JAERI-Research
94-013

STABILITY ANALYSIS OF EXTERNAL KINK MODE FOR ITER L-MODE PROFILE PLASMAS

September 1994

Shinji TOKUDA and Takahisa OZEKI

日本原子力研究所
Japan Atomic Energy Research Institute

本レポートは，日本原子力研究所が不定期に公刊している研究報告書です。
入手の問合わせは，日本原子力研究所技術情報部情報資料課（〒319-11 茨城県那珂郡東海村）あて，お申し越しください。なお，このほかに財団法人原子力弘済会資料センター（〒319-11 茨城県那珂郡東海村日本原子力研究所内）で複写による実費頒布をおこなっております。

This report is issued irregularly.
Inquiries about availability of the reports should be addressed to Information Division, Department of Technical Information, Japan Atomic Energy Research Institute, Tokai-mura, Naka-gun, Ibaraki-ken 319-11, Japan.

編集兼発行　日本原子力研究所
印　　　刷　いばらき印刷㈱

Stability Analysis of External Kink Mode for ITER L-mode Profile Plasmas

Shinji TOKUDA and Takahisa OZEKI

Department of Fusion Plasma Research
Naka Fusion Research Establishment
Japan Atomic Energy Research Institute
Naka-machi, Naka-gun, Ibaraki-ken

(Received August 2, 1994)

A stability analysis is made for the n=1 external kink mode (n:toroidal mode number) to the predicted ITER L-mode profiles. The beta limit (g_T) for this kink mode is sufficiently higher than the design value of g_T =2.0~2.4 for the L-mode profiles in case of the assumed current profile even with a finite but small edge current. However, in case of q_o less than unity (q_o :safety factor on the magnetic axis) the beta limit for the kink mode is significantly reduced: g_T is 1.0 for q_o =0.8 without a conducting wall. A conducting wall located near the mid-plane has a stronger stabilizing effect than a wall located near the null point.

Keywords: Tokamak, MHD Stability, Beta Limit, External Kink Mode, L-mode, ITER Physics R & D

ITER Lモード分布プラズマの外部キンクモード安定性解析

日本原子力研究所那珂研究所炉心プラズマ研究部
徳田　伸二・小関　隆久

(1994年8月2日受理)

ITERにおいて予想されるLモード分布のn＝1外部キンクモードにたいする安定性解析を行った（n：トロイダルモード数）。Lモード分布が想定した電流分布をもつ場合では、プラズマ周辺部で小さいが有限の電流があっても、キンクモードのベータ値限界（g_T）は設計値g_T＝2.0～2.4より十分に高い。しかしながら、q_0が1より小さい場合、キンクモードのベータ値限界はかなり減少する（q_0：磁気軸での安全係数）。たとえば、q_0＝0.8で導体壁のない場合、g_Tは1である。中心面近くに置かれた導体壁にはヌル点近くに置かれた導体壁よりも強い安定化効果がある。

那珂研究所：〒311-01　茨城県那珂郡那珂町大字向山801-1

Contents

目　　次

1. Introduction

The L–mode profiles for ITER are predicted by the PRETOR 1–1/2 dimensional transport code which incorporates the Rebut-Lallia-Watkins transport model [1]. The study of ideal MHD stability for these profiles are necessary to specify the conservative beta value which can be realized in long pulse operation by comfortable margins for the deviations from the predicted profiles. This study involves the sensitivity analysis of the stability for deviations from such assumed profiles.

In the present paper, we investigate the stability of the n = 1 external kink mode for the predicted ITER L-mode profiles (n: toroidal mode number). The stability of the n = 1 external kink mode strongly depends on the edge current, the safety factor on the magnetic axis and the position of a conducting wall. In the present work, we study the effects of them on the beta limit of this mode by varying the predicted L–mode profiles.

In Sec. 2 we describe equilibria used in the present work. In Sec. 3 we analyze the stability of the n = 1 external kink mode by using the up-down asymmetric version of the ideal MHD stability code, JAERI-ERATO [2], and we give summary in Sec. 4 .

2. Equilibria for the ITER L-mode profile

Equilibria in a single null configuration are numerically computed by the MEUDAS code [3] with the following parameters:

Major radius R_0 = 8.21 m,

Plasma radius a = 3.0 m,

Ellipticity at 95 % ψ-surface κ_{95} = 1.56,

Triangularity δ = 0.31,

Toroidal Filed B_t = 5.89 T,

Total Plasma Current I_p = 25 MA.

1. Introduction

The L–mode profiles for ITER are predicted by the PRETOR 1–1/2 dimensional transport code which incorporates the Rebut-Lallia-Watkins transport model [1]. The study of ideal MHD stability for these profiles are necessary to specify the conservative beta value which can be realized in long pulse operation by comfortable margins for the deviations from the predicted profiles. This study involves the sensitivity analysis of the stability for deviations from such assumed profiles.

In the present paper, we investigate the stability of the n = 1 external kink mode for the predicted ITER L-mode profiles (n: toroidal mode number). The stability of the n = 1 external kink mode strongly depends on the edge current, the safety factor on the magnetic axis and the position of a conducting wall. In the present work, we study the effects of them on the beta limit of this mode by varying the predicted L–mode profiles.

In Sec. 2 we describe equilibria used in the present work. In Sec. 3 we analyze the stability of the n = 1 external kink mode by using the up-down asymmetric version of the ideal MHD stability code, JAERI-ERATO [2], and we give summary in Sec. 4 .

2. Equilibria for the ITER L-mode profile

Equilibria in a single null configuration are numerically computed by the MEUDAS code [3] with the following parameters:

Major radius $R_0 = 8.21$ m,

Plasma radius a = 3.0 m,

Ellipticity at 95 % ψ-surface $\kappa_{95} = 1.56$,

Triangularity $\delta = 0.31$,

Toroidal Filed $B_t = 5.89$ T,

Total Plasma Current $I_p = 25$ MA.

The current profile chosen in the study is

$$J_{//} \propto (1-\alpha)(1-\Psi^{\beta 1})^{\beta 2} + \alpha, \quad (1)$$

and pressure profile is

$$-\frac{dp}{d\psi} \propto \Psi^{\alpha 1} - \Psi^{\alpha 2} + \sigma \exp[-h(1-\Psi)^2], \quad (2)$$

where Ψ is the normalized poloidal flux function ($0 \le \Psi \le 1$). Parameters α and σ give edge values of $J_{//}$ and p' , respectively, and h gives the width of the pressure profile near the edge. The parameters α_1, α_2, β_1 and β_2 are adjusted to fit the PRETOR (L–mode) profile. Figure 1 shows an equilibrium with $g_T = 5.5$, $q_0 = 1.05$ and $\alpha = \sigma = 0$ where g_T is the Troyon coefficient defined by $g_T = \beta$ (%) a(m) B_0(T)/ Ip(MA), and q_0 is the safety factor on the magnetic axis. The design value of g_T is 2.0 ~ 2.4 for the L–mode profiles. The ballooning modes are locally unstable in the region of the maximum pressure gradient above g_T of 2.7 for the present profile.

3. Stability Analysis of the n = 1 External Kink Mode

The beta values are increased for the fixed profiles expressed by Eqs. (1) and (2) and the stability of the n = 1 external kink mode is analyzed by the JAERI-ERATO code. In computing eigenvalues (squared growth rates) we use the equi-arc coordinate system where the poloidal angle χ is defined by $d\chi/dl =$ *const.* on each flux surface (*l*: length of equi contour line of the flux). The shape of a conducting wall is assumed to be given by

$$Rw(\chi) = R_{axis} + R_{scl}(Rs(\chi) - R_{axis}), \quad (3.a)$$

$$Zw(\chi) = Z_{axis} + Z_{scl}(Zs(\chi) - Z_{axis}). \quad (3.b)$$

Here $\chi = 0$ corresponds to the outer point on the mid-plane of the torus. When $R_{scl} = Z_{scl}$, the shape of the conducting wall is similar to the plasma surface and the ratio a_w/a is characterized by the value of R_{scl} in the present work (a_w: radius of the wall).

The current profile chosen in the study is

$$J_{//} \propto (1-\alpha)\,(1-\Psi^{\beta 1})^{\beta 2} + \alpha\,, \qquad (1)$$

and pressure profile is

$$-\frac{dp}{d\psi} \propto \Psi^{\alpha 1} - \Psi^{\alpha 2} + \sigma \exp[-h\,(1-\Psi)^2]\,, \qquad (2)$$

where Ψ is the normalized poloidal flux function ($0 \le \Psi \le 1$). Parameters α and σ give edge values of $J_{//}$ and p' , respectively, and h gives the width of the pressure profile near the edge. The parameters α_1, α_2, β_1 and β_2 are adjusted to fit the PRETOR (L–mode) profile. Figure 1 shows an equilibrium with $g_T = 5.5$, $q_0 = 1.05$ and $\alpha = \sigma = 0$ where g_T is the Troyon coefficient defined by $g_T = \beta$ (%) a(m) B_0(T)/ Ip(MA), and q_0 is the safety factor on the magnetic axis. The design value of g_T is 2.0 ~ 2.4 for the L–mode profiles. The ballooning modes are locally unstable in the region of the maximum pressure gradient above g_T of 2.7 for the present profile.

3. Stability Analysis of the n = 1 External Kink Mode

The beta values are increased for the fixed profiles expressed by Eqs. (1) and (2) and the stability of the n = 1 external kink mode is analyzed by the JAERI-ERATO code. In computing eigenvalues (squared growth rates) we use the equi-arc coordinate system where the poloidal angle χ is defined by $d\chi/dl = const.$ on each flux surface (l: length of equi contour line of the flux). The shape of a conducting wall is assumed to be given by

$$Rw(\chi) = R_{axis} + R_{scl}\,(Rs(\chi) - R_{axis}), \qquad (3.a)$$

$$Zw(\chi) = Z_{axis} + Z_{scl}\,(Zs(\chi) - Z_{axis}). \qquad (3.b)$$

Here $\chi = 0$ corresponds to the outer point on the mid-plane of the torus. When $R_{scl} = Z_{scl}$, the shape of the conducting wall is similar to the plasma surface and the ratio a_w/a is characterized by the value of R_{scl} in the present work (a_w: radius of the wall).

In Fig. 2 the convergence of the growth rate against radial mesh number N is shown for equilibria with $q_0 = 1.05$ and $a_w = \infty$. The following calculations use 140 radial and 180 poloidal mesh numbers.

3.1 Effect of Edge Profile

We first analyzed the effect of the edge current on the n = 1 external kink mode. In this study α and σ in Eqs. (1) and (2) are limited to small amounts of value because the L–mode profiles are considered to have small edge current and pressure gradient. The value of h in Eq. (2) is set to 10 so that the edge pressure profile does not affect the global pressure profile. We also fix q_0 to 1.05 and assume no conducting walls ($a_w = \infty$). Figure 3 shows the dependence of the squared growth rate γ^2 of the mode on the Troyon coefficient g_T for different values of the parameter α and $\sigma = 0$. We obtain the beta limit $g_T = 5.0$ for $\alpha = 0$ (no edge current), which corresponds to the predicted L–mode profile in our present analysis, and $g_T = 4.6$ for $\alpha = 0.2$ (Fig. 3). We also examined the effect of the pressure gradient p' (= $dp/d\psi$) at the edge on the stability of the mode. Figure 4(a) shows the dependence of γ^2 on g_T for $\alpha = 0.2$, $\sigma = 0$ and $\alpha = 0.2$, $\sigma = 0.1$. The profiles of pressure gradient $dp/d\psi$ for these cases are shown in Figs. 4(b) and 4(c). The results indicates that the effect of edge p' on g_T is weak for the present L–mode profiles.

We next examined the mode structure and the driving terms of the mode for the predicted L–mode profiles. Figure 5 illustrates the radial structure of poloidal Fourier harmonics $X_m(s)$ of the displacement for $\alpha = \sigma = 0$ and g_T = 6.1. Here $X_m(s)$ is defined by

$$X(s, \theta) = \sum_m X_m(s) \exp(im\theta - in\phi) . \quad (4)$$

In Eq. (4) $X = \xi \bullet \nabla\psi$ (ξ: displacement vector) and θ is the poloidal angle in the straight field line coordinate system, ϕ the toroidal angle around the axis of torus and $s = \sqrt{\Psi}$. We also show in Fig. 6 the radial distribution of the potential energy W (red line) together with the contributions from the kink (green line) and ballooning (blue line) terms. Harmonics of $m \geq 2$ localizing near the surface are dominant. We also see both kink and ballooning terms near the surface contribute to destabilize the mode.

3.2 *q_0 Dependence of Beta Limit*

To study the q_0 dependence of the stability we make a sequence of equilibria by using the scaling [4], $\psi_{new}(R,Z) = \sigma_{scale}\psi_{old}(R,Z)$, $p'_{old} = \sigma_{scale}p'_{new}$, and $(FF')_{new} = \sigma_{scale}(FF')_{old}$ with the fixed $F(\Psi = 0)$ where $\sigma_{scale} = q_{0,old}/q_{0,new}$ (F: toroidal field function). The coefficient g_T is approximately calculated by $g_{T,new} = \sigma_{scale}\, g_{T,old}$. The shape of a conducting wall is given by Eq. (3) with $R_{scl} = Z_{scl}$. The squared growth rates of the mode are plotted in Fig. 7 for $a_w/a = \infty$, 2.0 and 1.5, with $q_0 = 0.95$, $g_T = 2.7$ in Fig. 7(a) and $q_0 = 0.8$, $g_T = 3.1$ in Fig. 7(b), respectively. The mode structure of the unstable mode for $q_0 = 0.8$, as illustrated in Fig. 8(a), is quite different from that for $q_0 = 1.05$ (Fig. 5). The $m = 1$ harmonic is the most dominant and $m = 3$ harmonic is also excited near the surface. By wall stabilization, such harmonics are suppressed as shown in Figure 8(b). When q_0 is less than unity the mode is destabilized mainly by the kink term in the inner region as shown in Figs. 9 (a) and 9 (b), and it has a global structure implying a strong effect on the plasma.

Figure 10 summarizes the present stability analyses. The beta limit of the $n = 1$ external kink mode for the predicted L–mode profiles with $q_0 \geq 1$ is sufficiently high compared with the beta limit of the high n ballooning modes and with the design value for g_T. However, when q_0 becomes to be less than unity, the beta limit of the $n = 1$ mode decreases to $g_T = 1.0$ for $a_w/a = \infty$ and $g_T = 1.7$ for $a_w/a = 1.5$, both of which are less than the design value.

3.3 Shape Effect of a Conducting Wall

In Subsection 3.2 the ratio a_w/a was changed with keeping the shape of the conducting wall similar to the plasma surface. However, from a practical point of view, it is sometimes difficult to locate the wall near null points. Therefore, it is important to clarify the shape effect of the wall on the stability. For this study we compute the growth rate of the $n = 1$ mode for various values of R_{scl} and Z_{scl} in Eq.(3) which characterize the values of a_w/a and the distance between the null point and the wall, respectively.

The shape of the conducting wall in Fig. 11(a) is similar to the plasma surface and $a_w/a = 2.5$. The shape of the conducting wall in Fig. 11(b) has the same value of a_w/a as in Fig. 11(a) but the different distance between the null point and the wall, which is characterized by different Z_{scl} with the same R_{scl}. On the other hand, the shape of the wall in Fig. 11(c) has the smaller value of $a_w/a = 1.5$ but the same distance between the null point and the wall compared with those in Fig. 11(a).

The results are shown in Fig. 12 (a) for $q_0 = 1.05$, $g_T = 6.1$ and in Fig. 12 (b) for $q_0 = 0.8$, $g_T = 3.1$. These results imply that a conducting wall located near the mid-plane is more effective than a wall near the null point to stabilize the $n = 1$ external kink mode, and that only the ratio a_w/a adopted in the present work gives a good measure in the study of stabilization by a wall even with different distance between the null point and the wall. The detailed analysis on the shape effect will be reported in the near future.

4. Summary

We have investigated the stability of the $n = 1$ external kink mode for the predicted ITER L–mode profiles and performed the sensitivity analysis of the beta limit for such profiles. The design value of g_T is set in the range of $2.0 \sim 2.4$. We have calculated beta limits for the equilibria obtained by varying the L–mode profile. The results are as follows.

3.3 *Shape Effect of a Conducting Wall*

In Subsection 3.2 the ratio a_w/a was changed with keeping the shape of the conducting wall similar to the plasma surface. However, from a practical point of view, it is sometimes difficult to locate the wall near null points. Therefore, it is important to clarify the shape effect of the wall on the stability. For this study we compute the growth rate of the n = 1 mode for various values of R_{scl} and Z_{scl} in Eq.(3) which characterize the values of a_w/a and the distance between the null point and the wall, respectively.

The shape of the conducting wall in Fig. 11(a) is similar to the plasma surface and $a_w/a = 2.5$. The shape of the conducting wall in Fig. 11(b) has the same value of a_w/a as in Fig. 11(a) but the different distance between the null point and the wall, which is characterized by different Z_{scl} with the same R_{scl}. On the other hand, the shape of the wall in Fig. 11(c) has the smaller value of a_w/a =1.5 but the same distance between the null point and the wall compared with those in Fig. 11(a).

The results are shown in Fig. 12 (a) for $q_0 = 1.05$, $g_T = 6.1$ and in Fig. 12 (b) for $q_0 = 0.8$, $g_T = 3.1$. These results imply that a conducting wall located near the mid-plane is more effective than a wall near the null point to stabilize the n = 1 external kink mode, and that only the ratio a_w/a adopted in the present work gives a good measure in the study of stabilization by a wall even with different distance between the null point and the wall. The detailed analysis on the shape effect will be reported in the near future.

4. Summary

We have investigated the stability of the n = 1 external kink mode for the predicted ITER L–mode profiles and performed the sensitivity analysis of the beta limit for such profiles. The design value of g_T is set in the range of 2.0 ~ 2.4. We have calculated beta limits for the equilibria obtained by varying the L–mode profile. The results are as follows.

(1) The Troyon coefficient g_T = 5.0 is obtained for the n = 1 external kink mode with the predicted L–mode profiles. The beta limit gives g_T = 4.5 in the case of $J_{//\,edge}/J_{//0}$ = 20 % with q_0 of 1.05. The effect of edge p' on the beta limit of this mode is weaker than that of edge $J_{//}$ for the present L–mode profiles.

(2) When q_0 becomes less than unity, on the other hand, the beta limit for the n = 1 external kink mode significantly decreases, resulting in g_T = 1.0 in case of no conducting wall. The conducting wall with a_w/a = 1.5 can stabilize the mode, restoring g_T = 1.7. However, both values are less than the design value of g_T .

(3) The unstable mode has a localized structure near the plasma surface for the case of q_0 = 1.05, while the mode structure is a global one with the dominant m = 1 harmonic for the case of q_0 = 0.8.

Our calculations predict that it is necessary to maintain the PRETOR L-mode profile with small variations in order to assure the design valu of g_T.

We also studied the shape effect of a conducting wall on the stability of the n = 1 external kink mode. We found that a wall located near the mid-plane of the torus is more effective for stabilization than the wall near the null point .

Acknowledgment

The authors wish to thank Drs. H. Kishimoto, M. Azumi and H. Maeda for their continuous encouragement.

References

[1] J. Hogan, (private communication).

[2] S. Tokuda, T. Tsunematsu and H. Ozeki, "Up-down asymmetric version of JAERI-ERATO code", in preparation.

[3] M. Azumi, (private communication).

[4] R. Gruber, F. Troyon, D. Berger, L.C. Bernard, S. Rousset, et al., Computer Phys. Communications, **21**(1981), 323.

(1) The Troyon coefficient $g_T = 5.0$ is obtained for the n = 1 external kink mode with the predicted L–mode profiles. The beta limit gives $g_T = 4.5$ in the case of $J_{//\,edge}/J_{//0} = 20$ % with q_0 of 1.05. The effect of edge p' on the beta limit of this mode is weaker than that of edge $J_{//}$ for the present L–mode profiles.

(2) When q_0 becomes less than unity, on the other hand, the beta limit for the n = 1 external kink mode significantly decreases, resulting in $g_T = 1.0$ in case of no conducting wall. The conducting wall with $a_w/a = 1.5$ can stabilize the mode, restoring $g_T = 1.7$. However, both values are less than the design value of g_T .

(3) The unstable mode has a localized structure near the plasma surface for the case of $q_0 = 1.05$, while the mode structure is a global one with the dominant m = 1 harmonic for the case of $q_0 = 0.8$.

Our calculations predict that it is necessary to maintain the PRETOR L-mode profile with small variations in order to assure the design valu of g_T.

We also studied the shape effect of a conducting wall on the stability of the n = 1 external kink mode. We found that a wall located near the mid-plane of the torus is more effective for stabilization than the wall near the null point .

Acknowledgment

The authors wish to thank Drs. H. Kishimoto, M. Azumi and H. Maeda for their continuous encouragement.

References

[1] J. Hogan, (private communication).

[2] S. Tokuda, T. Tsunematsu and H. Ozeki, "Up-down asymmetric version of JAERI-ERATO code", in preparation.

[3] M. Azumi, (private communication).

[4] R. Gruber, F. Troyon, D. Berger, L.C. Bernard, S. Rousset, et al., Computer Phys. Communications, **21**(1981), 323.

(1) The Troyon coefficient g_T = 5.0 is obtained for the n = 1 external kink mode with the predicted L–mode profiles. The beta limit gives g_T = 4.5 in the case of $J_{//\,edge}/J_{//0}$ = 20 % with q_0 of 1.05. The effect of edge p' on the beta limit of this mode is weaker than that of edge $J_{//}$ for the present L–mode profiles.

(2) When q_0 becomes less than unity, on the other hand, the beta limit for the n = 1 external kink mode significantly decreases, resulting in g_T = 1.0 in case of no conducting wall. The conducting wall with a_w/a = 1.5 can stabilize the mode, restoring g_T = 1.7. However, both values are less than the design value of g_T .

(3) The unstable mode has a localized structure near the plasma surface for the case of q_0 = 1.05, while the mode structure is a global one with the dominant m = 1 harmonic for the case of q_0 = 0.8.

Our calculations predict that it is necessary to maintain the PRETOR L-mode profile with small variations in order to assure the design valu of g_T.

We also studied the shape effect of a conducting wall on the stability of the n = 1 external kink mode. We found that a wall located near the mid-plane of the torus is more effective for stabilization than the wall near the null point .

Acknowledgment

The authors wish to thank Drs. H. Kishimoto, M. Azumi and H. Maeda for their continuous encouragement.

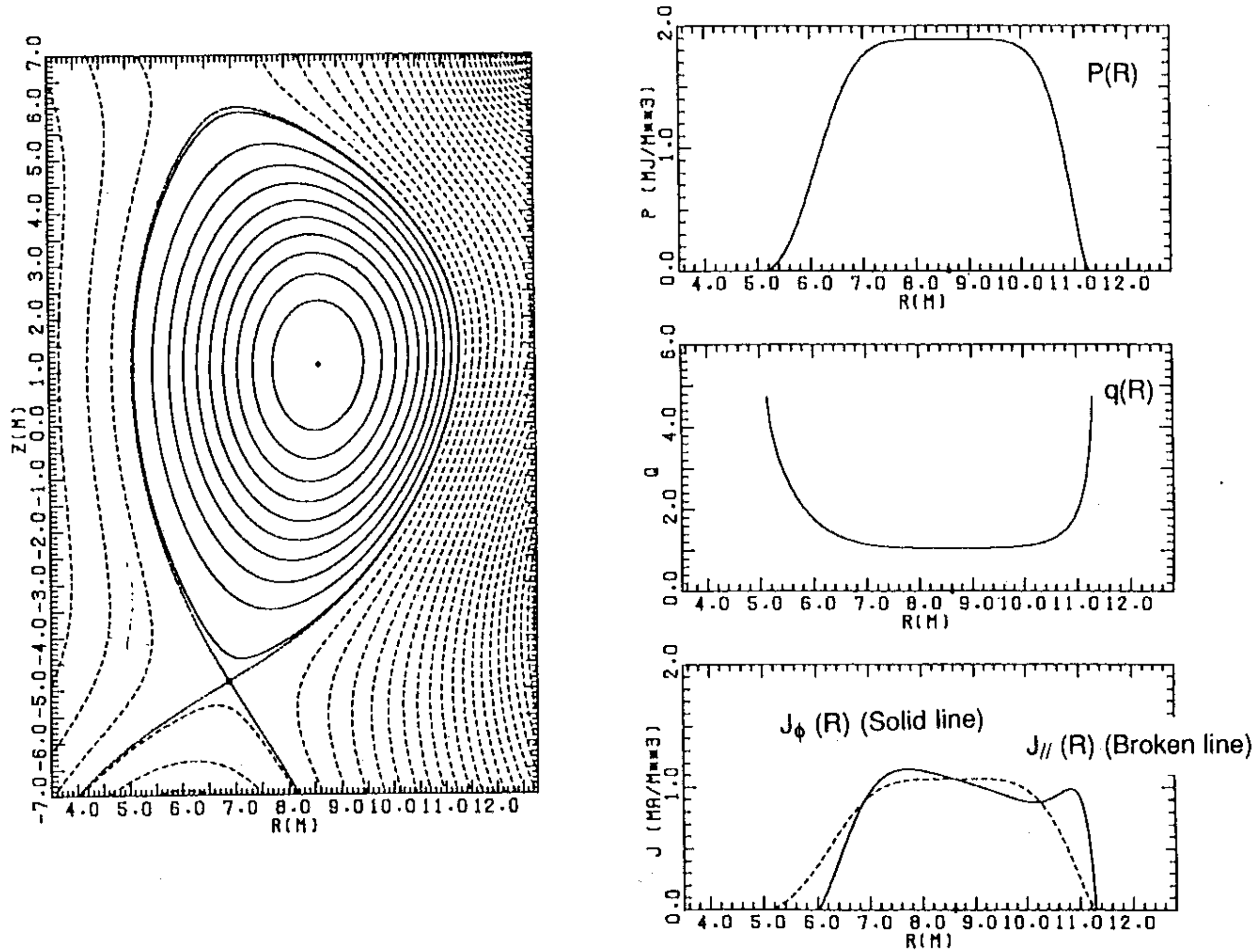
References

[1] J. Hogan, (private communication).

[2] S. Tokuda, T. Tsunematsu and H. Ozeki, "Up-down asymmetric version of JAERI-ERATO code", in preparation.

[3] M. Azumi, (private communication).

[4] R. Gruber, F. Troyon, D. Berger, L.C. Bernard, S. Rousset, et al., Computer Phys. Communications, **21**(1981), 323.



MEUDASPL

BETA-*=	9.09864
BETA-T=	7.54390
BETA-J=	1.49985
TCU =	24.99984
BTV =	48.37300
Q-AXIS=	1.05050
Q-SURF=	4.72786
Q-95 =	3.36256
Q-J =	2.96870
TOT-PR=	2419.38179
PO/PAV=	1.81457
COIL-0=	12.43972
COIL-1=	-0.69777
COIL-2=	11.20500
COIL-3=	-11.00107
COIL-4=	-12.23000
COIL-5=	-6.32300
COLI-6=	1.85600
RMAJ =	8.21571
RPLA =	3.09119
R-AXIS=	8.61171
Z-AXIS=	1.12105
S-AXIS=	-28.29674
R-SEP =	6.87852
Z-SEP =	-4.83984
S-SEP =	0.28537
VOLUME=	2324.98295
ELIP =	1.66763
TRIG =	0.35619
EL-95 =	1.58225
LP =	16.20667
LI =	0.86240
Q-STAR=	3.42437
TROYON=	5.49215
RHOQ1 =	0.00000
BETP1 =	0.00000
ICP =	6 2 1
CP(1) =	1.50000
CP(2) =	2.00000
CP(3) =	5.00000
CP(4) =	0.00100
CP(6) =	2.00000
CP(7) =	1.36887
CP(8) =	0.00000
CP(9) =	0.00000
CP(10)=	0.20000

Fig. 1 Equilibrium in a single null configuration for g_T=5.5:two dimensional flux contours ψ(R, Z), pressure p, safety factor q, and current profiles against the major radius. Profiles of current and pressure are given by Eqs. (1) and (2) with $\alpha=\sigma=0$.

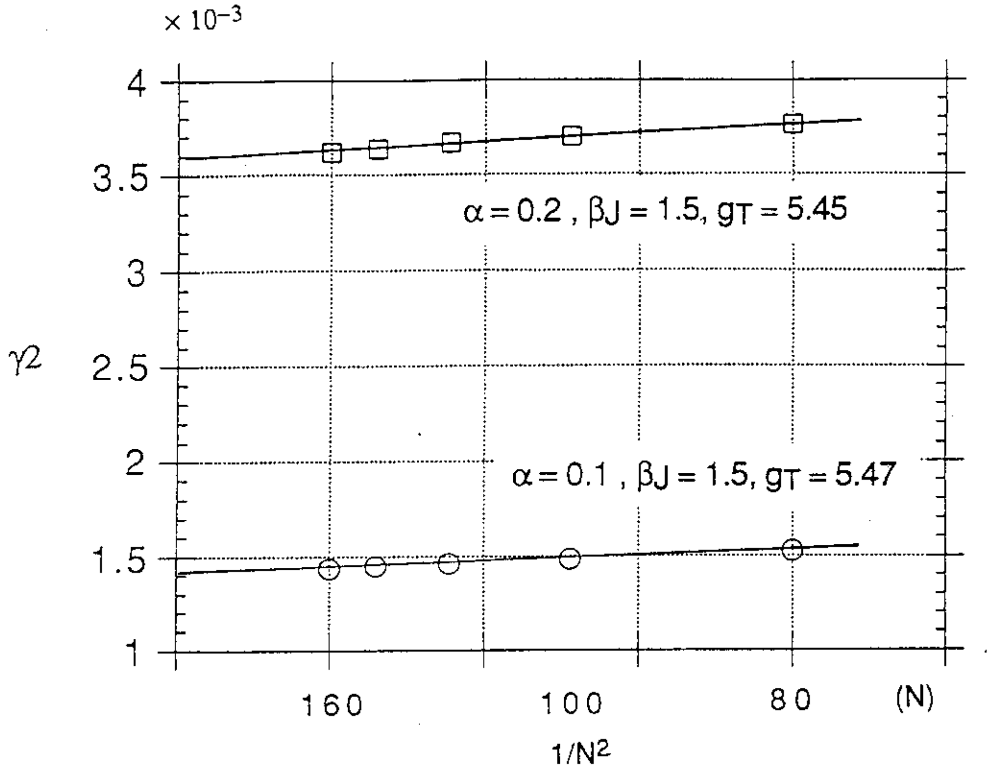


Fig. 2 Squared Growth rate γ^2 vs. $1/N^2$, where N is the number of the radial mesh. The number of poloidal mesh is fixed to 180.

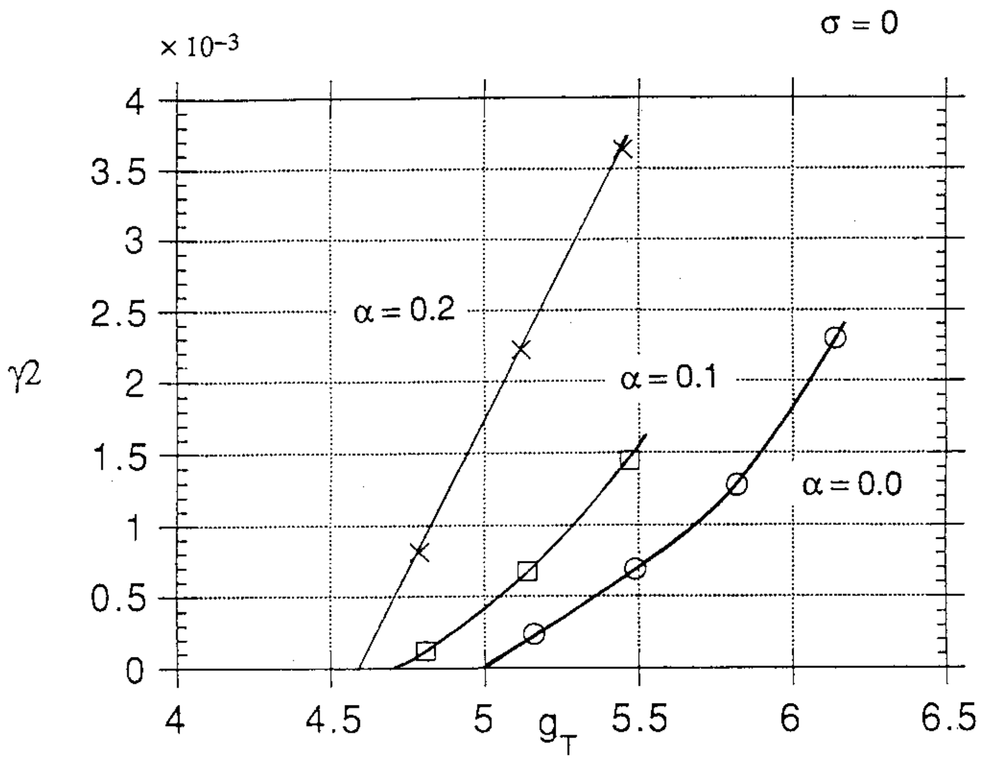


Fig. 3 Depenedence of squared growth rate γ^2 on g_T in cases of α=0, 0.1 and 0.2.

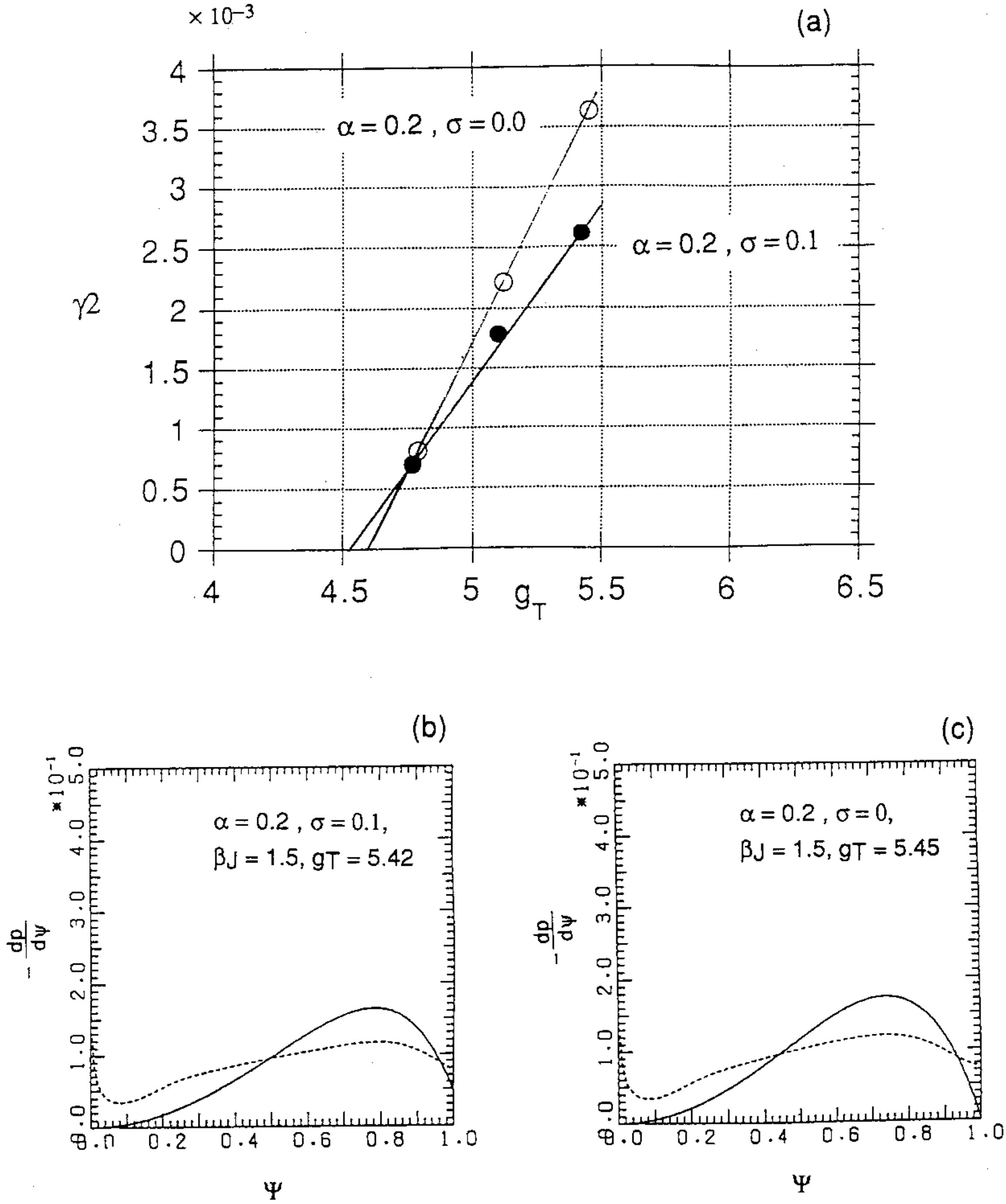


Fig. 4 (a) Dependence of squared growth rate γ^2 on g_T in cases of α=0.2, σ=0 and α=0.2, σ=0.1. Pressure gradient dp/dΨ (solid line) for (b) α=0.2, σ=0.1 and (c) α=0.2, σ=0. The broken lines show the critical pressure gradient against the high-n ballooning modes.

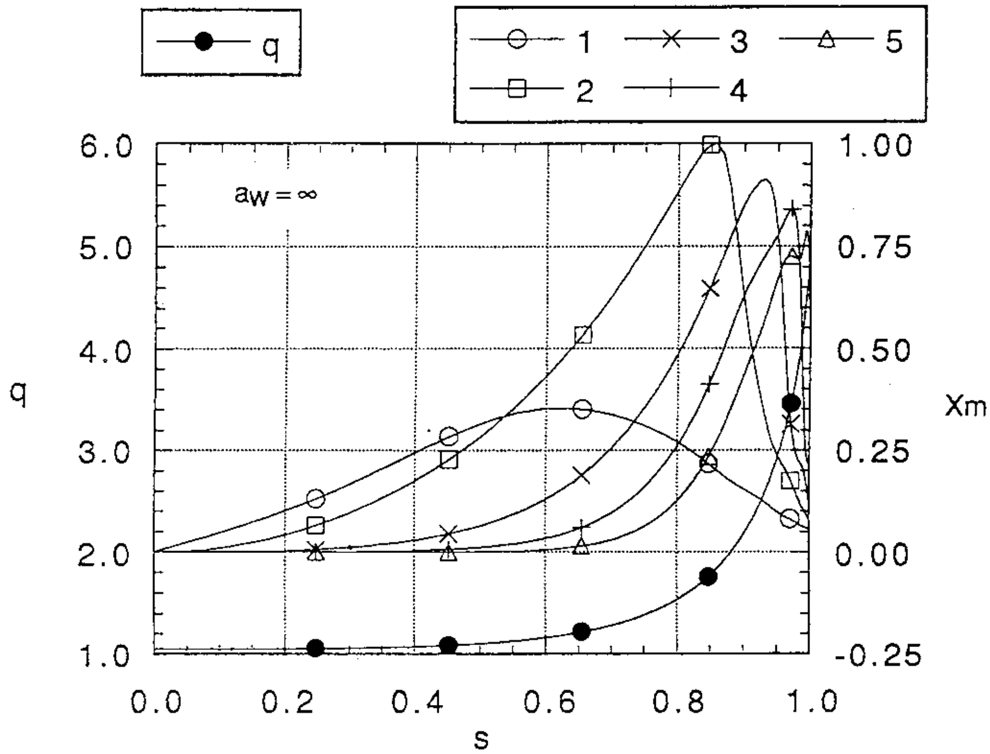


Fig. 5 Radial structure of poloidal Fourier harmonics Xm (s) of the displacement for $\alpha=\sigma=0$ and g_T=6.1. Harmonics of m≧2 localizing near the surface are dominant.

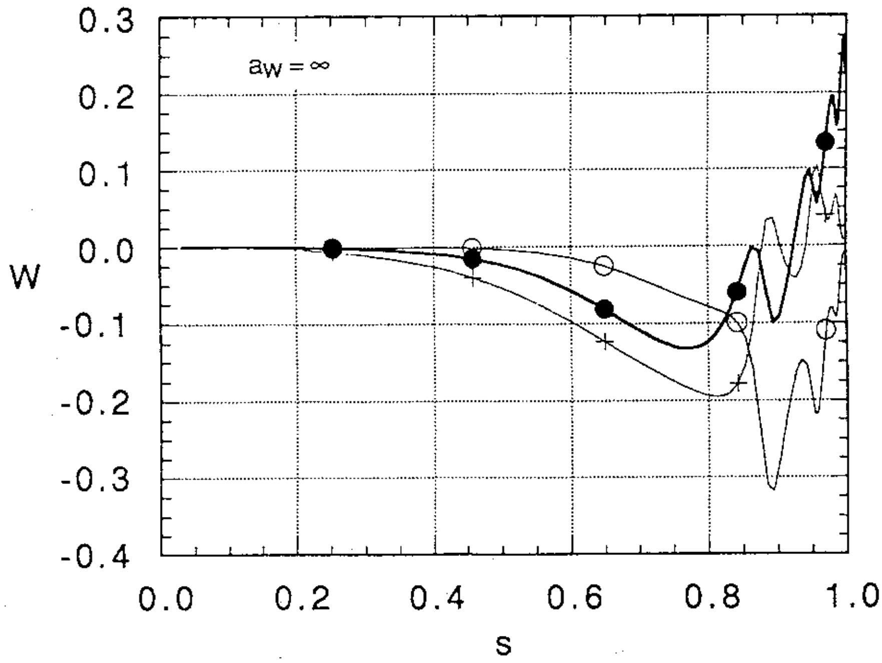
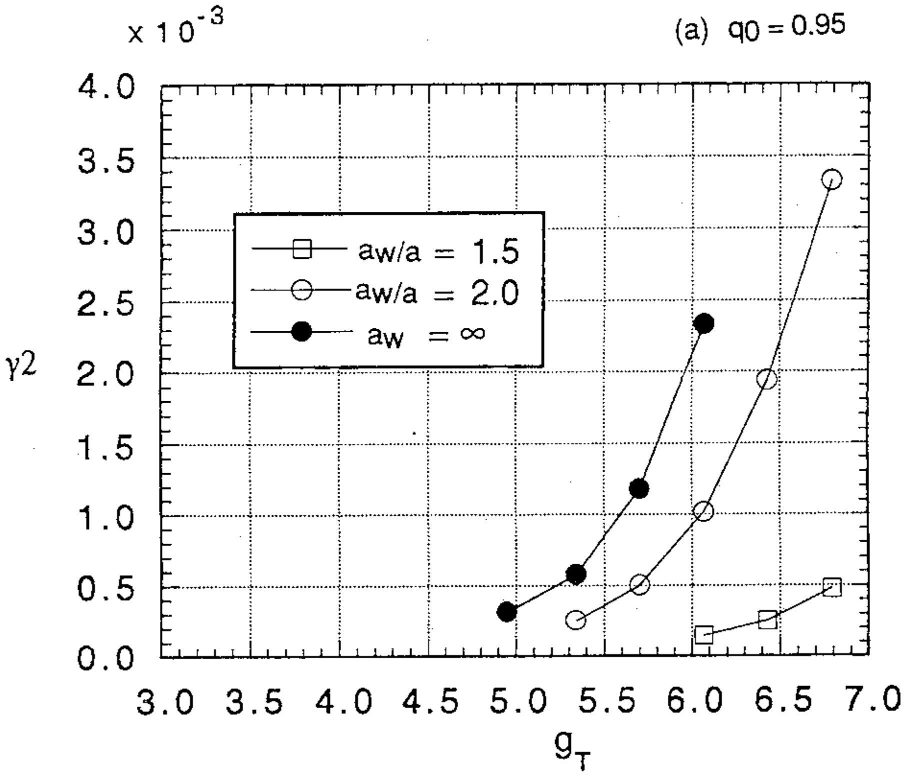


Fig. 6 Radial distribution of the potential energy W (red line) of the unstable mode for $\alpha=\sigma=0$ and g_T=6.1. The green and blue lines are the kink and ballooning contributions, respectively.



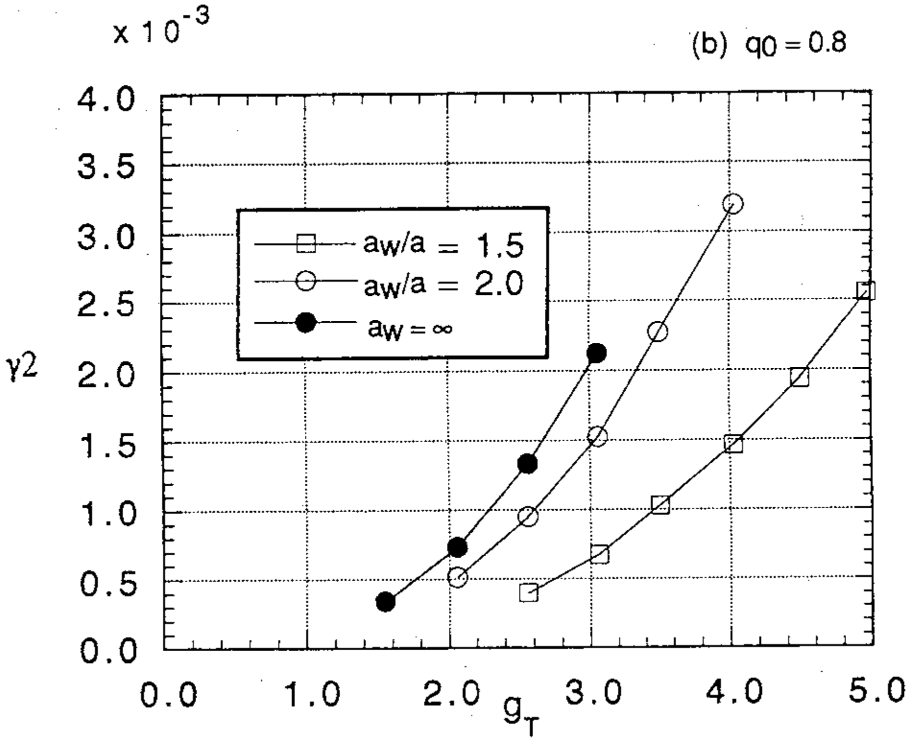


Fig. 7 Dependence of squared growth rate γ^2 on g_T for different three values of a_w/a. (a) is for q_o=0.95 and (b) is for q_o=0.8.

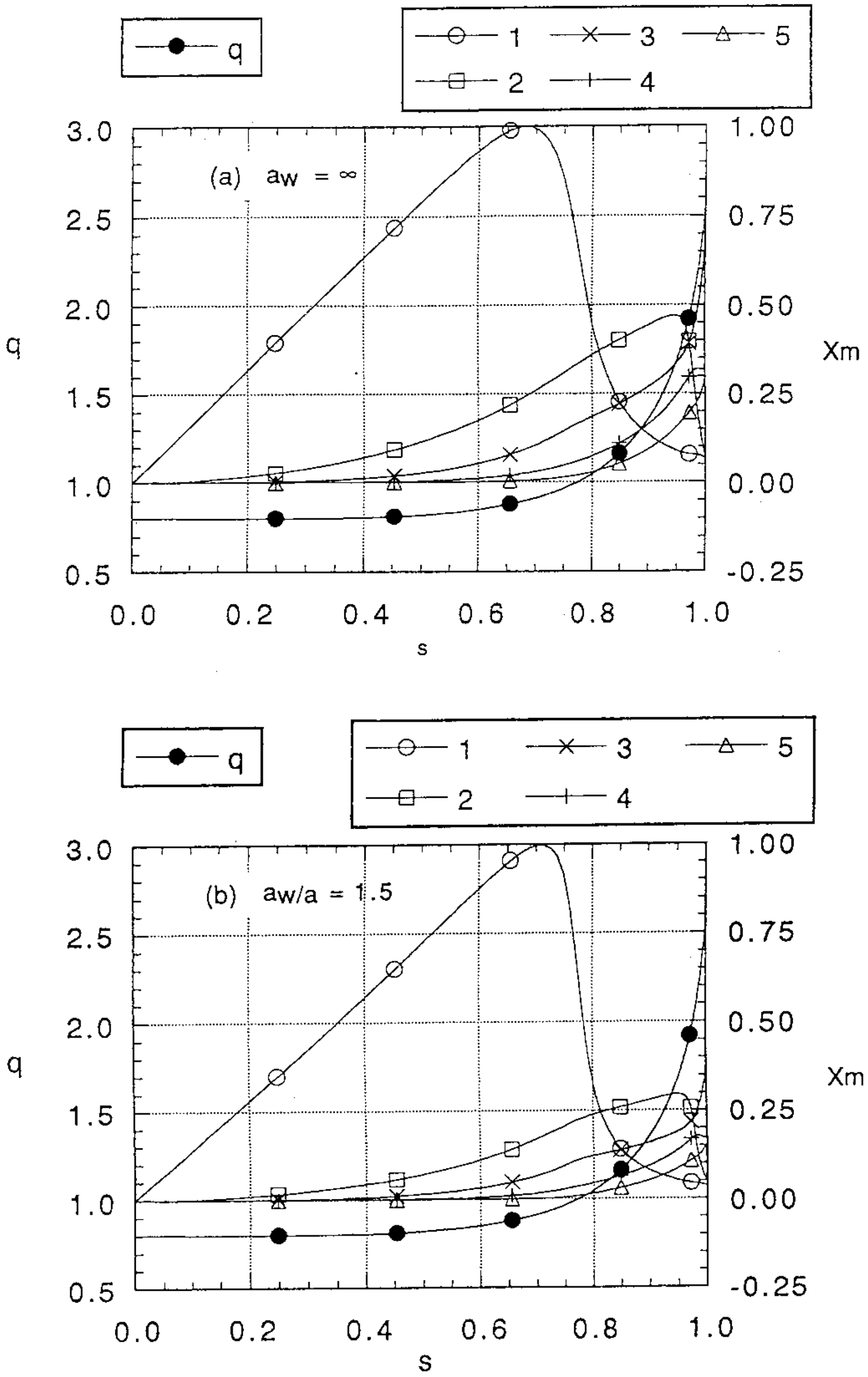
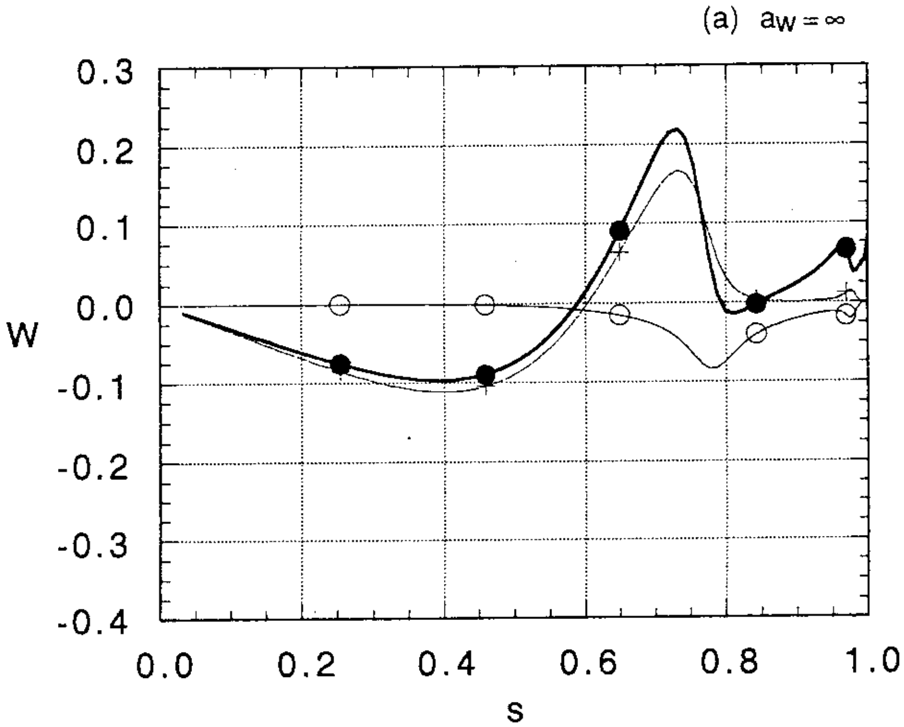


Fig. 8 Radial structure of the unstable mode in the case of g_T=3.1 and q_0=0.8. (a) is for $a_w=\infty$, and (b) is for a_w/a=1.5. In both cases the most dominant harmonic is the m=1 harmonic, and the mode has a global structure in the plasma.



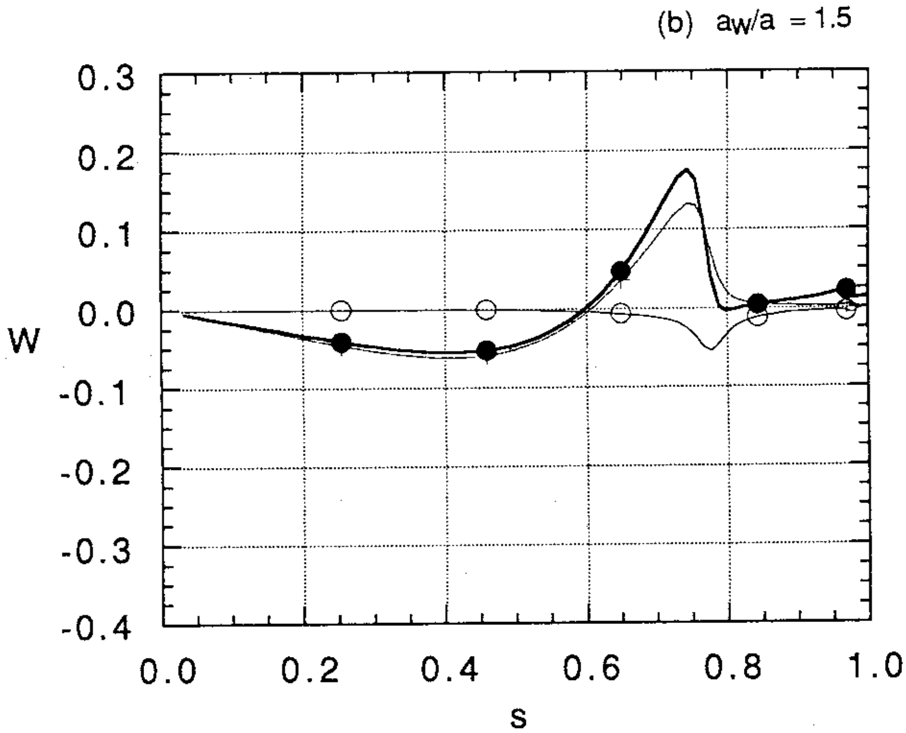


Fig. 9 Radial distribution of the potential energy W (red line) of the mode in the case of g_T=3.1 and q_0=0.8. (a) is for a_w =∞, and (b) is for a_w/a=1.5. The mode is destabilized mainly by the kink term (green line) in the inner region of the plasma. The blue line denotes the ballooning term.

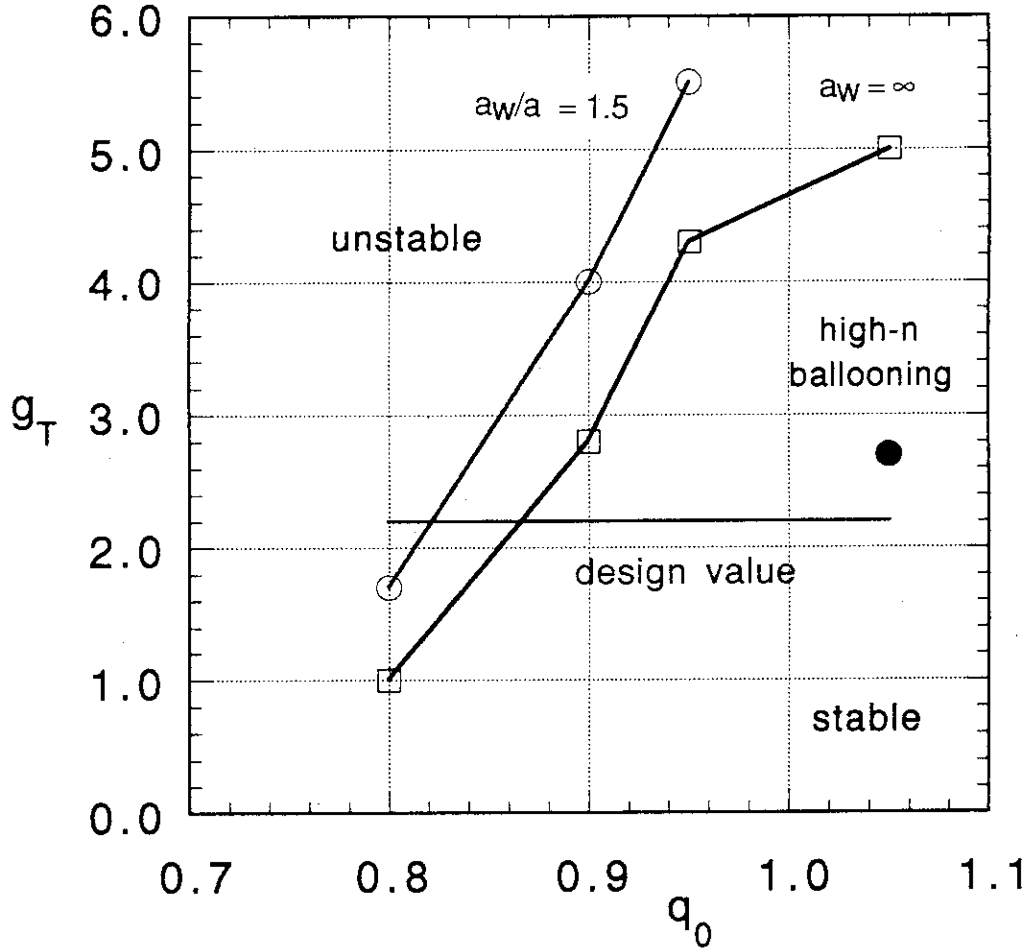


Fig. 10 Beta limit of the n=1 external kink mode for $a_w=\infty$ (black line) and $a_w/a=1.5$ (red line). The solid circle (•) denotes the beta limit of high-n ballooning modes for $q_0=1.05$. The blue line shows the design value of g_T

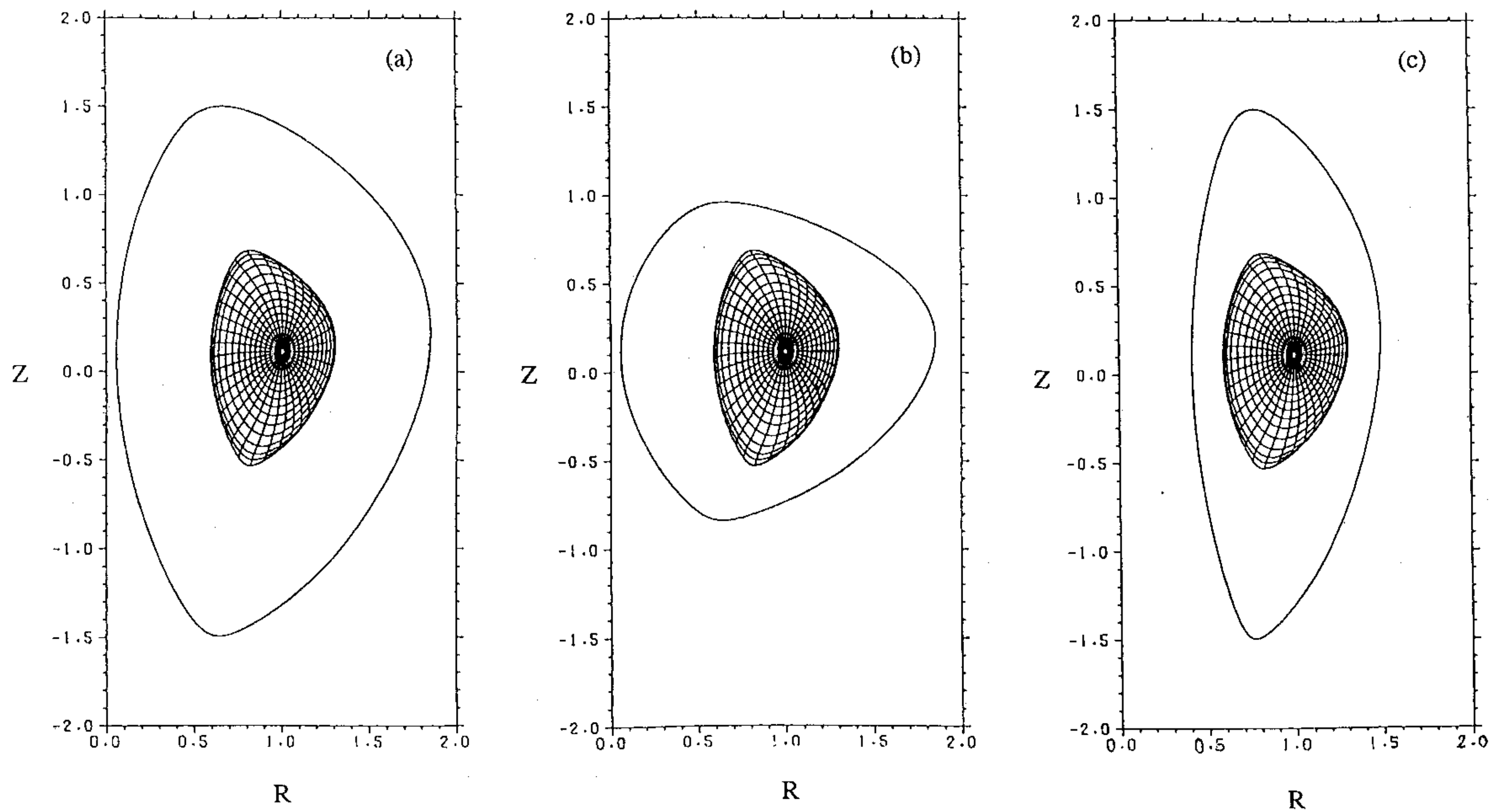
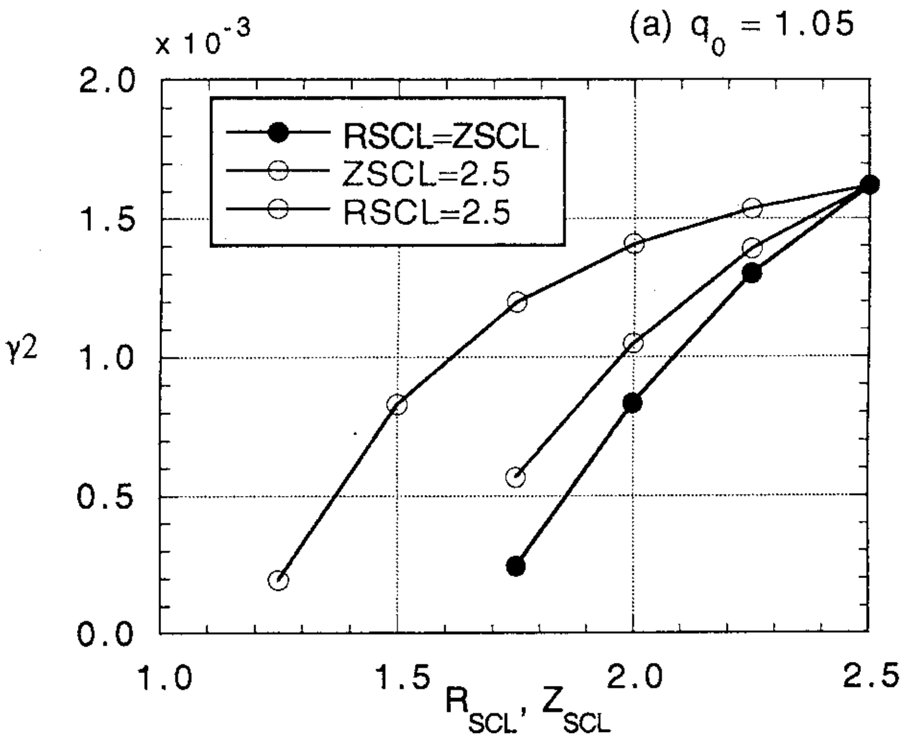


Fig. 11 Shapes of the conducting wall for (a) $R_{scl}=Z_{scl}=2.5$ for which case the shape of the wall is similar to the plasma surface, (b) $R_{scl}=2.5$ and $Z_{scl}=1.5$, and (c) $R_{scl}=1.5$ and $Z_{scl}=2.5$.



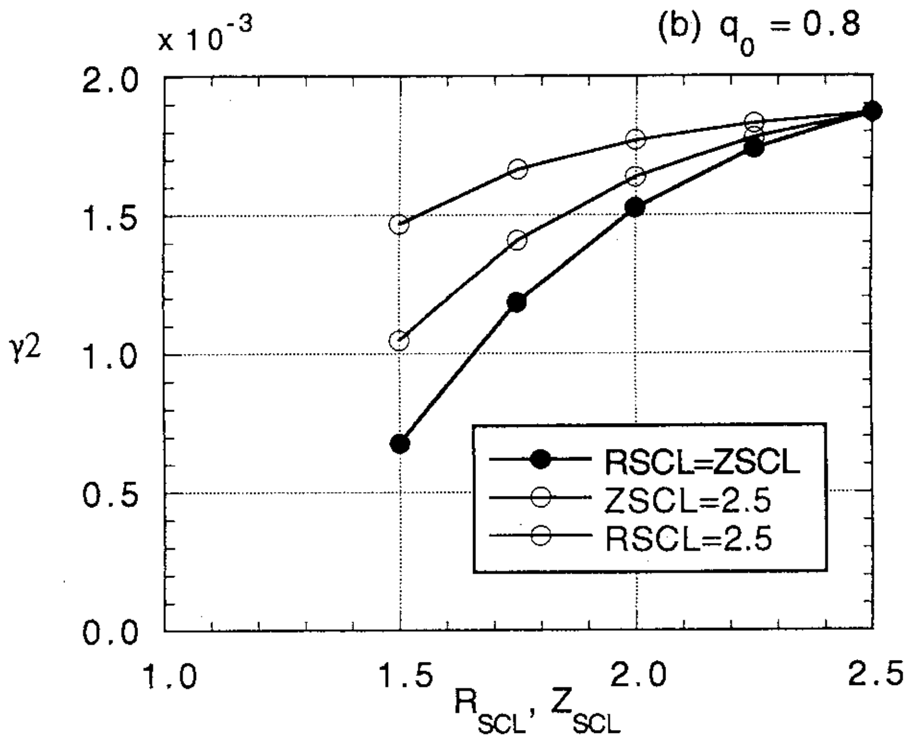


Fig. 12 Dependence of the squared growth γ^2 on the parameters R_{scl} and Z_{scl} for (a) q_o=1.05 and g_T=6.1 and for (b) q_o=0.8 and g_T=3.1.