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Rayleigh–Taylor Instability in Strong Media, Experimental Study*

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1 Introduction

An example of Rayleigh-Taylor instability [1, 2] is perturbation growth on the surface of a plate accelerated by pressure applied from one side. Instability evolution eventually leads to complete breakage of the layer being accelerated. RT instability evolution in strong media essentially differs from that in fluids. Here perturbation growth is impeded with shear stresses which occur at medium deformation. As a result, material strength can considerably prolong the layer acceleration process, and hence increase the value of maximum achievable velocity.

Up to now the features of the RT instability in strong media have not been sufficiently studied. There are contradictions in the theory. Thus, according to [3, 4], instability depends on the perturbation wavelength, and all perturbations with a wavelength higher than some critical value are unstable

$$\lambda > \lambda_{cr} \approx \frac{4\pi G}{\rho g} \approx \frac{4\pi C^2}{g}$$

where G is the material shear modulus, ρ is the density, g is the acceleration, and C is the shear wave velocity.

By Drucker's theory, the instability condition is the initial perturbation amplitude [5]

$$\alpha_0 < \alpha_{cr} \approx \frac{2\sigma_T}{\rho g}$$

where σ_T is the material yield point.

Instability is not therewith dependent on a perturbation wavelength. This conclusion was confirmed by the results of experimental studies of an aluminum plate RT instability performed by Barnes [6, 7].

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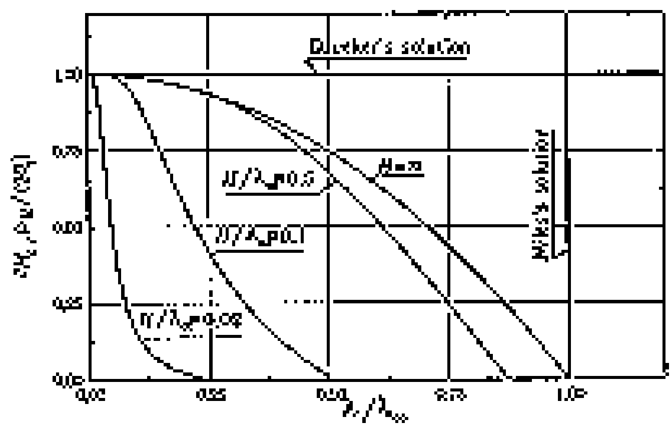


Figure 1: Boundaries of variously thick elasto-plastic layer stability found on the basis of approximate analytical solution [9].

However, as it was shown in our theoretic-computational and experimental studies (1987 and 1988 VNIIEF reports, as well as [8, 9]) and in [10], Drucker's theory is valid but only for very short wavelengths ($\lambda \ll \lambda_{cr}$) and in the general case, instability depends on many factors, including perturbation wavelengths and amplitude, layer thickness, and loading nature. The instability region is schematically shown in Fig 1 [9].

Moreover, in the progress of our theoretic-computational studies we found that, in contrast to ideal fluid, 3D perturbations in strong materials can be more stable than in 2D.

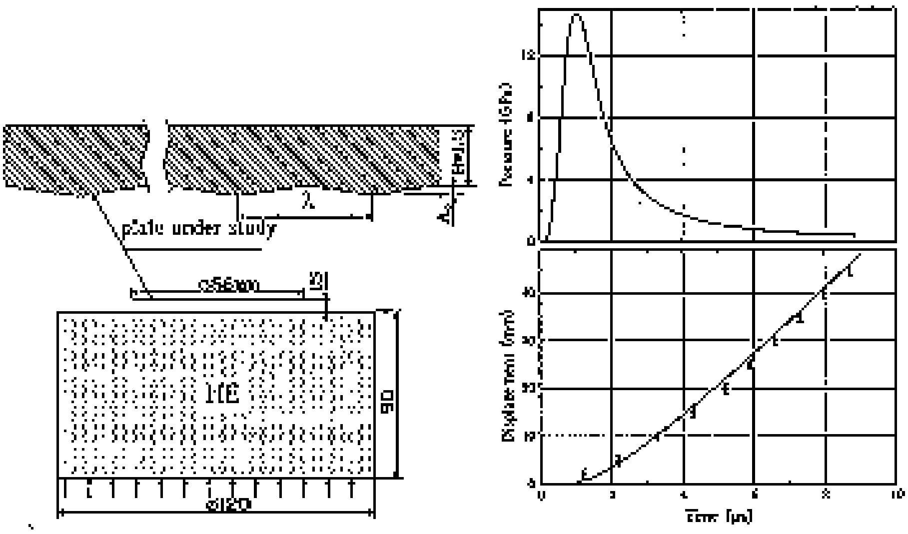
This paper presents principal experimental results of studies which confirm earlier found features of the process of RT instability in strong media.

2 Experimental Setup and Results

The experimental assembly sketched in Fig 2 is similar to that used in [6, 7].

The tested plate made of annealed aluminum alloy (AMg-6) was located at the end of a cylindrical HE charge which was fused by a plane shock wave from the opposite side. To secure shock-free plate loading (without shock wave generation) a vacuum gap was made between HE and the plate. At the plate surface facing HE, periodic perturbations were preset. When furrows were made only in one direction, 2D perturbations were generated. When furrows were made in two mutually perpendicular directions, 3D perturbations were generated. The depth of the furrows determined the initial perturbation amplitude.

Fig. 2 gives time dependencies of loading pressure and plate displacement.



(a) (b)

Figure 2: (a) Experimental assembly sketch. (b) Plate pressure and displacement vs. time.

A current plate configuration was recorded using the roentgenographic method. The experimental assembly was situated relative to the X-facility so that at the time of the survey, the radiation direction was the same as one of the directions of the furrows generating the perturbations. The plate images from the X shots were subjected to numerical processing which yielded the plate contour.

In the experiments, the effect of perturbation wavelength and initial amplitude on stability and perturbation growth rate was cleared up. Evolutions of 2D and 3D perturbations with the same initial amplitudes and wavelength were compared.

Figs 3 and 4 show experimental points and computed dependencies of a current perturbation amplitude at the surface being loaded on plate displacement for 2D configuration at various perturbation wavelengths and initial amplitudes. The RT instability process was modeled using the Lagrangian code [8] in the visco-elasto-plastic approximation. For the initial perturbation amplitude, the mean value is taken with account of manufacture error.

Fig 5 shows the boundary of the instability region for the 2D perturbations obtained based on experimental and numerical results.

From the results given in Figs 3, 4, and 5, it follows that the increase in the initial perturbation amplitude transfers the process into the instability region. In parallel with this, the increase in wavelength at the same initial perturbation amplitude leads

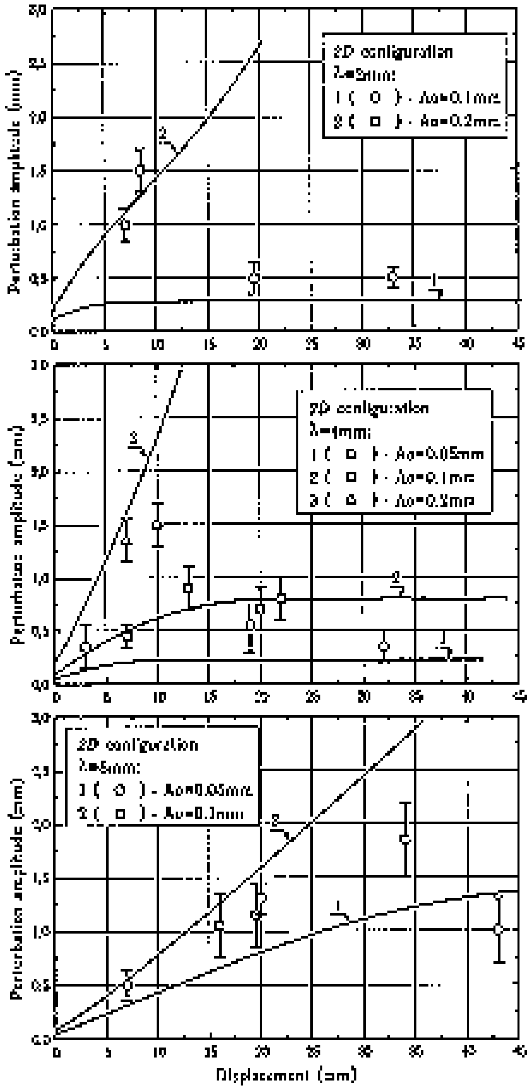


Figure 3: Initial perturbation amplitude effect on perturbation evolution.

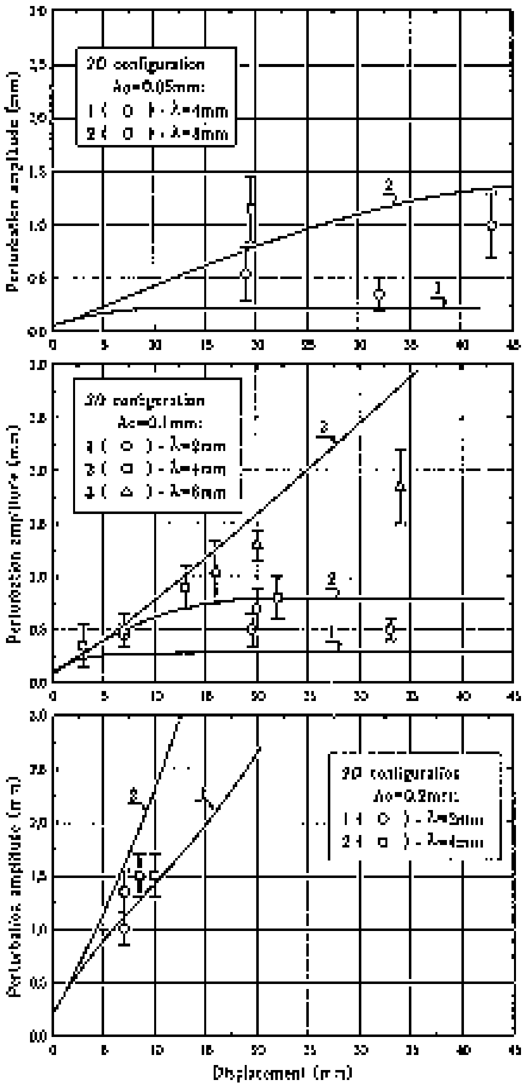


Figure 4: Perturbation wavelength effect on perturbation evolution.

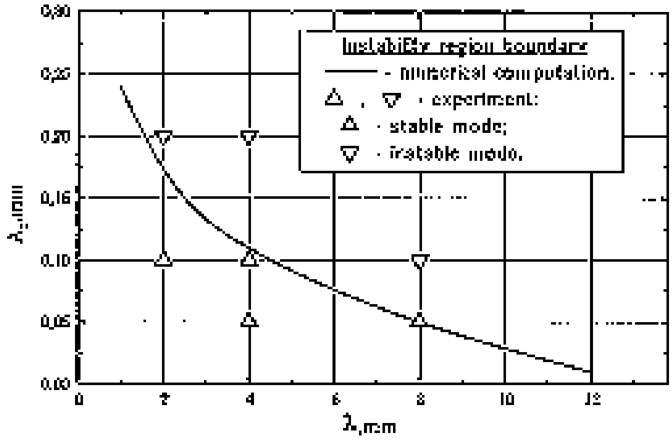


Figure 5: Instability region boundary.

to a similar result. Thus, perturbation stability depends both on perturbation initial amplitude and wavelength, and this fact confirms the conclusions of [8, 9, 10].

Another issue considered in the course of the experiments was that of perturbation dimension effect on perturbation evolution. Fig 6 shows the results of experiments with 2D and 3D perturbations from which it follows that within the considered wavelength range, in contrast to the ideal fluid case, 3D perturbations develop slower that in 2D.

With account of essential strength effect on the perturbation growth character [8, 9, 10], the obtained experimental results are a unique source of information for construction of visco-elasto-plastic models of strong materials within a wide strain rate range (up to 10^7sec^{-1}).

References

[1] Taylor, G.I., The instability of liquid surfaces when accelerated in a direction perpendicular to their planes, Proceedings of the Royal Soc., 1950, v.201, N1065, p.192.

[2] Sharp, D. H., An Overview of Rayleigh-Taylor Instability, Physica 12D, pp.3–18, 1984.

[3] Miles, J. W., Taylor Instability of a flat plate, General Atomics Rep. GAMD-7335, 1960.

[4] Bakhrakh, S. M., Kovalev, N. P., Taylor instability in elastic-plastic media, Proc. of the 5^{th} All-Union Conference on numerical methods for solving elasticity and plasticity theory problems, Novosibirsk, 1978, p.22–36.

[5] Drucker, D. C., "Taylor instability" of a surface of an elastic-plastic plate, Mechanics Today, v.5 (Nermat-Nasser, ed.), Pergamon Press, 1980, p.37–47.

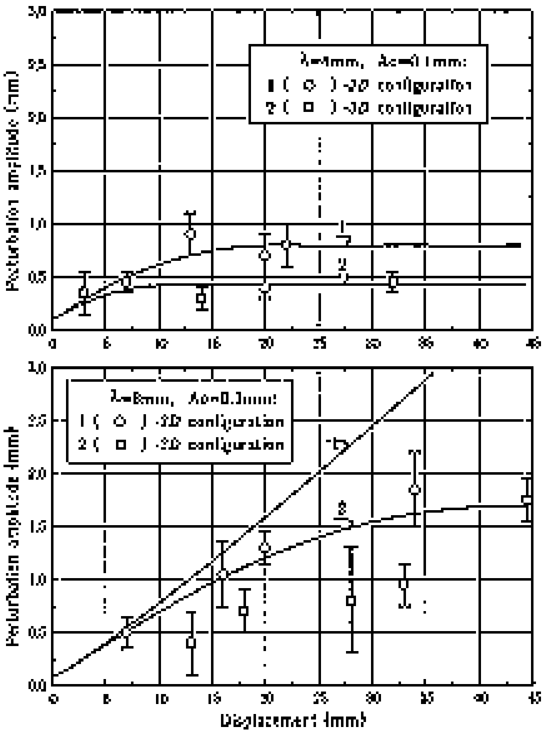


Figure 6: Perturbation amplitude vs. plate displacement for 2D and 3D configurations.

[6] Barnes, J. F., Blewett, P. J., McQueen, R. G., Meyer, K. A., Venable, D., Taylor instability in solids, J. Appl. Phys., 1974, v.45, pp.727–732.

[7] Barnes, J. F., Janney, D. H., London, R. K., et al., Further experimentation on Taylor instability in solids, J. Appl. Phys, 1980, v.51, p.4678.

[8] Abakumov, A. I., Lebedev, A. I., Nizovtseva, I. A., Nizovtsev, P. N., Rayevsky, V. A., Rayleigh-Taylor instability in elasto-plastic medium, Numerical study, VANT. Ser. Teor. i Prikl. Fizika, 1990, No.3, p.14–19.

[9] Nizovtsev, P. N., Rayevsky, V. A., Approximate analytical solution of Rayleigh-Taylor instability problem in strong media, VANT. Ser. Teor. i Prikl. Fizika, 1991, No.3, p.11–17.

[10] Robinson, A. C., Swegle, J. W., Acceleration instability in elastic-plastic solids, 1. Numerical simulations of plate acceleration, 2. Analytical techniques, J. Appl. Phys., 1989, v.66, N.7, p.2838–2872.