2	367.0
	1.4	247.0	593.6	-592.5	-244.1	293.8	1.687	993.1	-989.7	6.807	81.94	-68.33	87.34	-4.019	-210.2	1.996	-197.0	-613.3	335.2
	1.6	263.8	634.5	-633.4	-261.1	335.7	1.476	992.9	-989.9	6.776	72.51	-58.96	76.52	8.804	-183.8	-3.292	-180.3	-862.5	310.3
	1.8	279.6	672.9	-671.8	-277.1	377.7	1.312	992.7	-990.1	6.757	65.20	-51.69	68.36	17.40	-164.3	-7.333	-168.2	-1065	[illegible]
	2.0	294.6	709.2	-708.2	-292.2	419.7	1.181	992.6	-990.2	6.741	59.33	-45.85	61.90	23.49	-148.9	-9.840	-159.3	-1237	277.8

表—5~7

$\frac{a}{h}=400$

m	a/l	T_1	T_2	T_1'	T_2'	Θ	X_1	X_2	X_2'	U_1	U_2	U_2'	V_1	V_2	V_1'	V_2'	W_1	W_2	W_2'
1	0.3	87.18	199.0	-194.2	-75.66	24.23	27.28	1349	-1295	36.65	1439	-1366.2	3447	-7797	-8287	3248	-3618×10	3184×10	3712×10
	0.4	98.97	229.1	-225.0	-89.03	32.30	20.47	1342	-1301	24.00	1076.4	-1028.4	2303	-4929	-5532	2054	-2713×10	2349×10	2878×10
	0.6	119.2	279.7	-276.4	-111.1	48.46	13.64	1335	-1308	14.95	716.2	-686.3	1308	-2546	-3141	1060.9	-1811×10	1493×10	2022×10
	0.8	136.5	322.6	-319.7	-129.4	64.61	10.230	1332	-1312	11.78	537.8	-514.2	882.6	-1575	-2122	655.9	-1361×10	10501	1587×10
	1.0	151.8	360.4	-357.8	-145.5	80.76	8.185	1330	-1314	10.319	431.2	-410.5	654.6	-1070.6	-1573	446.5	-10918	7741	1323×10
	1.2	165.7	394.6	-392.2	-160.0	96.91	6.821	1329	-1315	9.523	360.2	-341.2	515.2	-773.0	-1238	322.5	-9128	6166	1145×10
	1.4	178.5	425.9	-423.7	-173.2	113.1	5.845	1328	-1316	9.041	309.6	-291.5	422.2	-580.6	-1014.9	242.3	-7853	4888	10175
	1.6	190.5	455.1	-453.1	-185.5	129.2	5.115	1327	-1317	8.731	271.7	-254.3	356.6	-448.8	-857.3	187.4	-6902	3924	9211
	1.8	201.7	482.7	-480.7	-197.1	145.4	4.547	1326	-1317	8.517	242.3	-225.3	307.9	-354.2	-740.4	147.9	-6166	3169	8456
	2.0	212.4	508.7	-506.8	-208.0	161.5	4.091	1326	-1318	8.363	218.7	-202.0	270.7	-283.4	-650.9	118.5	-5579	2560	7847
2	0.3	119.2	279.7	-276.4	-111.1	48.46	13.64	1335	-1308	14.95	716.2	-686.3	1308	-2546	-3141	1060.9	-1811×10	1493×10	2022×10
	0.4	136.5	322.6	-319.7	-129.4	64.61	10.230	1332	-1312	11.78	537.8	-514.2	882.6	-1575	-2122	655.9	-1361×10	10501	1587×10
	0.6	165.7	394.6	-392.2	-160.0	96.91	6.821	1329	-1315	9.523	360.2	-341.2	515.2	-773.0	-1238	322.5	-9128	6166	1145×10
	0.8	190.5	455.1	-453.1	-185.5	129.2	5.115	1327	-1317	8.731	271.7	-254.3	356.6	-448.8	-857.3	187.4	-6902	3924	9211
	1.0	212.4	508.7	-506.8	-208.0	161.5	4.091	1326	-1318	8.363	218.7	-202.0	270.7	-283.4	-650.9	118.5	-5579	2560	7847
	1.2	232.3	557.0	-555.3	-228.2	193.8	3.410	1325	-1318	8.165	183.5	-167.2	212.8	-187.1	-523.9	78.30	-4709	1639	6926
	1.4	250.5	601.5	-599.9	-246.8	226.1	2.922	1325	-1319	8.045	158.3	-142.2	182.1	-125.9	-438.5	52.77	-4096	969.6	6257
	1.6	267.6	641.4	-639.9	-264.1	258.4	2.557	1324	-1319	7.967	139.4	-123.5	156.8	-84.60	-377.1	35.56	-3644	459.2	5746
	1.8	283.6	681.8	-680.4	-280.3	290.7	2.273	1324	-1320	7.912	124.8	-108.95	137.7	-64.47	-331.1	23.39	-3300	58.76	5341
	2.0	298.8	717.3	-716.0	-295.7	323.0	2.046	1324	-1320	7.874	113.1	-97.30	123.0	-34.16	-296.2	14.51	-3032	-275.5	5011
3	0.3	144.3	342.0	-339.3	-137.7	72.69	0.2093	1331	-1313	10.929	478.5	-456.6	253.3	-1286	-1810	536.3	-1211×10	9117	1460×10
	0.4	165.7	394.6	-392.2	-160.0	96.91	6.821	1329	-1315	9.523	360.2	-341.2	515.2	-773.0	-1238	322.5	-9128	6166	1145×10
	0.6	201.7	482.7	-480.7	-197.1	145.4	4.547	1326	-1317	8.517	242.3	-225.3	307.9	-354.2	-740.4	147.9	-6166	3169	8456
	0.8	232.3	557.0	-555.3	-228.2	193.8	3.410	1325	-1318	8.165	183.5	-167.2	212.8	-187.1	-523.9	78.30	-4709	1639	6926
	1.0	257.2	622.5	-621.0	-255.6	242.3	2.728	1325	-1319	8.002	148.3	-132.3	148.4	-103.37	-405.5	43.37	-3854	698.6	5986
	1.2	283.6	681.8	-680.4	-280.3	290.7	2.273	1324	-1320	7.912	124.8	-108.95	137.7	-64.47	-331.1	23.39	-3300	54.76	5341
	1.4	306.2	736.4	-735.2	-303.1	339.2	1.948	1324	-1320	7.860	108.04	-92.37	116.9	-25.37	-281.2	10.955	-2919	-419.4	4868
	1.6	327.1	787.2	-786.0	-324.2	387.7	1.705	1324	-1320	7.825	95.48	-79.83	101.89	-5.920	-245.3	0.2744	-2645	-787.4	4499
	1.8	346.7	834.8	-833.6	-344.0	436.1	1.516	1323	-1320	7.802	85.72	-70.12	90.03	7.620	-218.1	-2.894	-2443	-1084.7	4203
	2.0	365.3	879.8	-878.7	-362.7	484.6	1.364	1323	-1320	7.784	77.91	-62.34	81.74	17.15	-197.1	-7.202	-2290	-1332	3955

$\frac{a}{h}=500$

m	a/l	T_1	T_2	T_1'	T_2'	Θ	X_1	X_2	X_2'	U_1	U_2	U_2'	V_1	V_2	V_1'	V_2'	W_1	W_2	W_2'
1	0.3	102.30	235.0	-229.9	-90.16	27.09	30.50	1683	-1622	40.98	1794	-1712	4543	-10341	-10920	4303	-5049×10	4513×10	5174×10
	0.4	116.4	270.6	-266.2	-105.87	36.12	22.88	1675	-1629	26.84	1342	-1289	3024	-6558	-7270	2739	-3790×10	3337×10	3998×10
	0.6	140.4	330.5	-326.9	-131.8	54.18	15.25	1668	-1637	16.71	893.3	-860.5	1710	-3406	-4110	1418	-2528×10	2026×10	2795×10
	0.8	160.9	381.2	-378.1	-153.5	72.24	11.44	1664	-1641	13.17	670.7	-644.3	1150	-2118	-2765	881.8	-1900×10	1523×10	2184×10
	1.0	179.1	425.9	-423.1	-172.4	90.30	9.151	1661	-1643	11.54	537.6	-514.5	850.0	-1450	-2044	603.9	-1523×10	1154×10	1815×10
	1.2	195.6	466.3	-463.8	-189.5	108.36	7.626	1660	-1645	10.648	449.0	-427.7	667.0	-1054.6	-1605	439.2	-1273×10	9053	1566×10
	1.4	210.7	503.3	-501.0	-205.1	126.4	6.535	1659	-1646	10.108	385.8	-365.6	545.1	-797.7	-1311	332.4	-10939	7267	1388×10
	1.6	227.5	537.9	-535.7	-219.6	144.5	5.718	1658	-1647	9.761	338.5	-319.0	459.2	-621.7	-1104	259.2	-9606	5921	1253×10
	1.8	238.2	570.4	-568.6	-233.2	162.5	5.083	1657	-1647	9.523	301.7	-282.7	395.6	-494.8	-951.5	206.3	-8573	4868	1148×10
	2.0	250.8	601.2	-599.2	-246.1	180.6	4.574	1657	-1648	9.351	272.3	-253.6	346.9	-400.2	-834.7	166.9	-7749	4021	10630
2	0.3	140.4	330.5	-326.9	-131.8	54.18	15.25	1668	-1637	16.71	893.3	-860.5	1710	-3406	-4110	1418	-2528×10	2026×10	2795×10
	0.4	160.9	381.2	-378.1	-153.5	72.24	11.44	1664	-1641	13.17	670.7	-644.3	1150	-2118	-2765	881.8	-1900×10	1523×10	2184×10
	0.6	195.6	466.3	-463.8	-189.5	108.36	7.626	1660	-1645	10.648	449.0	-427.7	667.0	-1054.6	-1605	439.2	-1273×10	9053	1566×10
	0.8	227.5	537.9	-535.7	-219.6	144.5	5.718	1658	-1647	9.761	338.5	-319.0	459.2	-621.7	-1104	259.2	-9606	5921	1253×10
	1.0	250.8	601.2	-599.2	-246.1	180.6	4.574	1657	-1648	9.351	272.3	-253.6	346.9	-400.2	-834.7	166.9	-7749	4021	10630
	1.2	274.3	658.3	-656.5	-270.0	216.7	3.812	1656	-1648	9.129	228.3	-210.0	277.9	-270.7	-668.5	113.0	-6525	2740	9349
	1.4	296.0	710.9	-709.3	-292.0	252.8	3.267	1656	-1649	8.994	196.8	-178.8	231.6	-188.1	-557.3	78.64	-5659	1813	8421
	1.6	316.1	759.8	-758.8	-312.4	288.9	3.059	1655	-1649	9.529	173.9	-154.8	198.6	-132.1	-477.8	55.33	-5019	1108	7717
	1.8	335.1	805.9	-804.5	-331.6	325.1	2.541	1655	-1650	8.847	154.9	-137.2	173.9	-92.46	-418.6	38.78	-4530	550.7	7159
	2.0	353.1	849.5	-848.1	-349.7	361.2	2.287	1655	-1650	8.804	140.3	-122.7	155.0	-63.34	-372.8	26.67	-4145	97.75	6706
3	0.3	170.2	404.2	-401.3	-163.2	81.27	10.167	1662	-1642	12.22	596.7	-572.2	979.7	-1736	-2356	723.1	-1690×10	1318×10	1979×10
	0.4	195.6	466.3	-463.8	-189.5	108.36	7.626	1660	-1645	10.648	449.0	-427.7	667.0	-1054.6	-1605	439.2	-1273×10	9053	1566×10
	0.6	238.2	570.4	-568.4	-233.2	162.5	5.083	1657	-1647	9.523	301.7	-282.7	395.6	-494.8	-951.5	206.3	-8573	4868	1148×10
	0.8	274.3	658.3	-656.5	-270.0	216.7	3.812	1656	-1648	9.129	228.3	-210.0	277.9	-270.7	-668.5	113.0	-6525	2740	9349
	1.0	306.2	736.0	-734.4	-302.4	270.9	3.050	1655	-1649	8.947	184.3	-166.4	213.8	-157.6	-514.5	65.93	-5317	1438	8047
	1.2	335.1	805.9	-804.5	-331.6	325.1	2.541	1655	-1650	8.804	140.3	-122.7	155.0	-63.34	-418.6	38.78	-4530	550.7	7159
	1.4	361.8	870.5	-869.2	-358.5	379.2	2.178	1654	-1650	8.789	134.0	-116.4	147.1	-51.70	-354.1	21.80	-3984	-99.03	6510
	1.6	386.5	930.5	-929.3	-383.4	433.4	1.906	1654	-1650	8.748	118.3	-100.82	127.6	-23.51	-307.2	10.055	-3587	-600.2	6008
	1.8	409.7	986.8	-985.6	-406.8	487.6	1.694	1654	-1650	8.923	106.13	-88.68	113.0	-5.695	-272.6	2.621	-3291	-1002.4	5607
	2.0	431.7	1039.9	-1038.8	-429.0	541.8	1.525	1654	-1651	8.703	96.36	-78.95	101.81	2.833	-245.4	-2.020	-3065	-1335	5274

$\frac{a}{h}=600$

m	a/l	T_1	T_2	T_1'	T_2'	Θ	X_1	X_2	X_2'	U_1	U_2	U_2'	V_1	V_2	V_1'	V_2'	W_1	W_2	W_2'
1	0.3	116.7	269.7	-263.7	-103.97	29.67	33.41	2016	-1949	44.89	2149.2	-2039	5689	-1302×10	-1369×10	5404	-6634×10	5993×10	6786×10
	0.4	133.0	310.1	-305.0	-121.9	39.56	25.07	2008	-1958	29.40	1608	-1549	3780	-8277	-9096	3434	-4980×10	4438×10	5232×10
	0.6	160.5	378.8	-375.1	-151.6	59.35	16.70	1999	-1966	18.31	1070.2	-1033.6	2130	-4318	-5125	1792	-3322×10	2850×10	3643×10
	0.8	184.1	436.9	-433.7	-176.3	79.13	12.53	1995	-1970	14.43	803.4	-774.6	1429	-2696	-3438	1119	-2495×10	2045×10	2839×10
	1.0	205.0	488.1	-485.2	-198.0	98.91	10.025	1993	-1973	12.64	643.9	-618.6	1053.3	-1854	-2536	721.4	-2010×10	1557×10	2352×10
	1.2	223.9	534.5	-531.8	-217.5	118.7	8.354	1991	-1974	11.66	537.7	-514.4	824.9	-1355	-1986	512.1	-1670×10	1232×10	2025×10
	1.4	241.9	577.0	-574.6	-235.4	138.5	7.159	1990	-1976	11.07	461.9	-439.7	672.7	-1030.0	-1619	427.6	-1435×10	9971	1790×10
	1.6	257.6	616.7	-614.4	-252.1	158.3	6.264	1989	-1976	10.673	405.2	-383.8	565.5	-807.7	-1361	335.1	-1259×10	8704	1613×10
	1.8	272.9	654.0	-651.9	-267.7	178.0	5.568	1988	-1977	10.432	361.1	-340.2	486.3	-646.6	-1170	268.4	-1123×10	6822	1475×10
	2.0	287.4	689.2	-687.2	-282.5	197.8	5.011	1988	-1978	10.243	325.8	-305.3	415.8	-514.4	-1001.2	214.3	-10145	5710	1366×10
2	0.3	160.5	378.8	-375.1	-151.6	59.35	16.70	1999	-1966	18.31	1070.2	-1033.6	2130	-4318	-5125	1792	-3322×10	2850×10	3643×10
	0.4	184.1	436.9	-433.7	-176.3	79.13	12.53	1995	-1970	14.43	803.4	-774.6	1429	-2696	-3438	1119	-2495×10	2045×10	2839×10
	0.6	223.9	534.5	-531.8	-217.5	118.7	8.354	1991	-1974	11.66	537.7	-514.4	824.9	-1355	-1986	512.1	-1670×10	1232×10	2025×10
	0.8	257.6	616.7	-614.4	-252.1	158.3	6.264	1989	-1976	10.673	405.2	-383.8	565.5	-807.7	-1361	335.1	-1259×10	8704	1613×10
	1.0	287.4	689.2	-687.2	-282.5	197.8	5.011	1988	-1978	10.243	325.8	-305.3	415.8	-514.4	-1001.2	214.3	-10145	5710	1366×10
	1.2	314.3	754.9	-753.0	-309.8	237.4	4.176	1987	-1979	10.000	273.0	-253.0	329.9	-362.1	-818.6	150.8	-8527	4033	1196×10
	1.4	339.2	815.1	-813.4	-335.0	277.0	3.579	1986	-1979	9.852	235.3	-215.5	282.3	-256.6	-680.1	107.01	-7382	2821	10751
	1.6	362.2	871.3	-870.0	-358.3	316.5	3.132	1986	-1980	9.757	207.0	-187.5	241.4	-185.0	-581.6	77.22	-6533	1901	9832
	1.8	384.0	924.0	-922.5	-380.3	356.1	2.784	1986	-1980	9.691	185.0	-165.6	210.9	-134.0	-508.0	56.02	-5882	1176	9106
	2.0	404.6	973.9	-972.6	-401.1	395.7	2.505	1985	-1980	9.644	167.4	-148.1	182.6	-96.60	-451.7	40.46	-5369	375.9	8518
3	0.3	198.5	463.2	-460.2	-187.5	89.02	11.14	1994	-1972	13.39	714.2	-688.0	1216	-2215	-2926	921.7	-2220×10	1725×10	2569×10
	0.4	223.9	534.5	-531.8	-217.5	118.7	8.354	1991	-1974	11.66	537.7	-514.4	824.9	-1355	-1986	512.1	-1670×10	1232×10	2025×10
	0.6	272.9	654.0	-651.9	-267.7	178.0	5.568	1988	-1977	10.432	361.1	-340.2	486.3	-646.6	-1170	268.4	-1123×10	6822	1475×10
	0.8	314.3	754.9	-753.0	-309.8	237.4	4.176	1987	-1979	10.000	273.0	-253.0	329.9	-362.1	-818.6	150.8	-8527	4033	1196×10
	1.0	350.9	843.7	-842.0	-346.9	296.7	3.341	1986	-1979	9.801	220.2	-200.6	260.3	-217.7	-627.2	90.78	-6929	2332	10363
	1.2	384.0	924.0	-922.5	-380.3	356.1	2.784	1986	-1980	9.691	185.0	-165.6	210.9	-134.0	-508.0	56.02	-5882	1176	9106
	1.4	414.5	998.0	-996.0	-411.1	415.4	2.386	1985	-1980	9.627	159.9	-140.6	177.2	-81.55	-428.4	34.15	-5152	333.6	8264
	1.6	442.7	1066.8	-1065.5	-439.6	474.8	2.088	1985	-1981	9.583	141.1	-121.9	154.0	-46.35	-366.5	19.53	-4619	-313.7	7616
	1.8	469.6	1131.0	-1130	-466.7	534.1	1.856	1985	-1981	9.553	126.4	-107.33	136.0	-21.76	-327.5	9.294	-4218	-830.8	7100
	2.0	494.8	1192	-1191	-492.0	593.5	1.670	1984	-1981	9.534	114.7	-95.65	122.2	-4.039	-294.5	1.906	-3909	-1256	6674

表—8

[illegible] = 700

n	q/q	T_1	T_2	T_1'	T_2'	Θ	X_1	X_2	X_2'	U_1	U_2	U_2'	V_1	V_2	V_1'	V_2'	W_1	W_2	W_2'
1	0.3	130.5	301.9	-296.4	-117.3	32.05	36.08	2349	-2277	48.69	2528	-2055	1883	-582×10	-1457×10	6574	-8358×10	7612×10	8537×10
	0.4	148.7	347.8	-343.1	-132.9	42.74	27.08	2340	-2280	31.75	1610	-1547	4566	-10073	-10994	6186	-6274×10	5643×10	6569×10
	0.6	179.8	425.0	-421.2	-170.5	64.10	18.04	2331	-2295	19.77	1071.7	-1032.2	2567	-5272	-6045	2191	-4184×10	3635×10	4560×10
	0.8	206.4	490.4	-487.0	-198.3	85.47	13.53	2327	-2300	15.59	804.6	-773.4	1718	-3303	-4136	1373	-3142×10	2619×10	3545×10
	1.0	229.8	547.9	-544.9	-222.6	106.84	10.887	2324	-2302	13.65	644.9	-617.6	1264	-2279	-3044	947.5	-2518×10	2005×10	2931×10
	1.2	251.1	600.0	-597.2	-244.5	128.2	9.023	2322	-2304	12.60	538.7	-513.5	988.0	-1071	-2379	694.8	-2102×10	1593×10	2519×10
	1.4	270.7	647.6	-645.1	-264.6	149.6	7.732	2321	-2305	11.96	462.8	-438.9	804.3	-1276	-1937	530.6	-1805×10	1252×10	2223×10
	1.6	288.9	692.2	-689.8	-283.2	170.9	6.766	2320	-2306	11.55	406.0	-382.9	675.1	-997.1	-1626	417.7	-1584×10	10750	2000×10
	1.8	306.1	734.0	-731.8	-300.7	192.3	6.015	2319	-2307	11.27	361.9	-339.4	579.6	-807.8	-1396	336.1	-1412×10	9008	1826×10
	2.0	322.4	773.6	-771.5	-317.3	213.7	5.412	2319	-2308	11.06	326.6	-304.5	506.7	-661.0	-1220	275.0	-1275×10	7609	1686×10
2	0.3	179.8	425.0	-421.2	-170.5	64.10	18.04	2331	-2295	19.77	1071.7	-1032.2	2567	-5272	-6045	2191	-4184×10	3635×10	4560×10
	0.4	206.4	490.4	-487.0	-198.3	85.47	13.53	2327	-2300	15.59	804.6	-773.4	1718	-3303	-4136	1373	-3147×10	2619×10	3545×10
	0.6	251.1	600.0	-597.2	-244.5	128.2	9.023	2322	-2304	12.60	538.7	-513.5	988.0	-1071	-2379	694.8	-2102×10	1593×10	2519×10
	0.8	288.9	692.2	-689.8	-283.2	170.9	6.766	2320	-2306	11.55	406.0	-382.9	675.1	-997.1	-1626	417.7	-1584×10	10750	2006×10
	1.0	322.4	773.6	-771.5	-317.3	213.7	5.412	2319	-2308	11.06	326.6	-304.5	506.7	-661.0	-1220	275.0	-1275×10	7609	1686×10
	1.2	352.7	847.2	-845.2	-348.0	256.4	4.511	2318	-2309	10.801	273.8	-252.2	403.5	-459.4	-971.8	191.3	-10701	5500	1475×10
	1.4	380.6	914.9	-913.1	-376.2	299.1	3.866	2317	-2309	10.642	236.0	-216.8	334.4	-330.5	-805.0	137.5	-9251	3879	1323×10
	1.6	406.5	978.0	-976.3	-402.5	341.9	3.383	2317	-2310	10.539	207.8	-186.7	285.3	-234.5	-655.4	100.84	-8175	2826	1208×10
	1.8	431.0	1037.2	-1035.6	-427.2	384.6	3.007	2316	-2310	10.467	185.8	-164.8	248.7	-179.4	-599.3	74.83	-7347	1920	1112×10
	2.0	454.1	1093.2	-1091.7	-450.5	427.6	2.706	2316	-2311	10.417	168.2	-147.4	220.7	-133.1	-531.8	55.57	-6593	1186	10437
3	0.3	218.4	520.0	-516.8	-210.8	96.15	12.03	2325	-2301	14.46	715.8	-656.9	1460	-2718	-3516	1130	-2795×10	2279×10	3204×10
	0.4	251.1	600.0	-597.2	-244.5	128.2	9.023	2322	-2304	12.60	538.7	-513.5	988.0	-1071	-2379	694.8	-2102×10	1593×10	2519×10
	0.6	306.1	734.0	-731.8	-300.7	192.3	6.015	2319	-2307	11.27	361.9	-339.4	579.6	-807.8	-1396	336.1	-1412×10	9008	1826×10
	0.8	352.7	847.2	-845.2	-348.0	256.4	4.511	2318	-2309	10.801	273.8	-252.2	403.5	-459.4	-971.8	191.3	-10701	5500	1475×10
	1.0	398.8	947.0	-945.3	-389.6	320.5	3.609	2316	-2310	10.586	224.9	-195.8	307.9	-282.3	-741.8	117.6	-8476	3366	1262×10
	1.2	431.0	1037.2	-1035.6	-427.2	384.6	3.007	2316	-2310	10.467	185.8	-164.8	248.7	-179.4	-599.3	74.83	-7347	1920	1112×10
	1.4	465.3	1120	-1118.9	-461.8	448.7	2.577	2316	-2311	10.398	160.7	-139.9	209.0	-114.5	-503.7	47.82	-6417	[illegible]	[illegible]
	1.6	497.1	1198	-1196.2	-493.8	512.8	2.255	2315	-2311	10.351	141.8	-121.1	180.5	-70.80	-435.0	29.66	-5734	6760	[illegible]
	1.8	527.1	1270	-1268.7	-523.9	576.9	2.005	2315	-2311	10.321	127.2	-106.56	159.2	-40.20	-383.8	16.98	-5219	-5987	8675
	2.0	555.4	1339	-1337.9	-552.4	641.0	1.804	2315	-2311	10.298	115.5	-94.89	142.7	-12.96	-343.9	7.683	-4818	[illegible]	[illegible]

開水路不等流の相似理論的考察とその応用[1)]

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SIMILARITY THEORETICAL CONSIDERATION ABOUT NON-UNIFORM FLOW IN OPEN CHANNELS, AND IT'S APPLICATION

(JSCE July 1953)

Seizō Awazu, C.E. Member.

Synopsis The surface profile of non-uniform flow in open channel can be calculated by the Bernoulli's equation indicated as eq. (1).

This process can be treated mechanically for any boundary conditions.

The auther call them "Mechanical Analysis" for this method.

But it is used only in simple boundary case so the auther presents here a new consideration to complement the weak point of it, that is finded when we plan the experiment or analyse the data.

Then all variables containing in eq. (1), the auther write in a dimensionless form. Thus eq. (1) is rewriter as eq. (2).

And, surface profile can be calculated by eq. (2), the auther call them "Similarity Theoretical Analysis" for this process.

As it's application, in this paper the auther treated the surface profile in the open channels, that wide is given by sine function.

要旨 開水路不等流の水面形は (1) 式で示される Bernoulli の式を計算することによつて求められる。この過程は与えられた環境に対して機械的に行われるもので著者はこの解析法を機械的解析と呼ぶ。しかしこの方法は単一な環境のもとで起る現象を説明するには好都合であるが，さまざまの環境のもとで起る現象の類似性を見出すための実験計画あるいは資料の解析にはよい解析法ではない。これ等の欠点を補うために著者は新しい考えを提案する。

そこで (1) 式に含まれるすべての変数を無次元の形に書き，(2) 式のように書きかえる。そしてこの式

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