

Lecture 9: Stability of Elastic Structures

In lecture 8 we have formulated the condition of static equilibrium of bodies and structures by studying a small change (variation) of the total potential energy. The system was said to be in equilibrium if the first variation of the total potential energy vanishes. The analysis did not say anything about the stability of equilibrium. The present lecture will give an answer to that question by looking more carefully what is happening in the vicinity of the equilibrium state.

To illustrate the concept, consider a rigid body (a ball) sitting in an axisymmetric paraboloid, shown in Fig. (9.1).

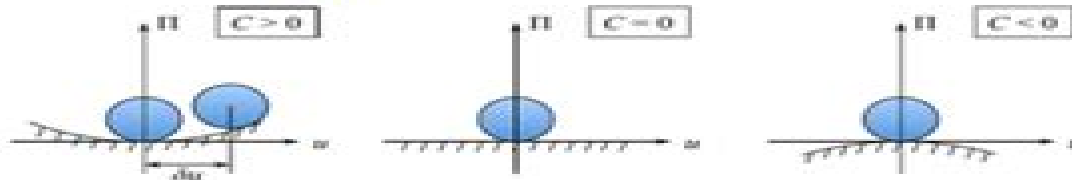


Figure 9.1: Illustration of stable, neutral and unstable equilibrium.

In the case of a rigid body the total potential energy is just the potential energy

$$\Pi = mgh = Cu^2 \quad (9.1)$$

where u is the horizontal displacement of the ball from the resting position. Let's calculate the first and second variation of the function $\Pi(u)$

$$\delta\Pi = \frac{\partial\Pi}{\partial u}\delta u = 2Cu\delta u \quad (9.2)$$

$$\delta^2\Pi = \delta(\delta\Pi) = 2C\delta u\delta u \quad (9.3)$$

At the origin of the coordinate system $u = 0$, so the first variation of Π is zero no matter what the sign of the coefficient C is. In the expression for the second variation, the product $\delta u\delta u = (\delta u)^2$ is always non-negative. Therefore, the sign of the second variation depends on the sign of the coefficient C . From Fig. 9.1 we infer that $C > 0$ corresponds to a *stable configuration*. The ball displaced by a small amount δu will return to the original position. By contrast, for $C < 0$, the ball, when displaced by a tiny amount δu , will roll down and disappear. We call this an *unstable behavior*. The case $C = 0$ corresponds to the *neutral equilibrium*.

One can formalize the above consideration to the elastic body (structure), where the total potential energy is a function of a scalar parameter, such as a displacement amplitude u . The function $\Pi(u)$ can be expanded in Taylor series around the reference point u_0

$$\Pi(u) = \Pi(u_0) + \left.\frac{d\Pi}{du}\right|_{u=u_0}(u - u_0) + \frac{1}{2}\left.\frac{d^2\Pi}{du^2}\right|_{u=u_0}(u - u_0)^2 + \dots \quad (9.4)$$

Stability Of Elastic Structures

Katrin Zwirgmaier



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