

# **VIBRATION ANALYSIS OF SINGLE - ANCHOR INFLATABLE DAMS**

by

Guruprasad V. Mysore

Thesis submitted to the Faculty of the  
Virginia Polytechnic Institute and State University  
in partial fulfillment of the requirements for the degree of  
Master of Science  
in  
Aerospace Engineering

**APPROVED**

---

**Dr. Stergios I. Liapis, Chairman      Dr. Raymond H. Plaut, Co-Chairman**

---

**Dr. Rakesh K. Kapania**

**June, 1997**

**Blacksburg, Virginia**

# VIBRATION ANALYSIS OF SINGLE-ANCHOR INFLATABLE DAMS

by

Guruprasad V. Mysore

(ABSTRACT)

Inflatable dams are flexible, cylindrical structures anchored to a foundation. They are used for a variety of purposes, e.g. diverting water for irrigation or groundwater recharging, impounding water for recreational purposes, and raising the height of existing dams or spillways.

The vibration behavior of such dams is analyzed. Single-anchor inflatable dams with fins are considered. First, a static analysis is performed which yields the equilibrium shapes of the dam, both in the presence and absence of water. Then, a dynamic analysis is undertaken which analyzes the small vibrations of the inflatable dam about the equilibrium configuration, both in the presence of water (hydrostatic water as well as parallel flowing water) and absence of water.

The dam is modeled as an elastic shell. It is assumed to be air-inflated and resting on a rigid foundation. The cross-sectional perimeter, material thickness, modulus of elasticity, and Poisson's ratio are given. The analysis is performed for different values of internal pressure and external water heads.

Initially, the dam is assumed to lie flat. The internal pressure is then increased slowly until it reaches the desired value. Then the external water is applied and the equilibrium configuration is obtained. Small vibrations about this configuration are considered. The water is assumed to be inviscid and incompressible, and potential theory is used. The infinite-frequency limit is assumed on the free surface. A boundary element technique is utilized to determine the behavior of the water, and the finite element program ABAQUS is used to analyze the structural behavior. Both the cases of fluid at rest and flowing parallel to

the dam are considered. The vibration frequencies and mode shapes are computed. The effect of the internal pressure of the dam is investigated, and the results are compared to those for the dam in the absence of external water.

## **Acknowledgments**

I would like to thank Dr. Liapis and Dr. Plaut for their advice, patience, and assistance in this research and thesis. I am also thankful to Dr. Kapania for his willingness to join the committee, read the thesis, and make valuable suggestions to improve the content of this thesis. Special thanks go to the members of my research group, particularly Fata Dewi and Jeremy Trowbridge for their constant encouragement and support during the course of this research. I also want to acknowledge financial support from the National Science Foundation under Grant No. CMS-9422248.

## Table of Contents

Chapter 1	INTRODUCTION.....	1
Chapter 2	LITERATURE REVIEW .....	5
Chapter 3	STATIC ANALYSIS.....	10
3.1	THE MODEL.....	10
3.2	ANALYSIS PROCEDURE.....	12
3.2.1	WITHOUT EXTERNAL WATER.....	12
3.2.2	WITH EXTERNAL WATER.....	12
Chapter 4	DYNAMIC ANALYSIS .....	20
4.1	LINEAR VIBRATIONS FORMULATION .....	20
4.1.1	WITHOUT EXTERNAL WATER.....	20
4.1.2	WITH EXTERNAL WATER.....	21
4.2	LINEAR VIBRATIONS : RESULTS .....	26
4.2.1	PROCEDURE VALIDATION.....	26
4.2.2	NUMERICAL RESULTS .....	28
4.2.2.1	WITHOUT EXTERNAL WATER.....	28
4.2.2.2	WITH EXTERNAL WATER.....	29
4.2.2.3	WITH PARALLEL FLOW.....	30
Chapter 5	CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH.....	55

5.1 CONCLUSIONS .....	55
5.2 SUGGESTIONS FOR FURTHER RESEARCH.....	56
REFERENCES.....	58
APPENDIX A: FINITE ELEMENT ANALYSIS USING ABAQUS.....	61
APPENDIX B: THE PANEL METHOD .....	66
Vita .....	68

## List of Illustrations

Figure 1. Cross section of inflatable dam impounding water.....	4
Figure 3.1 Figure showing the model information.....	14
Figure 3.2 A shell finite element` .....	15
Figure 3.3 Cross-sectional equilibrium shapes of the dam (at the center) without external water at different internal pressures .....	16
Figure 3.4 Equilibrium shapes of the dam (a) without water (b) with water, for $p_{int} = 1$ kPa.....	17
Figure 3.5 Equilibrium shapes of the dam (a) without water (b) with water, for $p_{int} = 30$ kPa.....	18
Figure 3.6 Cross-sectional equilibrium shapes of the dam (at the center) with different water levels for $p_{int} = 30$ kPa.....	19
Figure 4.1 Schematic diagram representing the boundary value domain.....	32
Figure 4.2 Schematic diagram showing the pressure forces on the dam.....	33
Figure 4.3 Model information for the double-anchored dam used by Dakshina Moorthy et al. (1995).....	34
Figure 4.4 Variation of frequencies with internal pressure, without water .....	35
Figure 4.5 First four vibration modes without external water, for $p_{int} = 1$ kPa .....	36
Figure 4.6 Cross sections of the modes in Fig. 4.5 at the center (solid curves) and at quarter lengths from the ends (dashed curves).....	37
Figure 4.7 First four vibration modes without external water, for $p_{int} = 30$ kPa .....	38

Figure 4.8 Cross sections of the modes in Fig. 4.7 at the center (solid curves) and at quarter lengths from the ends (dashed curves).....	39
Figure 4.9 Variation of frequency with external water head; ( $p_{int} = 30$ kPa) .....	40
Figure 4.10 First four vibration modes with external water, for $p_{int} = 1$ kPa .....	41
Figure 4.11 Cross sections of the modes in Fig. 4.10 at the center (solid curves) and at quarter lengths from the ends (dashed curves).....	42
Figure 4.12 First four vibration modes with external water, for $p_{int} = 30$ kPa .....	43
Figure 4.13 Cross sections of the modes in Fig. 4.12 at the center (solid curves) and at quarter lengths from the ends (dashed curves).....	44
Figure 4.14 First four modes with parallel flow of 1 m/s, for $p_{int} = 1$ kPa .....	45
Figure 4.15 Cross sections of the modes in Fig. 4.14 at the center (solid curves) and at quarter lengths from the ends (dashed curves).....	46
Figure 4.16 First four modes with parallel flow of 5 m/s, for $p_{int} = 1$ kPa .....	47
Figure 4.17 Cross sections of the modes in Fig. 4.16 at the center (solid curves) and at quarter lengths from the ends (dashed curves).....	48
Figure 4.18 First four modes with parallel flow of 1 m/s, for $p_{int} = 30$ kPa.....	49
Figure 4.19 Cross sections of the modes in Fig. 4.18 at the center (solid curves) and at quarter lengths from the ends (dashed curves).....	50
Figure 4.20 First four modes with parallel flow of 5 m/s, for $p_{int} = 30$ kPa.....	51
Figure 4.21 Cross sections of the modes in Fig. 4.20 at the center (solid curves) and at quarter lengths from the ends (dashed curves).....	52



## List of Tables

Table 4.1 <i>Natural frequencies (rad/sec) of a flexible circular cylinder</i> .....	53
Table 4.2 <i>Natural frequencies (rad/sec) of a double-anchored inflatable dam</i> .....	53
Table 4.3 <i>Natural frequencies (rad/sec) of the inflatable dam</i> .....	53
Table 4.4 <i>Natural frequencies (rad/sec) of the dam with parallel flow, for <math>p_{\text{int}} = 1 \text{ kPa}</math></i> .....	53
Table 4.5 <i>Natural frequencies (rad/sec) of the dam with parallel flow, for <math>p_{\text{int}} = 30 \text{ kPa}</math></i> .....	54