

FREE FLEXURAL (OR BENDING) VIBRATIONS ANALYSIS OF
CERTAIN GROUPS OF STIFFENED COMPOSITE PLATES OR PANELS
- - IN FLIGHT VEHICLE STRUCTURES- -

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ABSTRACT

“FREE FLEXURAL (OR BENDING) VIBRATIONS ANALYSIS OF
CERTAIN GROUPS OF STIFFENED COMPOSITE PLATES OR PANELS”

--In Flight Vehicle Structures--

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In this study, the “Free Flexural (or Bending) Vibrations of Stiffened Plates or Panels” are investigated in detail. Two different Groups of “Stiffened Plates” will be considered. In the first group, the “Type 4” and the “Type 6” of “Group I” of the “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel Systems” are theoretically analyzed and numerically solved by making use of the “Mindlin Plate Theory”. Here, the natural frequencies and the corresponding mode shapes, up to the sixth mode, are obtained for each “Dynamic System”. Some important parametric studies are also presented for each case. In the second group, the “Class 2” and the “Class 3” of the “Bonded and Stiffened Plate or Panel Systems” are also analyzed and solved in terms of the natural frequencies with their corresponding mode shapes. In this case, the “Plate Assembly” is constructed by bonding “Stiffening Plate Strips” to a “Base Plate or Panel” by dissimilar relatively thin adhesive layers. This is done with the purpose of reinforcing the “Base Plate or Panel” by these “Stiffening Strips” in the appropriate locations, so that the “Base Plate or Panel” will exhibit satisfactory dynamic response. The aforementioned “Bonded and Stiffened Systems” may also be used to repair a

damaged (or rather cracked) “Base Plate or Panel”. Here in the analysis, the “Base Plate or Panel”, the “Stiffening Plate Strips” as well as the in-between “adhesive layers” are assumed to be linearly elastic continua. They are assumed to be dissimilar “Orthotropic Mindlin Plates”. Therefore, the effects of shear deformations and rotary moments of inertia are considered in the theoretical formulation. In each case of the “Group I” and “Group II” problems, the “Governing System of Dynamic Equations” for every problem is reduced to the “First Order Ordinary Differential Equations”. In other words the “Free Vibrations Problem”, in both cases, is an “Initial and Boundary Value Problem” is reduced to a “Two-Point or Multi-Point Boundary Value Problem” by using the present “Solution Technique”. For this purpose, these “Governing Equations” are expressed in “compact forms” or “state vector” forms. These equations are numerically integrated by the so-called “Modified Transfer Matrix Method (MTMM) (with Interpolation Polynomials)”. In the numerical results, the mode shapes together with their corresponding non-dimensional natural frequencies are presented up to the sixth mode and for various sets of “Boundary Conditions” for each structural “System”. The effects of several important parameters on the natural frequencies of the aforementioned “Systems” are also investigated and are graphically presented for each “Stiffened and Stiffened and Bonded Plate or Panel System”. Additionally, in the case of the “Bonded and Stiffened System”, the significant effects of the “adhesive material properties” (i.e. the “Hard” adhesive and the “Soft” adhesive cases) on the dynamic response of the “plate assembly” are also presented.

Keywords: Free Vibrations, “Integrally-Stiffened and/or Stepped-Thickness Plates”, “Bonded and Stiffened Plates”, “Plates Reinforced by Bonded Stiffening Plate Strips”, “Modified Transfer Matrix Method (MTMM)”,

Özet

“KUVVETLENDİRİLMİŞ KOMPOZİT PLAKA VE PANELLERİN BAZI GRUPLARININ SERBEST TİTREŞİMLERİ”

--Hava Araçları Yapılarında--

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Bu çalışmada, kuvvetlendirilmiş “Plaka ve Panel Sistemlerin Serbest Titreşimleri” incelenmiştir. Bu bağlamda, ilk önce, “Kendinden-Kuvvetlendirilmiş Plaka ve Panel Sistemlerinden”, “Tip 4”, “Tip 6” teorik olarak analiz edilip ve numerik olarak, “Mindlin Plaka Teorisini” kullanarak, çözülmüştür. Burada doğal frekanslar ve onlarla ilgili mod şekilleri, 6 ncı moda kadar, her “Dinamik Sistemi”ne elde edilmiştir ve her “Problem” için önemli parametrik çalışmalar gösterilmiştir. İkinci aşamada, “Grup II” nin “Klas 2” ve “Klas 3” “Yapıştırılmış Kuvvetlendiricili Sistemi” çözülmüştür. Bu “Plaka Sistemi” bir kaç plakadan oluşmaktadır, kuvvetlendirici plakaları, ayrı çok ince adhesive tabakası ile taban plakaya yapıştırılmaktadır. Bu suretle, taban plakayı, uygun yerlerde daha güçlü hale getirip, ve istenen dinamik özellikleri elde edilecektir. Daha önce adı geçen yapıştırılmış

kuvvetlendiriciler onarım için de kullanılabilir. Bu çalışmada, yapıştırılmış kuvvetlendiriciler ve taban plaka aralarında bağlantı kuran yapıştırıcı tabakası bir linear continuous media dan oluşmaktadır. Ayrıca, bu plakalar, bir “Minlin “ plakası olarak analiz edilmiştir. Bu suretle, kesme deformasyonlar teorik formülasyon da göz önüne alınmıştır. Her “Problem” de “Yöneten Denklemler”, birinci derece adi diferansiyel denklemlerine dönüştürülmüştür. Bir başka ifade ile, “Serbest Titreşim” problem, ki bir başlangıç ve sınır değeri problemidir, adı geçen çözüm metodunu kullanarak, “İki Nokta ve Çok Nokta Sınır Değeri Problemine” dönüştürülmüştür. Bir sonraki kademede, “Yöneten Adi Diferansiyel Denklemler” “State Vector” şeklidne düzenlenmiştir. Bu denklemler, numerik çözüm metodu yani “Modified Transfer Matrix Method (MTMM)” kullanarak integre edilmiştir. Numerik sonuçlarda mod şekilleri ve onlarla ilgili frekanslar 6 ıncı moda kadar değişik sınır şartlarına göre sunulmuştur. Bazı önemli parametrelerin etkisi doğal frekanslar üzerine incelenmiş ve sunulmuştur. “Yapıştırılmış kuvvetlendiricili Plaka ve Panel Sistem”inde yapıştırıcının material özellikleri nin etkisi bu sistemin titreşim üzerinde de gösterilmiştir.

Anahtar kelimeler: “Serbest Titreşim”, “Kendinden Kuvvetlendiricili Plaka ve Panel Sistemi”, “Yapıştırılmış Kuvvetlendiricili ile Kuvvetlendirilmiş olan Plaka ve Panel Sistemi”, “Modified Transfer Matris Metodu (MTMM)”

Dedicated to Gazi Mustafa Kemal ATATÜRK

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Table of Contents

Abstract.....	iv
Acknowledgments	ix
CHAPTER 1.....	1
1.1 Introductory Remarks and Motivation.....	1
1.2 General Remarks about “Thesis” Topic and Problems	2
1.3 Literature Survey and Brief Review	3
CHAPTER 2.....	5
2.1 Main Purpose and Main objectives.....	5
2.2 Brief Definitions of Main PROBLEMS and Scope.....	5
2.3 Original Findings and Main Contributions of the Present Thesis	6
CHAPTER 3.....	12
3.1 Brief Remarks on Plate Theories.....	12
1. Classical Plate Theory	12
2. First Order Shear Deformation Plate Theories	13
3.2 First Order Shear Deformation Theory and Mindlin Plate Theory	14
3.3 Some Comments on Higher-Order Theories	19
CHAPTER 4. “Main PROBLEM 1” (Type 4): “Free Bending Vibrations Analysis of Integrally-Stiffened and/or Stepped-Thickness Rectangular Composite Mindlin Plates or Panels with <u>Two Integral</u> Plate Stiffeners”	21

4.1 Statement of the Problem	21
4.2 Main Assumptions and Analytical Modeling	23
4.3 Formulation of the Problem (Analytical Modeling).....	23
4.4 Reduction of Governing System of PDE's to First Order Ordinary Differential Equations	27
4.5 Non-Dimensional Governing System of ODE's in Expanded form for "Main Problem 1" (Type 4)	30
CHAPTER 5. Main PROBLEM 2" (Type 6): "Free Bending Vibrations Analysis of Integrally-Stiffened and/or Stepped-Thickness Rectangular Composite Mindlin Plates or Panels with <u>Three Integral</u> Plate Stiffeners"	36
5.1 Statement of the Problem	36
5.2 Main Assumptions and Analytical Modeling	38
5.3 Formulation of the Problem (Analytical Modeling).....	38
5.4 Reduction of Governing System of PDE's to First Order Ordinary Differential Equations	43
5.5 Non-Dimensional Governing System of ODE's in Expanded form for "Main PROBLEM 2" (Type 6)	46
CHAPTER 6. "Main PROBLEM 1" (Class 2): "Free Bending Vibrations Analysis of Rectangular Mindlin Composite Base Plates or Panels Reinforced with <u>Two Bonded</u> Stiffening Plate Strips"	55
6.1 Statement of the Problem	55
6.2 Main Assumptions and Analytical Modeling	57
6.3 Formulation of the Problem (Analytical Modeling).....	57
6.3.a Analysis of Adhesive Layer in the "Bonded Joint Regions"	57
6.3.b Analysis of Different Parts and obtaining the governing PDE's for each part	61
6.4 Reduction of Governing System of PDE's to First Order Ordinary Differential Equations	69

CHAPTER 7. “Main PROBLEM II” (Class 3): “Free Bending Vibrations Analysis of Rectangular Mindlin Composite Base Plates or Panels Reinforced with <u>Three Bonded Stiffening Plate Strips</u>”	77
7.1 Statement of the Problem	77
7.2 Main Assumptions and Analytical Modeling	79
7.3 Formulation of the Problem (Analytical Modeling).....	79
7.3.a Analysis of Adhesive Layer in the “Bonded Joint Regions”	79
7.3.b Analysis of Different Parts and obtaining the governing PDE’s for each part.....	84
7.4 Reduction of Governing System of PDE’s to First Order Ordinary Differential Equations	94
CHAPTER 8. METHOD OF SOLUTION	104
8.1 Introduction	104
8.2 Solution Method for “Main PROBLEM 1” (Type 4)	105
8.3 Solution Method for “Main PROBLEM 2” (Type 6)	122
8.4 Solution Method for “Main PROBLEM I” (Class 2)	144
8.5 Solution Method for “Main PROBLEM II” (Class 3)	162
CHAPTER 9. NUMERICAL RESULTS AND DISCUSSION	172
9.1 Some Remarks on Geometric and Material Characteristics	172
9.2 Comments on Boundary Conditions	172
9.3 Numerical Results and Discussion of “Main PROBLEM 1” (Type 4)	176
9.4 Numerical Results and Discussion of “Main PROBLEM 2” (Type 6)	213
9.5 Numerical Results and Discussion of “Main PROBLEM I” (Class 2)	250
9.6 Numerical Results and Discussion of “Main PROBLEM II” (Class 3)	324
9.7 Comments on Accuracy and Verification of the Present Solution Procedure	366

CHAPTER 10. CONCLUSIONS	369
10.1 Concluding Remarks on “Main PROBLEM 1” (Type 4) and “Main PROBLEM 2” (Type 6)	369
10.2 Concluding Remarks on “Main PROBLEM I” (Class 2) and “Main PROBLEM II” (Class 3)	370
 CHAPTER 11	
11.1 Recommendations for Future Study and Research	371
 References.....	372

TABLES

TABLE 1. Material Constants and Dimensions of “Stiffened Plate or Panel System With Two Plate Stiffeners”173

TABLE 2. Material Constants and Dimensions of “Stiffened Plate or Panel System With Three Plate Stiffener”174

TABLE 3. Material Properties and Dimensions of “Stiffened Plate or Panel System With Two Bonded Stiffening Plate Strips”175

TABLE 4. Convergence of Natural Frequencies In “Base Plate or Panel With Two Bonded Stiffening Plate Strips” Case (Ref: Present Study) and “Base Plate or Panel With a Non-Centrally Bonded Stiffening Plate Strip” Case (From Ref: Yuceoglu et al [V.12]).....367

TABLE 5. Convergence of Natural Frequencies In “Base Plate or Panel With Three Bonded Stiffening Plate Strips” Case (Ref: Present Study) and “Base Plate or Panel With A Non-Centrally Bonded Stiffening Plate Strip” Case (From Ref: Yuceoglu et al [V.12]).....368

FIGURES

Figure 1. “Groups” of “Stiffened Plate or Panel Systems”	8
Figure 2. Various “Types” of “Integrally-Stiffened and/or Stepped-Thickness Plates or Panels”	9
Figure 3. “Groups” of “Stiffened Plate or Panel Systems”	10
Figure 4. “Classes” of “Stiffened Plate or Panel Systems with Bonded Stiffener Plates” ...	11
Figure 5. The Coordinate system, Stress Resultants and Sign Conventions.....	14
Figure 6. “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Two Integral Plate Stiffeners”	22
Figure 7. “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Three Integral Plate Stiffeners”	37
Figure 8. “Stiffened Composite Base Plate or Panel System with Two Bonded Stiffening Plate Strips”	56
Figure 9. Deformations of Mindlin Plates and in-between Adhesive Layers in the “Bonded Joint”	58
Figure 10. “Stiffened Composite Base Plate or Panel System with Three Bonded Stiffening Plate Strips”	78
Figure 11. Deformations of Mindlin Plates and in-between Adhesive Layers in the “Bonded Joint”	80
Figure 12. Mode Shapes and Dimensionless Natural Frequencies of “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Two Integral Plate Stiffeners”, (“Orthotropic” Case), (Boundary Conditions in y -direction CC).....	177

Figure 13. Mode Shapes and Dimensionless Natural Frequencies of “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Two Integral Plate Stiffeners”, (“Orthotropic” Case), (Boundary Conditions in y-direction SS).....178

Figure 14. Mode Shapes and Dimensionless Natural Frequencies of “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Two Integral Plate Stiffeners” (“Orthotropic” Case), (Boundary Conditions in y-direction FF).....179

Figure 15. Mode Shapes and Dimensionless Natural Frequencies of “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Two Integral Plate Stiffeners” (“Orthotropic” Case), (Boundary Conditions in y-direction CS).....180

Figure 16. Mode Shapes and Dimensionless Natural Frequencies of “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Two Integral Plate Stiffeners” (“Orthotropic” Case), (Boundary Conditions in y-direction CF).....181

Figure 17. Mode Shapes and Dimensionless Natural Frequencies of “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Two Integral Plate Stiffeners” (“Orthotropic” Case), (Boundary Conditions in y-direction SF).....182

Figure 18. Mode Shapes and Dimensionless Natural Frequencies of “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Two Integral Plate Stiffeners” (“Isotropic” Case), (Boundary Conditions in y-direction CC).....183

Figure 19. Mode Shapes and Dimensionless Natural Frequencies of “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Two Integral Plate Stiffeners” (“Isotropic” Case), (Boundary Conditions in y-direction SS).....184

Figure 20. Mode Shapes and Dimensionless Natural Frequencies of “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Two Integral Plate Stiffeners” (“Isotropic” Case), (Boundary Conditions in y-direction FF).....185

Figure 21. Mode Shapes and Dimensionless Natural Frequencies of “Integrally-Stiffened

and/or Stepped-Thickness Plate or Panel System with Two Integral Plate Stiffeners”
(“Isotropic” Case), (Boundary Conditions in y-direction CS).....186

**Figure 22. Mode Shapes and Dimensionless Natural Frequencies of “Integrally-Stiffened
and/or Stepped-Thickness Plate or Panel System with Two Integral Plate Stiffeners”**
(“Isotropic” Case), (Boundary Conditions in y-direction CF).....187

**Figure 23. Mode Shapes and Dimensionless Natural Frequencies of “Integrally-Stiffened
and/or Stepped-Thickness Plate or Panel System with Two Integral Plate Stiffeners”**
(“Isotropic” Case), (Boundary Conditions in y-direction SF).....188

**Figure 24. “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Aspect Ratio a/L” in “Integrally-Stiffened
and/or Stepped-Thickness Plate or Panel System with Two Stiffeners”**
(“Orthotropic Case”) ,189

(a) Boundary Conditions In y-Directions CC,

(b) Boundary Conditions In y-Directions SS

**Figure 25. “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Aspect Ratio a/L” in “Integrally-Stiffened
and/or Stepped-Thickness Plate or Panel System with Two Stiffeners”**
(“Orthotropic Case”) ,.....190

(a) Boundary Conditions In y-Directions FF,

(b) Boundary Conditions In y-Directions CS

**Figure 26. “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Aspect Ratio a/L” in “Integrally-Stiffened
and/or Stepped -Thickness Plate or Panel System with Two Stiffeners”,**
(“Orthotropic Case”).....191

(a) Boundary Conditions In y-Directions CF,

(b) Boundary Conditions In y-Directions SF

Figure 27. “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Stiffeners Length Ratio $\ell_1 (\ell_{II})/L$ ” in “Integrally-Stiffened and/or Stepped -Thickness Plate or Panel System with Two Stiffeners”

(“Orthotropic Case”) ,.....192

(a) Boundary Conditions In y-Directions CC

(b) Boundary Conditions In y-Directions SS

Figure 28. “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Stiffeners Length Ratio $\ell_1 (\ell_{II})/L$ ” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Two Stiffeners”

(“Orthotropic Case”) ,..... 193

(a) Boundary Conditions In y-Directions FF

(b) Boundary Conditions In y-Directions CS

Figure 29. “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Stiffeners Length Ratio $\ell_1 (\ell_{II})/L$ ” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Two Stiffeners”194

(“Orthotropic Case”)

(a) Boundary Conditions In y-Directions CF

(b) Boundary Conditions In y-Directions SF

Figure 30. “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Thickness Ratio $h_3 (=h_4= h_5)/h_1(=h_2 =0.04)$ ” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Two Stiffeners”

(“Orthotropic Case”) ,.....195

(a) Boundary Conditions In y-Directions CC

(b) Boundary Conditions In y-Directions SS

Figure 31. “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Thickness Ratio $h_3 (=h_4= h_5)/h_1(=h_2 =0.04)$ ” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Two Stiffeners”

(“Orthotropic Case”)196

(a) Boundary Conditions In y-Directions FF

(b) Boundary Conditions In y-Directions CS

Figure 32. “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Thickness Ratio $h_3 (=h_4= h_5)/h_1(=h_2 =0.04)$ ” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Two Stiffeners”

(“Orthotropic Case”) ,197

(a) Boundary Conditions In y-Directions CF

(b) Boundary Conditions In y-Directions SF

Figure 33. “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Bending Stiffness Ratio $D_{22}^{(1)} (=D_{22}^{(2)}) / D_{22}^{(3)} (=D_{22}^{(4)}= D_{22}^{(5)})$ ” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Two Stiffeners”

(“Orthotropic Case”),198

(a) Boundary Conditions In y-Directions CC

(b) Boundary Conditions In y-Directions SS

Figure 34. “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Bending Stiffness Ratio $D_{22}^{(1)} (=D_{22}^{(2)}) / D_{22}^{(3)} (=D_{22}^{(4)}= D_{22}^{(5)})$ ” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Two Stiffeners”

(“Orthotropic Case”),199

(a) Boundary Conditions In y-Directions FF

(b) Boundary Conditions In y-Directions CS

Figure 35. “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Bending Stiffness Ratio $D_{22}^{(1)} (=D_{22}^{(2)}) / D_{22}^{(3)} (=D_{22}^{(4)}= D_{22}^{(5)})$ ” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Two Stiffeners”

(“Orthotropic Case”),.....200

(a) Boundary Conditions In y-Directions CF

(b) Boundary Conditions In y-Directions SF

Figure 36. “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Aspect Ratio a/L ” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Two Stiffeners”

(“Isotropic Case”),201

(a) Boundary Conditions In y-Directions CC

(b) Boundary Conditions In y-Directions SS

Figure 37. “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Aspect Ratio a/L ” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Two Stiffeners”

(“Isotropic Case”),202

(a) Boundary Conditions In y-Directions FF

(b) Boundary Conditions In y-Directions CS

Figure 38. “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Aspect Ratio a/L ” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Two Stiffeners”

(“Isotropic Case”),203

(a) Boundary Conditions In y-Directions SF

(b) Boundary Conditions In y-Directions CF

Figure 39. “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Aspect Ratio a/L ” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Two Stiffeners”

(“Isotropic Case”),.....204

(a) Boundary Conditions In y-Directions CC

(b) Boundary Conditions In y-Directions SS

Figure 40. “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Aspect Ratio a/L” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Two Stiffeners”

(“Isotropic Case”),.....205

(a) Boundary Conditions In y-Directions FF

(b) Boundary Conditions In y-Directions CS

Figure 41. “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Aspect Ratio a/L” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Two Stiffeners”

(“Isotropic Case”),.....206

(a) Boundary Conditions In y-Directions CF

(b) Boundary Conditions In y-Directions SF

Figure 42. “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Thickness Ratio $h_3 (=h_4= h_5)/h_1(=h_2 =0.04)$ ” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Two Stiffeners”

(“Isotropic Case”),.....207

(a) Boundary Conditions In y-Directions CC

(b) Boundary Conditions In y-Directions SS

Figure 43. “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Thickness Ratio $h_3 (=h_4= h_5)/h_1(=h_2 =0.04)$ ” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Two Stiffeners

(“Isotropic Case”),.....208

(a) Boundary Conditions In y-Directions FF

(b) Boundary Conditions In y-Directions CS

Figure 44. “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Thickness Ratio $h_3 (=h_4= h_5)/h_1(=h_2 =0.04)$ ” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Two Stiffeners”

(“Isotropic Case”),.....209

(a) Boundary Conditions In y-Directions CF

(b) Boundary Conditions In y-Directions SF

Figure 45. “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Bending Stiffness Ratio $D_{22}^{(1)} (=D_{22}^{(2)}) / D_{22}^{(3)} (=D_{22}^{(4)}= D_{22}^{(5)})$ ” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Two Stiffeners”

(“Isotropic Case”),210

(a) Boundary Conditions In y-Directions CC

(b) Boundary Conditions In y-Directions SS

Figure 46. “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Bending Stiffness Ratio $D_{22}^{(1)} (=D_{22}^{(2)}) / D_{22}^{(3)} (=D_{22}^{(4)}= D_{22}^{(5)})$ ” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Two Stiffeners”

(“Isotropic Case”),211

(a) Boundary Conditions In y-Directions FF

(b) Boundary Conditions In y-Directions CS

Figure 47. “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Bending Stiffness Ratio $D_{22}^{(1)} (=D_{22}^{(2)}) / D_{22}^{(3)} (=D_{22}^{(4)}= D_{22}^{(5)})$ ” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Two Stiffeners”

(“Isotropic Case”),212

(a) Boundary Conditions In y-Directions CF

(b) Boundary Conditions In y-Directions SF

Figure 48. Mode Shapes and Dimensionless Natural Frequencies of “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Three Integral Plate Stiffeners”, (“Orthotropic” Case), (Boundary Conditions in y-direction CC).....214

Figure 49. Mode Shapes and Dimensionless Natural Frequencies of “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Three Integral Plate Stiffeners”, (“Orthotropic” Case), (Boundary Conditions in y-direction SS).....215

Figure 50. Mode Shapes and Dimensionless Natural Frequencies of “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Three Integral Plate Stiffeners” (“Orthotropic” Case), (Boundary Conditions in y-direction FF).....216

Figure 51. Mode Shapes and Dimensionless Natural Frequencies of “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Three Integral Plate Stiffeners” (“Orthotropic” Case), (Boundary Conditions in y-direction CS).....217

Figure 52. Mode Shapes and Dimensionless Natural Frequencies of “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Three Integral Plate Stiffeners” (“Orthotropic” Case), (Boundary Conditions in y-direction CF).....218

Figure 53. Mode Shapes and Dimensionless Natural Frequencies of “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Three Integral Plate Stiffeners” (“Orthotropic” Case), (Boundary Conditions in y-direction SF).....219

Figure 54. Mode Shapes and Dimensionless Natural Frequencies of “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Three Integral Plate Stiffeners” (“Isotropic” Case), (Boundary Conditions in y-direction CC).....220

Figure 55. Mode Shapes and Dimensionless Natural Frequencies of “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Three Integral Plate Stiffeners”

(“Isotropic” Case), (Boundary Conditions in y-direction SS).....221

Figure 56. Mode Shapes and Dimensionless Natural Frequencies of “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Three Integral Plate Stiffeners”

(“Isotropic” Case), (Boundary Conditions in y-direction FF).....222

Figure 57. Mode Shapes and Dimensionless Natural Frequencies of “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Three Integral Plate Stiffeners”

(“Isotropic” Case), (Boundary Conditions in y-direction CS).....223

Figure 58. Mode Shapes and Dimensionless Natural Frequencies of “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Three Integral Plate Stiffeners”

(“Isotropic” Case), (Boundary Conditions in y-direction CF).....224

Figure 59. Mode Shapes and Dimensionless Natural Frequencies of “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Three Integral Plate Stiffeners”

(“Isotropic” Case), (Boundary Conditions in y-direction SF).....225

Figure 60. “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Aspect Ratio a/L” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Three Stiffeners”

(“Orthotropic Case”) ,226

(a) Boundary Conditions In Y-Directions CC,

(b) Boundary Conditions In Y-Directions SS

Figure 61. “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Aspect Ratio a/L” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Three Stiffeners”

(“Orthotropic Case”) ,.....227

(a) Boundary Conditions In Y-Directions FF,

(b) Boundary Conditions In Y-Directions CS

Figure 62. “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Aspect Ratio a/L ” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Three Stiffeners”, (“Orthotropic Case”).....228

(a) Boundary Conditions In Y-Directions CF,

(b) Boundary Conditions In Y-Directions SF

Figure 63. “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Stiffeners Length Ratio $\ell_i (= \ell_{II} = \ell_{III})/L$ ” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Three Stiffeners” (“Orthotropic Case”) ,.....229

(a) Boundary Conditions In Y-Directions CC

(b) Boundary Conditions In Y-Directions SS

Figure 64. “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Stiffeners Length Ratio $\ell_i (= \ell_{II} = \ell_{III})/L$ ” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Three Stiffeners” (“Orthotropic Case”) ,.....230

(a) Boundary Conditions In Y-Directions FF

(b) Boundary Conditions In Y-Directions CS

Figure 65. “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Stiffeners Length Ratio $\ell_i (= \ell_{II} = \ell_{III})/L$ ” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Three Stiffeners” (“Orthotropic Case”)231

(a) Boundary Conditions In Y-Directions CF

(b) Boundary Conditions In Y-Directions SF

Figure 66 “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Thickness Ratio $h_4 (=h_5= h_6= h_7)/h_1 (=h_2= h_3 =0.04)$ ” in “Integrally- Stiffened and/or Stepped-Thickness Plate or Panel System with Three Stiffeners”

(“Orthotropic Case”),.....232

(a) Boundary Conditions In Y-Directions CC

(b) Boundary Conditions In Y-Directions SS

Figure 67 “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Thickness Ratio $h_4 (=h_5= h_6= h_7)/h_1 (=h_2= h_3 =0.04)$ ” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Three Stiffeners”

(“Orthotropic Case”),.....233

(a) Boundary Conditions In Y-Directions FF

(b) Boundary Conditions In Y-Directions CS

Figure 68 “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Thickness Ratio $h_4 (=h_5= h_6= h_7)/h_1 (=h_2= h_3 =0.04)$ ” in “Integrally- Stiffened and/or Stepped-Thickness Plate or Panel System with Three Stiffeners”

(“Orthotropic Case”),.....234

(a) Boundary Conditions In Y-Directions CF

(b) Boundary Conditions In Y-Directions SF

Figure 69 “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Bending Stiffness Ratio $D_{22}^{(4)} (=D_{22}^{(5)}= D_{22}^{(6)}= D_{22}^{(7)}) / D_{22}^{(1)} (= D_{22}^{(2)}= D_{22}^{(3)})$ ” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Three Stiffeners”

(“Orthotropic Case”),.....235

(a) Boundary Conditions In Y-Directions CC

(b) Boundary Conditions In Y-Directions SS

Figure 70 “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Bending Stiffness Ratio $D_{22}^{(4)}$ ($=D_{22}^{(5)}=D_{22}^{(6)}=D_{22}^{(7)}$) / $D_{22}^{(1)}$ ($=D_{22}^{(2)}=D_{22}^{(3)}$)” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Three Stiffeners”

(“Orthotropic Case”),.....236

(a) Boundary Conditions In Y-Directions FF

(b) Boundary Conditions In Y-Directions CS

Figure 71 “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Bending Stiffness Ratio $D_{22}^{(4)}$ ($=D_{22}^{(5)}=D_{22}^{(6)}=D_{22}^{(7)}$) / $D_{22}^{(1)}$ ($=D_{22}^{(2)}=D_{22}^{(3)}$)” in Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Three Stiffeners”

(“Orthotropic Case”),.....237

(a) Boundary Conditions In Y-Directions CF

(b) Boundary Conditions In Y-Directions SF

Figure 72 “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Aspect Ratio a/L ” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Three Stiffeners”

(“Isotropic Case”),238

(a) Boundary Conditions In Y-Directions CC

(b) Boundary Conditions In Y-Directions SS

Figure 73 “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Aspect Ratio a/L ” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Three Stiffeners”

(“Isotropic Case”),239

(a) Boundary Conditions In Y-Directions FF

(b) Boundary Conditions In Y-Directions CS

Figure 74 “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Aspect Ratio a/L ” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Three Stiffeners”

(“Isotropic Case”),240

(a) Boundary Conditions In Y-Directions SF

(b) Boundary Conditions In Y-Directions CF

Figure 75 “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Aspect Ratio a/L ” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Three Stiffeners”

(“Isotropic Case”),.....241

(a) Boundary Conditions In Y-Directions CC

(b) Boundary Conditions In Y-Directions SS

Figure 76 “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Aspect Ratio a/L ” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Three Stiffeners”

(“Isotropic Case”),.....242

(a) Boundary Conditions In Y-Directions FF

(b) Boundary Conditions In Y-Directions CS

Figure 77 “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Aspect Ratio a/L ” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Three Stiffeners”

(“Isotropic Case”),.....243

(a) Boundary Conditions In Y-Directions CF

(b) Boundary Conditions In Y-Directions SF

Figure 78 “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Thickness Ratio $h_4 (=h_5= h_6= h_7)/h_1 (=h_2= h_3 =0.04)$ ” in “Integrally-Stiffened and/or Stepped-Thickness Plate or Panel System with Three Stiffeners”

(“Isotropic Case”),.....244

(a) Boundary Conditions In Y-Directions CC

(b) Boundary Conditions In Y-Directions SS

Figure 79 “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Thickness Ratio $h_4 (=h_5= h_6= h_7)/h_1(=h_2= h_3 =0.04)$ ” in “Integrally-Stiffened and/or Stepped -Thickness Plate or Panel System with Three Stiffeners”

(“Isotropic Case”),.....245

(a) Boundary Conditions In Y-Directions FF

(b) Boundary Conditions In Y-Directions CS

Figure 80 “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Thickness Ratio $h_4 (=h_5= h_6= h_7)/h_1(=h_2= h_3 =0.04)$ ” in “Integrally-Stiffened and/or Stepped -Thickness Plate or Panel System with Three Stiffeners”

(“Isotropic Case”),.....246

(a) Boundary Conditions In Y-Directions CF

(b) Boundary Conditions In Y-Directions SF

Figure 81 “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Bending Stiffness Ratio $D_{22}^{(4)} (=D_{22}^{(5)}= D_{22}^{(6)}= D_{22}^{(7)}) / D_{22}^{(1)} (= D_{22}^{(2)}= D_{22}^{(3)})$ ” in “Integrally- Stiffened and/or Stepped -Thickness Plate or Panel System with Three Stiffeners”

(“Isotropic Case”),247

(a) Boundary Conditions In y-Directions CC

(b) Boundary Conditions In y-Directions SS

Figure 82 “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Bending Stiffness Ratio $D_{22}^{(4)} (=D_{22}^{(5)}= D_{22}^{(6)}= D_{22}^{(7)}) / D_{22}^{(1)} (= D_{22}^{(2)}= D_{22}^{(3)})$ ” in “Integrally- Stiffened and/or Stepped -Thickness Plate or Panel System with Three Stiffeners”

(“Isotropic Case”),.....248

(a) Boundary Conditions In y-Directions FF

(b) Boundary Conditions In y-Directions CS

Figure 83 “Dimensionless Nat Freq’s $\bar{\Omega}$ ” versus “Bending Stiffness Ratio $D_{22}^{(4)} (=D_{22}^{(5)}= D_{22}^{(6)}= D_{22}^{(7)}) / D_{22}^{(1)} (= D_{22}^{(2)}= D_{22}^{(3)})$ ” in “Integrally- Stiffened and/or Stepped -Thickness Plate or Panel System with Three Stiffeners”

(“Isotropic Case”),249

(a) Boundary Conditions In y-Directions CF

(b) Boundary Conditions In y-Directions SF

Figure 84.a Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate or panel with Two Bonded Stiffening Plate Strips” , (“Orthotropic” Case with “Hard” adhesive) (Boundary Conditions in y-direction FFFFCC)251

Figure 84.b Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate or Panel with Two Bonded Stiffening Plate Strips” , (“Orthotropic” Case with “Soft” adhesive) (Boundary Conditions in y-direction FFFFCC).....252

Figure 84.c Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate or Panel with Two Bonded Stiffening Plate Strips” , (“Orthotropic” Case with “Hard” adhesive) (Boundary Conditions in y-direction FFFFCC).....253

Figure 85.a Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate or Panel with Two Bonded Stiffening Plate Strips” , (“Orthotropic” Case with “Hard” adhesive)(Boundary Conditions in y-direction FFFFSS).....254

Figure 85.b Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate or Panel with Two Bonded Stiffening Plate Strips” , (“Orthotropic” Case with “Soft” adhesive)(Boundary Conditions in y-direction FFFFSS).....255

Figure 86.a Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate or Panel with Two Bonded Stiffening Plate Strips” , (“Orthotropic” Case with “Hard” adhesive)(Boundary Conditions in y-direction FFFFFF).....256

Figure 86.b Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate or Panel with Two Bonded Stiffening Plate Strips” , (“Orthotropic” Case with “Soft” adhesive)(Boundary Conditions in y-direction FFFFFF).....257

Figure 87.a Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate or Panel with Two Bonded Stiffening Plate Strips” , (“Orthotropic” Case with “Hard” adhesive)(Boundary Conditions in y-direction FFFCS).....258

Figure 87.b Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate or Panel with Two Bonded Stiffening Plate Strips” , (“Orthotropic” Case with “Soft” adhesive)(Boundary Conditions in y-direction FFFCS).....259

Figure 88.a Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate or Panel with Two Bonded Stiffening Plate Strips” , (“Orthotropic” Case with “Hard” adhesive)(Boundary Conditions in y-direction FFFCF).....260

Figure 88.b Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate or Panel with Two Bonded Stiffening Plate Strips” , (“Orthotropic” Case with “Soft” adhesive)(Boundary Conditions in y-direction FFFCF).....261

Figure 89.a Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate or Panel with Two Bonded Stiffening Plate Strips” , (“Orthotropic” Case with “Hard” adhesive)(Boundary Conditions in y-direction FFFSF).....262

Figure 89.b Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate or Panel with Two Bonded Stiffening Plate Strips” , (“Orthotropic” Case with “Soft” adhesive)(Boundary Conditions in y-direction FFFSF).....263

Figure 90.a Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate or Panel with Two Bonded Stiffening Plate Strips” , (“Isotropic” Case with “Hard” adhesive) (Boundary Conditions in y-direction FFFCC).....264

Figure 90.b Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate or Panel with Two Bonded Stiffening Plate Strips” , (“Isotropic” Case with “Soft” adhesive) (Boundary Conditions in y-direction FFFCC).....265

Figure 91.a Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate or Panel with Two Bonded Stiffening Plate Strips” , (“Isotropic” Case with “Hard” adhesive) (Boundary Conditions in y-direction FFFSS).....266

Figure 91.b Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate or Panel with Two Bonded Stiffening Plate Strips” , (“Isotropic” Case with “Soft” adhesive) (Boundary Conditions in y-direction FFFFSS).....267

Figure 92.a Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate or Panel with Two Bonded Stiffening Plate Strips” , (“Isotropic” Case with “Hard” adhesive) (Boundary Conditions in y-direction FFFFFF).....268

Figure 92.b Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate or Panel with Two Bonded Stiffening Plate Strips” , (“ Isotropic” Case with “Soft” adhesive) (Boundary Conditions in y-direction FFFFFF).....269

Figure 93.a Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate or Panel with Two Bonded Stiffening Plate Strips” , (“ Isotropic” Case with “Hard” adhesive) (Boundary Conditions in y-direction FFFFCS).....270

Figure 93.b Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate or Panel with Two Bonded Stiffening Plate Strips” , (“ Isotropic” Case with “Soft” adhesive) (Boundary Conditions in y-direction FFFFCS).....271

Figure 94.a Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate or Panel with Two Bonded Stiffening Plate Strips” , (“ Isotropic” Case with “Hard” adhesive) (Boundary Conditions in y-direction FFFF CF).....272

Figure 94.b Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate or Panel with Two Bonded Stiffening Plate Strips” , (“ Isotropic” Case with “Soft” adhesive) (Boundary Conditions in y-direction FFFF CF).....273

Figure 95.a Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate or Panel with Two Bonded Stiffening Plate Strips” , (“ Isotropic” Case with “Hard” adhesive) (Boundary Conditions in y-direction FFFF SF).....274

Figure 95.b Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate or Panel with Two Bonded Stiffening Plate Strips” , (“ Isotropic” Case with “Soft” adhesive) (Boundary Conditions in y-direction FFFSF).....275

Figure 96 Dimensionless Nat. Freqs versus “Aspect Ratio a/L” in “Orthotropic Base Plate with Two Bonded Stiffening Plate Strips”, (“Orthotropic” Case), (Boundary Conditions in y-direction FFFCC),276

 a) “Hard” Adhesive Case

 b) “Soft” Adhesive Case

Figure 97 Dimensionless Nat. Freqs versus “Aspect Ratio a/L” in “Orthotropic Base Plate with Two Bonded Stiffening Plate Strips”, (“Orthotropic” Case), (Boundary Conditions in y-direction FFFSS),.....277

 a) “Hard” Adhesive Case

 b) “Soft” Adhesive Case

Figure 98 Dimensionless Nat. Freqs versus “Aspect Ratio a/L” in “Orthotropic Base Plate with Two Bonded Stiffening Plate Strips”, (“Orthotropic” Case), (Boundary Conditions in y-direction FFFFF),.....278

 a) “Hard” Adhesive Case

 b) “Soft” Adhesive Case

Figure 99 Dimensionless Nat. Freqs versus “Aspect Ratio a/L” in “Orthotropic Base Plate with Two Bonded Stiffening Plate Strips”, (“Orthotropic” Case), (Boundary Conditions in y-direction FFFCS),.....279

 a) “Hard” Adhesive Case

 b) “Soft” Adhesive Case

Figure 100 Dimensionless Nat. Freqs versus “Aspect Ratio a/L ” in “Orthotropic Base Plate with Two Bonded Stiffening Plate Strips”, (“Orthotropic” Case),

(Boundary Conditions in y-direction FFFFCF),.....280

- a) “Hard” Adhesive Case
- b) “Soft” Adhesive Case

Figure 101 Dimensionless Nat. Freqs versus “Aspect Ratio a/L ” in “Orthotropic Base Plate with Two Bonded Stiffening Plate Strips”, (“Orthotropic” Case),

(Boundary Conditions in y-direction FFFFSF),.....281

- a) “Hard” Adhesive Case
- b) “Soft” Adhesive Case

Figure 102 Dimensionless Nat. Freqs versus “Stiffener Length (or Width) Ratio $\ell_i(=\ell_{ii})/L$ ” in “Orthotropic Base Plate with Two Bonded Stiffening Plate Strips”.

(“Orthotropic” Case),

(Boundary Conditions in y-direction FFFFCF),.....282

- a) “Hard” Adhesive Case
- b) “Soft” Adhesive Case

Figure 103 Dimensionless Nat. Freqs versus “Stiffener Length (or Width) Ratio $\ell_i(=\ell_{ii})/L$ ” in “Orthotropic Base Plate with Two Bonded Stiffening Plate Strips”.

(“Orthotropic” Case),

(Boundary Conditions in y-direction FFFFSF),.....283

- a) “Hard” Adhesive Case
- b) “Soft” Adhesive Case

Figure 104 Dimensionless Nat. Freqs versus “Stiffener Length (or Width) Ratio

$\ell_1(=\ell_{II})/L$ in “Orthotropic Base Plate with Two Bonded Stiffening Plate Strips”.
 (“Orthotropic” Case),
 (Boundary Conditions in y-direction FFFFFF).....284

- a) “Hard” Adhesive Case
- b) “Soft” Adhesive Case

Figure 105 Dimensionless Nat. Freqs versus “Stiffener Length (or Width) Ratio

$\ell_1(=\ell_{II})/L$ in “Orthotropic Base Plate with Two Bonded Stiffening Plate Strips”.
 (“Orthotropic” Case),
 (Boundary Conditions in y-direction FFFFCF).....285

- a) “Hard” Adhesive Case
- b) “Soft” Adhesive Case

Figure 106 Dimensionless Nat. Freqs versus “Stiffener Length (or Width) Ratio

$\ell_1(=\ell_{II})/L$ in “Orthotropic Base Plate with Two Bonded Stiffening Plate Strips”.
 (“Orthotropic” Case),
 (Boundary Conditions in y-direction FFFFCF).....286

- a) “Hard” Adhesive Case
- b) “Soft” Adhesive Case

Figure 107 Dimensionless Nat. Freqs versus “Stiffener Length (or Width) Ratio

$\ell_1(=\ell_{II})/L$ in “Orthotropic Base Plate with Two Bonded Stiffening Plate Strips”.
 (“Orthotropic” Case),
 (Boundary Conditions in y-direction FFFFSF).....287

- a) “Hard” Adhesive Case
- b) “Soft” Adhesive Case

**Figure 108 Dimensionless Nat. Freqs versus “Thickness Ratio $h_3/h_1(= h_2)$ ” in
“Orthotropic Base Plate with Two Bonded Stiffening Plate Strips”.
(“Orthotropic” Case),
(Boundary Conditions in y-direction FFFFCC).....288**

- a) “Hard” Adhesive Case
- b) “Soft” Adhesive Case

**Figure 109 Dimensionless Nat. Freqs versus “Thickness Ratio $h_3/h_1(= h_2)$ ” in
“Orthotropic Base Plate with Two Bonded Stiffening Plate Strips”.
(“Orthotropic” Case),
(Boundary Conditions in y-direction FFFFSS).....289**

- a) “Hard” Adhesive Case
- b) “Soft” Adhesive Case

**Figure 110 Dimensionless Nat. Freqs versus “Thickness Ratio $h_3/h_1(= h_2)$ ” in
“Orthotropic Base Plate with Two Bonded Stiffening Plate Strips”.
(“Orthotropic” Case),
(Boundary Conditions in y-direction FFFFFF).....290**

- a) “Hard” Adhesive Case
- b) “Soft” Adhesive Case

**Figure 111 Dimensionless Nat. Freqs versus “Thickness Ratio $h_3/h_1(= h_2)$ ” in
“Orthotropic Base Plate with Two Bonded Stiffening Plate Strips”.
(“Orthotropic” Case),
(Boundary Conditions in y-direction FFFFCS).....291**

- a) “Hard” Adhesive Case

b) "Soft" Adhesive Case

Figure 112 Dimensionless Nat. Freqs versus "Thickness Ratio $h_3/h_1 (= h_2)$ " in

"Orthotropic Base Plate with Two Bonded Stiffening Plate Strips".

("Orthotropic" Case),

(Boundary Conditions in y-direction FFFFCF).....292

a) "Hard" Adhesive Case

b) "Soft" Adhesive Case

Figure 113 Dimensionless Nat. Freqs versus "Thickness Ratio $h_3/h_1 (= h_2)$ " in

"Orthotropic Base Plate with Two Bonded Stiffening Plate Strips".

("Orthotropic" Case),

(Boundary Conditions in y-direction FFFFSF).....293

a) "Hard" Adhesive Case

b) "Soft" Adhesive Case

Figure 114 Dimensionless Nat. Freqs versus "Bending Stiffness Ratio $D_{22}^{(3)} / D_{22}^{(1)} (=D_{22}^{(2)})$ "

in "Orthotropic Base Plate with Two Bonded Stiffening Plate Strips".

("Orthotropic" Case)

(Boundary Conditions in y-direction FFFCC).....294

a) "Hard" Adhesive Case

b) "Soft" Adhesive Case

Figure 115 Dimensionless Nat. Freqs versus "Bending Stiffness Ratio $D_{22}^{(3)} / D_{22}^{(1)} (=D_{22}^{(2)})$ "

in "Orthotropic Base Plate with Two Bonded Stiffening Plate Strips".

("Orthotropic" Case)

(Boundary Conditions in y-direction FFFSS).....295

a) "Hard" Adhesive Case

b) "Soft" Adhesive Case

Figure 116 Dimensionless Nat. Freqs versus "Bending Stiffness Ratio $D_{22}^{(3)} / D_{22}^{(1)} (=D_{22}^{(2)})$ " in "Orthotropic Base Plate with Two Bonded Stiffening Plate Strips".

("Orthotropic" Case)

(Boundary Conditions in y-direction FFFFFF).....296

a) "Hard" Adhesive Case

b) "Soft" Adhesive Case

Figure 117 Dimensionless Nat. Freqs versus "Bending Stiffness Ratio $D_{22}^{(3)} / D_{22}^{(1)} (=D_{22}^{(2)})$ " in "Orthotropic Base Plate with Two Bonded Stiffening Plate Strips".

("Orthotropic" Case)

(Boundary Conditions in y-direction FFFFCS).....297

a) "Hard" Adhesive Case

b) "Soft" Adhesive Case

Figure 118 Dimensionless Nat. Freqs versus "Bending Stiffness Ratio $D_{22}^{(3)} / D_{22}^{(1)} (=D_{22}^{(2)})$ " in "Orthotropic Base Plate with Two Bonded Stiffening Plate Strips".

("Orthotropic" Case)

(Boundary Conditions in y-direction FFFFCF).....298

a) "Hard" Adhesive Case

b) "Soft" Adhesive Case

Figure 119 Dimensionless Nat. Freqs versus "Bending Stiffness Ratio $D_{22}^{(3)} / D_{22}^{(1)} (=D_{22}^{(2)})$ " in "Orthotropic Base Plate with Two Bonded Stiffening Plate Strips".

("Orthotropic" Case)

(Boundary Conditions in y-direction FFFFSF).....299

a) "Hard" Adhesive Case

b) "Soft" Adhesive Case

Figure 120 Dimensionless Nat. Freqs versus "Aspect Ratio a/L " in "Orthotropic Base Plate with Two Bonded Stiffening Plate Strips", ("Isotropic" Case),
(Boundary Conditions in y-direction FFFFCC),.....300

a) "Hard" Adhesive Case

b) "Soft" Adhesive Case

Figure 121 Dimensionless Nat. Freqs versus "Aspect Ratio a/L " in "Isotropic Base Plate With Two Bonded Stiffening Plate Strips", ("Isotropic" Case),
(Boundary Conditions in y-direction FFFFSS),.....301

a) "Hard" Adhesive Case

b) "Soft" Adhesive Case

Figure 122 Dimensionless Nat. Freqs versus "Aspect Ratio a/L " in "Isotropic Base Plate with Two Bonded Stiffening Plate Strips", ("Isotropic" Case),
(Boundary Conditions in y-direction FFFFFF),.....302

a) "Hard" Adhesive Case

b) "Soft" Adhesive Case

Figure 123 Dimensionless Nat. Freqs versus "Aspect Ratio a/L " in "Isotropic Base Plate with Two Bonded Stiffening Plate Strips", ("Isotropic" Case),
(Boundary Conditions in y-direction FFFFCS),.....303

a) "Hard" Adhesive Case

b) "Soft" Adhesive Case

Figure 124 Dimensionless Nat. Freqs versus "Aspect Ratio a/L " in "Isotropic Base Plate

with Two Bonded Stiffening Plate Strips”, (“Isotropic” Case),
 (Boundary Conditions in y-direction FFFFCF),.....304

- a) “Hard” Adhesive Case
- b) “Soft” Adhesive Case

Figure 125 Dimensionless Nat. Freqs versus “Aspect Ratio a/L ” in “Isotropic Base Plate
 with Two Bonded Stiffening Plate Strips”, (“Isotropic” Case),
 (Boundary Conditions in y-direction FFFFSF),.....305

- a) “Hard” Adhesive Case
- b) “Soft” Adhesive Case

Figure 126 Dimensionless Nat. Freqs versus “Stiffener Length (or Width) Ratio
 $\ell_i(=\ell_{ii})/L$ ” in “Isotropic Base Plate with Two Bonded Stiffening Plate Strips”.
 (“Isotropic” Case),
 (Boundary Conditions in y-direction FFFFCF),.....306

- a) “Hard” Adhesive Case
- b) “Soft” Adhesive Case

Figure 127 Dimensionless Nat. Freqs versus “Stiffener Length (or Width) Ratio
 $\ell_i(=\ell_{ii})/L$ ” in “Isotropic Base Plate with Two Bonded Stiffening Plate Strips”.
 (“Isotropic” Case),
 (Boundary Conditions in y-direction FFFFSF),.....307

- a) “Hard” Adhesive Case
- b) “Soft” Adhesive Case

Figure 128 Dimensionless Nat. Freqs versus “Stiffener Length (or Width) Ratio
 $\ell_i(=\ell_{ii})/L$ ” in “Isotropic Base Plate with Two Bonded Stiffening Plate Strips”.

(“Isotropic” Case),

(Boundary Conditions in y-direction FFFFFF).....308

a) “Hard” Adhesive Case

b) “Soft” Adhesive Case

Figure 129 Dimensionless Nat. Freqs versus “Stiffener Length (or Width) Ratio

$\ell_i(=\ell_{ii})/L$ in “Isotropic Base Plate with Two Bonded Stiffening Plate Strips”.

(“Isotropic” Case),

(Boundary Conditions in y-direction FFFFCF).....309

a) “Hard” Adhesive Case

b) “Soft” Adhesive Case

Figure 130 Dimensionless Nat. Freqs versus “Stiffener Length (or Width) Ratio

$\ell_i(=\ell_{ii})/L$ in “Isotropic Base Plate with Two Bonded Stiffening Plate Strips”.

(“Isotropic” Case),

(Boundary Conditions in y-direction FFFFCF).....310

a) “Hard” Adhesive Case

b) “Soft” Adhesive Case

Figure 131 Dimensionless Nat. Freqs versus “Stiffener Length (or Width) Ratio

$\ell_i(=\ell_{ii})/L$ in “Isotropic Base Plate with Two Bonded Stiffening Plate Strips”.

(“Isotropic” Case),

(Boundary Conditions in y-direction FFFFSF).....311

a) “Hard” Adhesive Case

b) “Soft” Adhesive Case

Figure 132 Dimensionless Nat. Freqs versus “Thickness Ratio $h_3/h_1(=h_2)$ ” in

“Isotropic Base Plate with Two Bonded Stiffening Plate Strips”.
(“Isotropic” Case),
(Boundary Conditions in y-direction FFFFCC).....312

- a) **“Hard” Adhesive Case**
- b) **“Soft” Adhesive Case**

Figure 133 Dimensionless Nat. Freqs versus “Thickness Ratio $h_3/h_1(= h_2)$ ” in

“Isotropic Base Plate with Two Bonded Stiffening Plate Strips”.
(“Isotropic” Case),
(Boundary Conditions in y-direction FFFFSS).....313

- a) **“Hard” Adhesive Case**
- b) **“Soft” Adhesive Case**

Figure 134 Dimensionless Nat. Freqs versus “Thickness Ratio $h_3/h_1(= h_2)$ ” in

“Isotropic Base Plate with Two Bonded Stiffening Plate Strips”.
(“Isotropic” Case),
(Boundary Conditions in y-direction FFFFFF).....314

- a) **“Hard” Adhesive Case**
- b) **“Soft” Adhesive Case**

Figure 135 Dimensionless Nat. Freqs versus “Thickness Ratio $h_3/h_1(= h_2)$ ” in

“Isotropic Base Plate with Two Bonded Stiffening Plate Strips”.
(“Isotropic” Case),
(Boundary Conditions in y-direction FFFFCS).....315

- a) **“Hard” Adhesive Case**
- b) **“Soft” Adhesive Case**

**Figure 136 Dimensionless Nat. Freqs versus “Thickness Ratio $h_3/h_1(= h_2)$ ” in
“Isotropic Base Plate with Two Bonded Stiffening Plate Strips”.**

(“Isotropic” Case),

(Boundary Conditions in y-direction FFFCF).....316

- a) “Hard” Adhesive Case
- b) “Soft” Adhesive Case

**Figure 137 Dimensionless Nat. Freqs versus “Thickness Ratio $h_3/h_1(= h_2)$ ” in
“Isotropic Base Plate with Two Bonded Stiffening Plate Strips”.**

(“Isotropic” Case),

(Boundary Conditions in y-direction FFFSF).....317

- a) “Hard” Adhesive Case
- b) “Soft” Adhesive Case

**Figure 138 Dimensionless Nat. Freqs versus “Bending Stiffness Ratio $D_{22}^{(3)} / D_{22}^{(1)} (=D_{22}^{(2)})$ ”
in “Isotropic Base Plate with Two Bonded Stiffening Plate Strips”.**

(“Isotropic” Case)

(Boundary Conditions in y-direction FFFCC).....318

- a) “Hard” Adhesive Case
- b) “Soft” Adhesive Case

**Figure 139 Dimensionless Nat. Freqs versus “Bending Stiffness Ratio $D_{22}^{(3)} / D_{22}^{(1)} (=D_{22}^{(2)})$ ”
in “Isotropic Base Plate with Two Bonded Stiffening Plate Strips”.**

(“Isotropic” Case)

(Boundary Conditions in y-direction FFFSS).....319

- a) “Hard” Adhesive Case

b) "Soft" Adhesive Case

Figure 140 Dimensionless Nat. Freqs versus "Bending Stiffness Ratio $D_{22}^{(3)} / D_{22}^{(1)} (=D_{22}^{(2)})$ " in "Isotropic Base Plate with Two Bonded Stiffening Plate Strips".

("Isotropic" Case)

(Boundary Conditions in y-direction FFFFFF).....320

a) "Hard" Adhesive Case

b) "Soft" Adhesive Case

Figure 141 Dimensionless Nat. Freqs versus "Bending Stiffness Ratio $D_{22(3)} / D_{22}^{(1)} (=D_{22}^{(2)})$ " in "Isotropic Base Plate with Two Bonded Stiffening Plate Strips".

("Isotropic" Case)

(Boundary Conditions in y-direction FFFFCF).....321

a) "Hard" Adhesive Case

b) "Soft" Adhesive Case

Figure 142 Dimensionless Nat. Freqs versus "Bending Stiffness Ratio $D_{22}^{(3)} / D_{22}^{(1)} (=D_{22}^{(2)})$ " in "Isotropic Base Plate with Two Bonded Stiffening Plate Strips".

("Isotropic" Case)

(Boundary Conditions in y-direction FFFFCF).....322

a) "Hard" Adhesive Case

b) "Soft" Adhesive Case

Figure 143 Dimensionless Nat. Freqs versus "Bending Stiffness Ratio $D_{22}^{(3)} / D_{22}^{(1)} (=D_{22}^{(2)})$ " in "Isotropic Base Plate with Two Bonded Stiffening Plate Strips".

("Isotropic" Case)

(Boundary Conditions in y-direction FFFFSS).....323

a) "Hard" Adhesive Case

b) "Soft" Adhesive Case

Figure 144.a Mode Shapes and Dimensionless Nat. Freqs of "Composite Base Plate or Panel with Three Bonded Stiffening Plate Strips" , (" Orthotropic" Case with "Hard" adhesive) (Boundary Conditions in y-direction FFFFFCC).....325

Figure 144.b Mode Shapes and Dimensionless Nat. Freqs of "Composite Base Plate or Panel with Three Bonded Stiffening Plate Strips" , (" Orthotropic" Case with "Soft" adhesive) (Boundary Conditions in y-direction FFFFFCC).....326

Figure 144.c Mode Shapes and Dimensionless Nat. Freqs of "Composite Base Plate or Panel with Three Bonded Stiffening Plate Strips" , (" Orthotropic" Case with "Hard" adhesive) (Boundary Conditions in y-direction FFFFFCC).....327

Figure 145.a Mode Shapes and Dimensionless Nat. Freqs of "Composite Base Plate or Panel with Three Bonded Stiffening Plate Strips" , (" Orthotropic" Case with "Hard" adhesive) (Boundary Conditions in y-direction FFFFFSS).....328

Figure 145.b Mode Shapes and Dimensionless Nat. Freqs of "Composite Base Plate or Panel with Three Bonded Stiffening Plate Strips" , (" Orthotropic" Case with "Soft" adhesive) (Boundary Conditions in y-direction FFFFFSS).....329

Figure 146.a Mode Shapes and Dimensionless Nat. Freqs of "Composite Base Plate

or Panel with Three Bonded Stiffening Plate Strips” ,
 (“ Orthotropic” Case with “Hard” adhesive)
 (Boundary Conditions in y-direction FFFFFFFCS).....330

Figure 146.b Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate
 or Panel with Three Bonded Stiffening Plate Strips” ,
 (“ Orthotropic” Case with “Soft” adhesive)
 (Boundary Conditions in y-direction FFFFFFFCS).....331

Figure 147.a Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate
 or Panel with Three Bonded Stiffening Plate Strips” ,
 (“ Orthotropic” Case with “Hard” adhesive)
 (Boundary Conditions in y-direction FFFFFFFCF).....332

Figure 147.b Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate
 or Panel with Three Bonded Stiffening Plate Strips” ,
 (“ Orthotropic” Case with “Soft” adhesive)
 (Boundary Conditions in y-direction FFFFFFFCF).....333

Figure 148.a Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate
 or Panel with Three Bonded Stiffening Plate Strips” ,
 (“ Orthotropic” Case with “Hard” adhesive)
 (Boundary Conditions in y-direction FFFFFFFSF).....334

Figure 148.b Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate
 or Panel with Three Bonded Stiffening Plate Strips” ,
 (“ Orthotropic” Case with “Soft” adhesive)
 (Boundary Conditions in y-direction FFFFFFFSF).....335

Figure 149.a Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate or panel with Three Bonded Stiffening Plate Strips” , (“ Isortopic” Case with “Hard” adhesive) (Boundary Conditions in y-direction FFFFFCC).....336

Figure 149.b Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate or Panel with Three Bonded Stiffening Plate Strips” , (“ Isortopic” Case with “Soft” adhesive) (Boundary Conditions in y-direction FFFFFCC).....337

Figure 150.a Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate or Panel with Three Bonded Stiffening Plate Strips” , (“ Isortopic” Case with “Hard” adhesive) (Boundary Conditions in y-direction FFFFFSS).....338

Figure 150.b Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate or Panel with Three Bonded Stiffening Plate Strips” , (“ Isortopic” Case with “Soft” adhesive) (Boundary Conditions in y-direction FFFFFSS).....339

Figure 151.a Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate or Panel with Three Bonded Stiffening Plate Strips” , (“ Isortopic” Case with “Hard” adhesive) (Boundary Conditions in y-direction FFFFFCS).....340

Figure 151.b Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate or Panel with Three Bonded Stiffening Plate Strips” , (“ Isortopic” Case with “Soft” adhesive)

(Boundary Conditions in y-direction FFFFFCS).....341

**Figure 152.a Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate
or Panel with Three Bonded Stiffening Plate Strips” ,**

(“ Isortopic” Case with “Hard” adhesive)

(Boundary Conditions in y-direction FFFFFCF).....342

**Figure 152.b Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate
or Panel with Three Bonded Stiffening Plate Strips” ,**

(“ Isortopic” Case with “Soft” adhesive)

(Boundary Conditions in y-direction FFFFFCF).....343

**Figure 153.a Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate
or Panel with Three Bonded Stiffening Plate Strips” ,**

(“ Isortopic” Case with “Hard” adhesive)

(Boundary Conditions in y-direction FFFFFSF).....344

**Figure 153.b Mode Shapes and Dimensionless Nat. Freqs of “Composite Base Plate
or Panel with Three Bonded Stiffening Plate Strips” ,**

(“ Isortopic” Case with “Soft” adhesive)

(Boundary Conditions in y-direction FFFFFSF).....345

Figure 154 Dimensionless Nat. Freqs versus “Aspect Ratio a/L” in

“Orthotropic Base Plate with Three Bonded Stiffening Plate Strips”

(“Orthotropic” Case)

(Boundary Conditions in y-direction FFFFFCC).....346

a) “Hard” Adhesive Case

b) “Soft” Adhesive Case

**Figure 155 Dimensionless Nat. Freqs versus “Aspect Ratio a/L ” in
“Orthotropic Base Plate with Three Bonded Stiffening Plate Strips”
(“Orthotropic” Case)
(Boundary Conditions in y -direction FFFFFSS).....347**

- a) “Hard” Adhesive Case
- b) “Soft” Adhesive Case

**Figure 156 Dimensionless Nat. Freqs versus “Aspect Ratio a/L ” in
“Orthotropic Base Plate with Three Bonded Stiffening Plate Strips”
(“Orthotropic” Case)
(Boundary Conditions in y -direction FFFFFCS).....348**

- a) “Hard” Adhesive Case
- b) “Soft” Adhesive Case

**Figure 157 Dimensionless Nat. Freqs versus “Aspect Ratio a/L ” in
“Orthotropic Base Plate with Three Bonded Stiffening Plate Strips”
(“Orthotropic” Case)
(Boundary Conditions in y -direction FFFFFCF).....349**

- a) “Hard” Adhesive Case
- b) “Soft” Adhesive Case

**Figure 158 Dimensionless Nat. Freqs versus “Aspect Ratio a/L ” in
“Orthotropic Base Plate with Three Bonded Stiffening Plate Strips”
(“Orthotropic” Case)
(Boundary Conditions in y -direction FFFFFSF).....350**

- a) “Hard” Adhesive Case

b) "Soft" Adhesive Case

Figure 159 Dimensionless Nat. Freqs versus "Aspect Ratio a/L" in

"Orthotropic Base Plate with Three Bonded Stiffening Plate Strips"

("Isotropic" Case)

(Boundary Conditions in y-direction FFFFFCC).....351

a) "Hard" Adhesive Case

b) "Soft" Adhesive Case

Figure 160 Dimensionless Nat. Freqs versus "Aspect Ratio a/L" in

"Orthotropic Base Plate with Three Bonded Stiffening Plate Strips"

("Isotropic" Case)

(Boundary Conditions in y-direction FFFFFSS).....352

a) "Hard" Adhesive Case

b) "Soft" Adhesive Case

Figure 161 Dimensionless Nat. Freqs versus "Aspect Ratio a/L" in

"Orthotropic Base Plate with Three Bonded Stiffening Plate Strips"

("Isotropic" Case)

(Boundary Conditions in y-direction FFFFFCS).....353

a) "Hard" Adhesive Case

b) "Soft" Adhesive Case

Figure 162 Dimensionless Nat. Freqs versus "Aspect Ratio a/L" in

"Orthotropic Base Plate with Three Bonded Stiffening Plate Strips"

("Isotropic" Case)

(Boundary Conditions in y-direction FFFFFCF).....354

a) "Hard" Adhesive Case

b) "Soft" Adhesive Case

Figure 163 Dimensionless Nat. Freqs versus "Aspect Ratio a/L " in

"Orthotropic Base Plate with Three Bonded Stiffening Plate Strips"

("Isotropic" Case)

(Boundary Conditions in y-direction FFFFFSF).....355

a) "Hard" Adhesive Case

b) "Soft" Adhesive Case

Figure 164 Dimensionless Nat. Freqs versus "Thickness Ratio $h_4/h_1 (= h_2 = h_3)$ " in

"Orthotropic Base Plate with Three Bonded Stiffening Plate Strips"

("Orthotropic" Case)

(Boundary Conditions in y-direction FFFFFCC).....356

c) "Hard" Adhesive Case

d) "Soft" Adhesive Case

Figure 165 Dimensionless Nat. Freqs versus "Thickness Ratio $h_4/h_1 (= h_2 = h_3)$ " in

"Orthotropic Base Plate with Three Bonded Stiffening Plate Strips"

("Orthotropic" Case)

(Boundary Conditions in y-direction FFFFFSS).....357

c) "Hard" Adhesive Case

d) "Soft" Adhesive Case

Figure 166 Dimensionless Nat. Freqs versus "Thickness Ratio $h_4/h_1 (= h_2 = h_3)$ " in

"Orthotropic Base Plate with Three Bonded Stiffening Plate Strips"

("Orthotropic" Case)

(Boundary Conditions in y-direction FFFFFFCF).....358

c) "Hard" Adhesive Case

d) "Soft" Adhesive Case

Figure 167 Dimensionless Nat. Freqs versus "Thickness Ratio $h_4/h_1 (= h_2 = h_3)$ " in

"Orthotropic Base Plate with Three Bonded Stiffening Plate Strips"

("Orthotropic" Case)

(Boundary Conditions in y-direction FFFFFFCF).....359

c) "Hard" Adhesive Case

d) "Soft" Adhesive Case

Figure 168 Dimensionless Nat. Freqs versus "Thickness Ratio $h_4/h_1 (= h_2 = h_3)$ " in

"Orthotropic Base Plate with Three Bonded Stiffening Plate Strips"

("Orthotropic" Case)

(Boundary Conditions in y-direction FFFFFFSF).....360

c) "Hard" Adhesive Case

d) "Soft" Adhesive Case

Figure 169 Dimensionless Nat. Freqs versus "Thickness Ratio $h_4/h_1 (= h_2 = h_3)$ " in

"Orthotropic Base Plate with Three Bonded Stiffening Plate Strips"

("Isotropic" Case)

(Boundary Conditions in y-direction FFFFFFCC).....361

c) "Hard" Adhesive Case

d) "Soft" Adhesive Case

Figure 170 Dimensionless Nat. Freqs versus "Thickness Ratio $h_4/h_1 (= h_2 = h_3)$ " in

"Orthotropic Base Plate with Three Bonded Stiffening Plate Strips"

("Isotropic" Case)

(Boundary Conditions in y-direction FFFFFSS).....362

c) "Hard" Adhesive Case

d) "Soft" Adhesive Case

Figure 171 Dimensionless Nat. Freqs versus "Thickness Ratio $h_4/h_1 (= h_2 = h_3)$ " in

"Orthotropic Base Plate with Three Bonded Stiffening Plate Strips"

("Isotropic" Case)

(Boundary Conditions in y-direction FFFFFCS).....363

c) "Hard" Adhesive Case

d) "Soft" Adhesive Case

Figure 172 Dimensionless Nat. Freqs versus "Thickness Ratio $h_4/h_1 (= h_2 = h_3)$ " in

"Orthotropic Base Plate with Three Bonded Stiffening Plate Strips"

("Isotropic" Case)

(Boundary Conditions in y-direction FFFFFCF).....364

c) "Hard" Adhesive Case

d) "Soft" Adhesive Case

Figure 173 Dimensionless Nat. Freqs versus "Thickness Ratio $h_4/h_1 (= h_2 = h_3)$ " in

"Orthotropic Base Plate with Three Bonded Stiffening Plate Strips"

("Isotropic" Case)

(Boundary Conditions in y-direction FFFFFSF).....365

c) "Hard" Adhesive Case

d) "Soft" Adhesive Case