VERIFICATION FOR LARGE SPACE STRUCTURES

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Large Space Antenna Systems Technology - 1984
December 4-6, 1984

Traditionally, most aerospace structural systems must be subjected to some form of verification prior to flight. The verification procedure often includes the experimental identification of structural characteristics such as the natural frequencies and normal modes using modal tests. It may also include a direct structural integrity verification under simulated dynamic environments. In the past the design criteria for the structural systems were required to survive only the launch loads, hence these verification procedures were performed under a 1-g environment and posed no particular concern.

FOR CONVENTIONAL AEROSPACE STRUCTURES

- STRUCTURAL VERIFICATION PRIOR TO FLIGHT
- EXPERIMENTAL IDENTIFICATION OF STRUCTURAL DYNAMIC CHARACTERISTICS - LOADS MODEL VERIFICATION
- SIMULATED DYNAMIC ENVIRONMENTS FOR STRUCTURAL INTEGRITY
- DESIGN CRITERIA - LAUNCH LOADS IN 1.0 G

For true space structures erected/fabricated/deployed in orbit, the environment in space is quite benign, the applied loads are apt to be small, and the strength of the structure is not a pacing factor. On the other hand, the demands placed on antenna structures and solar reflectors for accurate positioning and the requirements of adequate stiffness to avoid undesirable structural distortions are often serious and thereby dictate the design.

For large space structures, the design criteria are different. The operational environments such as maneuver, deployment, docking, etc., are the events that are expected to generate the critical loads.

FOR LARGE SPACE STRUCTURES

- DESIGN CRITERIA - MANEUVER, DEPLOYMENT, DOCKING, ETC.
- STIFFNESS FOR ACCURATE POSITIONING AND SHAPE REQUIREMENTS
- ACCURATE DYNAMIC CHARACTERISTICS FOR ACTIVE CONTROL
- ZERO GRAVITY REQUIREMENT
- GROUND TEST VERIFICATION

The dynamic characteristics of the space structure related to the control and sensor/actuator location become the primary concerns for the verification. Therefore, instead of verifying the load carrying capability of the structure, properties such as modal density, range of natural frequencies, and modal displacements at the potential sensor/actuator location are important and must be simulated for the verification of the structure/control closed-loop system.

GROUND TEST CONSIDERATION

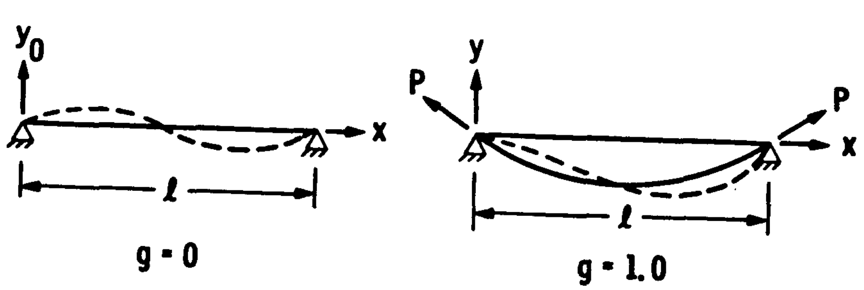
- GRAVITY EFFECTS ON DYNAMIC CHARACTERISTICS
- VERIFICATION OF LOAD CARRYING CAPABILITY NOT REQUIRED
- DYNAMIC CHARACTERISTICS RELATED TO CONTROL REQUIRED
- MODAL DENSITY, FREQUENCY RANGES, MODAL DISPLACEMENTS AT SENSOR/ACTUATOR LOCATIONS, ETC.

The generic structural element chosen for the study is a space beam which is a beam with a large slenderness ratio. For simplicity, the conditions of simple beam theory will be assumed. The figure shows the vibrating beam in a zero gravity environment and a 1-g gravity environment.

In what follows, the governing equation for the vibrating beam in a 1-g environment will be examined. The zero gravity condition will be treated as a special case in which the effects of the gravity will be eliminated.

A SPACE BEAM

- BEAM WITH LARGE SLENDERNESS RATIO
- GRAVITY EFFECTS ON DYNAMIC CHARACTERISTICS AS FUNCTION OF NON-DIMENSIONAL PARAMETERS



It is postulated that the response can be divided into two parts, namely, the static deflection due to gravity and the vibrational response. However, the induced axial force P remains unknown and the solution is a function of P. The fact that P is not zero indicates that both end supports are not movable and the beam must be stretched to accommodate the lateral deformation. This elongation along the axial direction should be a function of the reaction force P. It is obvious that the length increment can be related to the curvature due to lateral deflection.

GOVERNING EQUATIONS

$$EI \frac{\partial^4 y}{\partial x^4} - p \frac{\partial^2 y}{\partial x^2} + \rho \frac{\partial^2 y}{\partial t^2} = -\rho g$$

$$y(x,t) = y_s(x) + \bar{y}(x,t)$$

$$EI \frac{d^4 y_s}{dx} - p \frac{d^2 y_s}{dx^2} = -\rho g$$

$$EI \frac{\partial^4 \bar{y}}{\partial x^4} - p \frac{\partial^2 \bar{y}}{\partial x^2} + \rho \frac{\partial^2 \bar{y}}{\partial t^2} = 0$$

The static deflection due to gravity satisfies the simply supported end conditions and was obtained by the Galerkin's approximation method. For simplicity, the magnitude of the first derivative is limited to be small.

ASSUMPTIONS

$$y_s = \left(\frac{-1}{76.5 + 7.75(p\ell^2/EI)}\right) \frac{\rho g \ell^4}{EI} \sin\left(\frac{\pi x}{\ell}\right)$$

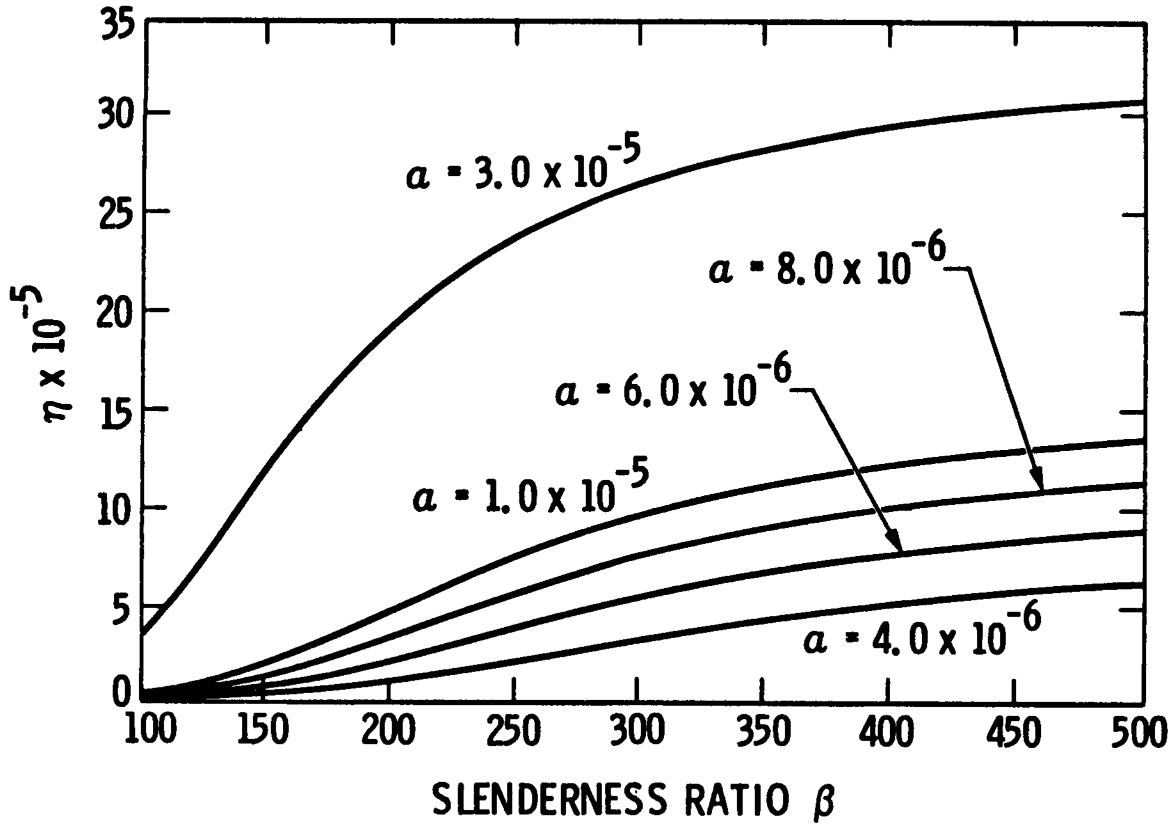
$$\left|\frac{dy_s}{dx}\right| \leq \frac{1}{10}$$

- <u>NON-DIMENSIONAL PARAMETERS</u>

NON-DIMENSIONAL WEIGHT	$\alpha = \frac{\rho g \ell}{AE}$
SLENDERNESS RATIO	$\beta = \frac{\ell}{r}, \; r^2 = \frac{I}{A}$
NON-DIMENSIONAL AXIAL FORCE	$\eta = \frac{P}{AE}$
WEIGHT-LENGTH PARAMETER	$\gamma = \frac{1}{2}\eta \cdot \beta^2$
NON-DIMENSIONAL FREQUENCY	$\lambda_\eta^2 = \frac{\rho \ell^4 \omega_\eta^2}{EI}$
FREQUENCY RATIO	$\Omega_\eta = \frac{\lambda_\eta}{\lambda_{n+1}}$

From the axial elongation condition, the axial force can be related to the gravity loading and slenderness ratio of the beam.

NON-DIMENSIONAL AXIAL FORCE



The eigenvalue and eigenvector are functions of a single non-dimensional parameter. For a simply supported case, the eigenvector is an invariant, independent of the beam geometry.

EIGENVALUES AND EIGENVECTORS

SIMPLY SUPPORTED CASE:

$$\lambda_\eta = \eta^2\pi^2\left(1 + \frac{2}{\eta^2\pi^2}\gamma\right)^{\frac{1}{2}}$$

$$\phi_\eta = a \sin\left(\eta\pi\frac{x}{\ell}\right)$$

BUILT-IN CASE:

$$\lambda_\eta = (1 - \cos\sigma_\eta \cosh\mu_\eta) + \gamma \sin\sigma_\eta \sinh\mu_\eta = 0$$

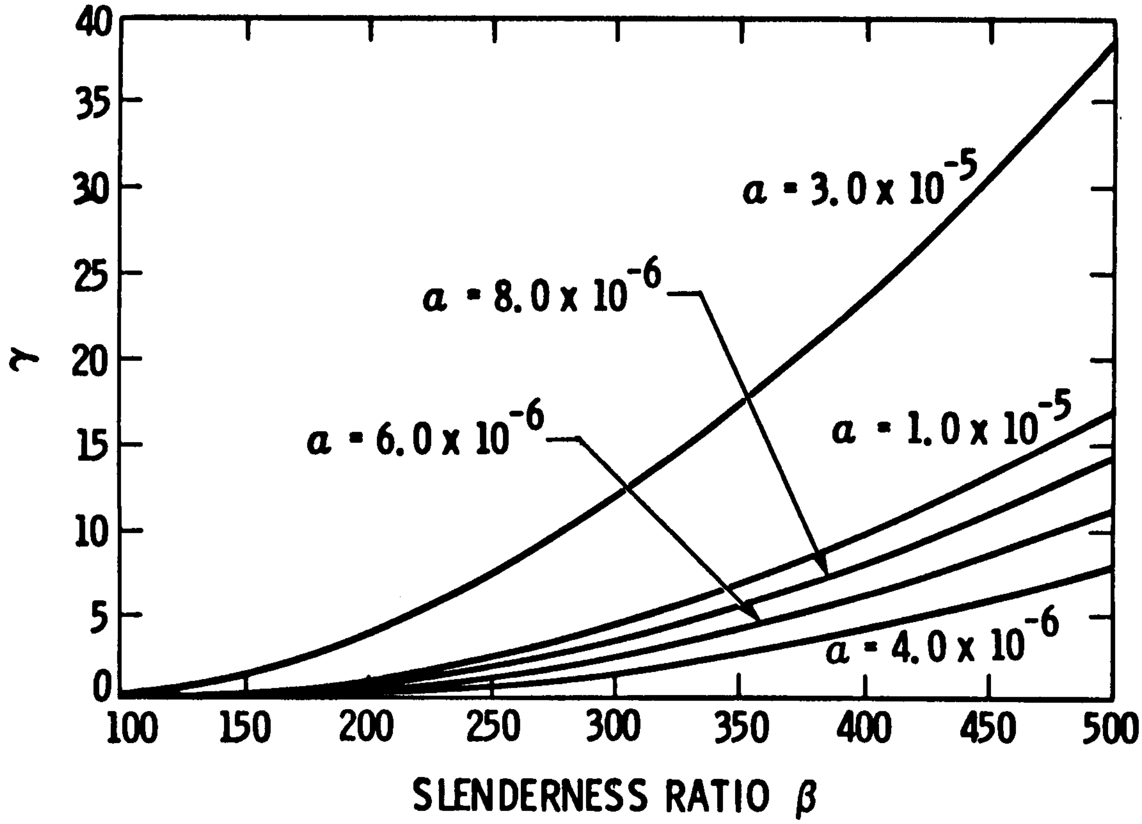
$$\sigma_\eta = (-\gamma + \sqrt{\ell^2 + \lambda_\eta})^{\frac{1}{2}}, \quad \mu_\eta = (\gamma + \sqrt{\ell^2 + \lambda_\eta})^{\frac{1}{2}}$$

$$\phi_\eta = \sin\left(\sigma_\eta \frac{x}{\ell}\right) - \frac{\sigma_\eta}{\mu_\eta}\sinh\left(\mu_\eta \frac{x}{\ell}\right)$$

$$+ \frac{\sigma_\eta(\cos\sigma_\eta - \cosh\mu_\eta)}{\sigma_\eta \sin\sigma_\eta + \mu_\eta \sinh\mu_\eta} \times \left[\cos\left(\mu_\eta \frac{x}{\ell}\right) - \cosh\left(\mu_\eta \frac{x}{\ell}\right)\right]$$

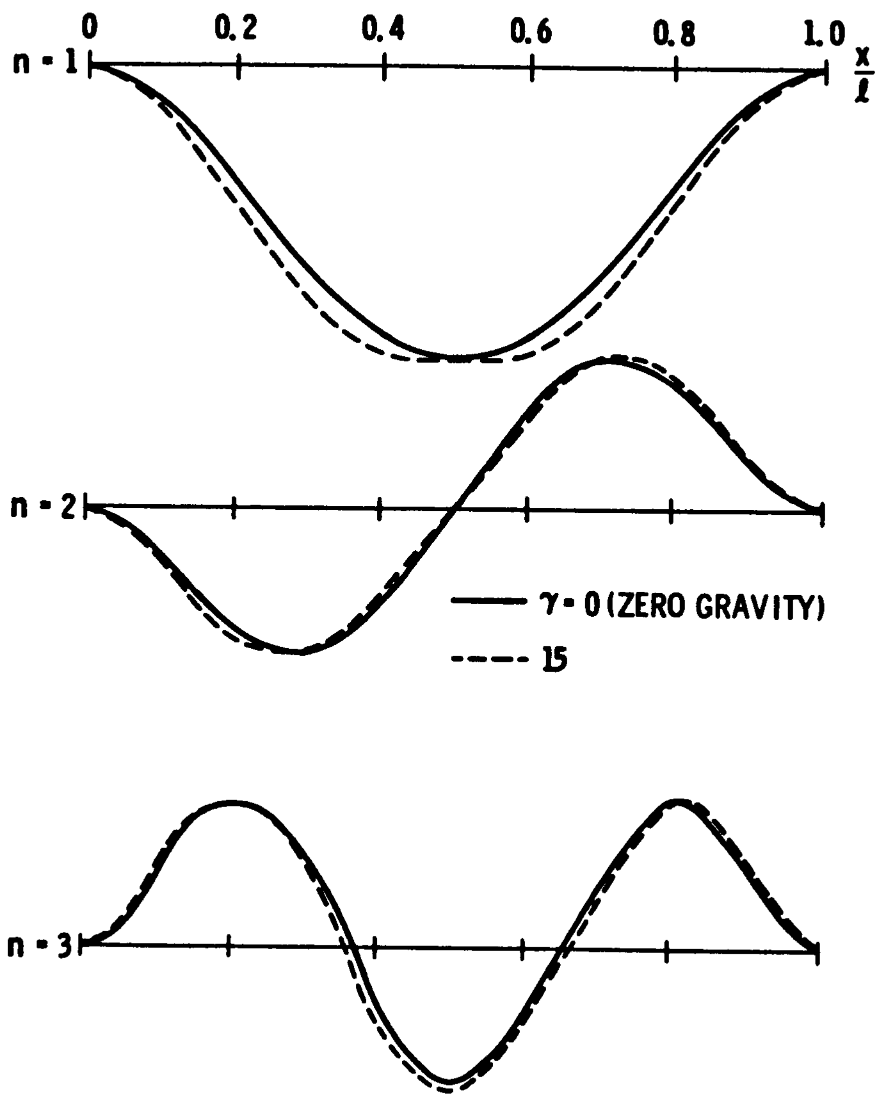
Once the geometry and the material properties of the beam are given, the weight-length parameter can be determined. On the other hand, for a given weight-length parameter, one may find a variety of beams with different geometric and material properties that will have the same parameter value.

WEIGHT LENGTH PARAMETER



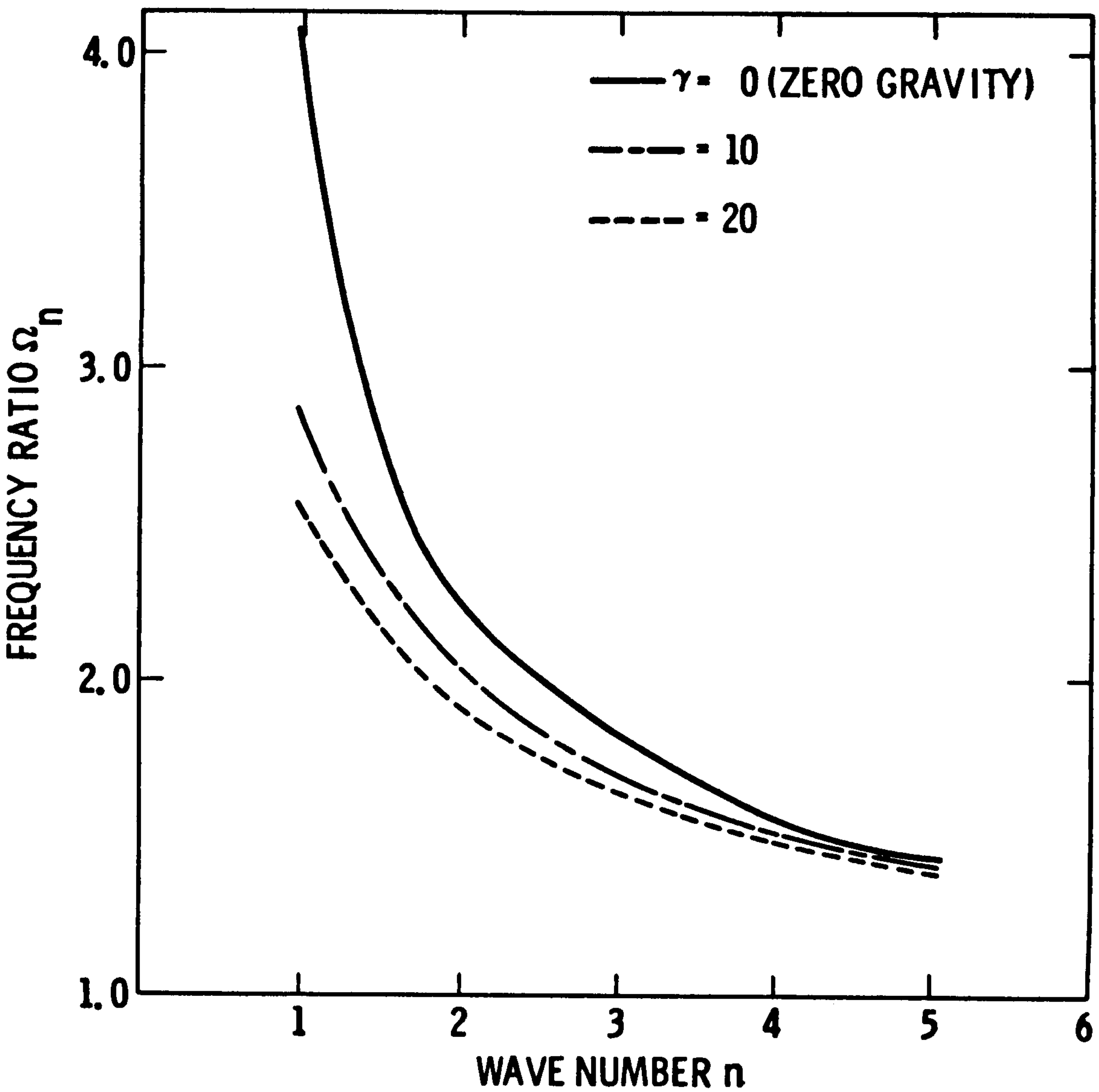
Unlike the case of simply supported boundary conditions, the mode shapes for the beams with built-in ends are a function of the weight-length parameters. However, the mode shapes for 0-g and 1-g are very similar.

MODE SHAPE COMPARISON



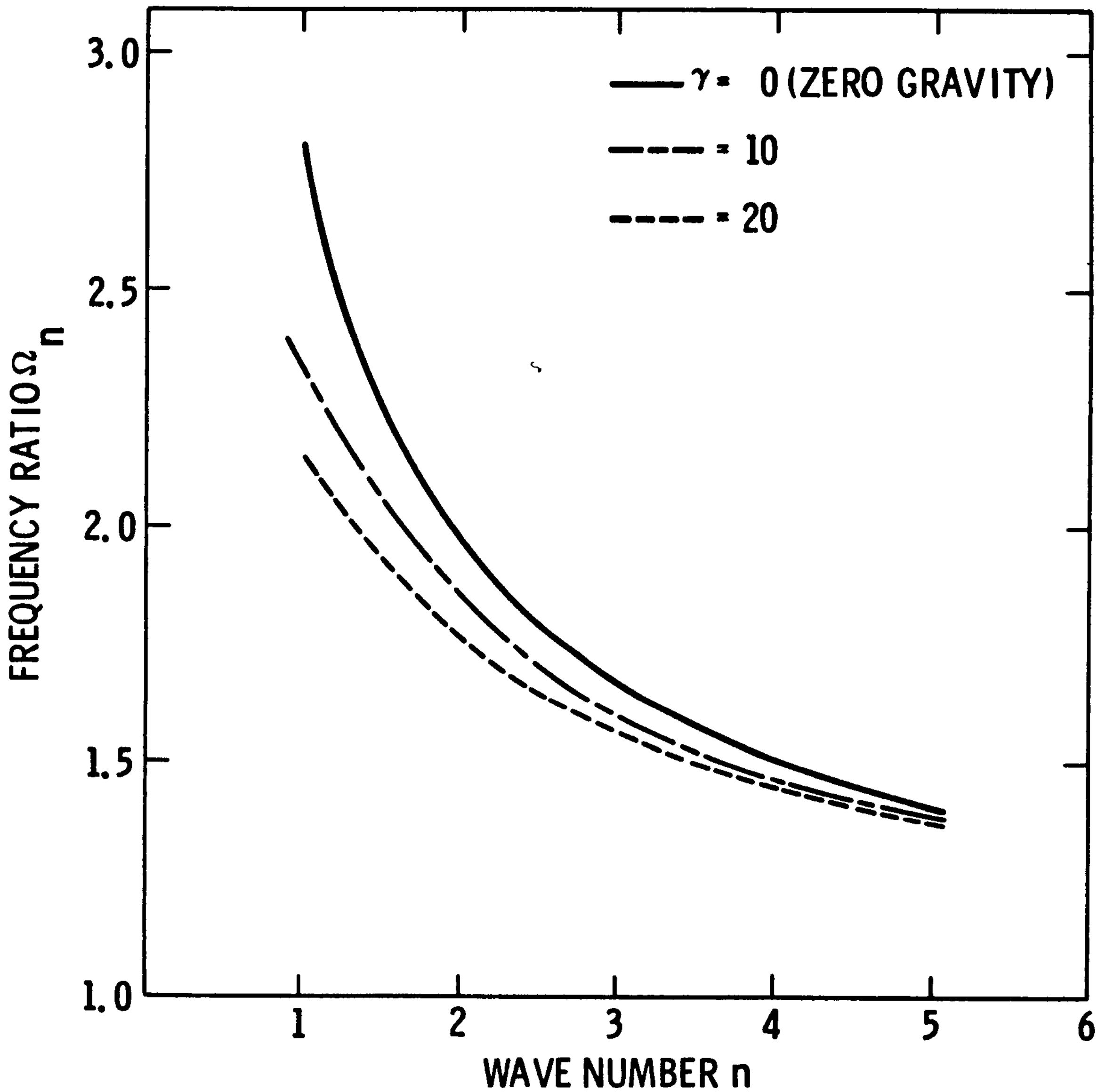
For a simply supported case, it is found that for lower modes with larger weight-length parameters the frequency ratio is quite different from that of the 0-g case. In other words, the higher frequency modes are easier to simulate by a scale model test than the lower frequency modes. Unfortunately, it is the latter that are in general, more important.

FREQUENCY RATIO FOR SIMPLY SUPPORTED CASE



For the case of built-in boundary conditions, similar results are found for the frequency ratio.

FREQUENCY RATIO FOR BUILT-IN CASE



For ground testing verification of large space structures the feasibility of using a scale model is dependent not only on the structure itself, but also on the control systems. Accurate modal displacements and modal density distributions are the important parameters to be considered. For large complex space structures the ground test may be very expensive and time consuming, such that the test consideration may become part of the design requirement. However, since very little experience is available in this respect, a more systematic study in realistic large space structural systems should be performed.

CONCLUDING REMARKS

- FOR A GIVEN SPACE BEAM WITH ITS WAVE-LENGTH PARAMETER, THE FREQUENCY DENSITY DEVIATION DUE TO 1 G CAN BE READILY FOUND.
- FOR A GIVEN ERROR TOLERANCE IN MODAL DENSITY, THE FEASIBILITY OF PERFORMING GROUND TESTING FOR VERIFICATION CAN BE DETERMINED.
- OTHER CHARACTERISTICS WILL BE INVESTIGATED.
- STUDIES ARE EXTENDED TO OTHER LARGE SPACE STRUCTURES.
- VERIFICATION OF STRUCTURES/CONTROL CLOSED LOOP SYSTEM WILL BE INVESTIGATED.