RESEARCH ON ELASTIC LARGE SPACE STRUCTURES

AS "PLANTS" FOR ACTIVE CONTROL

H. Ashley and A. von Flotow

Stanford University
Stanford, California

INTRODUCTION

- Modeling of large space structures (LSS) in terms of elastic wave propagation
- Scale effects on structural damping
- "Loss coefficients" of monolithic LSS
- Wave propagation in nondispersive and dispersive media (1-D and 2-D)
- Spectral separation of system response:

$$x(s) = H(s)[u(s) + iC(s)] \cong H_R(s)[u(s) + iC(s)] + \underbrace{[H(s) - H_R(s)][u_F(s) + iC_F(s)]}_{\text{correction term}}$$

where $H_R(s)$ is a reduced-order transfer function

- Reflection of waves from boundaries
- Modeling of discrete structures as equivalent continuous structures
- Dynamics of networks of elastic waveguides
- Control of systems with wave-related time delays
- Application to a 1-D system under active control: 0.12-sec lag predicted with Timoshenko beam idealization and empirically determined shear rigidity
- Significance of passive damping (ref. 1):
  1. A LSS with exactly zero damping is uncontrollable unless sensors and actuators are all collocated (often impractical)
  2. Even very small amounts of damping are important to practical success of control
- Some approximate effects of LSS linear scale L on a typical modal damping ratio ζ:
  1. For a "monolithic" element, ζ is proportional to material damping and decreases with decreasing frequency ω (i.e., with increasing L)
  2. Viscous friction dominates at joints; thus $\zeta \sim 1/L$
  3. Coulomb frection at joints and joint preload is dependent on rotational rate $\Omega \rightarrow \zeta \sim (\Omega L)^2$
  4. All sources active $\rightarrow \zeta$ between a constant and $\sim L^{-1}$

STUDY OF INTRINSIC DAMPING IN MONOLITHIC METALLIC STRUCTURE

- Two "semi-reversible" mechanisms seem feasible for LSS:

  1. Thermal relaxation

  2. Grain boundary relaxation (can give large values of ζ but required temperatures may be too high)

- Work in progress on thermal damping

- Properties of thermal damping

  1. Involves coupling between mechanical and entropy waves; e.g., for isotropic solid with $T = T_o + \Delta T$ and displacement $\vec{q} \equiv u\vec{i} + v\vec{j} + w\vec{k}$,

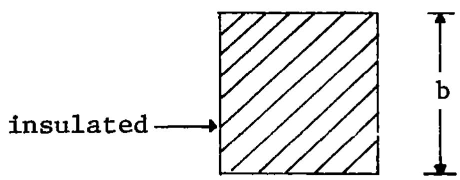
$$\frac{k}{\rho} \nabla^2 (\Delta T) - c_v \frac{\partial \Delta T}{\partial t} - \frac{T_o \alpha E}{\rho[1 - 2v]} \nabla \cdot \frac{\partial \vec{q}}{\partial t} = 0$$

$$\frac{\partial u}{\partial x} \equiv E_{xx} = \alpha \Delta T + \frac{\sigma_{xx} - \nu(\sigma_{yy} + \sigma_{zz})}{E}$$

$$\frac{\partial \sigma_{xx}}{\partial x} + \frac{\partial \sigma_{xy}}{\partial y} + \frac{\partial \sigma_{xz}}{\partial z} = \frac{\partial^2 u}{\partial t^2}$$

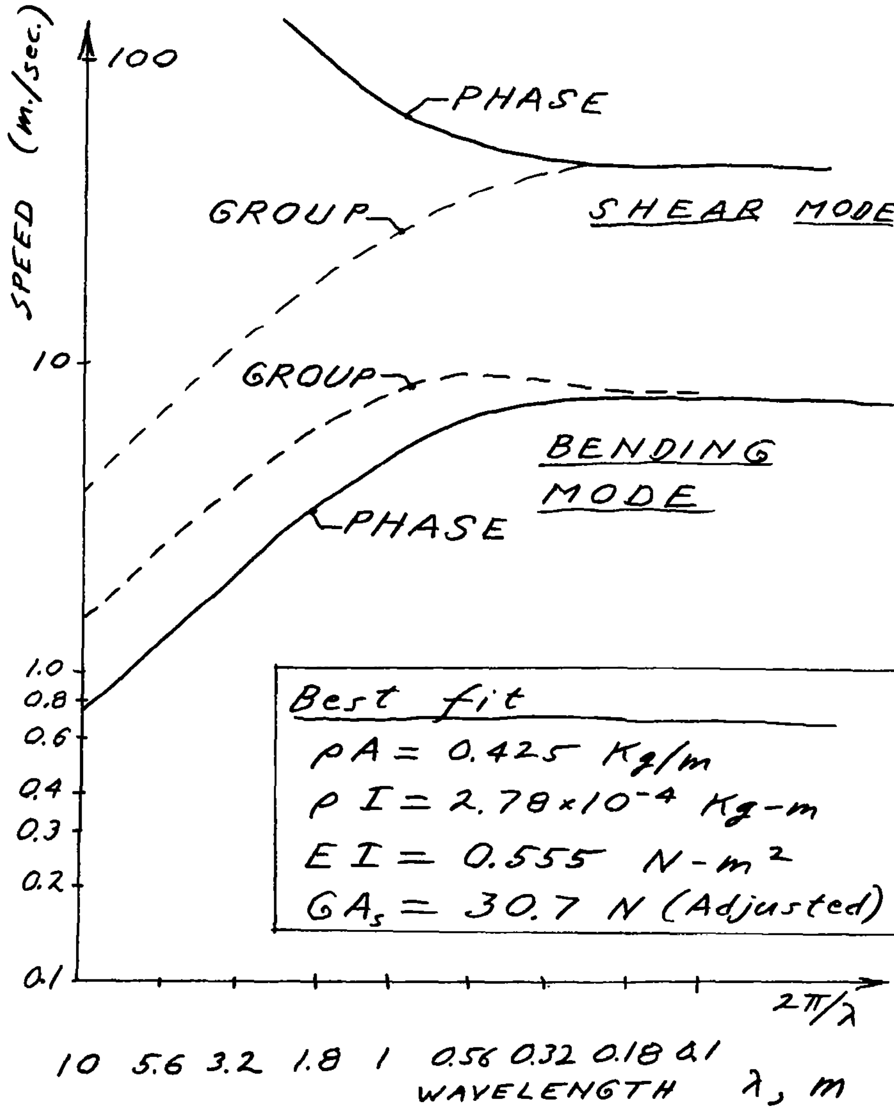
  2. ζ is configuration-dependent (e.g., 10^{-2} to 10^{-3} for beams and plates, 10^{-7} to 10^{-8} for bars and rods). Composite beams are under study.

  3. The value of ζ depends on frequency ω and material properties. E.g., for a rectangular beam of depth b:

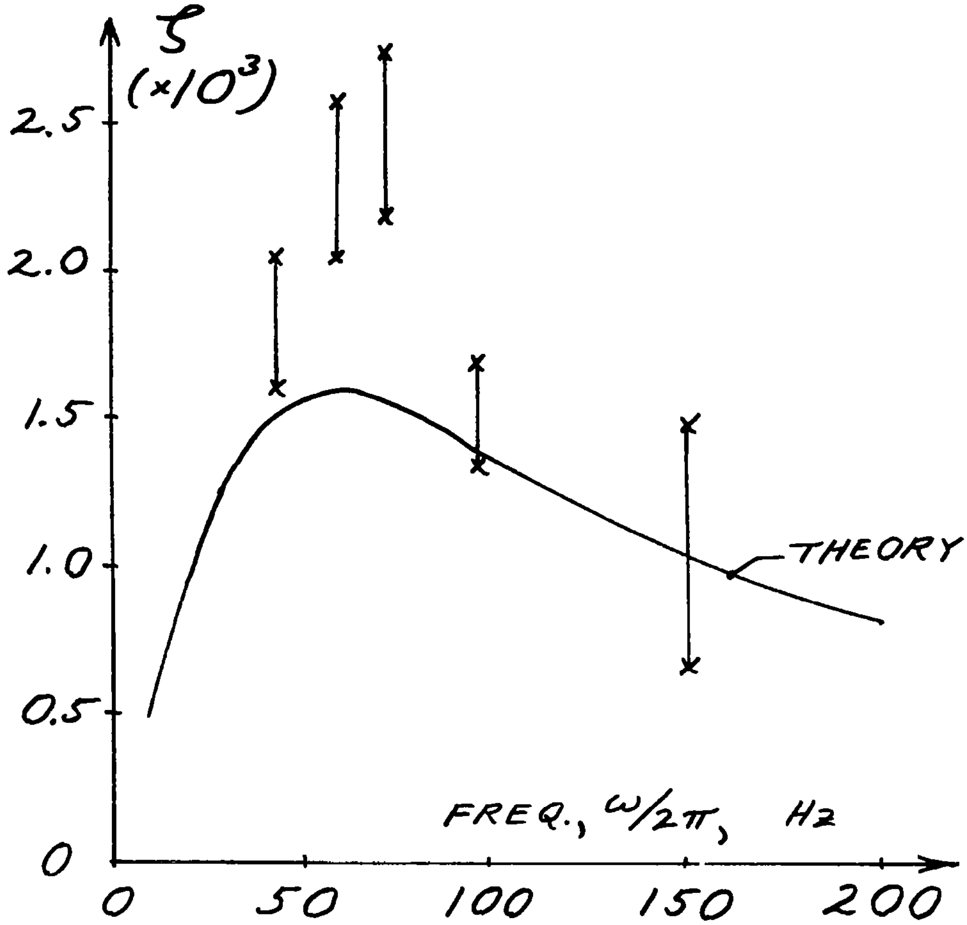


$$\zeta \approx 0.55 \frac{T_o E \alpha^2}{\rho c_v} \left[\frac{\omega \mu}{\omega^2 + \mu^2}\right] \quad \text{with} \quad \mu \equiv \left(\frac{\pi}{b}\right)^2 \frac{k}{\rho c_v} \quad \sec^{-1}$$

Metal (R.T.)	b, cm	$\zeta_{max} \times 10^{-3}$	ω for ζ_{max}, rad sec^{-1}
Al and alloys	10	1.53	0.083
	5	1.53	2.08
	1	1.53	8.31
Cu	10	0.73	0.112
Low-carbon steel	10	0.675	0.0225
Ti and alloys	10	0.18	0.0075
Ni and alloys	10	0.79	0.0141
Be	10	0.5 (est.)	0.061 (est.)
Mg	10	1.35	0.0844
Al at 1000 K	10	4.12	0.0755



Timoshenko beam waves.



Thermal damping theory compared with recent tests on free-free Al beams in vacuo.