

Using the Fictitious Force to Judge the Stability of Pipe String is Wrong

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Abstract: Pipes are under the trial of internal and external pressure of fluid in oil well drilling and production. Changes of internal and external pressure of fluid may affect equivalent axis force using for stability analysis of pipes in some cases. Errors in traditional mechanical model and fictitious force are discussed. Mechanical model representing true tubular conditions is established. Internal and external pressure of fluid and its changes have no effects on the stability of hanging pipes. Changes in internal and external pressure of fluid show effects on equivalent axis force and stability of pipes fixed at two ends. Equations for calculating equivalent axis force are established depending on constant axis strain. For pipes fixed at two ends, equivalent axis force decreases when internal pressure increases, equivalent axis force increases when external pressure increases; increase of internal pressure and decrease of external pressure may make equivalent axis force negative, even less than critical buckling force.

Keywords: Casing, tubing, external pressure, internal pressure, stability, buckling, fictitious force, equivalent axis force.

1. INTRODUCTION

All pipe strings in oil wells, such as drill string, casing string, tubing string and pumping rod string work under internal and external pressure. Internal and external pressures affect mechanical behavior of pipe strings, and sometimes, affect stability [1-4]. A Lubinski defined a fictitious force using energy method [1], and Chinese scholars introduced it to Chinese people [5-9], meanwhile used this force to judge stability conditions of pipe strings. However, is the mechanical model true? Is fictitious force really fictitious? Is the formula correct? Is the filed application effective? All of them are questioned [10, 11].

2. MISTAKES IN TRADITIONAL THEORY

2.1. Traditional Theory

Structural Stability Research Council of USA holds that the internal and external pressure on oil well pipes can cause the increase and decrease of pipe axis force, affecting the stability conditions. External pressure produces tension force in pipe strings. Internal pressure produces compressive force in pipe strings. A Lubinski defined this effect as fictitious force [1, 7, 8]

$$F_s = p_o A_o - p_i A_i \quad (1)$$

where, F_s is the fictitious force, p_o is the external pressure, A_o is the area of external circle of pipe, p_i is the internal pressure and A_i is the area of internal circle of pipe.

Equation (1) shows the mechanical model in (Fig. 1) [8, 9]. There are top and bottom chambers in a pressure vessel. The pressure is p in the top chamber. The pressure is p_o in the bottom chamber. There is an elastic tube, inner

radius R_i , outer radius R_o . There are two guiding columns and their radius is little smaller than R_i , one at the top and the other at the bottom. The bottom end of the pipe touches the bottom of the bottom chamber. The top end of the pipe is in the top chamber. The pipe can slide along the top guiding column under action of pressure p . Energy method is used here.

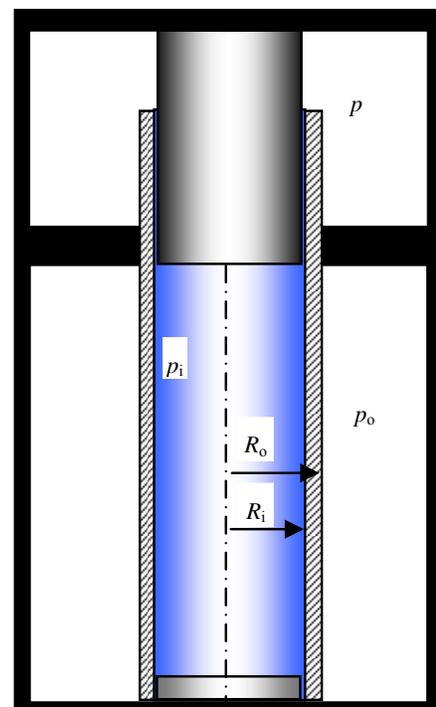


Fig. (1). Traditional mechanical model.

If there is a real axis force F_z in the section of pipes, then the effective axis force for pipe's stability calculation is [4].

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$$F_b = F_z + F_s = F_z + p_o A_o - p_i A_i \quad (2)$$

where, F_b is the effective axis force.

Use F_b to identify the stability condition. If $F_b > 0$, then the pipe is stable. If $F_b < 0$, then the pipe is in buckling station.

2.2. Mistakes

The mechanical model with two guiding columns in (Fig. 1) is not true. In oil wells, the true mechanical model is shown in (Fig. 2), A for a pipe hanging vertically, B and C for a pipe fixed at two ends. For a pipe hanging freely, $F_z = 0$, no matter how high the internal pressure is, the pipe can only expand both in length and in diameter, cannot buckle. If using equation (2) is applied to identify the stability condition, the pipe may be buckled. Thus, equation (1) and (2) are inapplicable. Equally, no matter how high the external pressure is, the pipe cannot buckle. For this reason, internal and external pressures themselves cannot cause the buckling of a hanging pipe.

3. TRUE MECHANICAL MODEL AND EFFECTS OF INTERNAL AND EXTERNAL PRESSURE ON EQUIVALENT AXIS FORCE OF A DOUBLE ENDS FIXED PIPE

For a double ends fixed pipe, both internal and external pressure cannot cause the buckling of a hanging pipe directly. The changes in internal and external pressure may cause equivalent axis force decrease, resulting pipe buckling.

In Fig. (2), A is a hanging pipe with internal pressure p_i , external pressure p_o , axis force F_z at the bottom, the equivalent axis force using for buckling analysis $F_a = F_z$. B is a hanging pipe with internal pressure p_{i1} , external pressure p_{o1} , axis force F_{z1} at the bottom, and it is fixed at the bottom after these loads are added, the equivalent axis force

using for buckling analysis $F_{a1} = F_{z1}$. Due to the loads in B, internal pressure turns into p_{i2} , external pressure turns into p_{o2} , axis force keeps F_{z1} at the bottom, as to C, how to calculate axis force F_{a2}

In Fig. (2) A, axis stress, radial stress and tangential stress are [12]

$$\begin{cases} \sigma_z = \frac{F_z + p_i A_i - p_o A_o}{A} = \frac{F_z + p_i \pi R_i^2 - p_o \pi R_o^2}{\pi(R_o^2 - R_i^2)} \\ \sigma_r = \frac{p_i R_i^2 - p_o R_o^2}{R_o^2 - R_i^2} - \frac{(p_i - p_o) R_i^2 R_o^2}{(R_o^2 - R_i^2) r^2} \\ \sigma_\theta = \frac{p_i R_i^2 - p_o R_o^2}{R_o^2 - R_i^2} + \frac{(p_i - p_o) R_i^2 R_o^2}{(R_o^2 - R_i^2) r^2} \end{cases} \quad (3)$$

where, σ_z is the axis stress, σ_r is the radial stress, σ_θ is the tangential stress, r is the radius.

The axis strain

$$\epsilon_z = \frac{1}{E} [\sigma_z - \mu(\sigma_r + \sigma_\theta)] = \frac{1}{E} \left[\frac{F_z + p_i \pi R_i^2 - p_o \pi R_o^2}{\pi(R_o^2 - R_i^2)} - 2\mu \frac{p_i R_i^2 - p_o R_o^2}{R_o^2 - R_i^2} \right] \quad (4)$$

where, E is the elastic module, μ is the Poisson's ratio.

In Fig. (2) B and C, axis strains are equal

$$\begin{aligned} & \frac{F_{z1} + p_{i1} \pi R_i^2 - p_{o1} \pi R_o^2}{\pi(R_o^2 - R_i^2)} - 2\mu \frac{p_{i1} R_i^2 - p_{o1} R_o^2}{R_o^2 - R_i^2} \\ &= \frac{F_{a2} + p_{i2} \pi R_i^2 - p_{o2} \pi R_o^2}{\pi(R_o^2 - R_i^2)} - 2\mu \frac{p_{i2} R_i^2 - p_{o2} R_o^2}{R_o^2 - R_i^2} \end{aligned} \quad (5)$$

then

$$\begin{aligned} F_{a2} &= F_{z1} + \pi(1 - 2\mu)[(p_{i1} - p_{i2})R_i^2 - (p_{o1} - p_{o2})R_o^2] \\ &= F_{z1} + (1 - 2\mu)[(p_{i1} - p_{i2})A_i - (p_{o1} - p_{o2})A_o] \end{aligned} \quad (6)$$

If internal pressure increases and/or external pressure decrease, equivalent axis force may be negative, even less than critical buckling load, resulting buckling.

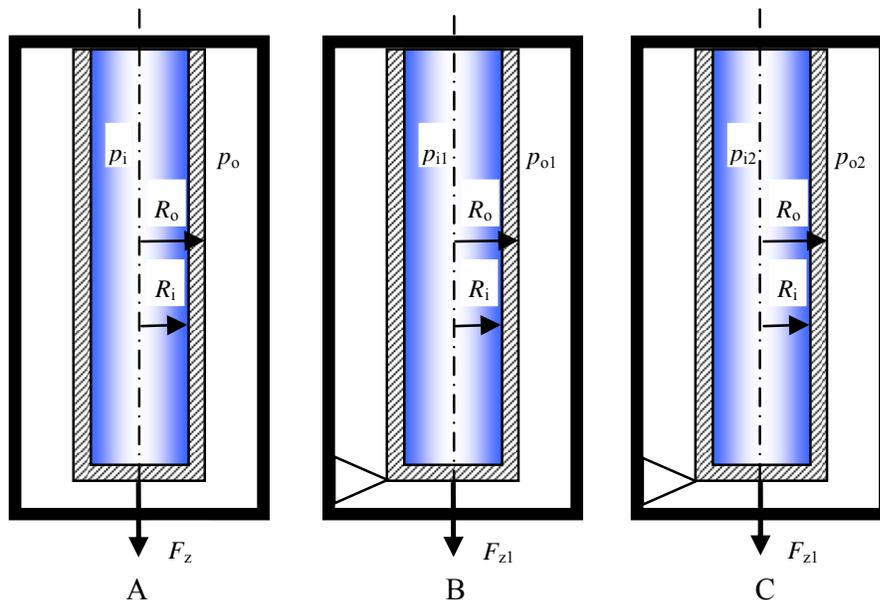


Fig. (2). True mechanical model.

For a pipe fixed at two ends, it is the changes of internal and external pressures, not the internal and external pressures themselves, changing the stability conditions.

The change of axis force, $(1-2\mu)[(p_{i1}-p_{i2})A_i-(p_{o1}-p_{o2})A_o]$, is the force acting on restriction such as cement sheath or anchor, due to the restriction, preventing axis expansion.

It can be verified that equation (6) is suitable for double end closed pipe. For column, $A_i=0$, equation (6) is also suitable. For double end opened pipe, $p_{i1}=p_{o1}$, $p_{i2}=p_{o2}$, equation (6) is still applicable.

4. CONCLUSIONS

- (1) Fictitious force used for pipe stability calculation is inapplicable.
- (2) Internal and external pressure cannot cause buckling of a hanging pipe string.
- (3) Internal and external pressures themselves can not cause buckling of a double ends fixed pipe string. For a double ends fixed pipe string, the changes of internal and external pressure can affect its stability. Equivalent axis force is a function of initial axis force, Poisson's ratio of pipe material, change of internal pressure, change of external pressure, area of internal circle of pipe and area of external circle of pipe.
- (4) For a double ends fixed pipe string, the increase in internal pressure decreases stability, the increase in external pressure increases stability.

CONFLICT OF INTEREST

The author(s) confirm that this article content has no conflicts of interest.

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NOMENCLATURE

A_i	= Area of internal circle of pipe
A_o	= Area of external circle of pipe
E	= Elastic module
F_a	= Equivalent axis force using for buckling analysis
F_{a1}	= Equivalent axis force using for buckling analysis before fixed at the bottom
F_{a2}	= Equivalent axis force using for buckling analysis after fixed at the bottom
F_b	= Effective axis force
F_s	= Fictitious force

F_z	= Real axis force
F_{z1}	= Real axis force at the bottom
p	= Pressure in the top chamber
p_i	= Internal pressure
p_{i1}	= Internal pressure before fixed at the bottom
p_{i2}	= Internal pressure after fixed at the bottom
p_o	= External pressure
p_{o1}	= External pressure before fixed at the bottom
p_{o2}	= External pressure after fixed at the bottom
r	= Radius
R_i	= Inner radius
R_o	= Outer radius
ε_z	= Axis strain
μ	= Poisson's ratio
σ_r	= Radial stress
σ_z	= Axis stress
σ_θ	= Tangential stress

SI unit is used.

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