I-125　水圧鉄管とライザー接合部の応力解析

埼玉大学　理工学部　正員○秋山成興
東京大学　工学部　正員　奥村敏恵
電源開発K.K.　正員　高橋光雄

1. はじめに

T型パイプ接手の応力集中，分布等の問題は，すでに[1]において，軸圧縮の場合について論じているが，ここでは，補強部の板厚増を考慮して設計の観点から述べてみたい。このタイプの典型的な例として，図-1に示す分岐構造をとり上げる。

これはライザーを介して上部内張管を水圧鉄管2本に分岐する場合を想定ている。各管の半径を適当にとれば，分岐管相互の干渉は考慮しなくてもよいので，今各々独立して考える。

荷重はもちろん内圧であるが，ライザー部（以下本管と云う。）のポート部によって生ずる軸方向および周方向の2方向膜応力状態を考え，水圧鉄管側（以下枝管と云う。）は周方向膜応力だけを考える。

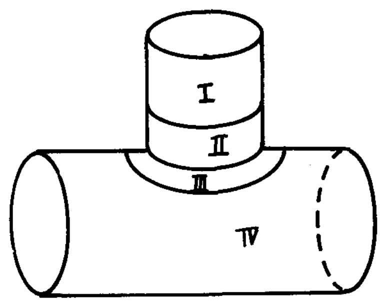


図-1

2. 基本応力状態

まず，基本応力状態としては図-2に示す $R \to \infty$ とした場合の応力状態を選ばねばならぬことは，解の構造から考えて明らかである。

したがって，この場合の解は次のように求まる。

$$\tilde{T}_{1,2} = \left\{ -4i\varepsilon_I^2 \tilde{C}_1 e^{\gamma_1 \xi} + (1+4i\varepsilon_I^2)\tilde{C}_2 e^{\gamma_2 \xi} \right\} \cos 2\varphi$$

$$\tilde{T}_{2,2} = \left\{ (1+4i\varepsilon_I^2)\tilde{C}_1 e^{\gamma_1 \xi} - 4i\varepsilon_I^2 \tilde{C}_2 e^{\gamma_2 \xi} \right\} \cos 2\varphi$$

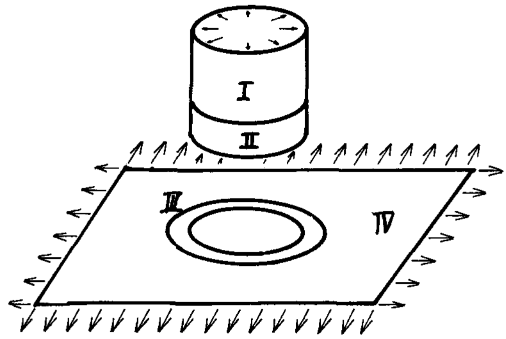
$$\tilde{S}_{,2} = \frac{1}{2}\left\{ 4i\varepsilon_I^2 \gamma_1 \tilde{C}_1 e^{\gamma_1 \xi} - (1+4i\varepsilon_I^2)\gamma_2 \tilde{C}_2 e^{\gamma_2 \xi} \right\} \sin 2\varphi$$

ここで，　$\gamma_1 = \sqrt{8 - \dfrac{i}{\varepsilon_I^2}}$ ，　$\gamma_2 = \sqrt{\dfrac{12}{\left(8 - \dfrac{i}{\varepsilon_I^2}\right)}}$ 　$\varepsilon_I = \sqrt{\dfrac{h}{3.305 r_0}}$

また，平板における基本応力状態は周知の極座標表示によるものであるから，こゝでは記さない。

3． 応力状態

さて，これらを使って実際の応力状態の各成分は次のように表わされる。



図－2

$$\tilde{Q}_{rr}^{I} = -\frac{i}{\varepsilon_I R r}\,\frac{1-i}{\sqrt{2}}\,\frac{(\cos 2\varphi+\frac{r^2}{R^2}\sin^4\varphi)(1-\frac{r^2}{R^2}\sin^2\varphi)^{1/2}}{(1-\frac{r^2}{R^2}\sin^4\varphi)^2}\,e^{\lambda_1(\varphi)\frac{\beta+\eta_1}{\varepsilon_I}}\,\tilde{\psi}_0^{I}(\varphi)\,+$$

$$+\left\{-4i\varepsilon_I^2\,\tilde{C}_1^{I}e^{\gamma_1(\beta+\eta_1)}+(1+4i\varepsilon_I^2)\,\tilde{C}_2^{I}\,e^{\gamma_2(\beta+\eta_1)}\right\}\cos 2\varphi+pr\,\frac{\frac{r^2}{R^2}\cos^2\varphi\,\sin^2\varphi}{1-\frac{r^2}{R^2}\sin^4\varphi}$$

$$\tilde{Q}_{rt}^{I} = \frac{i}{\varepsilon_I r^2}\,\frac{1-i}{\sqrt{2}}\,\frac{\frac{r^2}{R^2}\sin\varphi\cos\varphi\,(\cos 2\varphi+\frac{r^2}{R^2}\sin^4\varphi)}{(1-\frac{r^2}{R^2}\sin^4\varphi)^2}\,e^{\lambda_1(\varphi)\frac{\beta+\eta_1}{\varepsilon_I}}\,\tilde{\psi}_0^{I}(\varphi)\,+$$

$$+\frac{1}{2}\left\{4i\varepsilon_I^2\gamma_1\tilde{C}_1^{I}\,e^{\gamma_1(\beta+\eta_1)}-(1+4i\varepsilon_I^2)\gamma_2\tilde{C}_2^{I}\,e^{\gamma_2(\beta+\eta_1)}\right\}\sin 2\varphi\,-$$

$$-pr\,\frac{\frac{r}{R}\cos\varphi\sin\varphi\,(1-\frac{r^2}{R^2}\sin^2\varphi)^{1/2}}{1-\frac{r^2}{R^2}\sin^4\varphi}$$

$$\tilde{Q}_{tt}^{I} = \frac{1}{C_I r}\,\frac{1-\frac{r^2}{R^2}\sin^2\varphi}{1-\frac{r^2}{R^2}\sin^4\varphi}\,e^{\lambda_1(\varphi)\frac{\beta+\eta_1}{\varepsilon_I}}\,\tilde{\psi}_0^{I}(\varphi)\,+$$

$$+\left\{(1+4i\varepsilon_I^2)\,\tilde{C}_1^{I}e^{\gamma_1(\beta+\eta_1)}-4i\varepsilon_I^2\,\tilde{C}_2^{I}e^{\gamma_2(\beta+\eta_1)}\right\}\cos 2\varphi+pr\,\frac{1-\frac{r^2}{R^2}\sin^2\varphi}{1-\frac{r^2}{R^2}\sin^4\varphi}$$

$$\tilde{Q}_{rn}^{I} = \frac{i}{\varepsilon_I r^2}\,\frac{1-i}{\sqrt{2}}\,\frac{(1-\frac{r^2}{R^2}\sin^2\varphi)^{3/2}}{(1-\frac{r^2}{R^2}\sin^4\varphi)^{3/2}}\,e^{\lambda_1(\varphi)\frac{\beta+\eta_1}{\varepsilon_I}}\,\tilde{\psi}_0^{I}(\varphi)+i\varepsilon_I^2\left(\tilde{C}_1^{I}\gamma_1 e^{\gamma_1(\beta+\eta_1)}+\tilde{C}_2^{I}\gamma_2 e^{\gamma_2(\beta+\eta_1)}\right)\cos 2\varphi$$

$$\tilde{Q}_{rr}^{II} = -\frac{i}{\varepsilon_{II} R r}\,\frac{1-i}{\sqrt{2}}\,\frac{(\cos 2\varphi+\frac{r^2}{R^2}\sin^4\varphi)(1-\frac{r^2}{R^2}\sin^2\varphi)^{1/2}}{(1-\frac{r^2}{R^2}\sin^4\varphi)^2}\left\{\tilde{\psi}_0^{II}(\varphi)\,e^{\lambda_1(\varphi)\frac{\beta}{\varepsilon_{II}}}-\tilde{\psi}_1^{II}(\varphi)\,e^{-\lambda_1(\varphi)\frac{\beta+\eta_1}{\varepsilon_{II}}}\right\}+$$

$$+\left\{-4i\varepsilon_{II}^2\left(\tilde{C}_1^{II}e^{\gamma_1\beta}+\tilde{C}_2^{II}e^{-\gamma_1(\beta+\eta_1)}\right)+(1+4i\varepsilon_{II}^2)\left(\tilde{C}_3^{II}e^{\gamma_2\beta}+\tilde{C}_4^{II}e^{\gamma_2(\beta+\eta_1)}\right)\right\}\cos 2\varphi$$

$$+\;pr\,\frac{\frac{r^2}{R^2}\sin^2\varphi\cos^2\varphi}{1-\frac{r^2}{R^2}\sin^4\varphi}$$

$$
\begin{aligned}
\tilde{Q}_{vt}^{II} = {} & \frac{i}{\varepsilon_{II} r^2}\,\frac{1-i}{\sqrt{2}}\,\frac{\frac{r^2}{R^2}\sin\varphi\cos\varphi\left(\cos 2\varphi+\frac{r^2}{R^2}\sin^4\varphi\right)}{\left(1-\frac{r^2}{R^2}\sin^4\varphi\right)^2}\left\{\tilde{\psi}_0^{II}(\varphi)\,e^{\lambda_1(\varphi)\frac{\beta}{\varepsilon_{II}}}-\tilde{\psi}_1^{II}(\varphi)\,e^{-\lambda_1(\varphi)\frac{\beta+\eta_1}{\varepsilon_{II}}}\right\}+ \\
& +\frac{1}{2}\left\{4i\varepsilon_{II}^2\gamma_1\left(\tilde{C}_1^{II}e^{\gamma_1\beta}-\tilde{C}_2^{II}e^{-\gamma_1(\beta+\eta_1)}\right)-(1+4i\varepsilon_{II}^2)\gamma_2\left(\tilde{C}_3^{II}e^{\gamma_2\beta}-\tilde{C}_4^{II}e^{-\gamma_2(\beta+\eta_1)}\right)\right\}\sin 2\varphi \\
& -pr\,\frac{\frac{r}{R}\cos\varphi\sin\varphi\left(1-\frac{r^2}{R^2}\sin^2\varphi\right)^{1/2}}{1-\frac{r^2}{R^2}\sin^4\varphi}
\end{aligned}
$$

$$
\begin{aligned}
\tilde{Q}_{tt}^{II} = {} & \frac{1}{C_{II} r}\,\frac{1-\frac{r^2}{R^2}\sin^2\varphi}{1-\frac{r^2}{R^2}\sin^4\varphi}\left\{\tilde{\psi}_0^{II}(\varphi)\,e^{\lambda_1(\varphi)\frac{\beta}{\varepsilon_{II}}}+\tilde{\psi}_1^{II}(\varphi)\,e^{-\lambda_1(\varphi)\frac{\beta+\eta_1}{\varepsilon_{II}}}\right\}+ \\
& +\left\{(1+4i\varepsilon_{II}^2)\left(\tilde{C}_1^{II}e^{\gamma_1\beta}+\tilde{C}_2^{II}e^{-\gamma_1(\beta+\eta_1)}\right)-4i\varepsilon_{II}^2\left(\tilde{C}_3^{II}e^{\gamma_2\beta}+\tilde{C}_4^{II}e^{-\gamma_2(\beta+\eta_1)}\right)\right\}\cos 2\varphi+pr\,\frac{1-\frac{r^2}{R^2}\sin^2\varphi}{1-\frac{r^2}{R^2}\sin^4\varphi}
\end{aligned}
$$

$$
\begin{aligned}
\tilde{Q}_{vv}^{III} = {} & -\frac{i}{\varepsilon_{III} r^2}\,\frac{1-i}{\sqrt{2}}\,\frac{\left\{2\left(1-\frac{r^2}{R^2}\sin^2\varphi\right)-\left(1-\frac{r^2}{R^2}\sin^4\varphi\right)\right\}}{\left(1-\frac{r^2}{R^2}\sin^4\varphi\right)^2}\cos\varphi\left\{\tilde{\psi}_0^{III}(\varphi)\,e^{\lambda_2(\varphi)\frac{\beta}{\varepsilon_{III}}}-\tilde{\psi}_1^{III}(\varphi)\,e^{-\lambda_2(\varphi)\frac{\beta+\eta_2}{\varepsilon_{III}}}\right\} \\
& +\tilde{B}_0^{III}\rho^{-2}-\left(6\tilde{B}_2^{III}\rho^{-4}+2\tilde{C}_2^{III}+4\tilde{D}_2^{III}\rho^{-2}\right)\frac{\cos 2\varphi+\frac{r^2}{R^2}\sin^4\varphi}{1-\frac{r^2}{R^2}\sin^4\varphi}+pR\,\frac{\left\{\sin^2\varphi\left(1-\frac{r^2}{R^2}\sin^2\varphi\right)+\frac{1}{2}\left(1-\frac{R_i^2}{R^2}\right)\cos^2\varphi\right\}}{1-\frac{r^2}{R^2}\sin^4\varphi}
\end{aligned}
$$

$$
\begin{aligned}
\tilde{Q}_{vt}^{III} = {} & \frac{i}{\varepsilon_{III} r^2}\,\frac{1-i}{\sqrt{2}}\,\frac{\left(1-\frac{r^2}{R^2}\sin^2\varphi\right)^{1/2}\left\{2\left(1-\frac{r^2}{R^2}\sin^2\varphi\right)-\left(1-\frac{r^2}{R^2}\sin^4\varphi\right)\right\}\sin\varphi}{\left(1-\frac{r^2}{R^2}\sin^4\varphi\right)^2}\left\{\tilde{\psi}_0^{III}(\varphi)\,e^{\lambda_2(\varphi)\frac{\beta}{\varepsilon_{III}}}-\tilde{\psi}_1^{III}(\varphi)\,e^{-\lambda_2(\varphi)\frac{\beta+\eta_2}{\varepsilon_{III}}}\right\} \\
& -\left(6\tilde{A}_2^{III}\rho^{2}-6\tilde{B}_2^{III}\rho^{-4}+2\tilde{C}_2^{III}-2\tilde{D}_2^{III}\rho^{-2}\right)\frac{\sin 2\varphi\left(1-\frac{r^2}{R^2}\sin^2\varphi\right)^{1/2}}{1-\frac{r^2}{R^2}\sin^4\varphi}-\frac{pR}{2}\left(1+\frac{R_i^2}{R^2}\right)\frac{\cos\varphi\sin\varphi\left(1-\frac{r^2}{R^2}\sin^2\varphi\right)^{1/2}}{1-\frac{r^2}{R^2}\sin^4\varphi}
\end{aligned}
$$

$$
\begin{aligned}
\tilde{Q}_{tt}^{III} = {} & \frac{1}{C_{III} R}\,\frac{\cos^2\varphi}{1-\frac{r^2}{R^2}\sin^4\varphi}\left\{\tilde{\psi}_0^{III}(\varphi)\,e^{\lambda_2(\varphi)\frac{\beta}{\varepsilon_{III}}}+\tilde{\psi}_1^{III}(\varphi)\,e^{-\lambda_2(\varphi)\frac{\beta+\eta_2}{\varepsilon_{III}}}\right\}-\tilde{B}_0^{III}\rho^{-2}+ \\
& +\left\{12\tilde{A}_2^{III}\rho^{2}+6\tilde{B}_2^{III}\rho^{-4}+2\tilde{C}_2^{III}\right\}\frac{\cos 2\varphi+\frac{r^2}{R^2}\sin^4\varphi}{1-\frac{r^2}{R^2}\sin^4\varphi}+\frac{pR}{1-\frac{r^2}{R^2}\sin^4\varphi}\left\{\cos^2\varphi+\frac{1}{2}\left(1-\frac{R_i^2}{R^2}\right)\sin^2\varphi\left(1-\frac{r^2}{R^2}\sin^2\varphi\right)\right\}
\end{aligned}
$$

$$
\begin{aligned}
\tilde{Q}_{vn}^{III} = {} & \frac{i}{\varepsilon_{III} R r}\,\frac{1-i}{\sqrt{2}}\,\frac{\cos^3\varphi}{\left(1-\frac{r^2}{R^2}\sin^4\varphi\right)^{3/2}}\left\{\tilde{\psi}_0^{III}(\varphi)\,e^{\lambda_2(\varphi)\frac{\beta}{\varepsilon_{III}}}-\tilde{\psi}_1^{III}(\varphi)\,e^{-\lambda_2(\varphi)\frac{\beta+\eta_2}{\varepsilon_{III}}}\right\}- \\
& -i\varepsilon_{III}^3\left(24\tilde{A}_2^{III}\rho+8\tilde{D}_2^{III}\rho^{-3}\right)\frac{\cos 2\varphi+\frac{r^2}{R^2}\sin^4\varphi}{1-\frac{r^2}{R^2}\sin^4\varphi}
\end{aligned}
$$

Generalized Edge Effect の場合

$$
\begin{aligned}
\tilde{Q}_{vv}^{III} = {} & \frac{-ia}{\varepsilon_{III}^{2/3} r^2}\,\frac{\left\{2\left(1-\frac{r^2}{R^2}\sin^2\varphi\right)-\left(1-\frac{r^2}{R^2}\sin^4\varphi\right)\right\}}{\left(1-\frac{r^2}{R^2}\sin^4\varphi\right)^{3/2}}\exp\left\{-\frac{a}{2\left(1-\frac{r^2}{R^2}\right)^{1/2}}\,\frac{\left(\frac{\pi}{2}-\varphi\right)^2}{\varepsilon_{III}^{2/3}}\right\} \\
& \cdot\left[\exp\left\{-\frac{1+i}{\sqrt{2}}\,\frac{a^2\left(\frac{\pi}{2}-\varphi\right)}{\varepsilon_{III}^{1/3}}\right\}\left\{\tilde{A}_n^{III}\exp\left(\frac{a\beta}{\varepsilon_{III}^{2/3}}\right)-\tilde{B}_n^{III}\exp\left\{-\frac{a(\beta+\eta_2)}{\varepsilon_{III}^{2/3}}\right\}\right\}+\exp\left\{\frac{1+i}{\sqrt{2}}\,\frac{a^2\left(\frac{\pi}{2}-\varphi\right)}{\varepsilon_{III}^{1/3}}\right\}\left\{\tilde{C}_n^{III}\exp\left(\frac{a\beta}{\varepsilon_{III}^{2/3}}\right)-\right.\right. \\
& \left.\left.-\tilde{D}_n^{III}\exp\left\{-\frac{a(\beta+\eta_2)}{\varepsilon_{III}^{2/3}}\right\}\right\}\right]+\tilde{B}_0^{III}\rho^{-2}-\left(6\tilde{B}_2^{III}\rho^{-4}+2\tilde{C}_2^{III}+4\tilde{D}_2^{III}\rho^{-2}\right)\frac{\cos 2\varphi+\frac{r^2}{R^2}\sin^4\varphi}{1-\frac{r^2}{R^2}\sin^4\varphi}+ \\
& +\frac{pR}{1-\frac{r^2}{R^2}\sin^4\varphi}\left\{\sin^2\varphi\left(1-\frac{r^2}{R^2}\sin^2\varphi\right)+\frac{1}{2}\left(1-\frac{R_i^2}{R^2}\right)\cos^2\varphi\right\}
\end{aligned}
$$

$$\tilde{Q}_{vt}^{\mathrm{III}} = -\frac{i a^3}{\varepsilon_{\mathrm{III}} r^2}\frac{1+i}{\sqrt{2}}\exp\left\{-\frac{a}{2(1-\frac{r^2}{R^2})^{1/2}}\frac{(\frac{\pi}{2}-\varphi)^2}{\varepsilon_{\mathrm{III}}^{2/3}}\right\}\Big(\exp\left\{-\frac{1+i}{\sqrt{2}}\frac{a^2(\frac{\pi}{2}-\varphi)}{\varepsilon_{\mathrm{III}}^{1/3}}\right\}\left\{\hat{A}_n^{\mathrm{III}}\exp\left(\frac{a\beta}{\varepsilon_{\mathrm{III}}^{2/3}}\right)-\right.$$

$$\left.-\tilde{B}_n^{\mathrm{III}}\exp\left\{-\frac{a(\beta+\eta_2)}{\varepsilon_{\mathrm{III}}^{2/3}}\right\}\right\}+\exp\left\{\frac{1+i}{\sqrt{2}}\frac{a^2(\frac{\pi}{2}-\varphi)}{\varepsilon_{\mathrm{III}}^{1/3}}\right\}\left\{-\tilde{C}_n^{\mathrm{III}}\exp\left(\frac{a\beta}{\varepsilon_{\mathrm{III}}^{2/3}}\right)+\tilde{D}_n^{\mathrm{III}}\left\{-\frac{a(\beta+\eta_2)}{\varepsilon_{\mathrm{III}}^{2/3}}\right\}\right\}\Big] -$$

$$-(16\tilde{A}_2^{\mathrm{III}}\rho^2-6\tilde{B}_2^{\mathrm{III}}\rho^{-4}+2\tilde{C}_2^{\mathrm{III}}-2\tilde{D}_2^{\mathrm{III}}\rho^{-2})\frac{\sin 2\varphi(1-\frac{r^2}{R^2}\sin^2\varphi)^{1/2}}{1-\frac{r^2}{R^2}\sin^4\varphi}-\frac{PR}{2}\left(1+\frac{R_i^2}{R^2}\right)\frac{\cos\varphi\sin\varphi(1-\frac{r^2}{R^2}\sin^2\varphi}{1-\frac{r^2}{R^2}\sin^4\varphi}$$

$$\tilde{Q}_{tt}^{\mathrm{III}} = \frac{i a^2}{\varepsilon_{\mathrm{III}}^{4/3} r^2}\exp\left\{-\frac{a}{2(1-\frac{r^2}{R^2})^{1/2}}\frac{(\frac{\pi}{2}-\varphi)^2}{\varepsilon_{\mathrm{III}}^{2/3}}\right\}\cdot\Big[\exp\left\{-\frac{1+i}{\sqrt{2}}\frac{a^2(\frac{\pi}{2}-\varphi)}{\varepsilon_{\mathrm{III}}^{1/3}}\right\}\Big[\hat{A}_n^{\mathrm{III}}\exp\left(\frac{a\beta}{\varepsilon_{\mathrm{III}}^{2/3}}\right)+$$

$$+\hat{B}_n^{\mathrm{III}}\left\{-\frac{a(\beta+\eta_2)}{\varepsilon_{\mathrm{III}}^{2/3}}\right\}\Big\}+\exp\left\{\frac{1+i}{\sqrt{2}}\frac{a^2(\frac{\pi}{2}-\varphi)}{\varepsilon_{\mathrm{III}}^{1/3}}\right\}\left\{\hat{C}_n^{\mathrm{III}}\exp\left(\frac{a\beta}{\varepsilon_{\mathrm{III}}^{2/3}}\right)+\hat{D}_n^{\mathrm{III}}\left\{-\frac{a(\beta+\eta_2)}{\varepsilon_{\mathrm{III}}^{2/3}}\right\}\right\}\Big] +$$

$$-\tilde{B}_0^{\mathrm{III}}\rho^{-2}+(12\tilde{A}_2^{\mathrm{III}}\rho^2+6\tilde{B}_2^{\mathrm{III}}\rho^{-4}+2\tilde{C}_2^{\mathrm{III}})\frac{\cos 2\varphi+\frac{r^2}{R^2}\sin^4\varphi}{1-\frac{r^2}{R^2}\sin^4\varphi}+\frac{PR\{\cos^2\varphi+\frac{1}{2}(1-\frac{R_i^2}{R^2})\sin^2\varphi(1-\frac{r^2}{R^2}\sin}{1-\frac{r^2}{R^2}\sin^4\varphi}$$

$$\tilde{Q}_{vn}^{\mathrm{III}} = -\frac{a^3}{Rr}\exp\left\{-\frac{a}{2(1-\frac{r^2}{R^2})^{1/2}}\frac{(\frac{\pi}{2}-\varphi)^2}{\varepsilon_{\mathrm{III}}^{2/3}}\right\}\cdot\Big[\exp\left\{-\frac{1+i}{\sqrt{2}}\frac{a^2(\frac{\pi}{2}-\varphi)}{\varepsilon_{\mathrm{III}}^{1/3}}\right\}\left\{\tilde{A}_n^{\mathrm{III}}\exp\left(\frac{a\beta}{\varepsilon_{\mathrm{III}}^{2/3}}\right)-\right.$$

$$\left.-\tilde{B}_n^{\mathrm{III}}\exp\left\{-\frac{a(\beta+\eta_2)}{\varepsilon_{\mathrm{III}}^{2/3}}\right\}\right\}+\exp\left\{\frac{1+i}{\sqrt{2}}\frac{a^2(\frac{\pi}{2}-\varphi)}{\varepsilon_{\mathrm{III}}^{1/3}}\right\}\left\{\tilde{C}_n^{\mathrm{III}}\exp\left(\frac{a\beta}{\varepsilon_{\mathrm{III}}^{2/3}}\right)-\tilde{D}_n^{\mathrm{III}}\exp\left\{\frac{-a(\beta+\eta_2)}{\varepsilon_{\mathrm{III}}^{2/3}}\right\}\right\}\Big] -$$

$$-i\varepsilon_{\mathrm{III}}^2(24\tilde{A}_2^{\mathrm{III}}\rho+8\tilde{D}_2^{\mathrm{III}}\rho^{-3})\frac{\cos 2\varphi+\frac{r^2}{R^2}\sin^4\varphi}{1-\frac{r^2}{R^2}\sin^4\varphi}$$

$\tilde{Q}_{vv}^{\mathrm{IV}},\ldots,\hat{Q}_{vn}^{\mathrm{IV}}$ は $\tilde{Q}_{vv}^{\mathrm{III}}\ldots,\hat{Q}_{vn}^{\mathrm{III}}$ の式中 $\beta\to\infty$, $\rho\to\infty$ の時に0に収束する項だけを考えればよいので，こゝには記さない。

$$\lambda_1(\varphi)=\sqrt{\frac{1-\frac{r^2}{R^2}\sin^2\varphi}{1-\frac{r^2}{R^2}\sin^4\varphi}},\quad \lambda_2(\varphi)=\frac{\cos\varphi}{(1-\frac{r^2}{R^2}\sin^4\varphi)^{1/2}},\quad \varepsilon_{\mathrm{I}}=\sqrt{\frac{h_{\mathrm{I}}}{3.305r}},\quad \varepsilon_{\mathrm{II}}=\sqrt{\frac{h_{\mathrm{II}}}{3.305r}}$$

$$\varepsilon_{\mathrm{III}}=\sqrt{\frac{h_{\mathrm{III}}R}{3.305r^2}},\quad \varepsilon_{\mathrm{IV}}=\sqrt{\frac{h_{\mathrm{IV}}R}{3.305r^2}}$$

ホ. 積分常数の決定

前記の応力成分の表示式の中には未知関数 $\tilde{\psi}_0(\varphi)$, $\tilde{\psi}_1(\varphi)$，未定常数 $\tilde{A}_n, \tilde{B}_n, \tilde{C}_n, \tilde{D}_n$ 等が含まれているが，これらは各境界線上の応力変形の連続条件より定められる。

$\beta=-\eta_1$ 上で　$\tilde{Q}_{tt}^{\mathrm{I}}=\tilde{Q}_{tt}^{\mathrm{II}}$, $\tilde{Q}_{vt}^{\mathrm{I}}=\tilde{Q}_{vt}^{\mathrm{II}}$, $\tilde{Q}_{vv}^{\mathrm{I}}=\tilde{Q}_{vv}^{\mathrm{II}}$, $\tilde{Q}_{vn}^{\mathrm{I}}=\tilde{Q}_{vn}^{\mathrm{II}}$

$\beta=-\eta_2$ 上で　$\tilde{Q}_{tt}^{\mathrm{III}}=\tilde{Q}_{tt}^{\mathrm{IV}}$, $\tilde{Q}_{vt}^{\mathrm{III}}=\tilde{Q}_{vt}^{\mathrm{IV}}$, $\tilde{Q}_{vv}^{\mathrm{III}}=\tilde{Q}_{vv}^{\mathrm{IV}}$, $\tilde{Q}_{vn}^{\mathrm{III}}=\tilde{Q}_{vn}^{\mathrm{IV}}$

パイプの接合線上の連続条件は [1] を参照の事。

[1] 奥村，秋山，楼，島居：「パイプ接手近傍における境界攪乱応力の解析」第22回年次学術講演会講演概要