UNIVERSITY OF SOUTHAMPTON

# NON-FERROUS COMPOSITELY REINFORCED CONCRETE COLUMNS

by

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This thesis was submitted for the award of
Doctor of Philosophy

FACULTY OF ENGINEERING AND APPLIED SCIENCE
CIVIL AND ENVIRONMENTAL ENGINEERING

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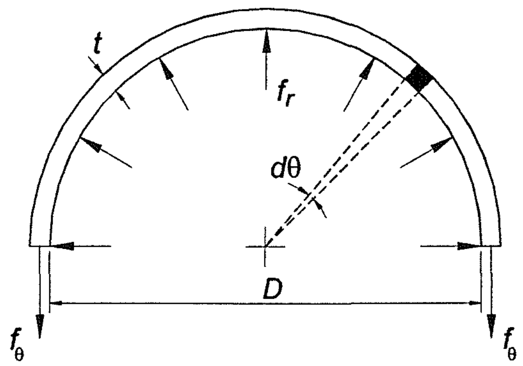
APPENDIX A

# THE HOOP STRESS IN A THIN SHELL SUBJECT TO INTERNAL PRESSURE




If $\theta$ is small arc length $\approx \frac{D}{2} d\theta$

Radial component of force on element $= f_r \frac{D}{2}.d\theta$

Vertical force component acting on element $= f_r \frac{D}{2}.d\theta.\sin\theta$

Total vertical force $= \int_0^\pi f_r \frac{D}{2} \sin\theta \, d\theta = f_r D$

Vertical equilibrium $\quad 2f_\theta t = f_r D$

$$f_r = \frac{2t}{D} f_\theta$$

# APPENDIX B

## EXPERIMENTAL STRESS-STRAIN CURVES FOR CONCRETE-FILLED E-GLASS FRP-COMPOSITE STUB COLUMNS

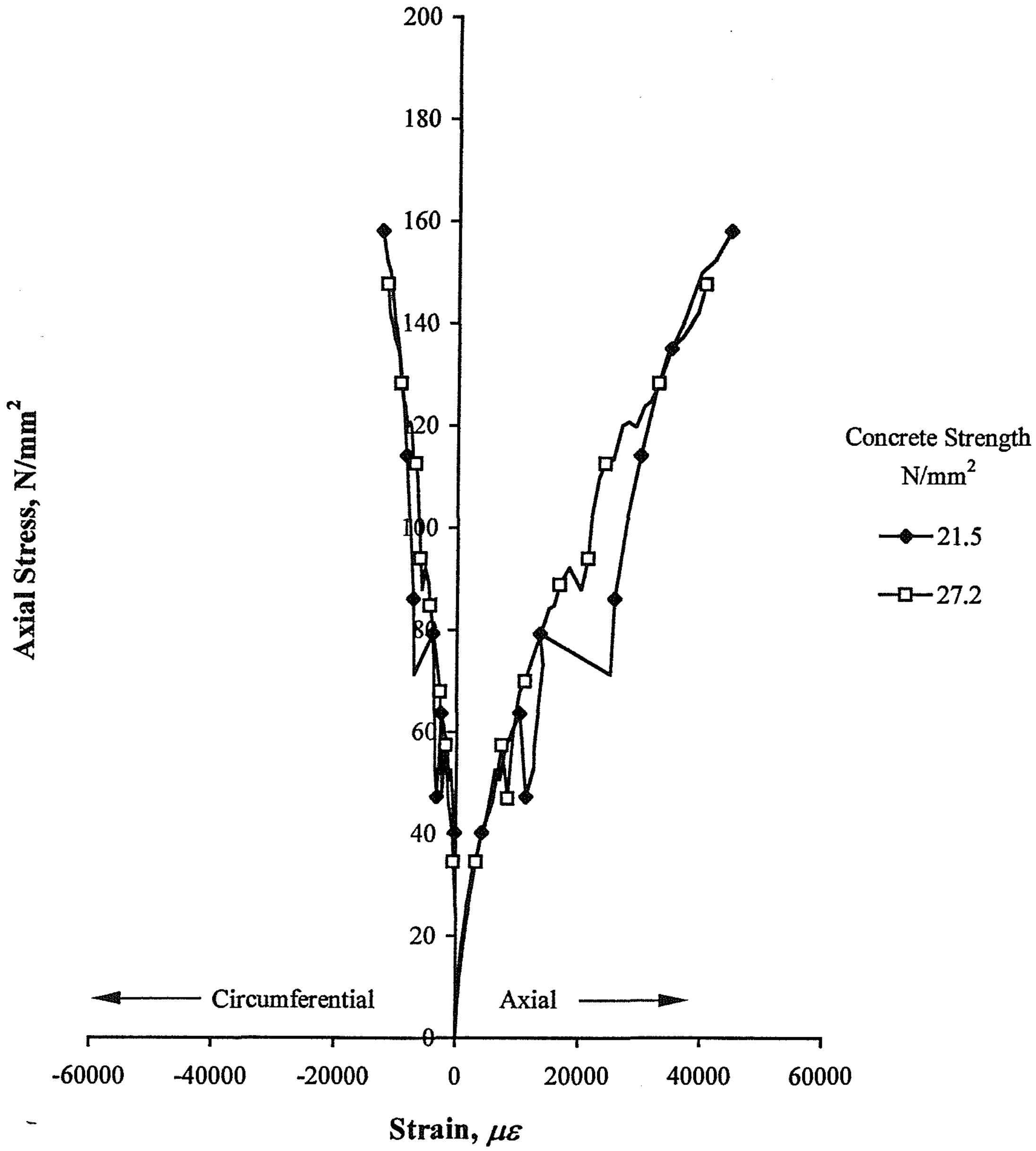



**Figure B.1.** Stress-strain curves for the 60 mm diameter concrete-filled stub columns confined with E-glass fibres orientated at 75.5 degrees.

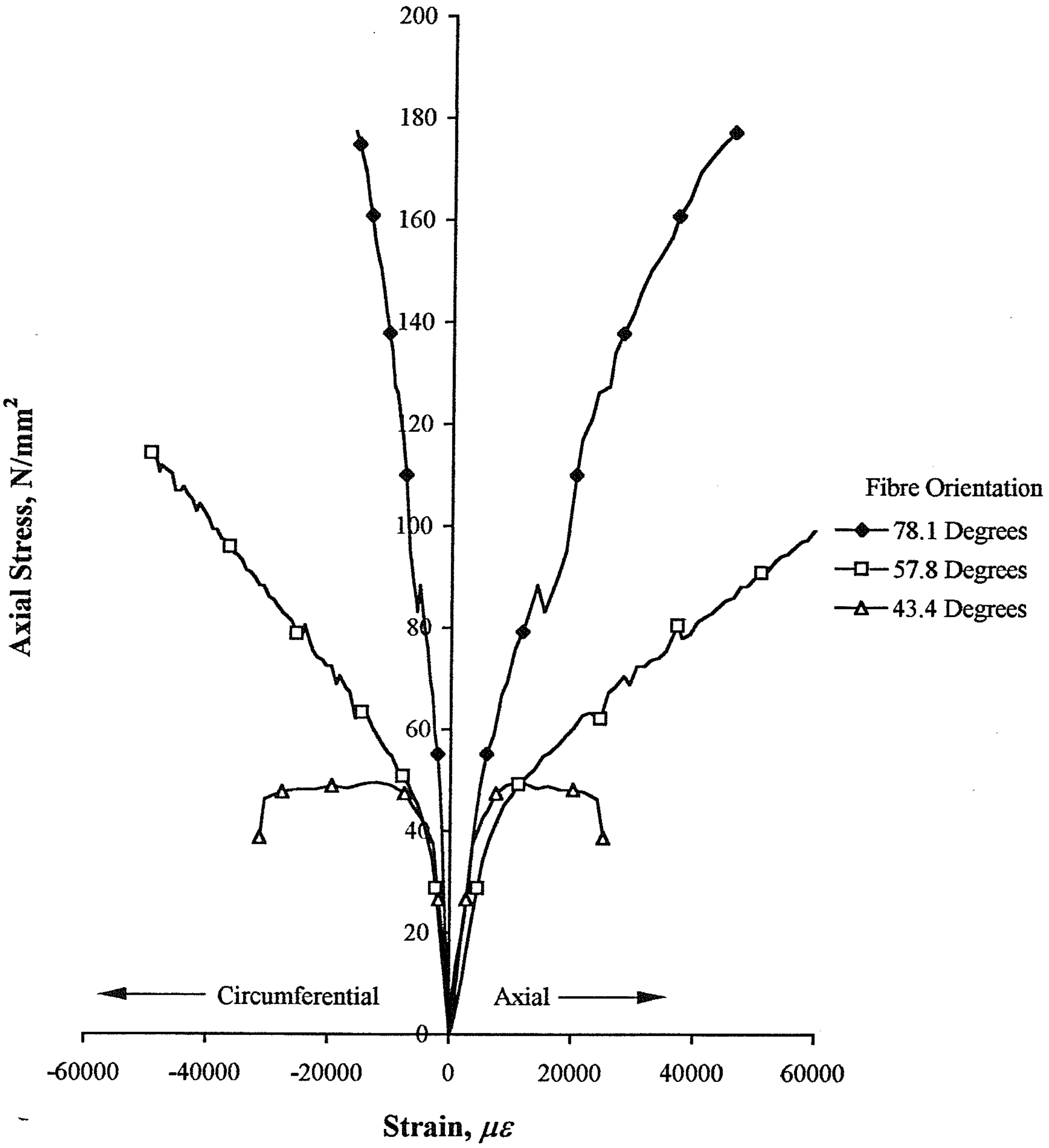



**Figure B.2.** Stress-strain curves for the 80 mm diameter concrete-filled stub columns confined with E-glass fibres (nominal concrete cube strength = 25 N/mm$^2$)

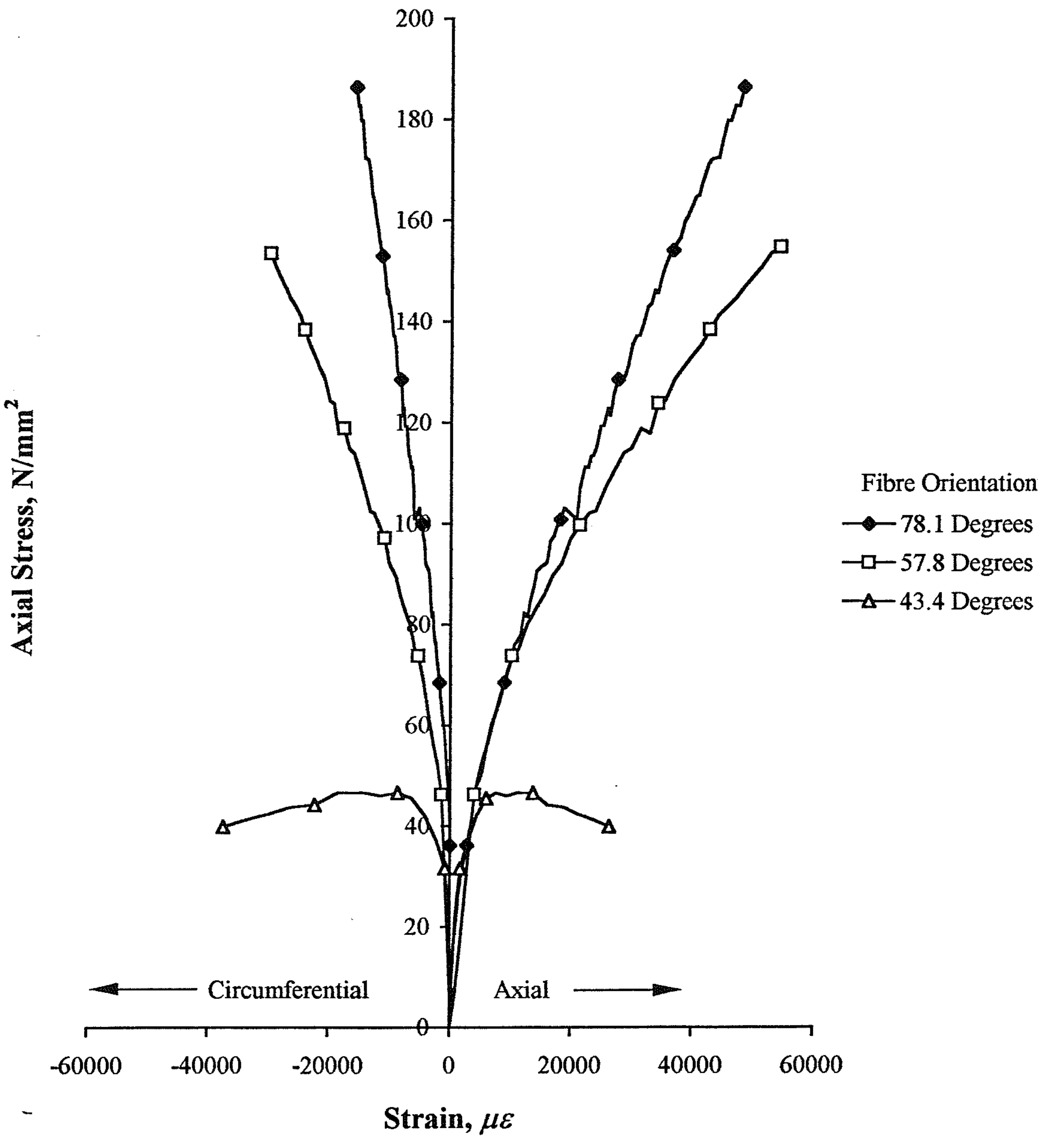



**Figure B.3.** Stress-strain curves for the 80 mm diameter concrete-filled stub columns confined with E-glass fibres (nominal concrete cube strength = 35 N/mm$^2$)

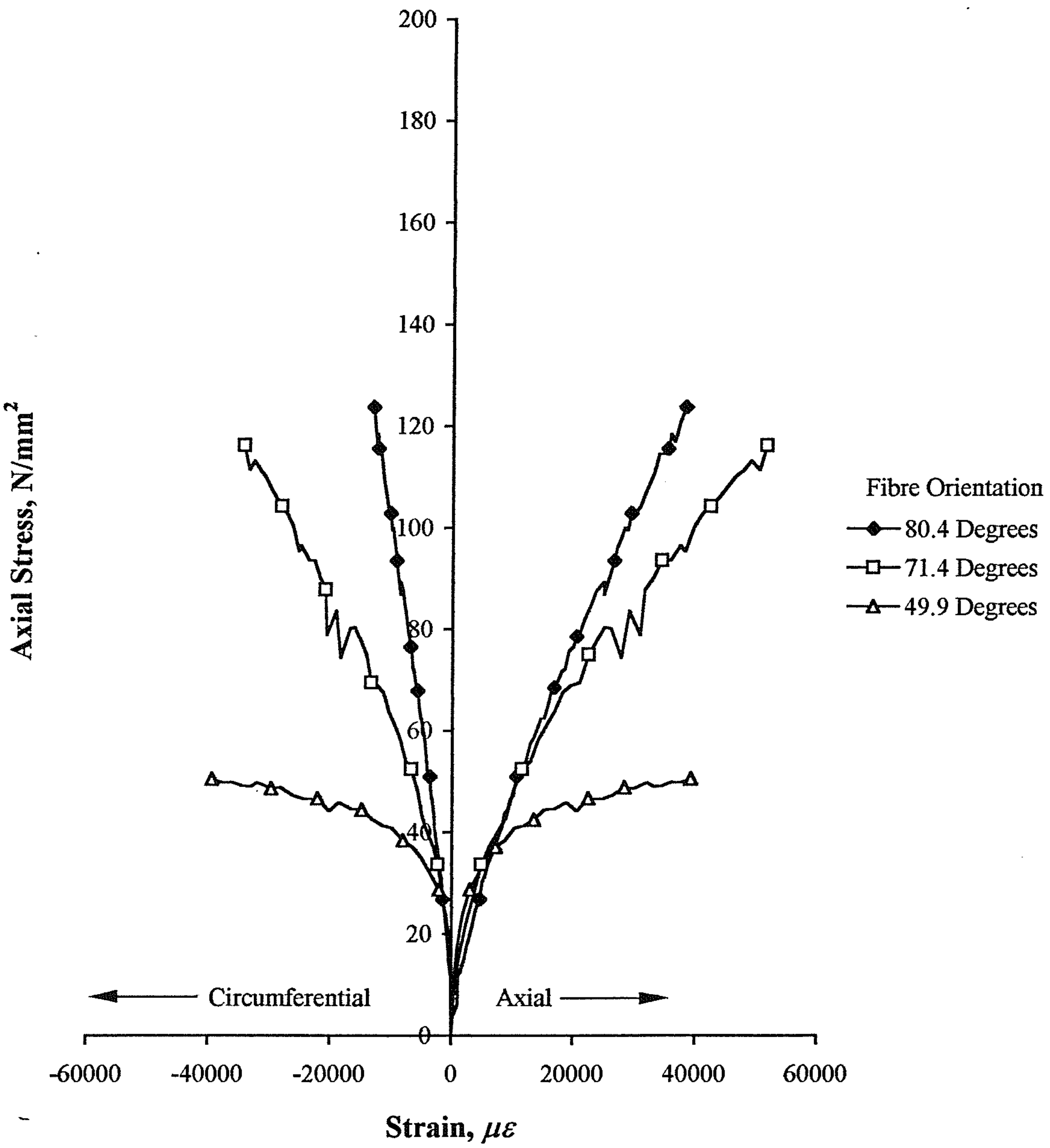



**Figure B.4.** Stress-strain curves for the 100 mm diameter concrete-filled stub columns confined with E-glass fibres (nominal concrete cube strength = 25 N/mm$^2$)

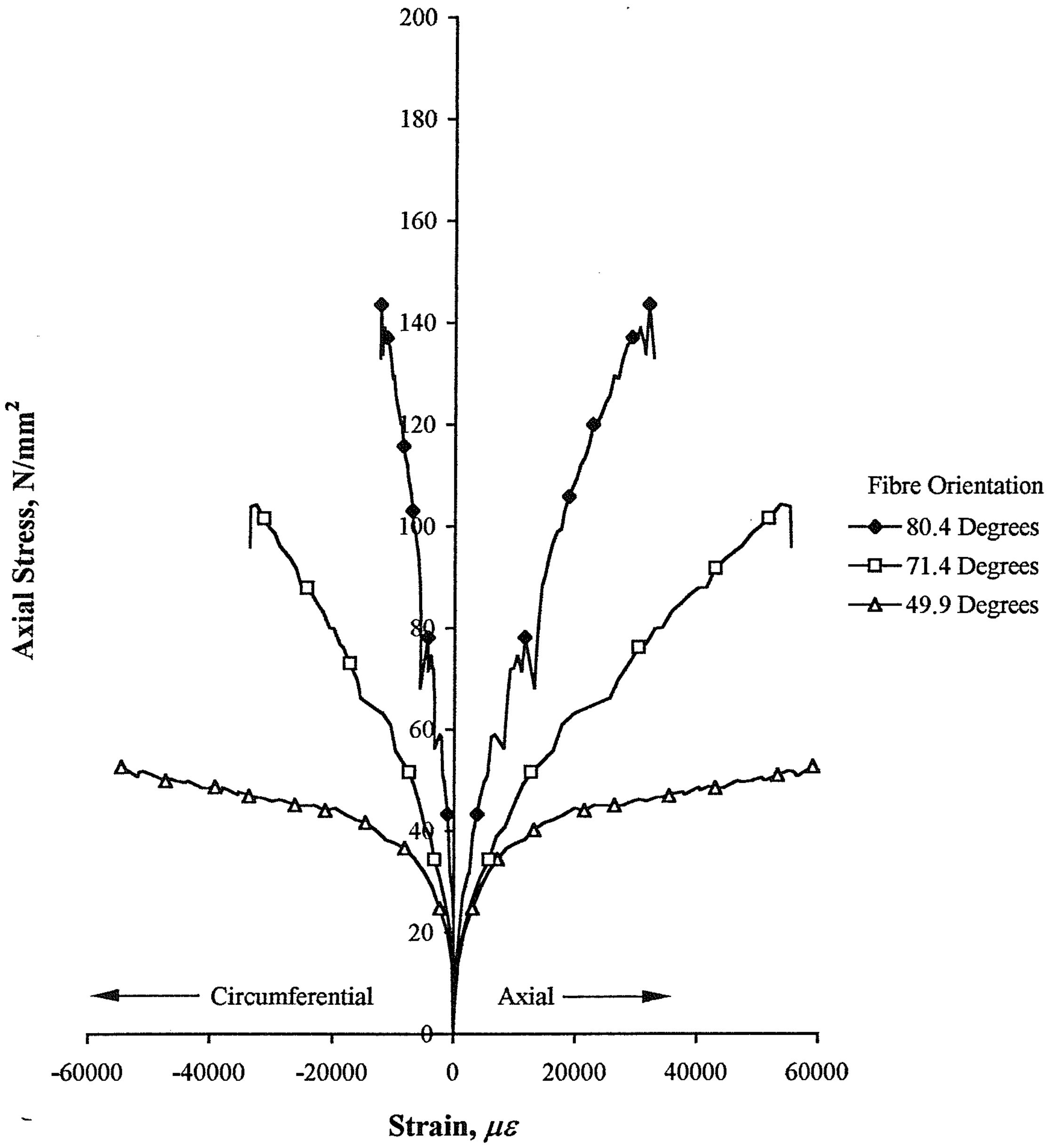



**Figure B.5.** Stress-strain curves for the 100 mm diameter concrete-filled stub columns confined with E-glass fibres (nominal concrete cube strength = 35 N/mm$^2$)

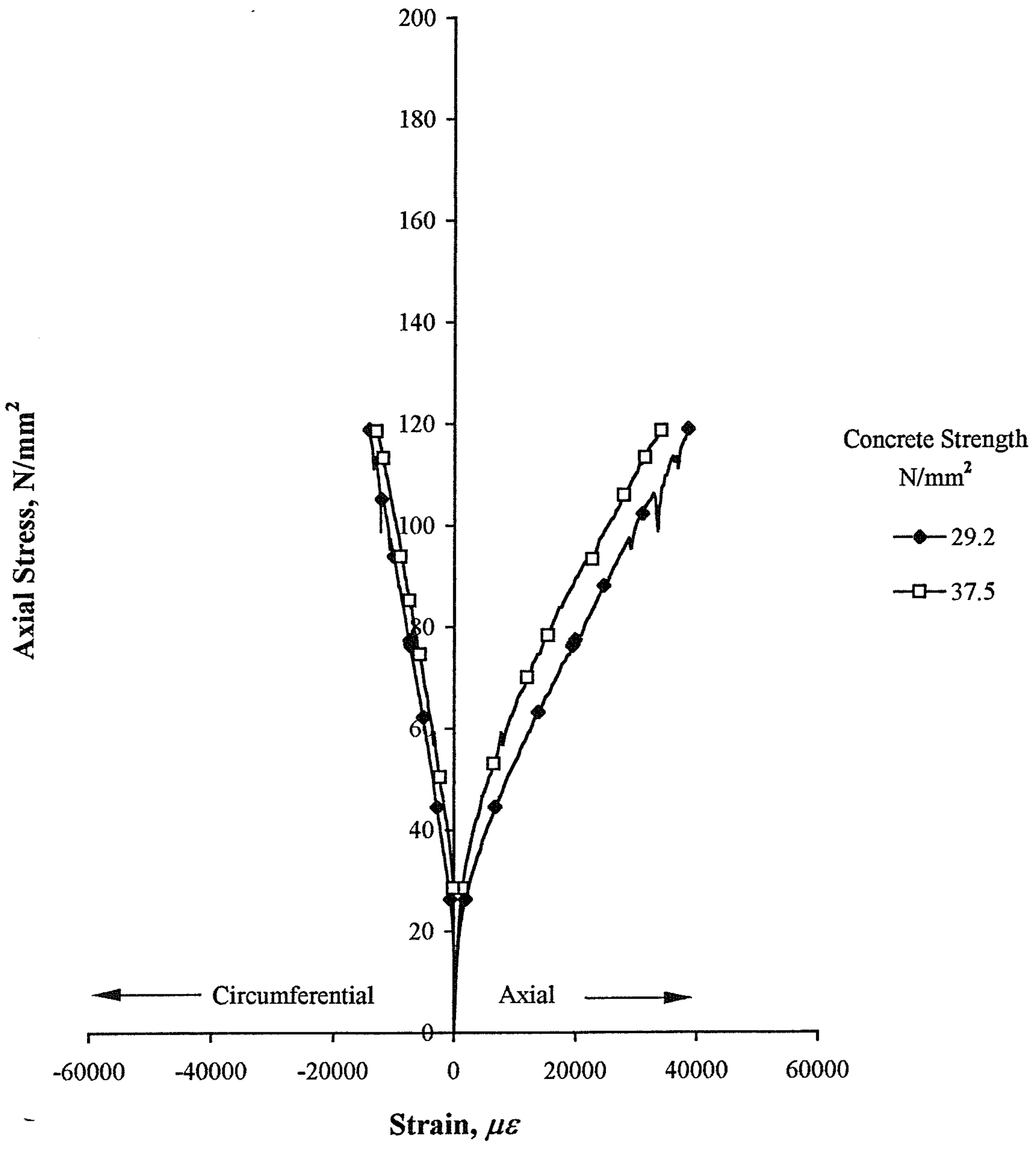



**Figure B.6.** Stress-strain curves for the 125 mm diameter concrete-filled stub columns confined with E-glass fibres orientated at 82.3 degrees

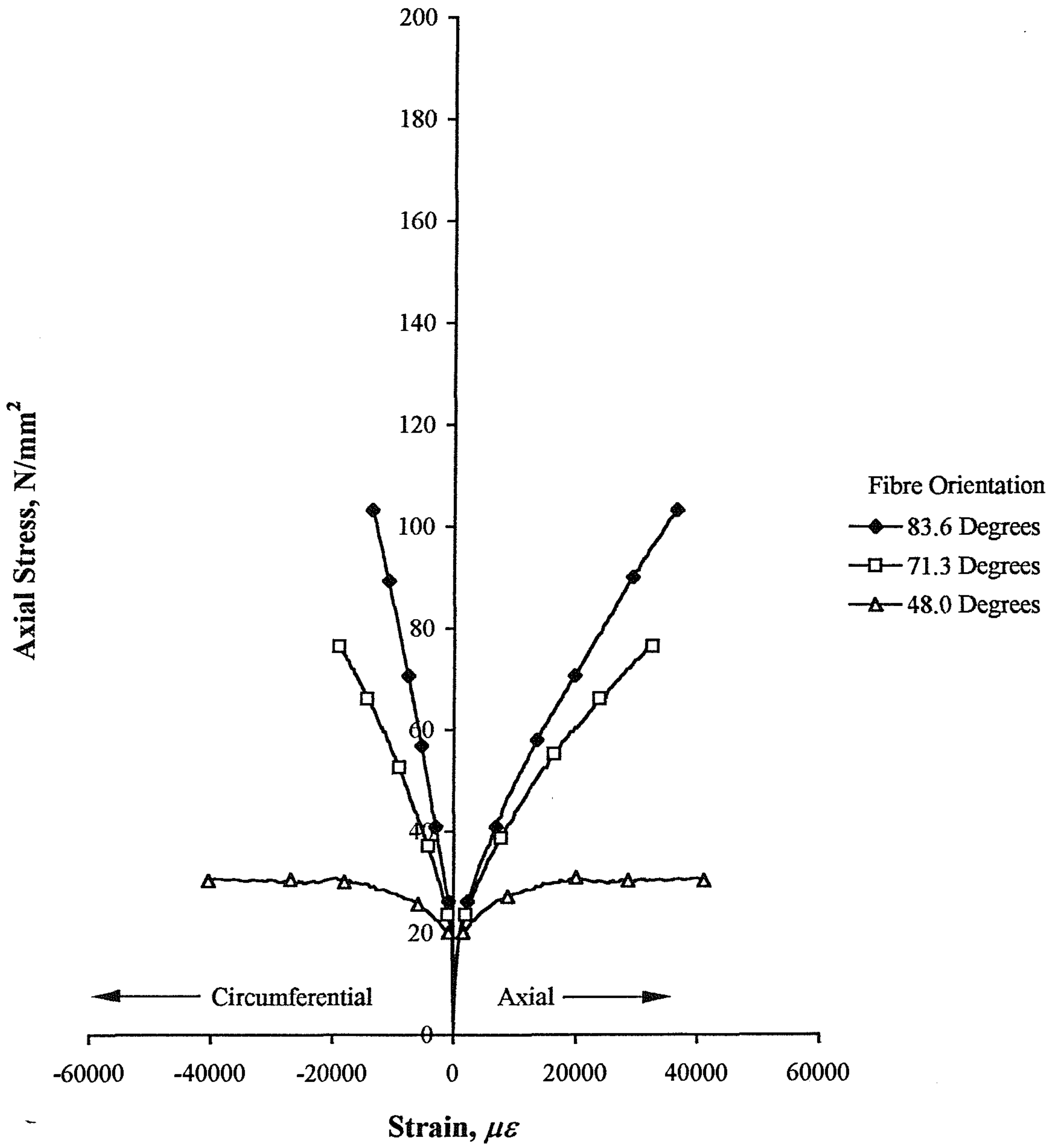



**Figure B.7.** Stress-strain curves for the 150 mm diameter concrete-filled stub columns confined with E-glass fibres (nominal concrete cube strength = 25 N/mm$^2$)

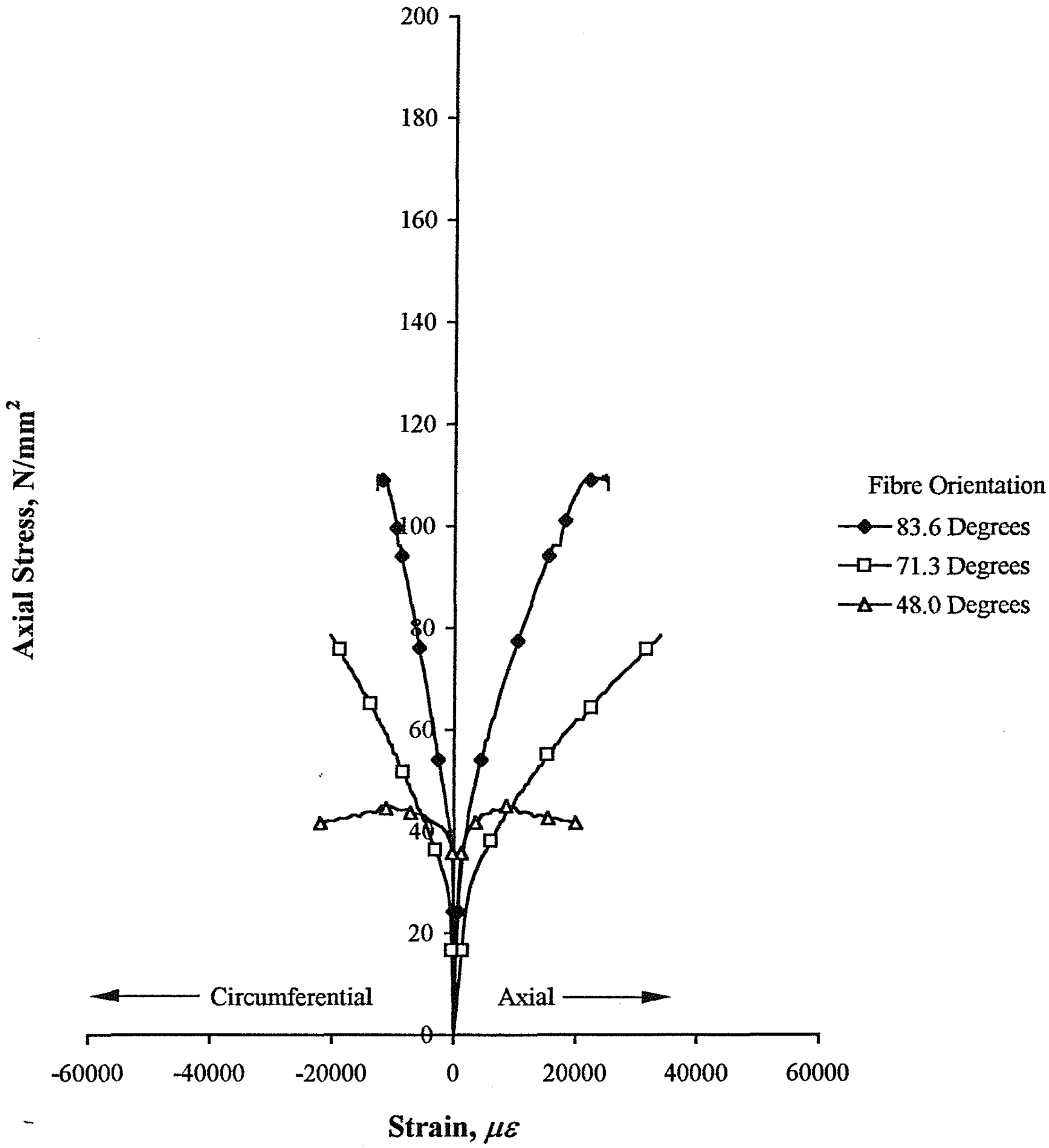



**Figure B.8.** Stress-strain curves for the 150 mm diameter concrete-filled stub columns confined with E-glass fibres (nominal concrete cube strength = 35 N/mm$^2$)

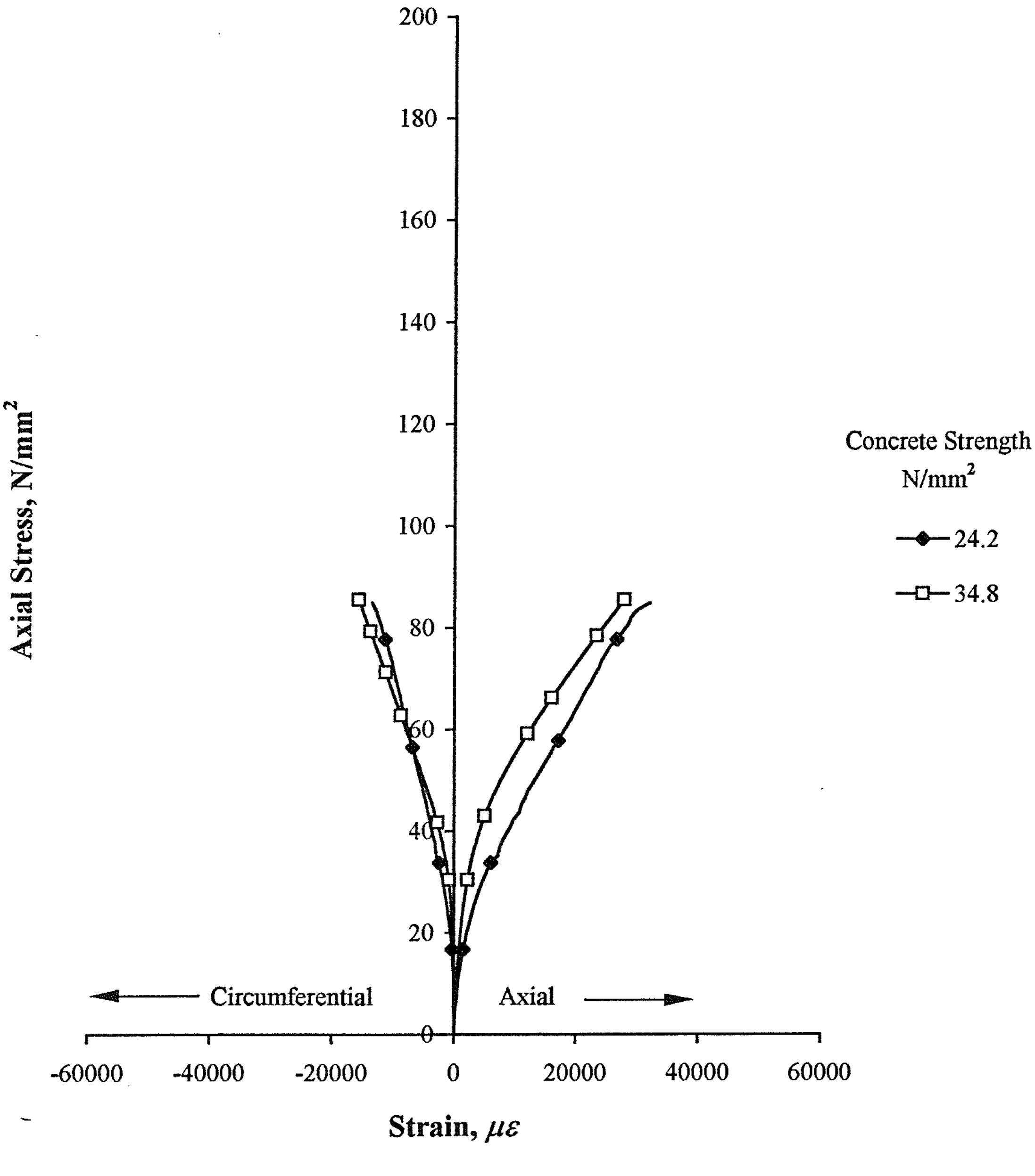



**Figure B.9.** Stress-strain curves for the 300 mm diameter concrete-filled stub columns confined with E-glass fibres orientated at 86.8 degrees

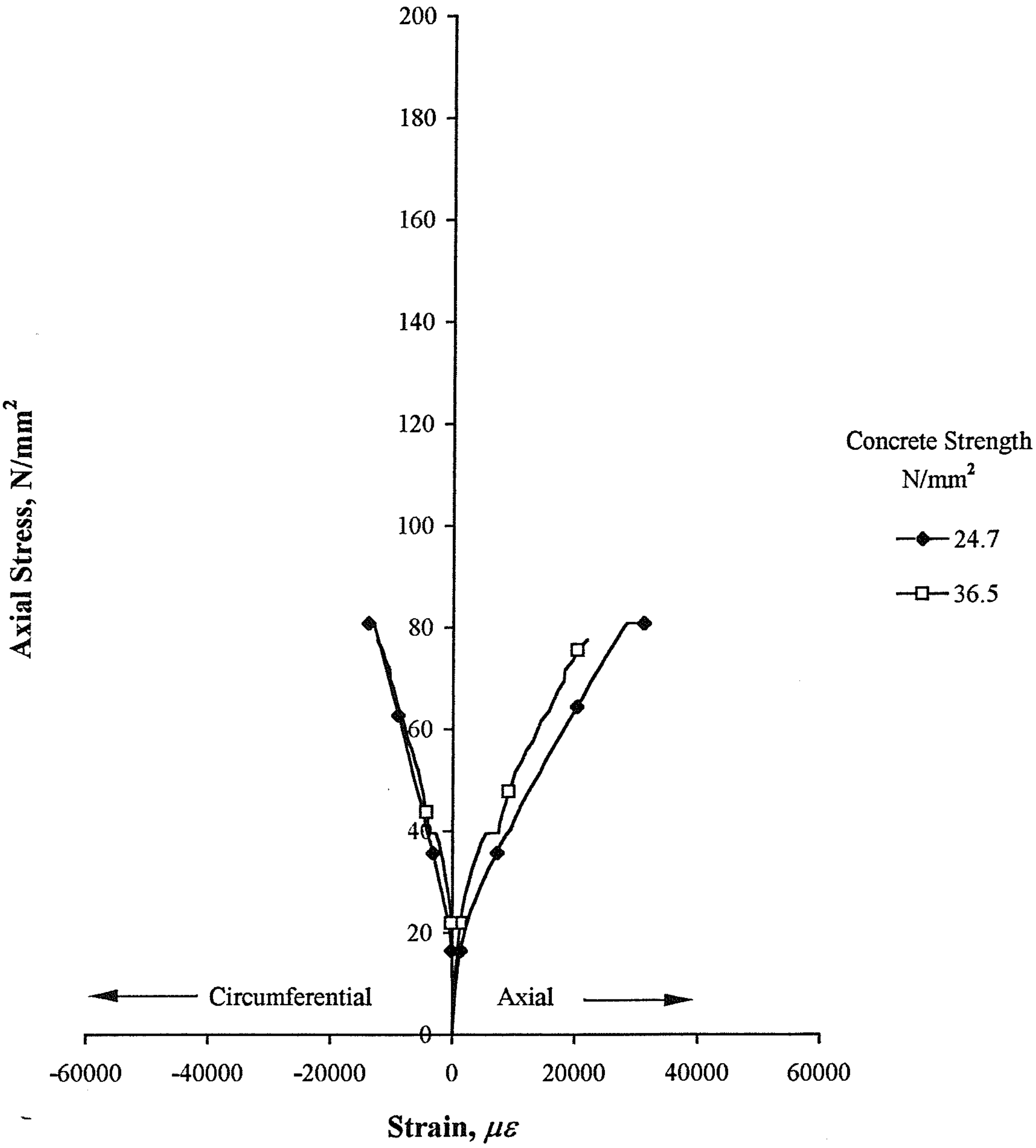



**Figure B.10.** Stress-strain curves for the 400 mm diameter concrete-filled stub columns confined with E-glass fibres orientated at 87.6 degrees

<u>APPENDIX C</u>

# EXPERIMENTAL STRESS-VOLUMETRIC STRAIN CURVES FOR CONCRETE-FILLED E-GLASS FRP-COMPOSITE STUB COLUMNS

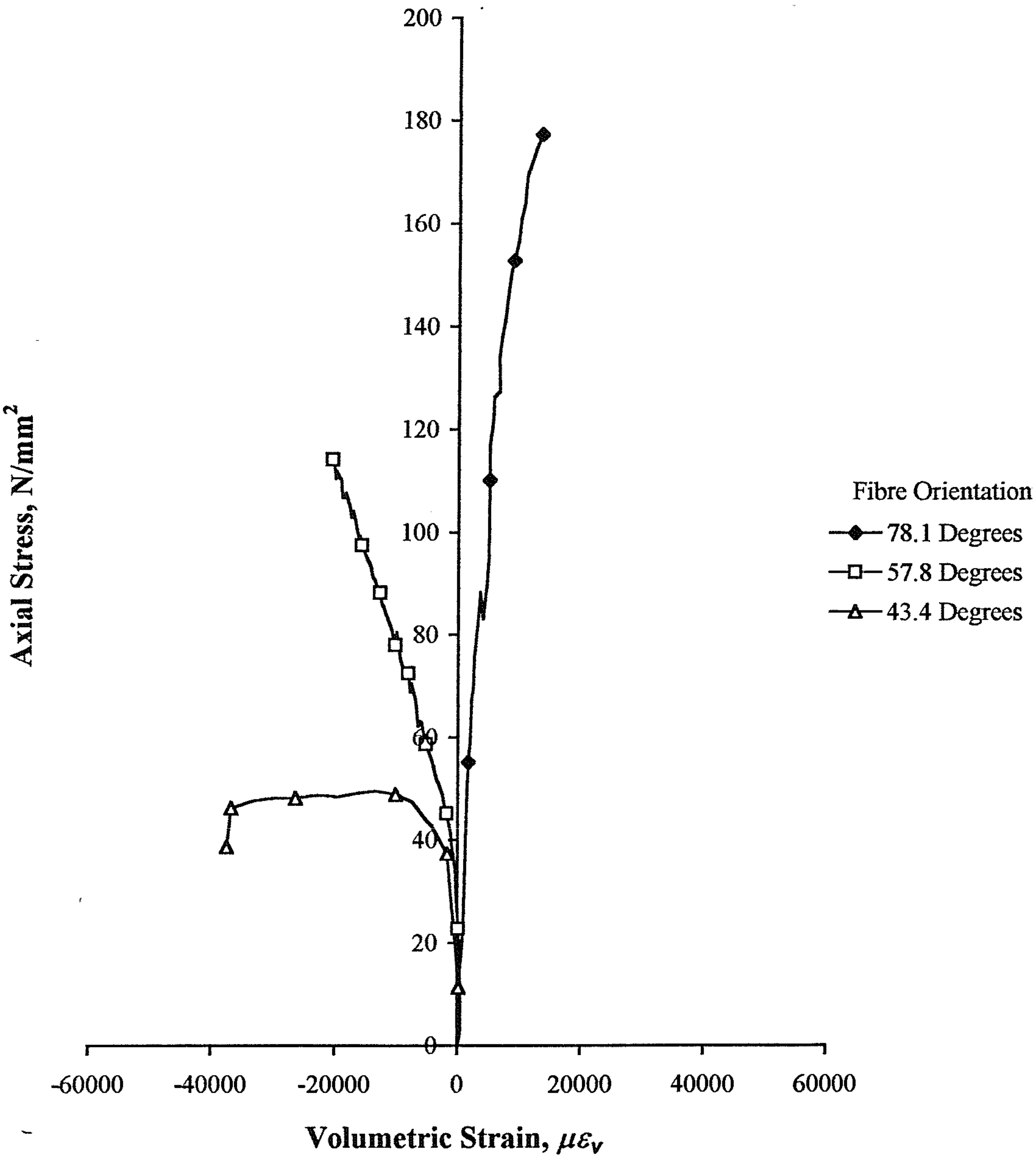



**Figure C.1.** Stress-volumetric strain curves for the 80 mm diameter concrete-filled stub columns confined with E-glass fibres (nominal concrete cube strength = 25 N/mm$^2$)

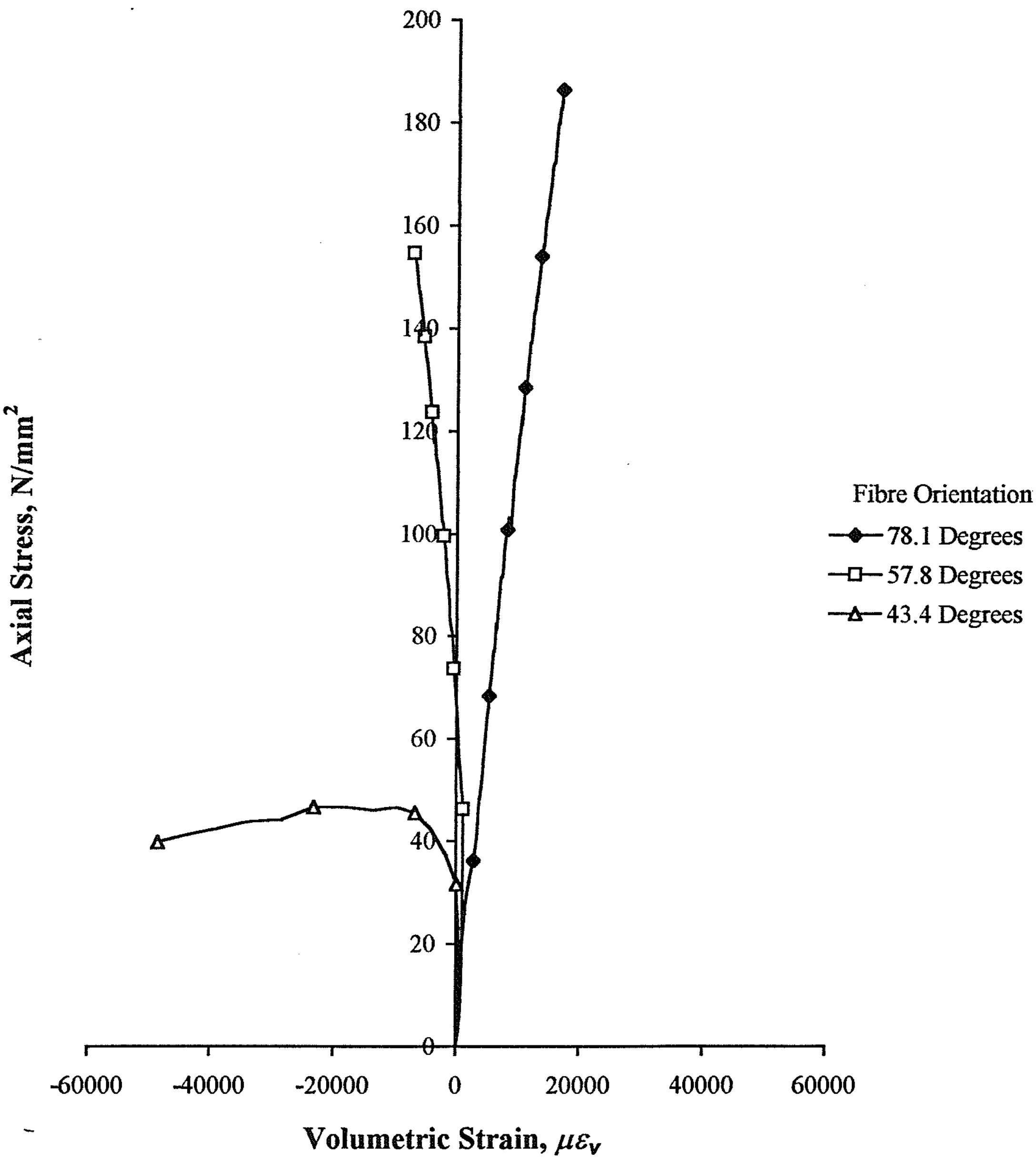



**Figure C.2.** Stress-volumetric strain curves for the 80 mm diameter concrete-filled stub columns confined with E-glass fibres (nominal concrete cube strength = 35 N/mm$^2$)

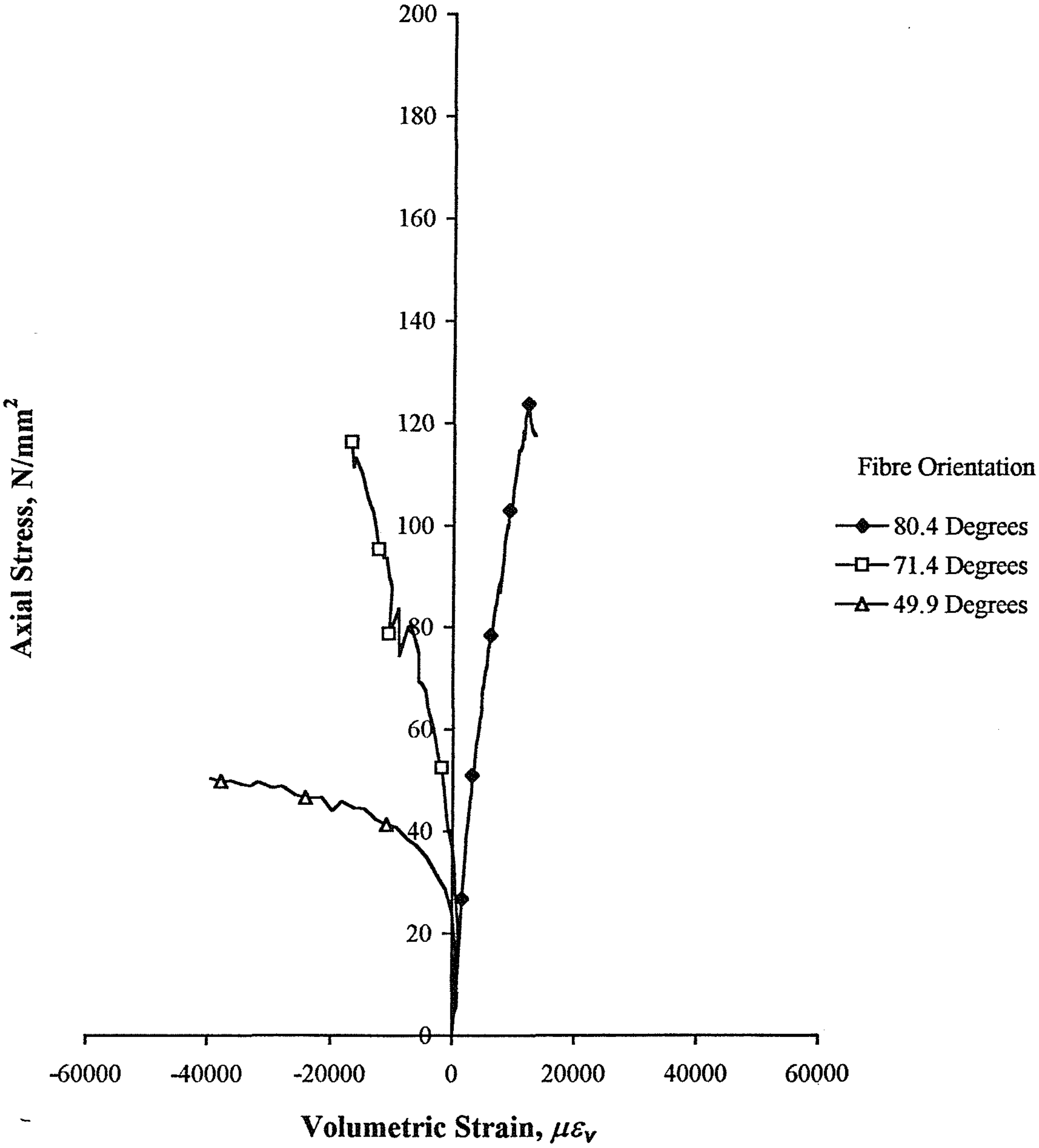



**Figure C.3.** Stress-volumetric strain curves for the 100 mm diameter concrete-filled stub columns confined with E-glass fibres (nominal concrete cube strength = 25 N/mm$^2$)

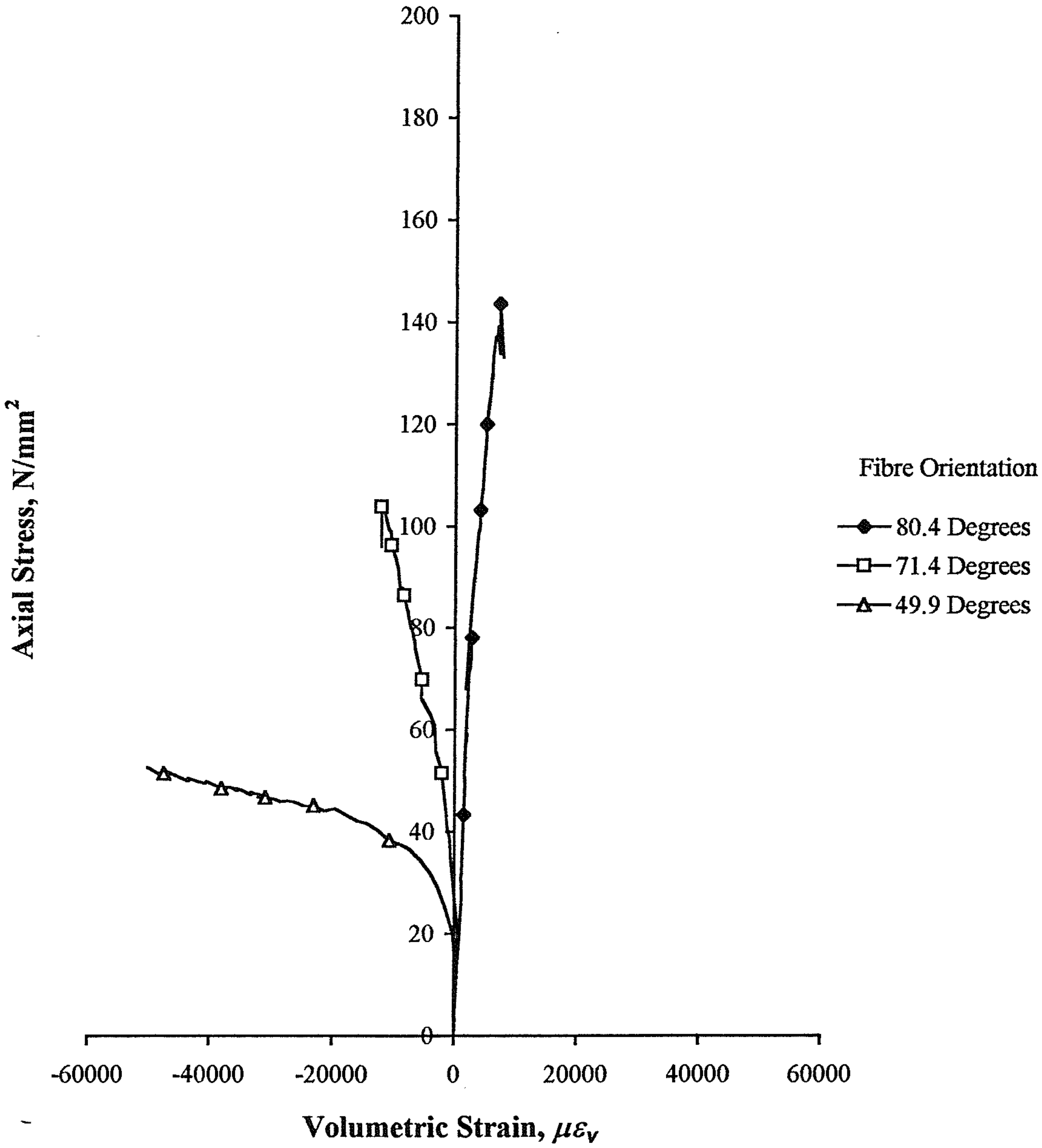



**Figure C.4.** Stress-volumetric strain curves for the 100 mm diameter concrete-filled stub columns confined with E-glass fibres (nominal concrete cube strength = 35 N/mm$^2$)

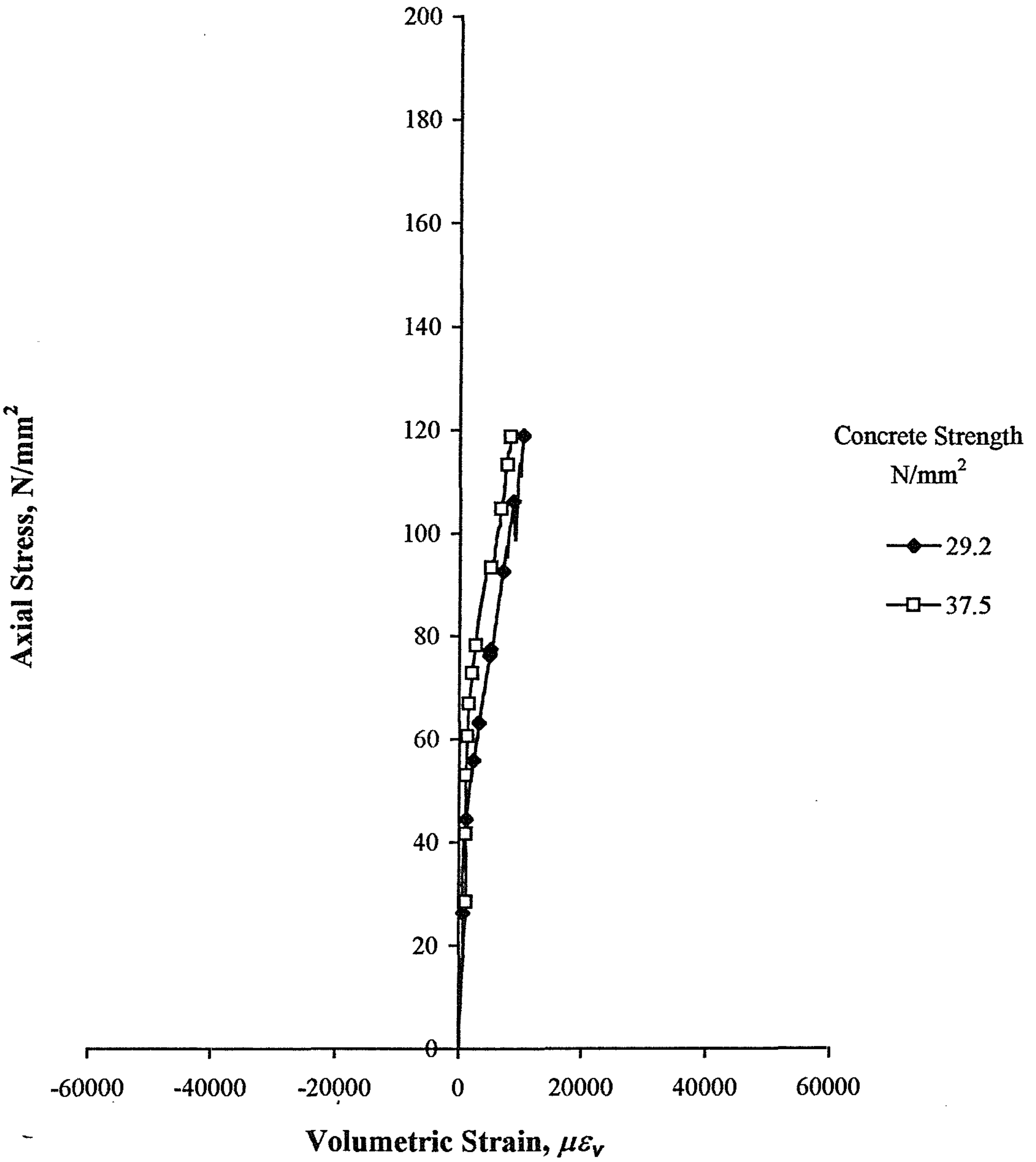



**Figure C.5.** Stress-volumetric strain curves for the 125 mm diameter concrete-filled stub columns confined with E-glass fibres orientated at 82.3 degrees

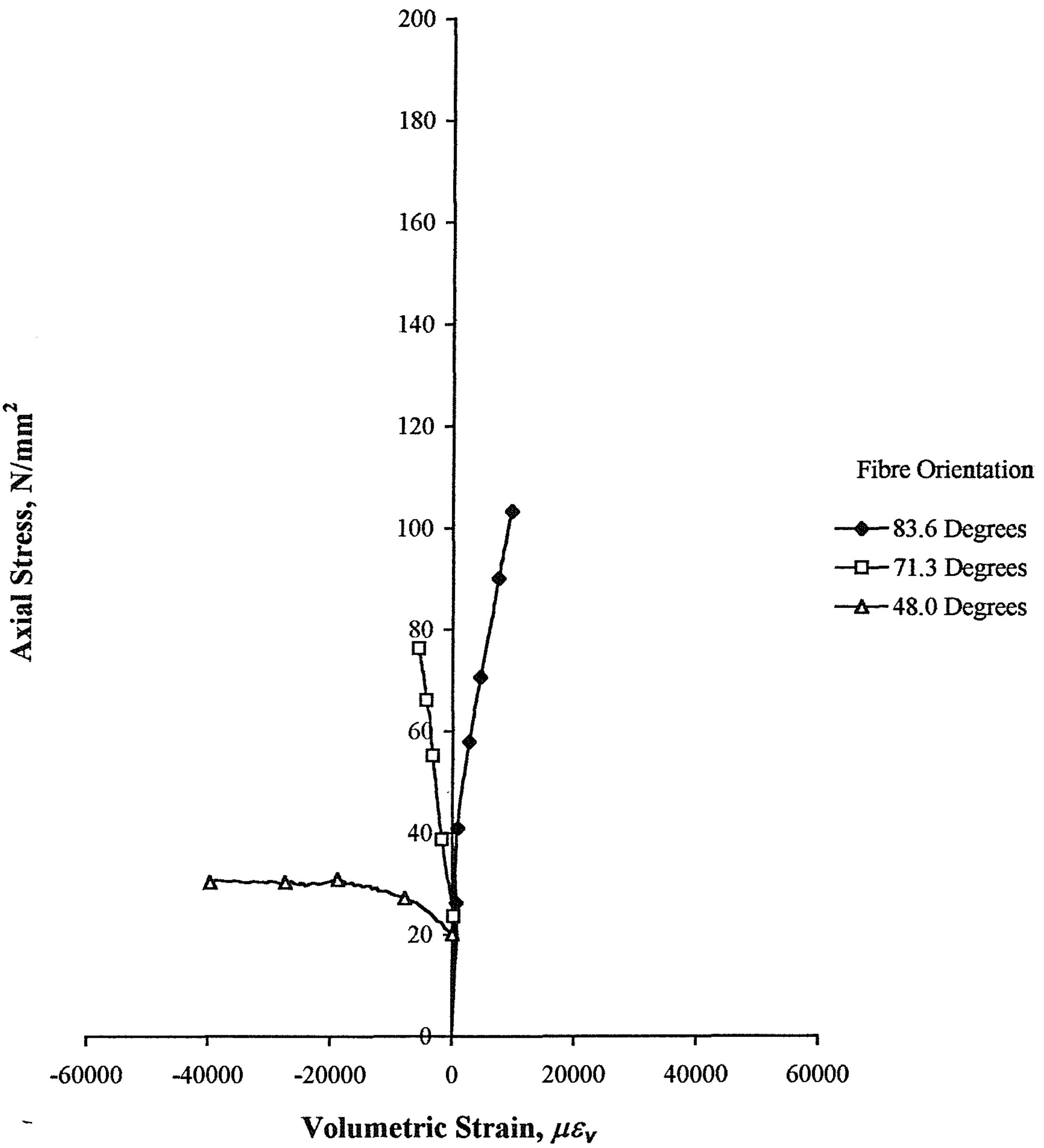



**Figure C.6.** Stress-volumetric strain curves for the 150 mm diameter concrete-filled stub columns confined with E-glass fibres (nominal concrete cube strength = 25 N/mm$^2$)

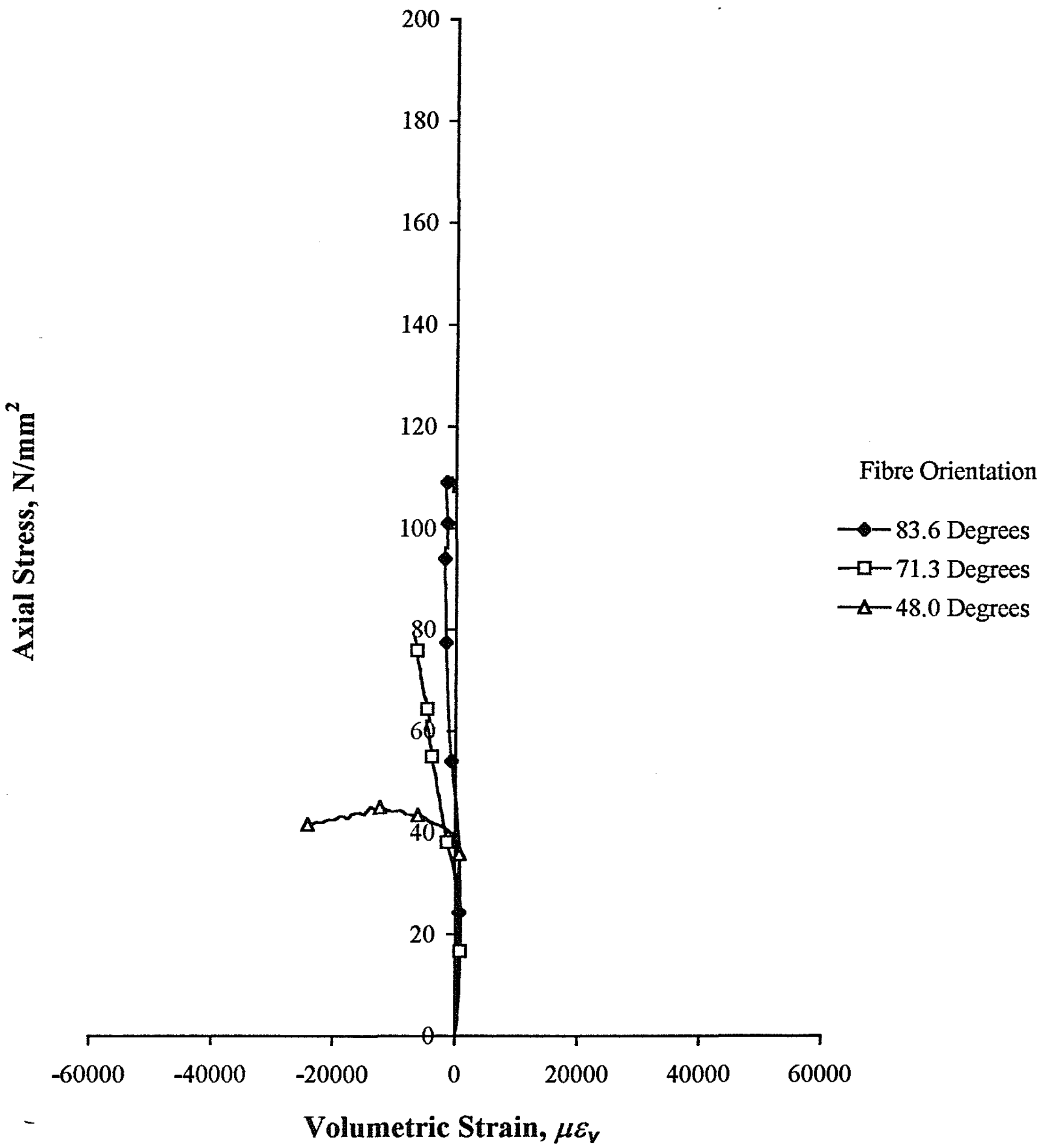



**Figure C.7.** Stress-volumetric strain curves for the 150 mm diameter concrete-filled stub columns confined with E-glass fibres (nominal concrete cube strength = 35 N/mm$^2$)

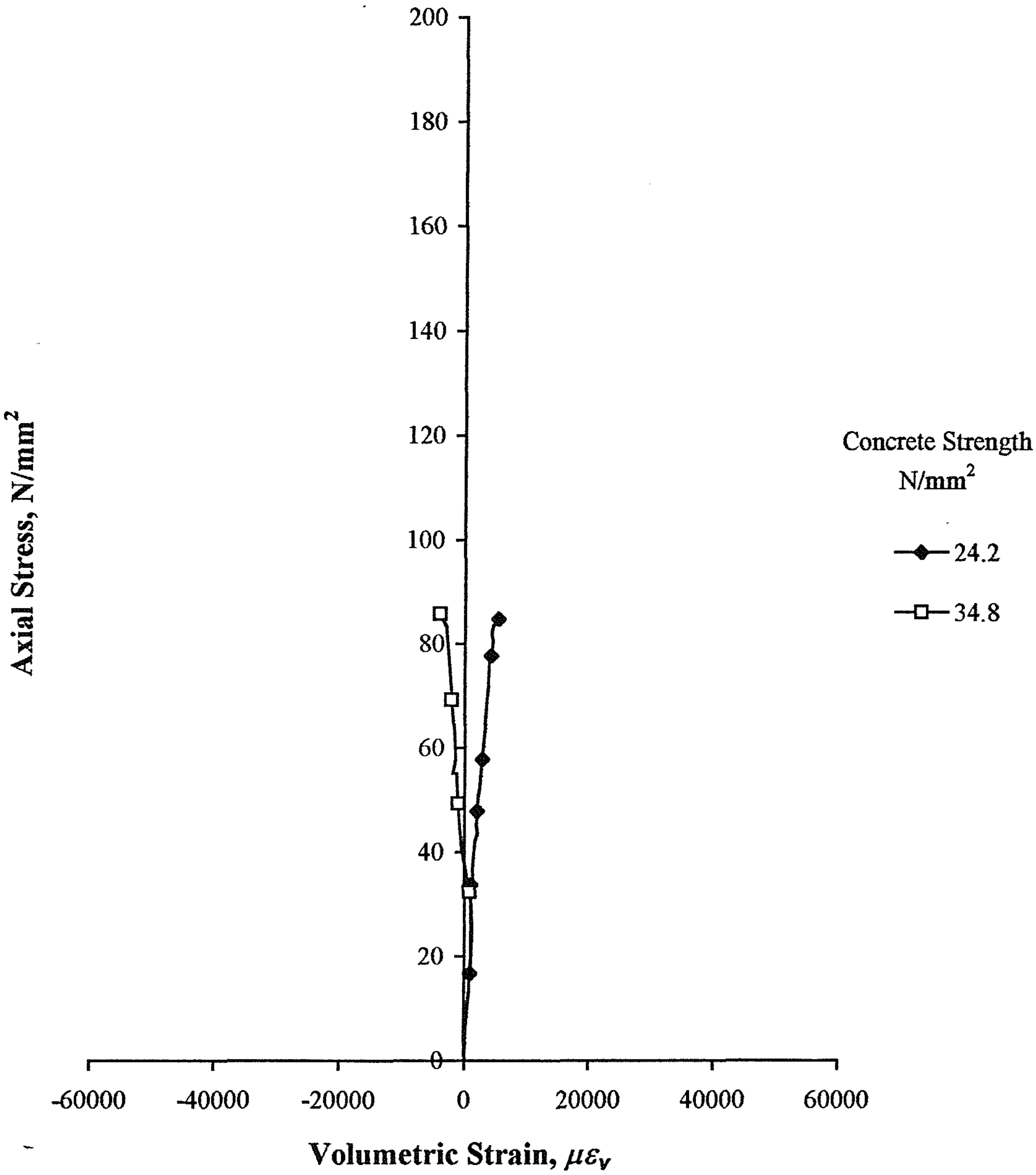



**Figure C.8.** Stress-volumetric strain curves for the 300 mm diameter concrete-filled stub columns confined with E-glass fibres orientated at 86.8 degrees

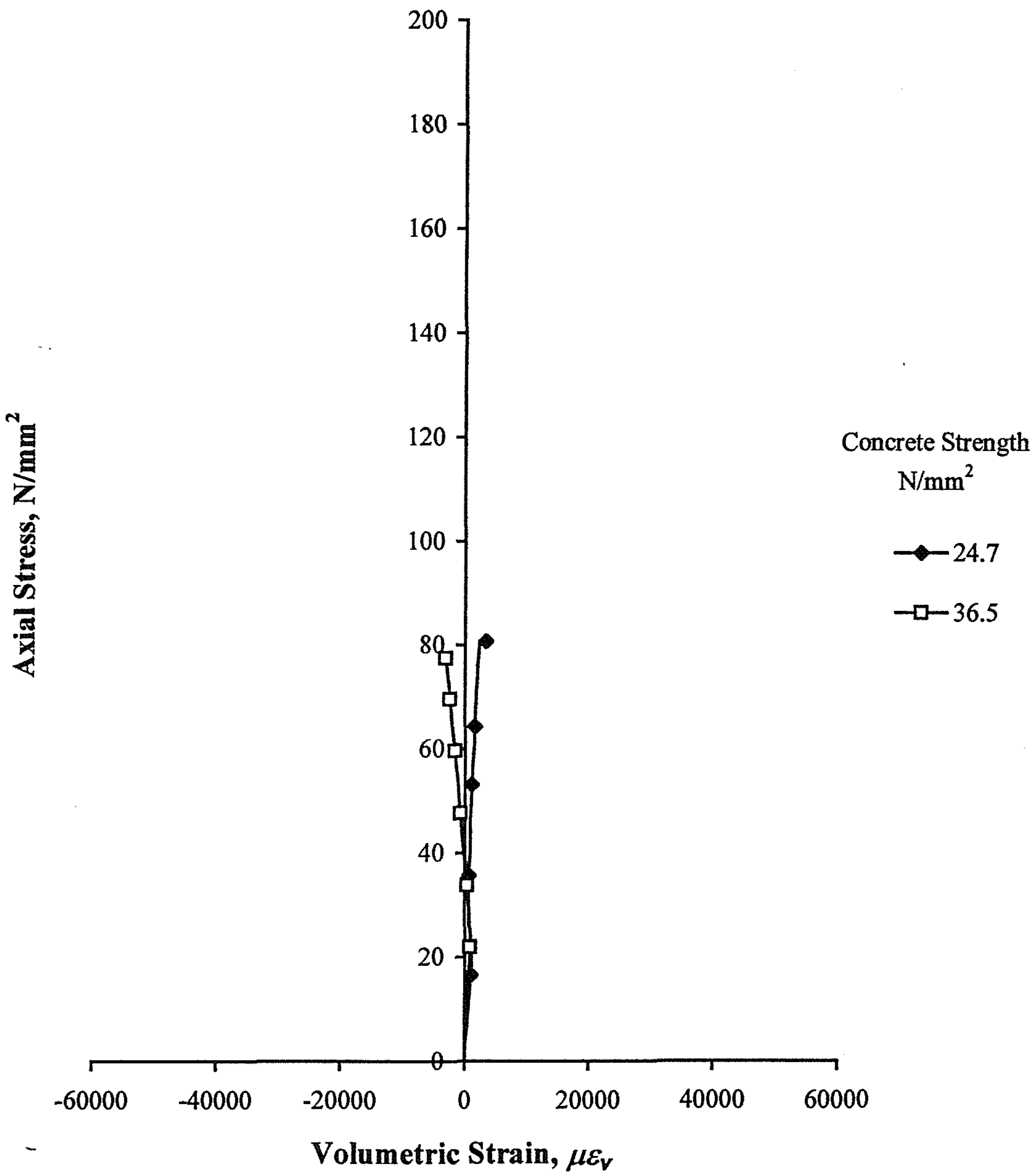



**Figure C.9.** Stress-volumetric strain curves for the 400 mm diameter concrete-filled stub columns confined with E-glass fibres orientated at 87.6 degrees

APPENDIX D

# COMPARISON OF THE THEORETICAL AND EXPERIMENTAL STRESS-STRAIN CURVES FOR CONCRETE-FILLED E-GLASS FRP-COMPOSITE STUB COLUMNS WITH A NOMINAL 90 DEGREE FIBRE ORIENTATION

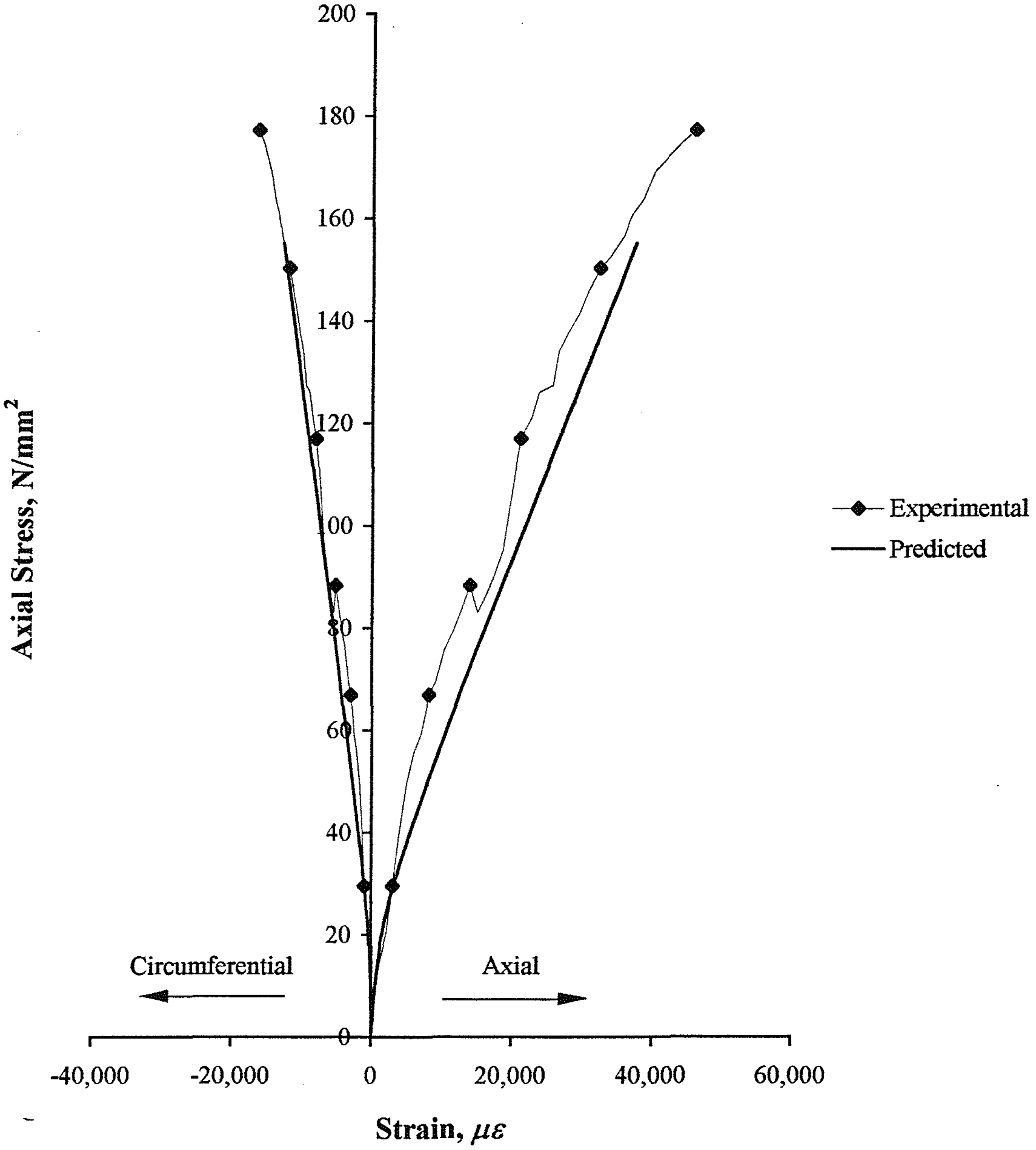



**Figure D.1.** Comparison of the theoretical and experimental stress-strain curves for the 80 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 78.1 degrees (concrete cube strength = 23.4 N/mm$^2$)

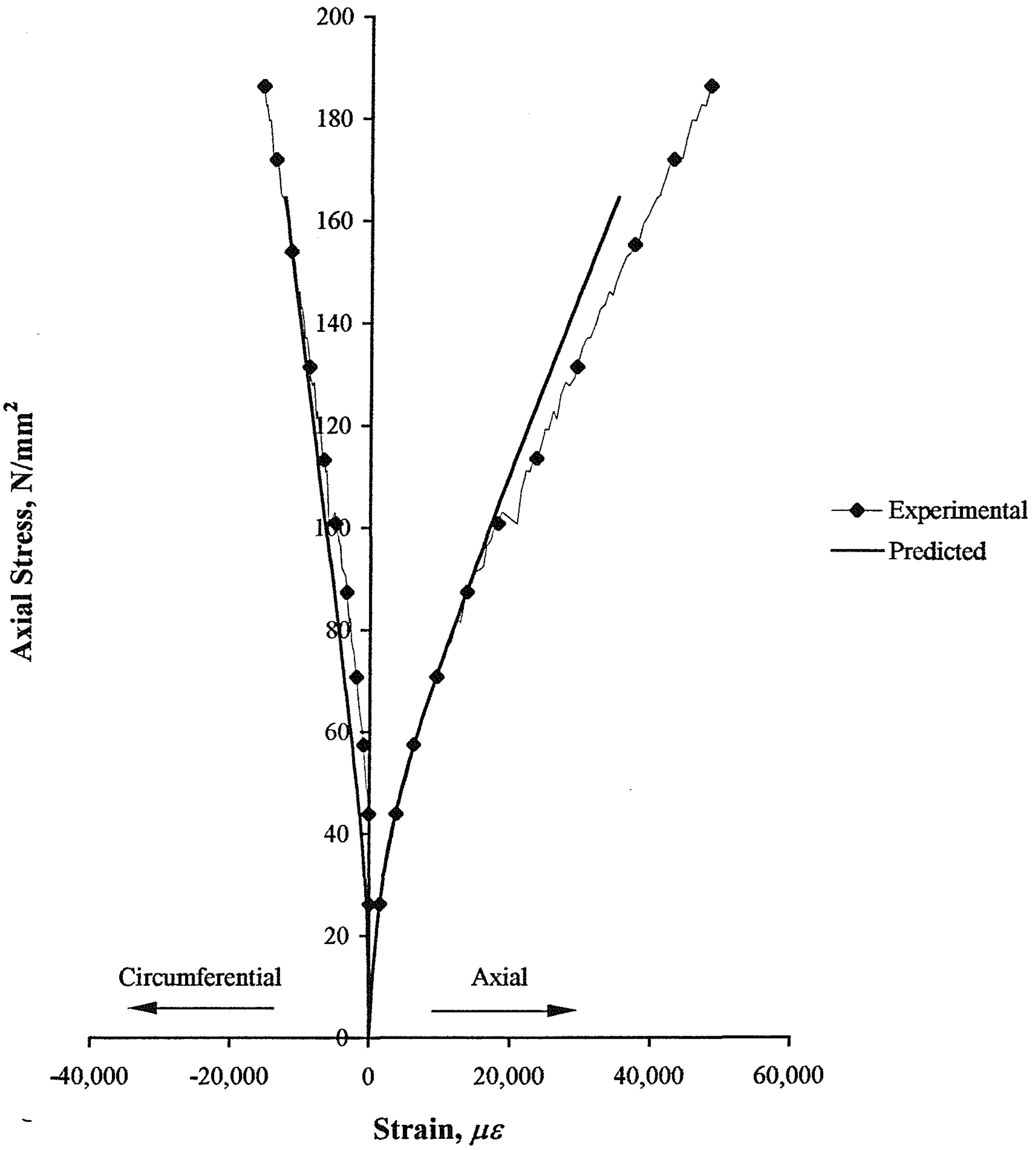



**Figure D.2.** Comparison of the theoretical and experimental stress-strain curves for the 80 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 78.1 degrees (concrete cube strength = 35.2 N/mm$^2$)

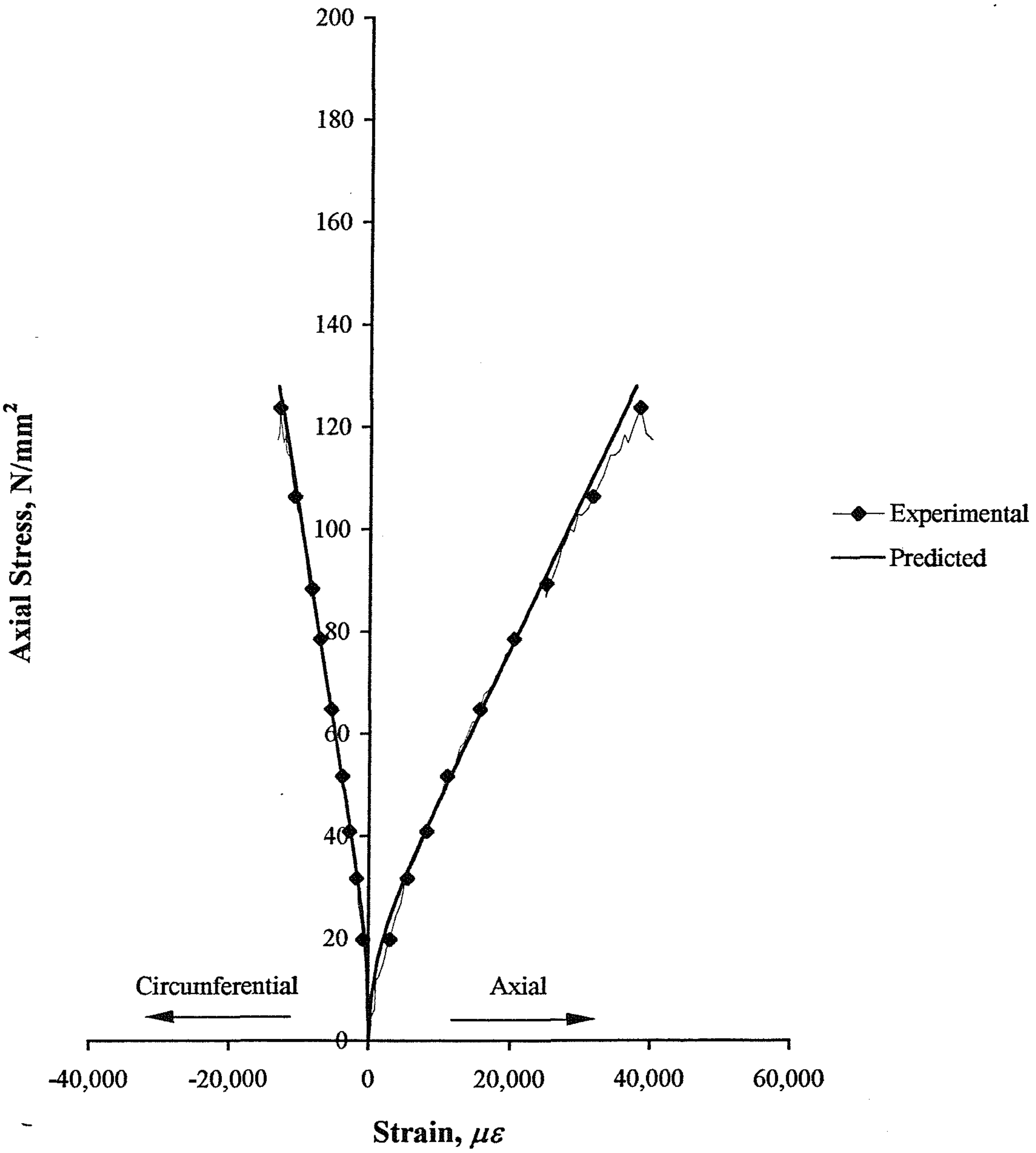



**Figure D.3.** Comparison of the theoretical and experimental stress-strain curves for the 100 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 80.4 degrees (concrete cube strength = 19.7 N/mm$^2$)

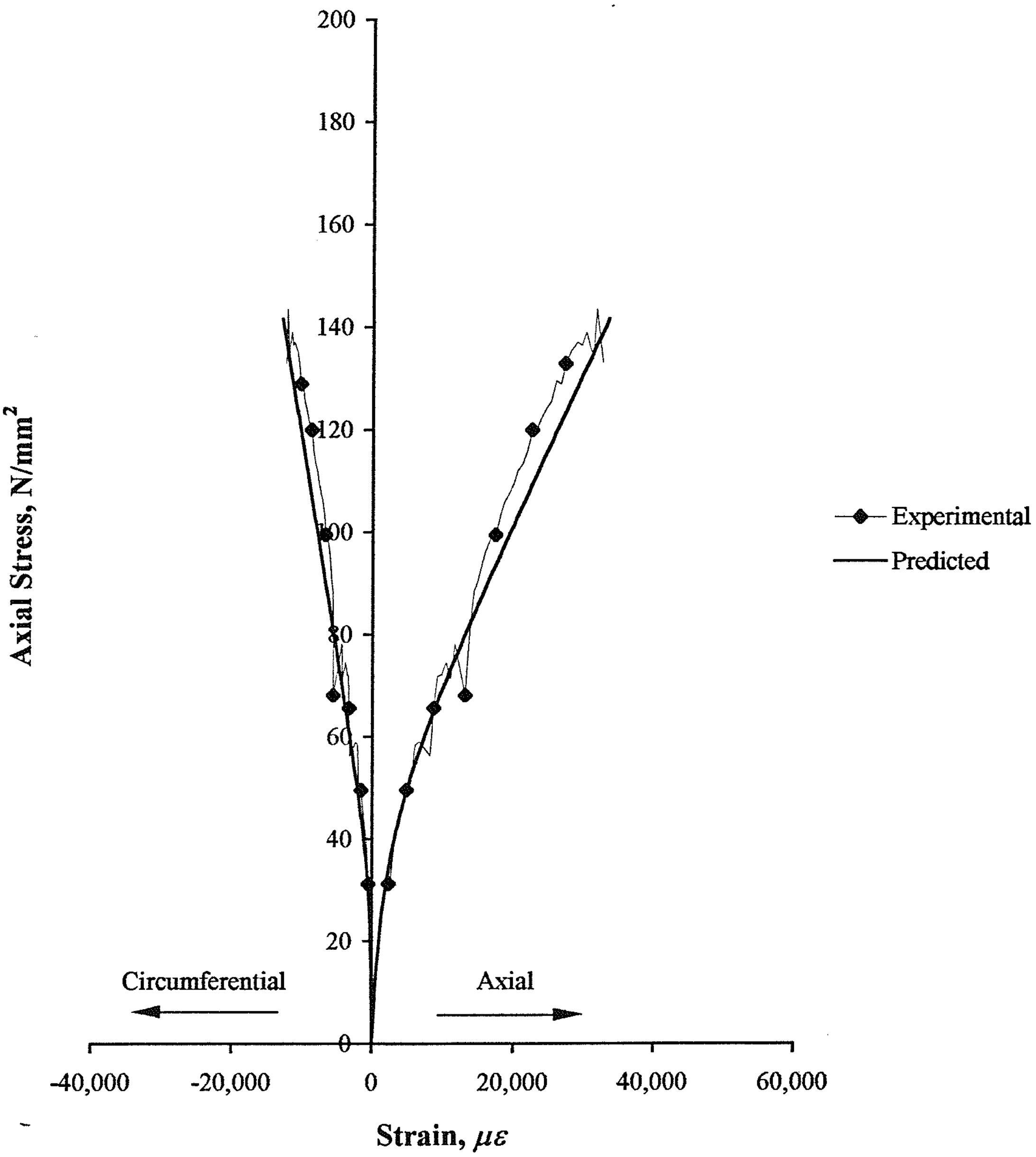



**Figure D.4.** Comparison of the theoretical and experimental stress-strain curves for the 100 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 80.4 degrees (concrete cube strength = 36.2 N/mm$^2$)

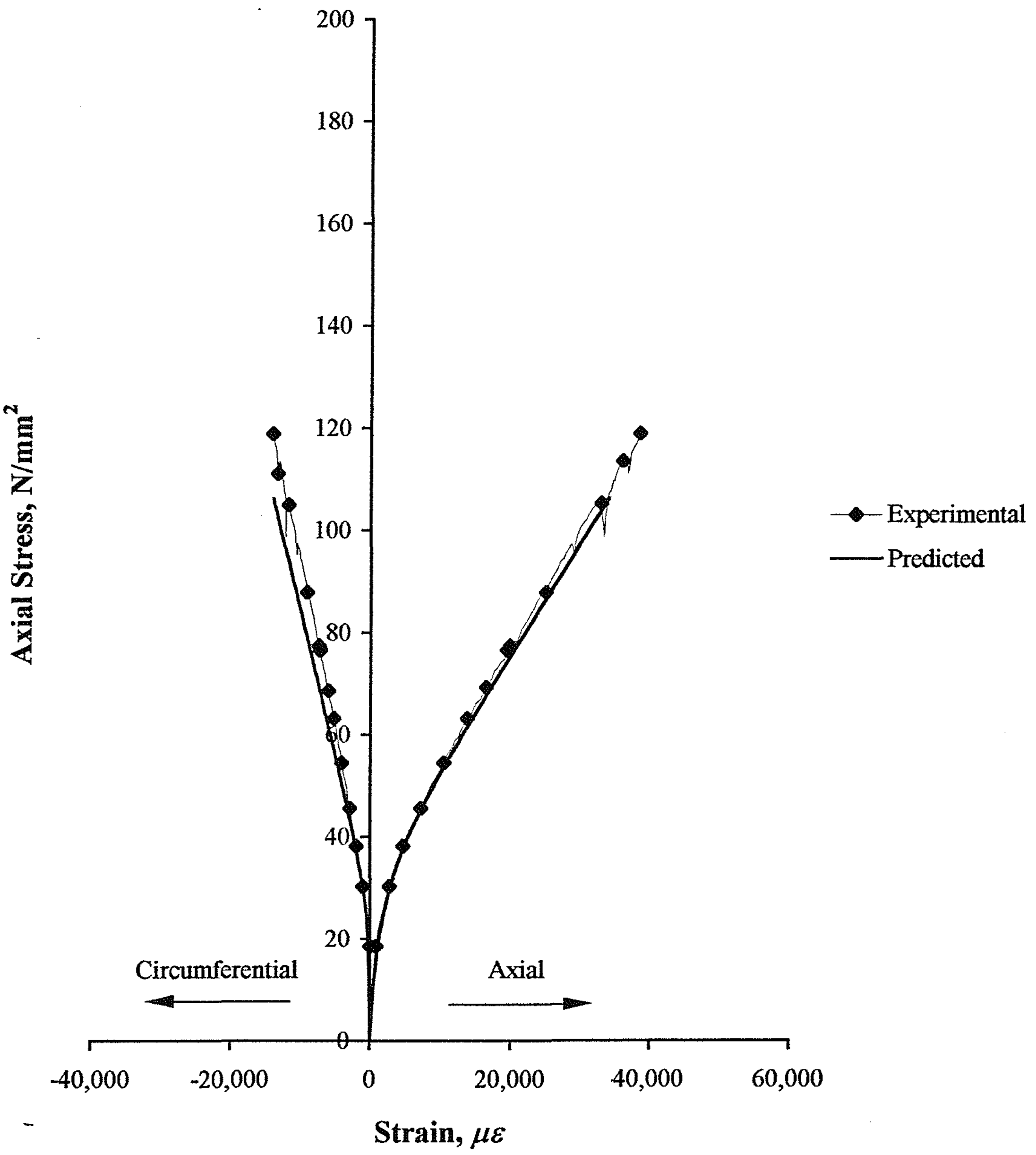



**Figure D.5.** Comparison of the theoretical and experimental stress-strain curves for the 125 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 82.3 degrees (concrete cube strength = 29.2 N/mm$^2$)

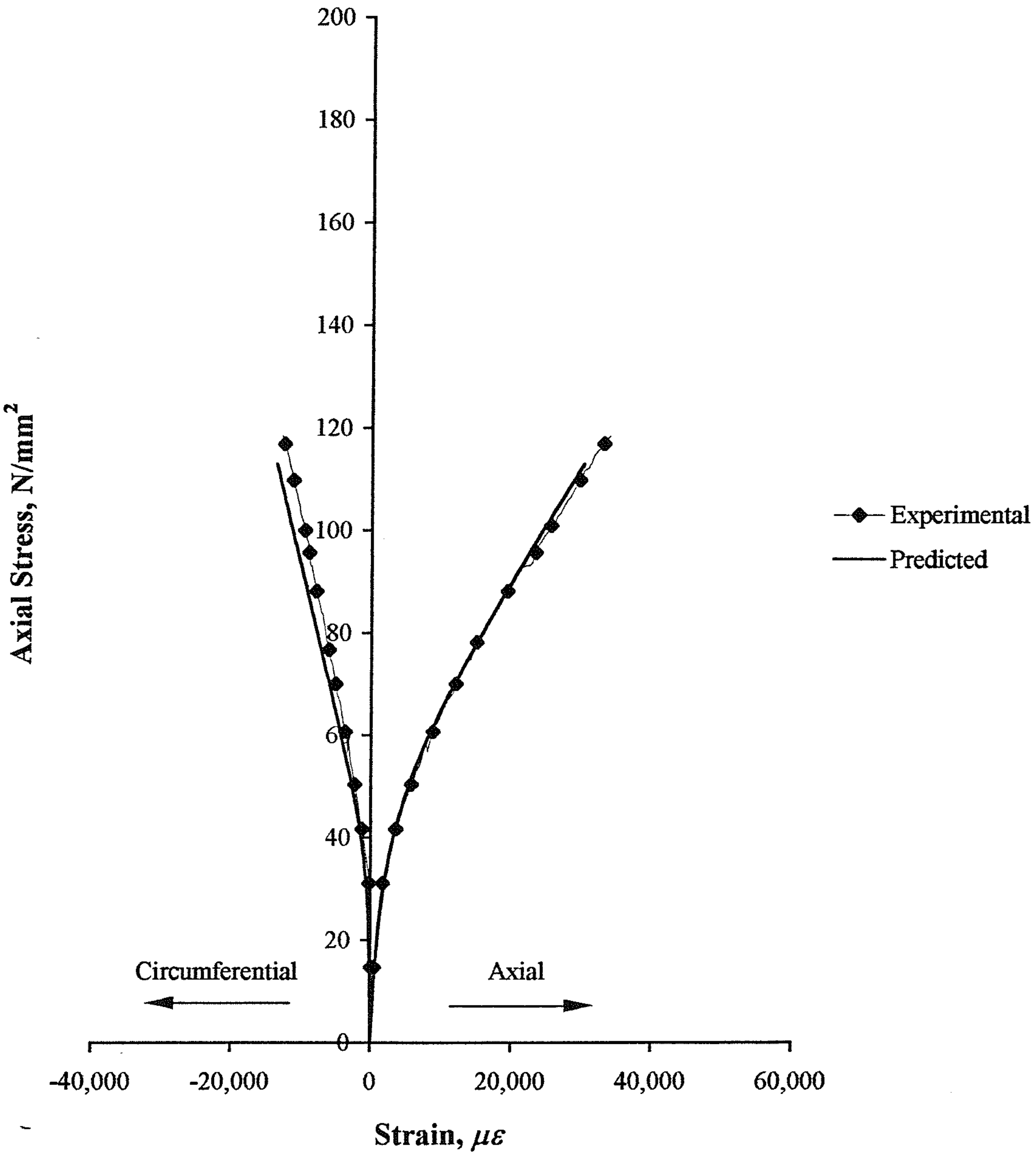



**Figure D.6.** Comparison of the theoretical and experimental stress-strain curves for the 125 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 82.3 degrees (concrete cube strength = 37.5 N/mm$^2$)

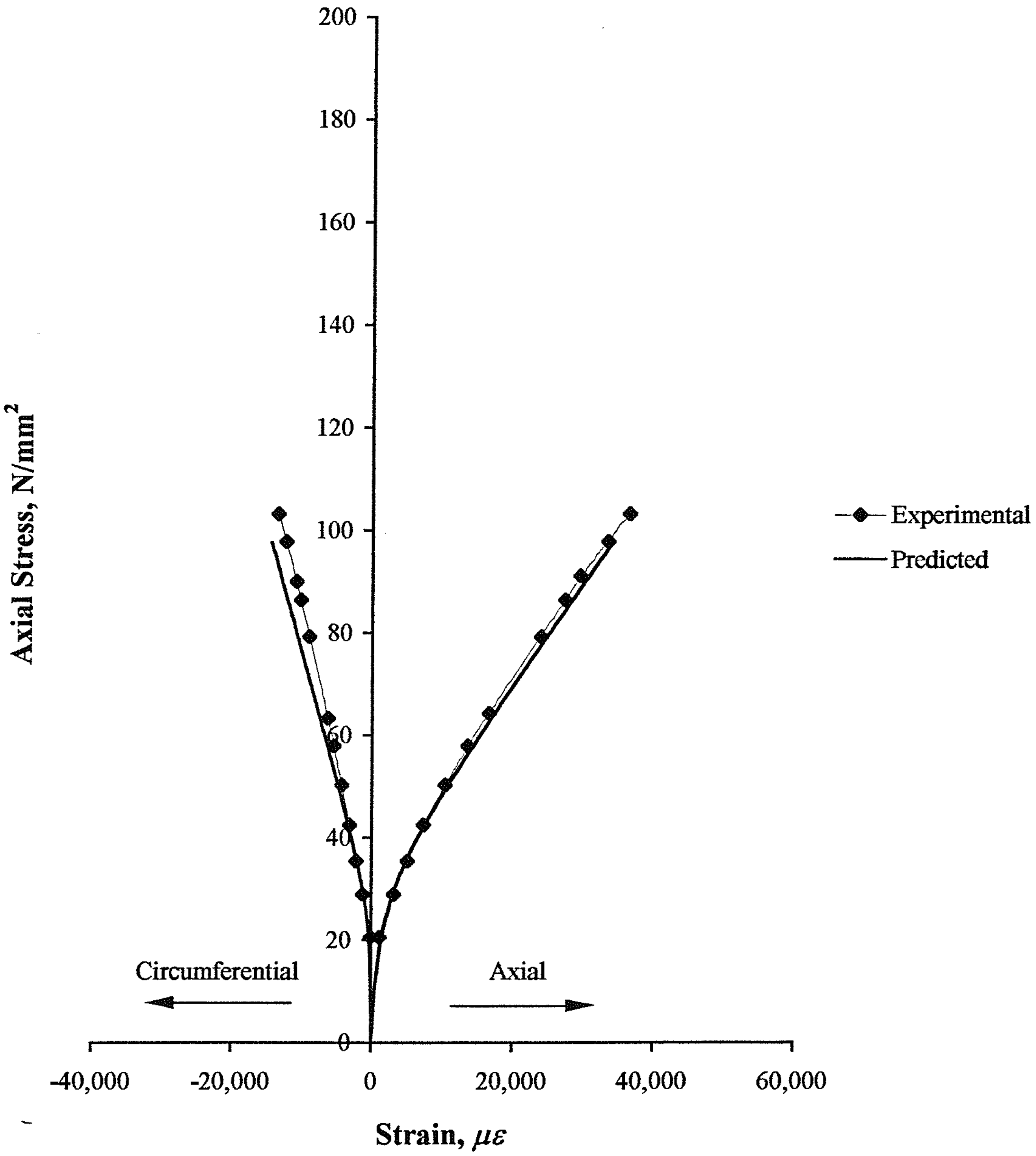



**Figure D.7.** Comparison of the theoretical and experimental stress-strain curves for the 150 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 83.6 degrees (concrete cube strength = 27.4 N/mm$^2$)

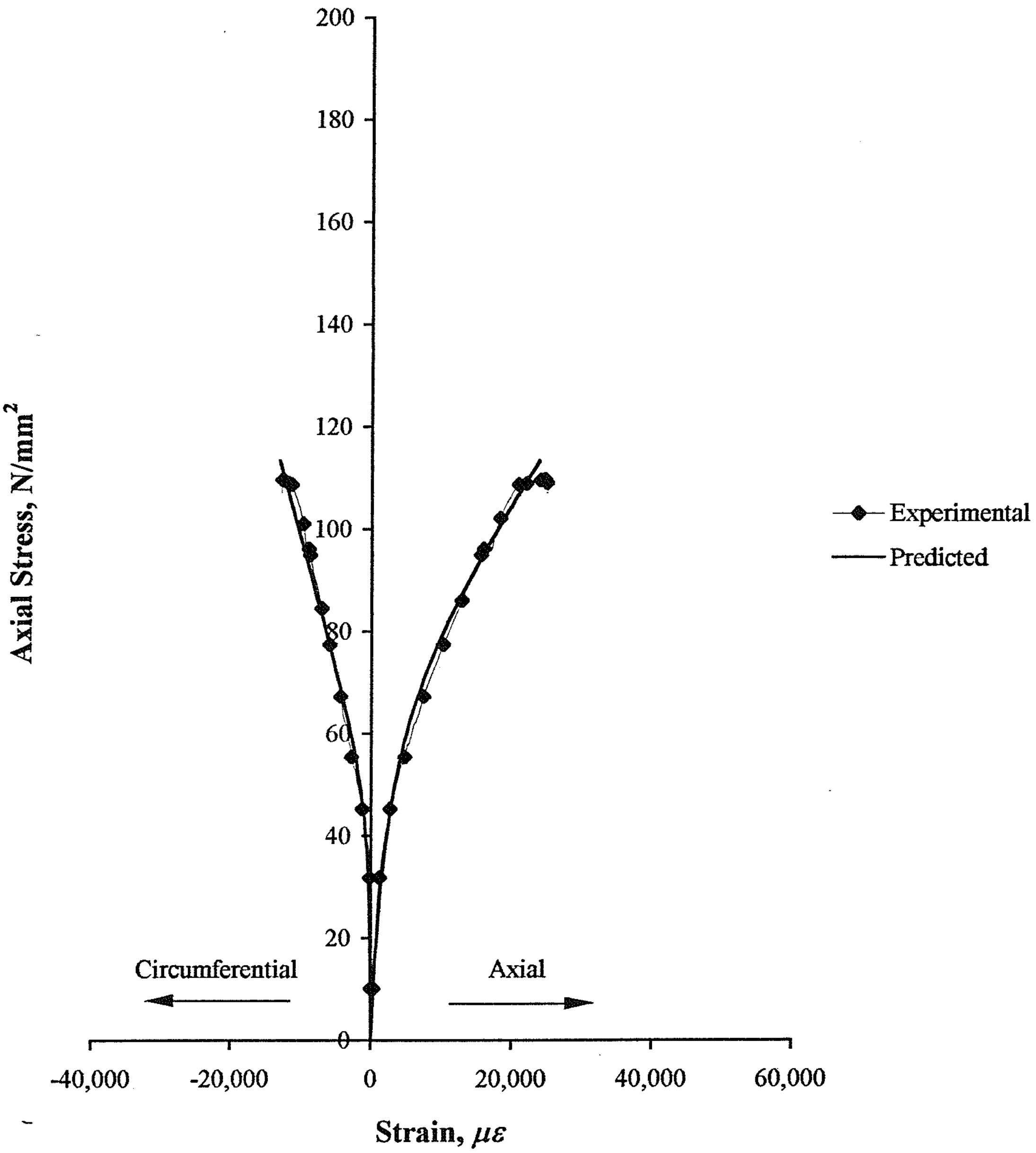



**Figure D.8.** Comparison of the theoretical and experimental stress-strain curves for the 150 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 83.6 degrees (concrete cube strength = 46.3 N/mm$^2$)

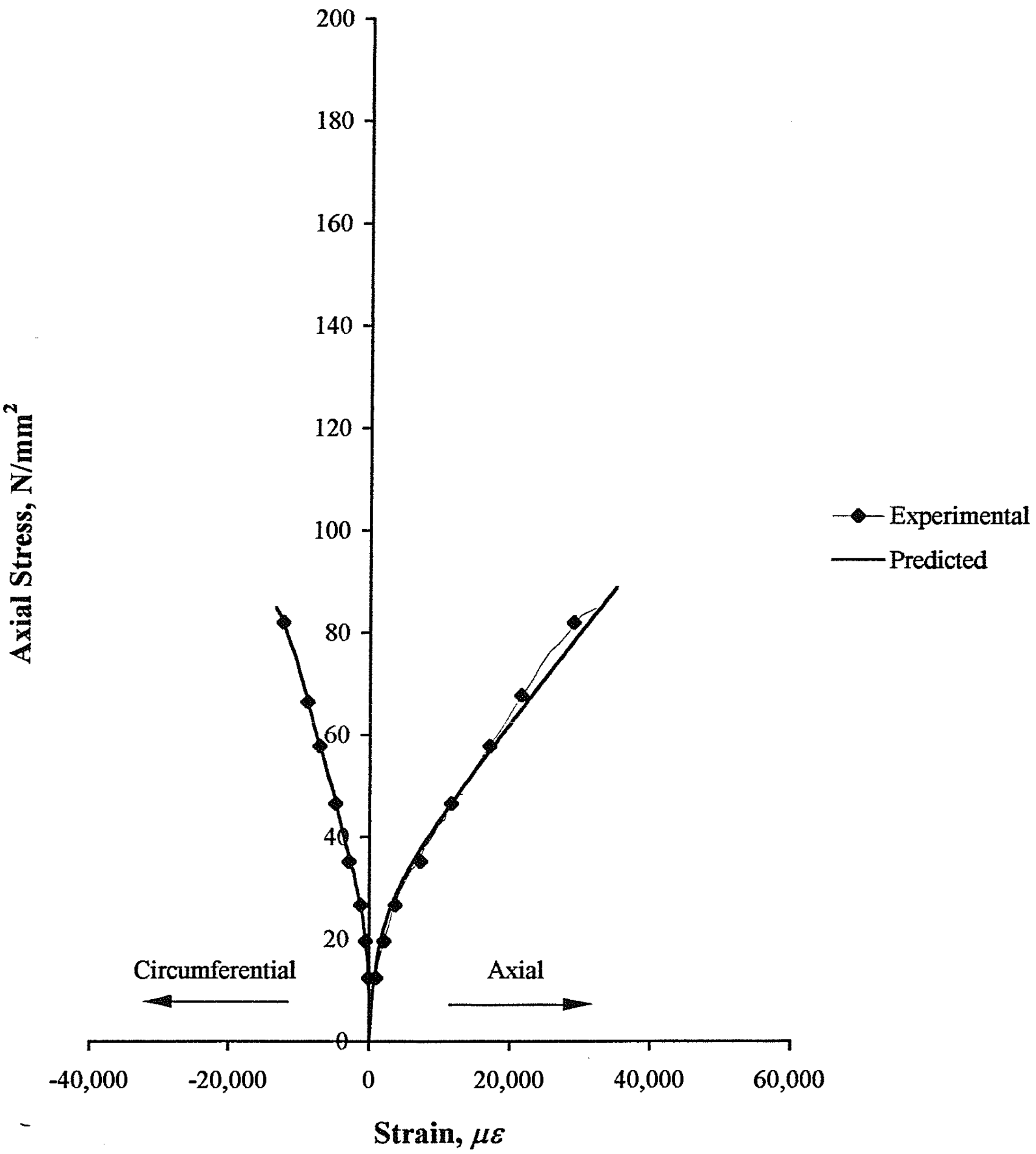



**Figure D.9.** Comparison of the theoretical and experimental stress-strain curves for the 300 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 86.8 degrees (concrete cube strength = 34.0 N/mm$^2$)

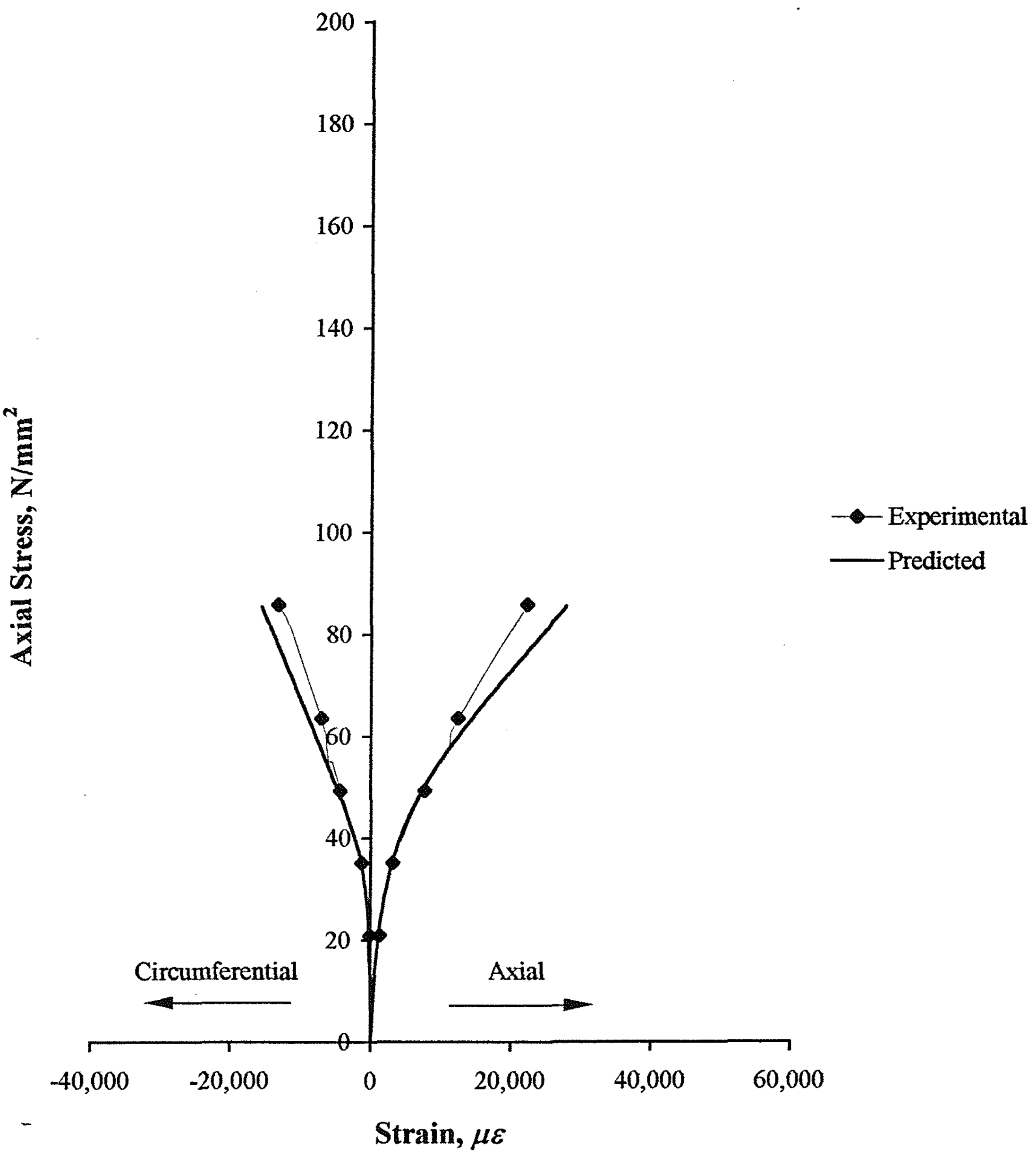



**Figure D.10.** Comparison of the theoretical and experimental stress-strain curves for the 300 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 86.8 degrees (concrete cube strength = 38.6 N/mm$^2$)

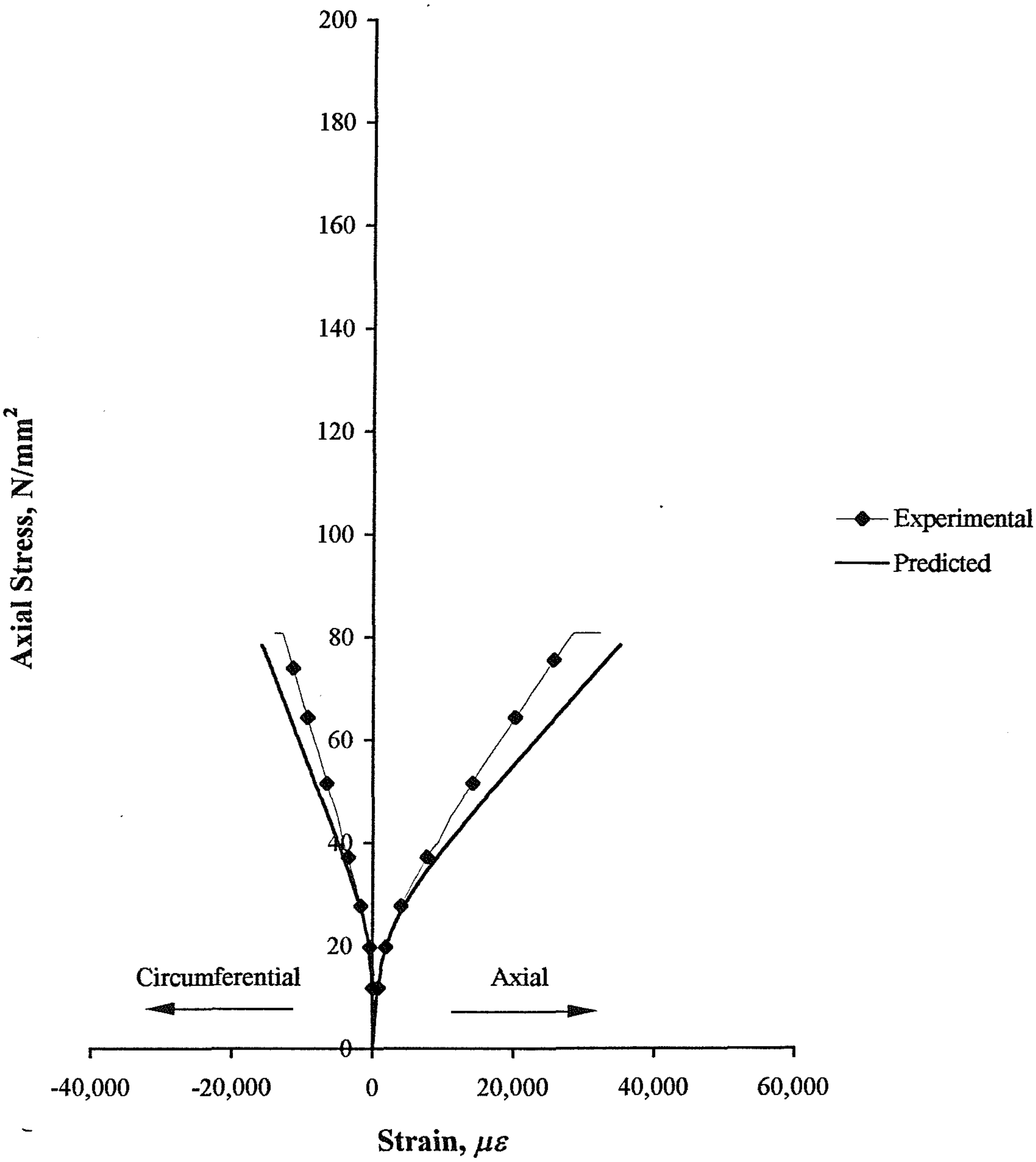



**Figure D.11.** Comparison of the theoretical and experimental stress-strain curves for the 400 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 87.6 degrees (concrete cube strength = 32.3 N/mm$^2$)

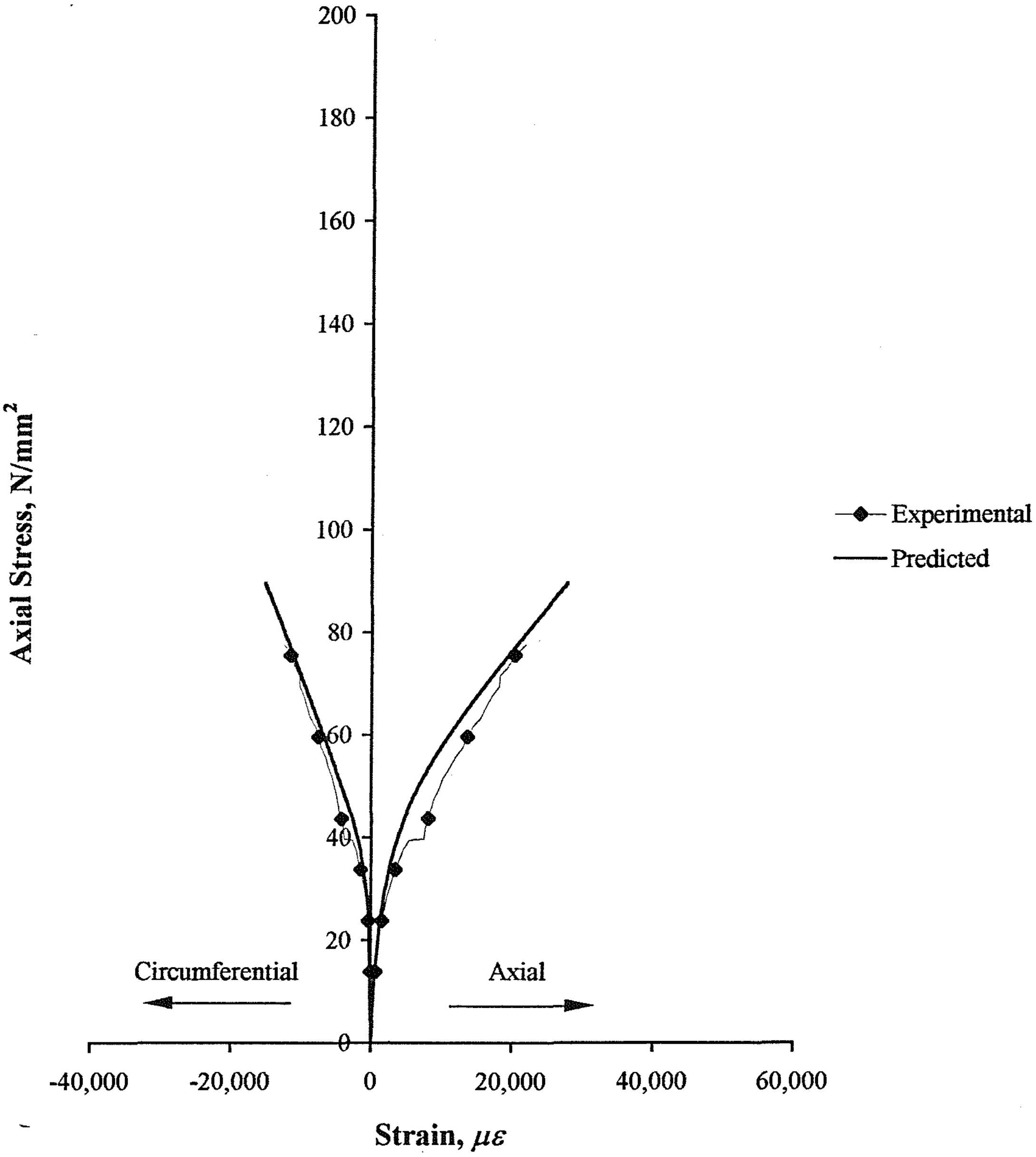



**Figure D.12.** Comparison of the theoretical and experimental stress-strain curves for the 400 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 87.6 degrees (concrete cube strength = 40.8 N/mm$^2$)

APPENDIX E

**COMPARISON OF THE THEORETICAL AND EXPERIMENTAL STRESS-VOLUMETRIC STRAIN CURVES FOR CONCRETE-FILLED E-GLASS FRP-COMPOSITE STUB COLUMNS WITH A NOMINAL 90 DEGREE FIBRE ORIENTATION**

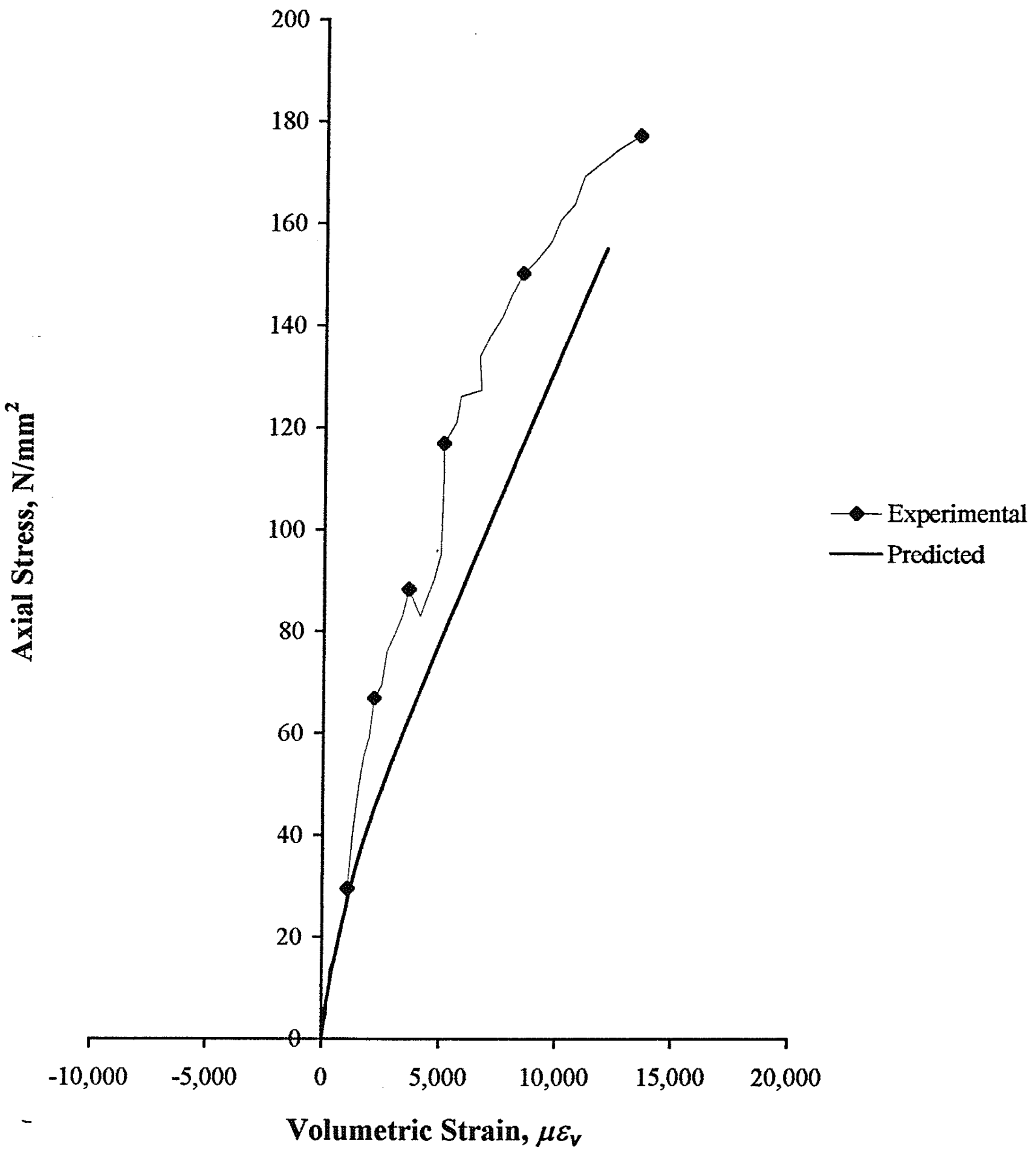



**Figure E.1.** Comparison of the theoretical and experimental stress-volumetric strain curves for the 80 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 78.1 degrees (concrete cube strength = 23.4 N/mm$^2$)

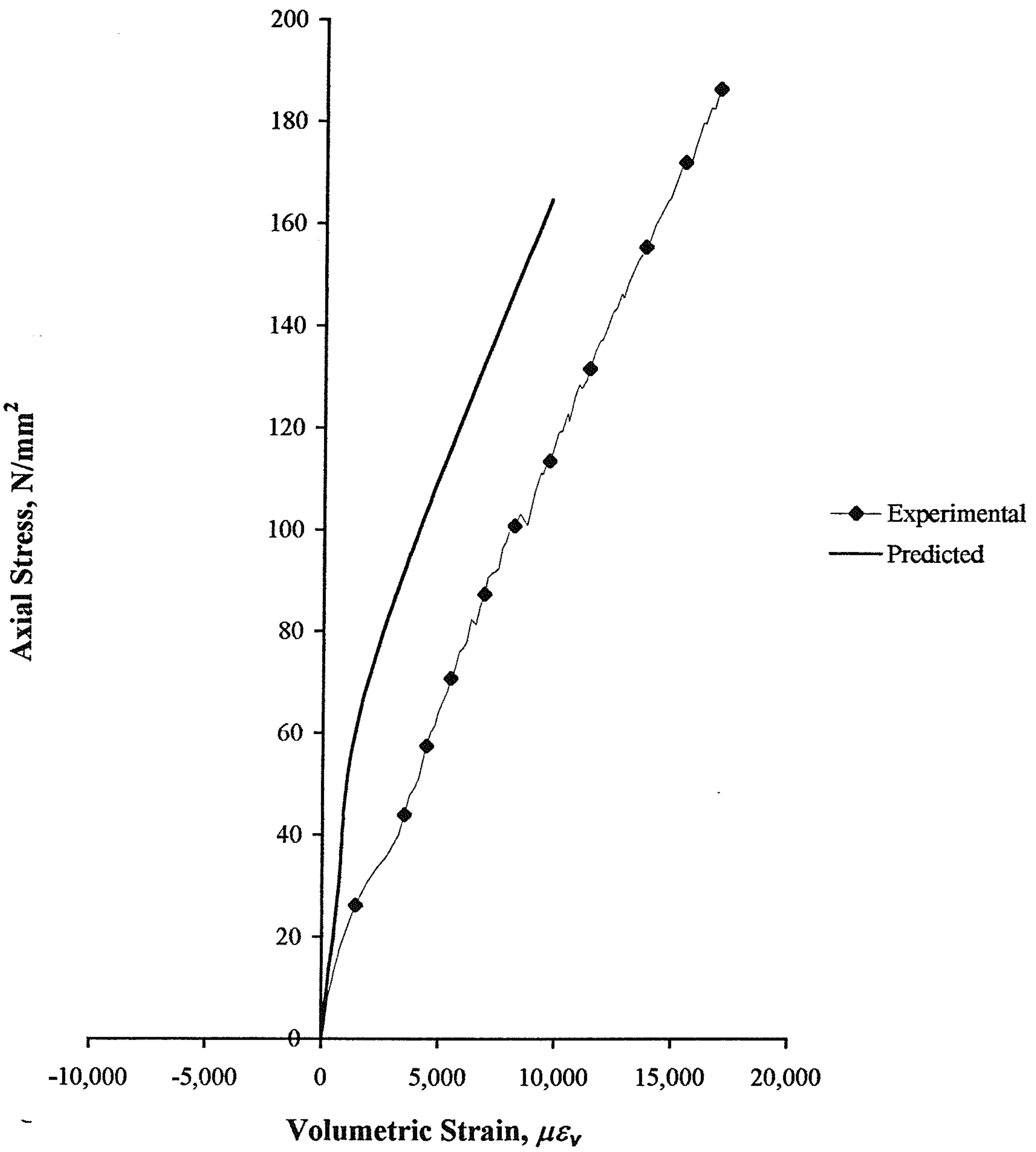



**Figure E.2.** Comparison of the theoretical and experimental stress-volumetric strain curves for the 80 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 78.1 degrees (concrete cube strength = 35.2 N/mm$^2$)

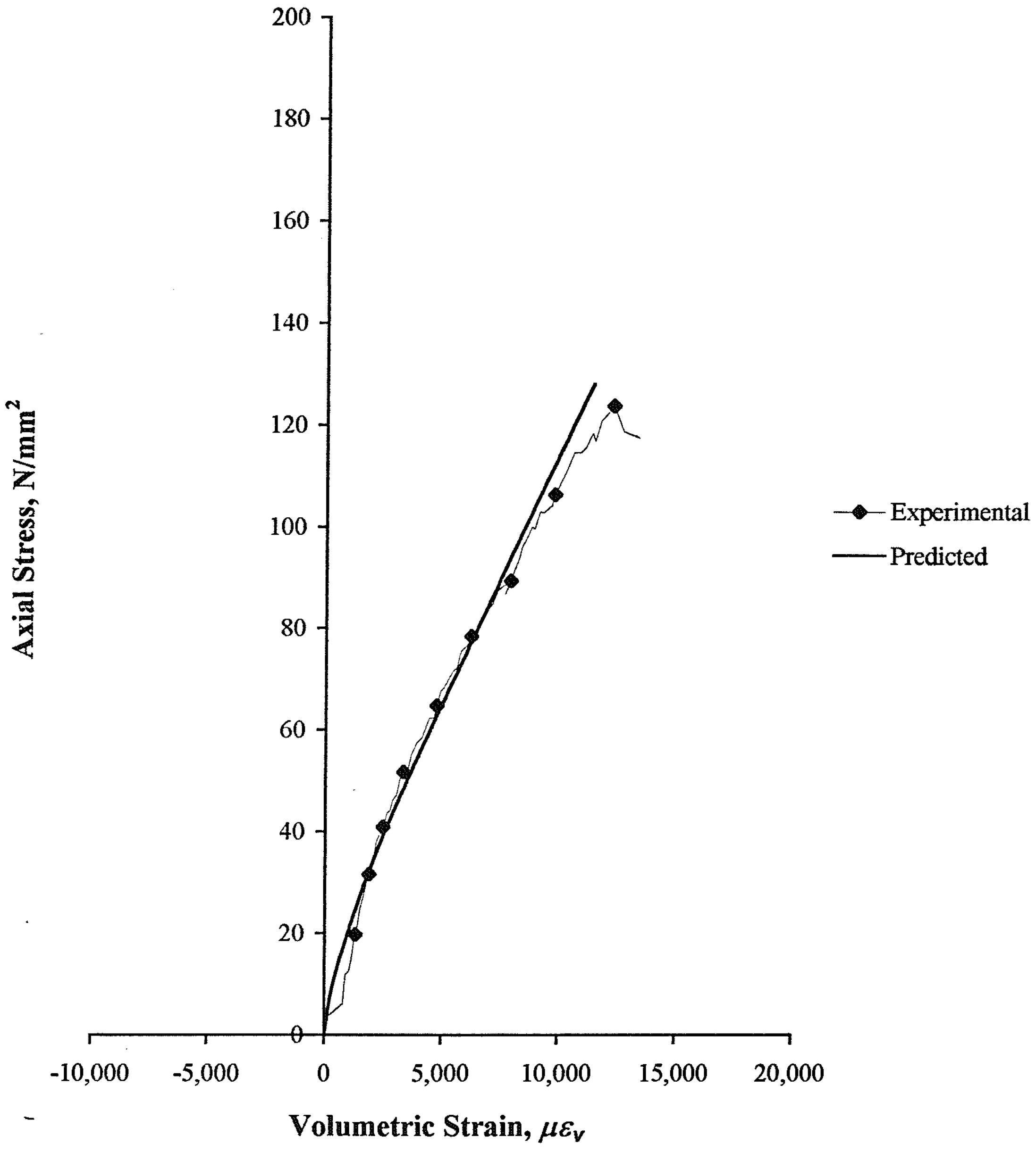



**Figure E.3.** Comparison of the theoretical and experimental stress-volumetric strain curves for the 100 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 80.4 degrees (concrete cube strength = 19.7 N/mm$^2$)

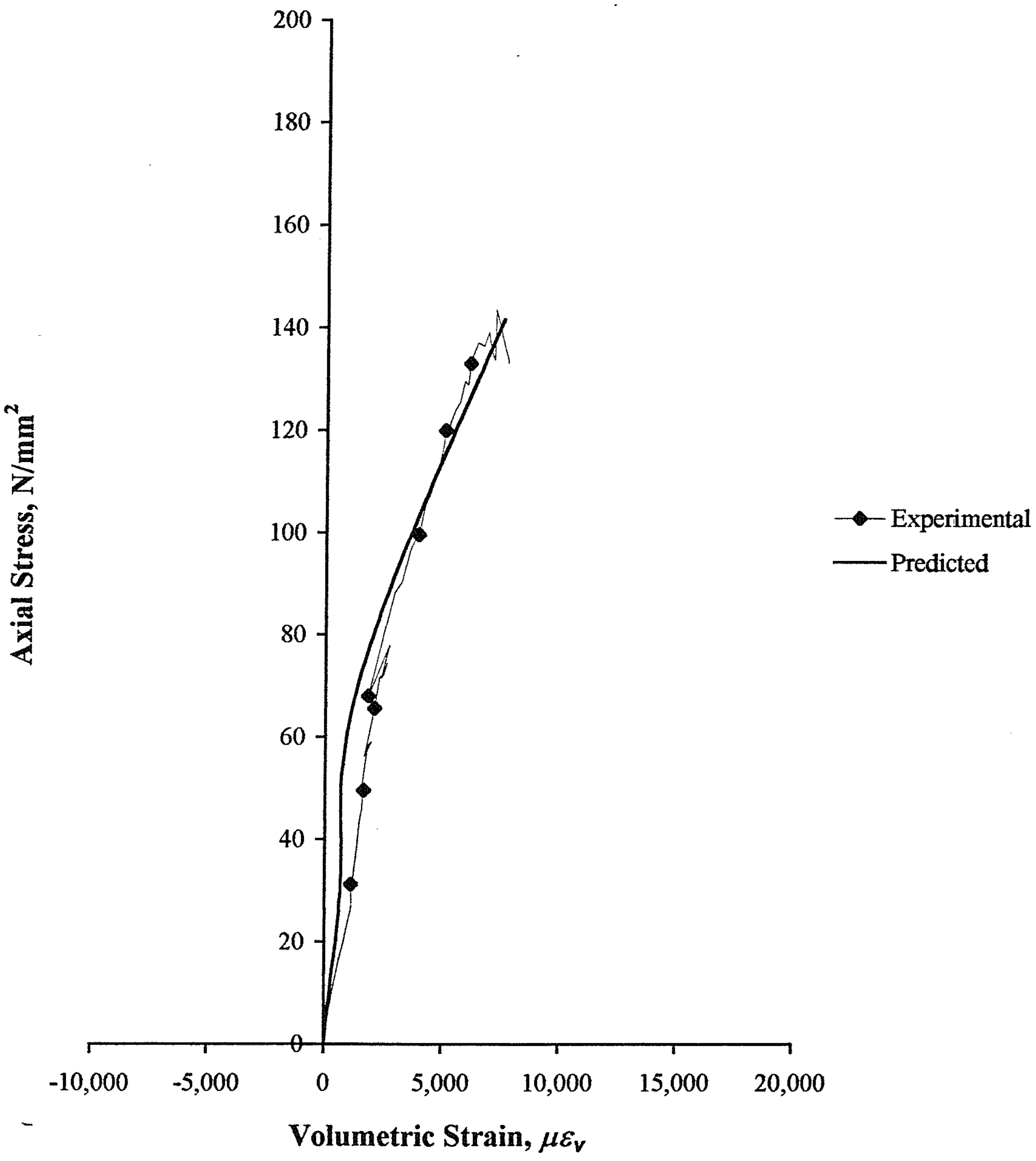



**Figure E.4.** Comparison of the theoretical and experimental stress-volumetric strain curves for the 100 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 80.4 degrees (concrete cube strength = 36.2 N/mm$^2$)

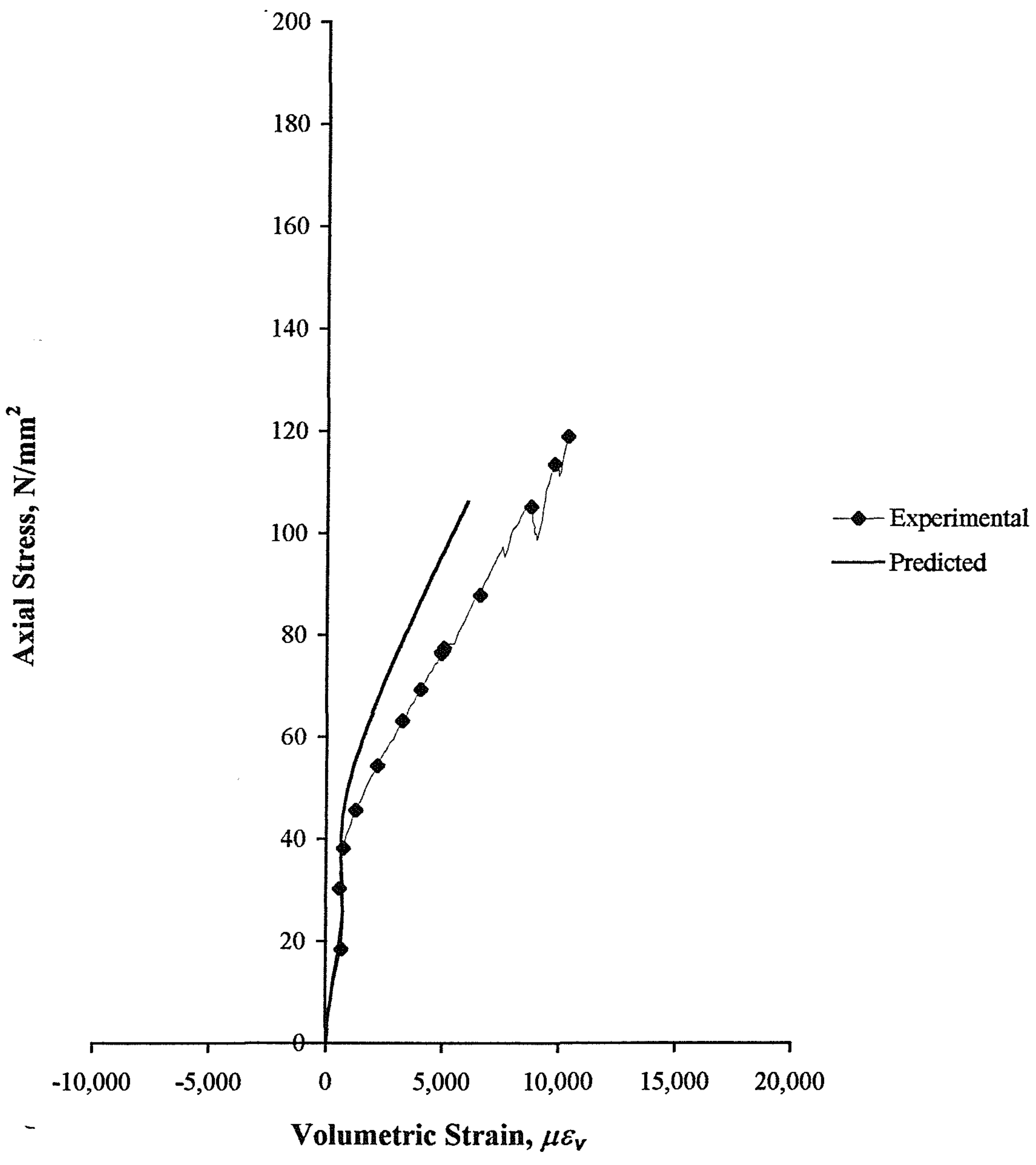



**Figure E.5.** Comparison of the theoretical and experimental stress-volumetric strain curves for the 125 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 82.3 degrees (concrete cube strength = 29.2 N/mm$^2$)

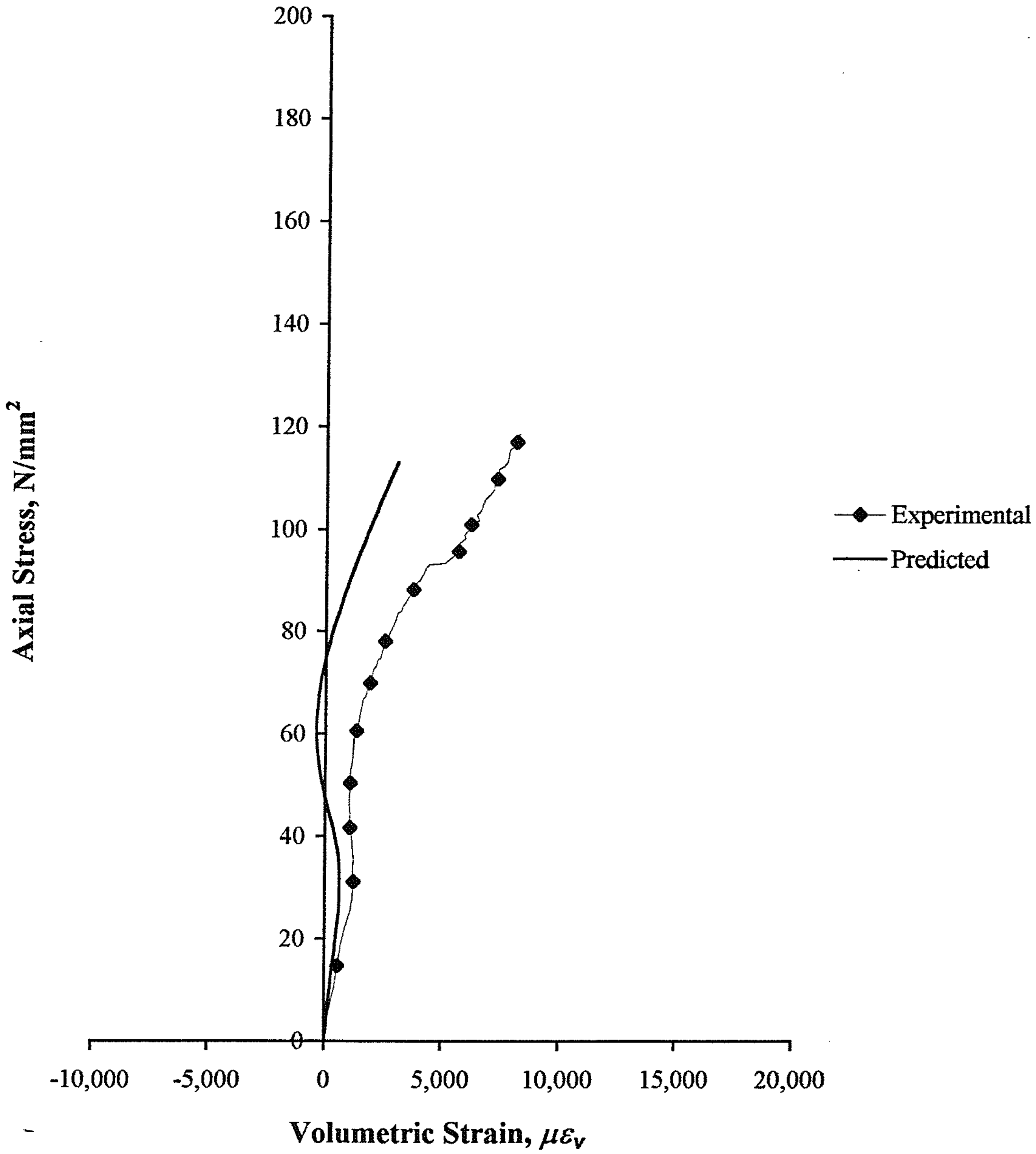



**Figure E.6.** Comparison of the theoretical and experimental stress-volumetric strain curves for the 125 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 82.3 degrees (concrete cube strength = 37.5 N/mm$^2$)

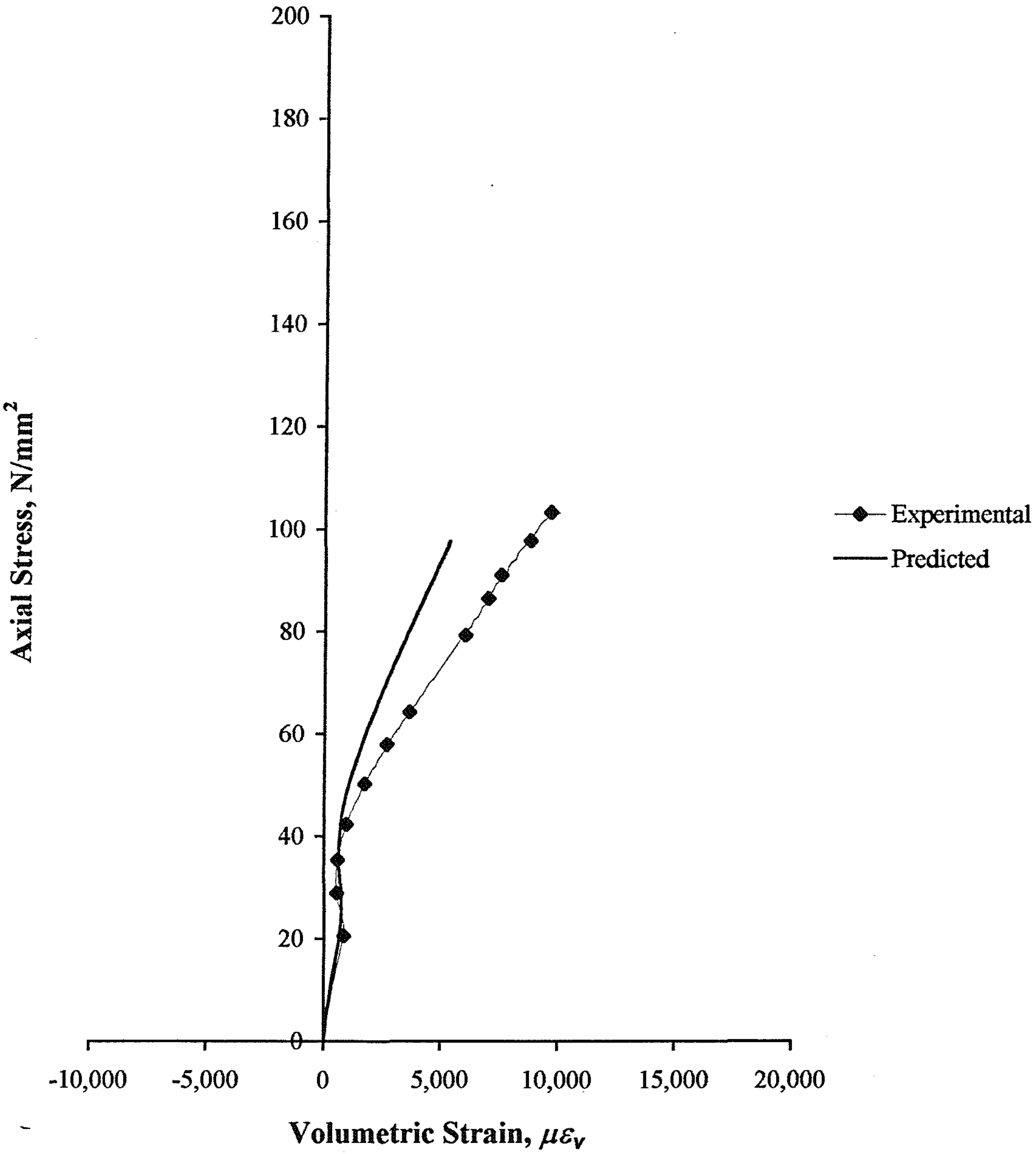



**Figure E.7.** Comparison of the theoretical and experimental stress-volumetric strain curves for the 150 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 83.6 degrees (concrete cube strength = 27.4 N/mm$^2$)

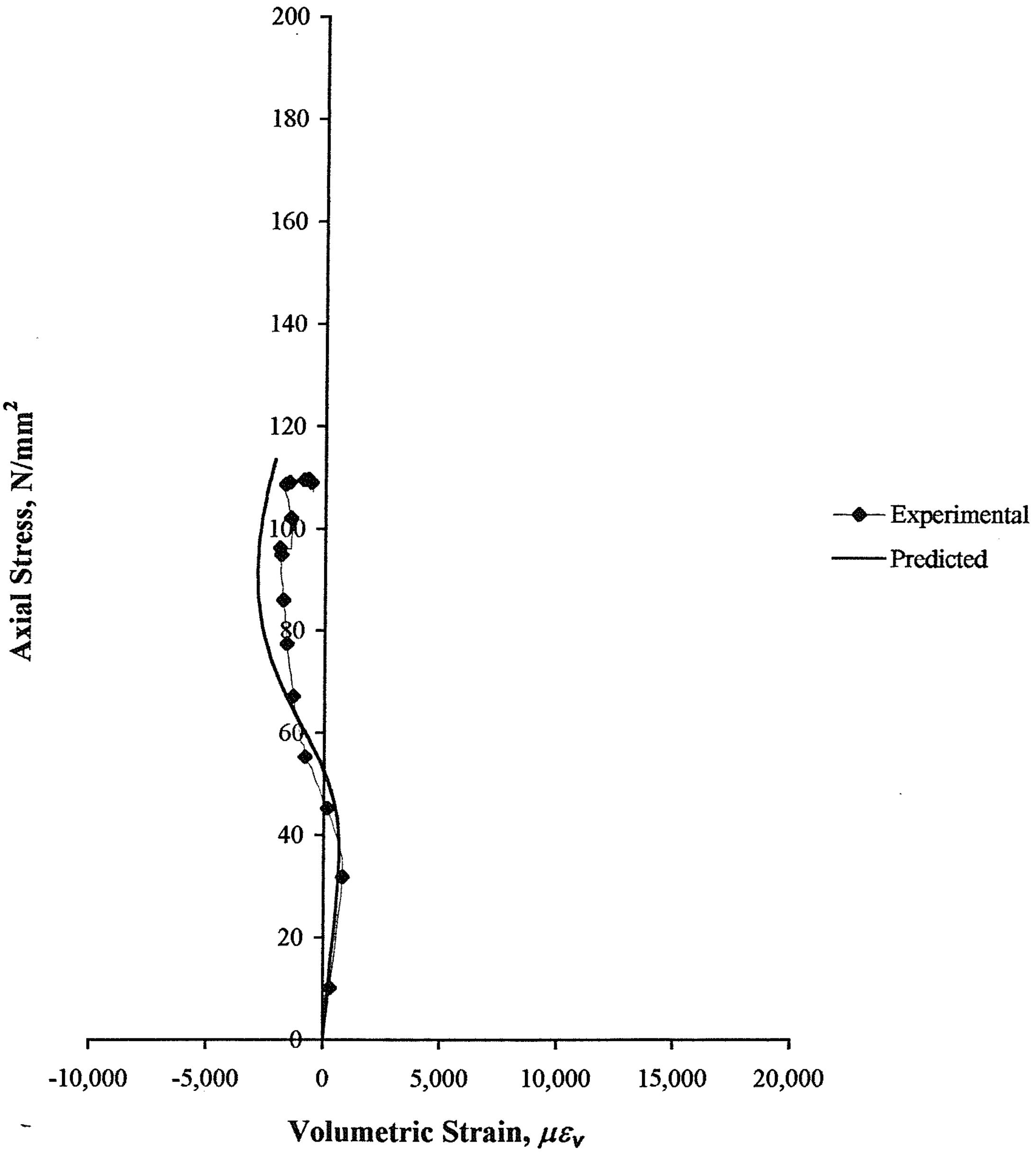



**Figure E.8.** Comparison of the theoretical and experimental stress-volumetric strain curves for the 150 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 83.6 degrees (concrete cube strength = 46.3 N/mm$^2$)

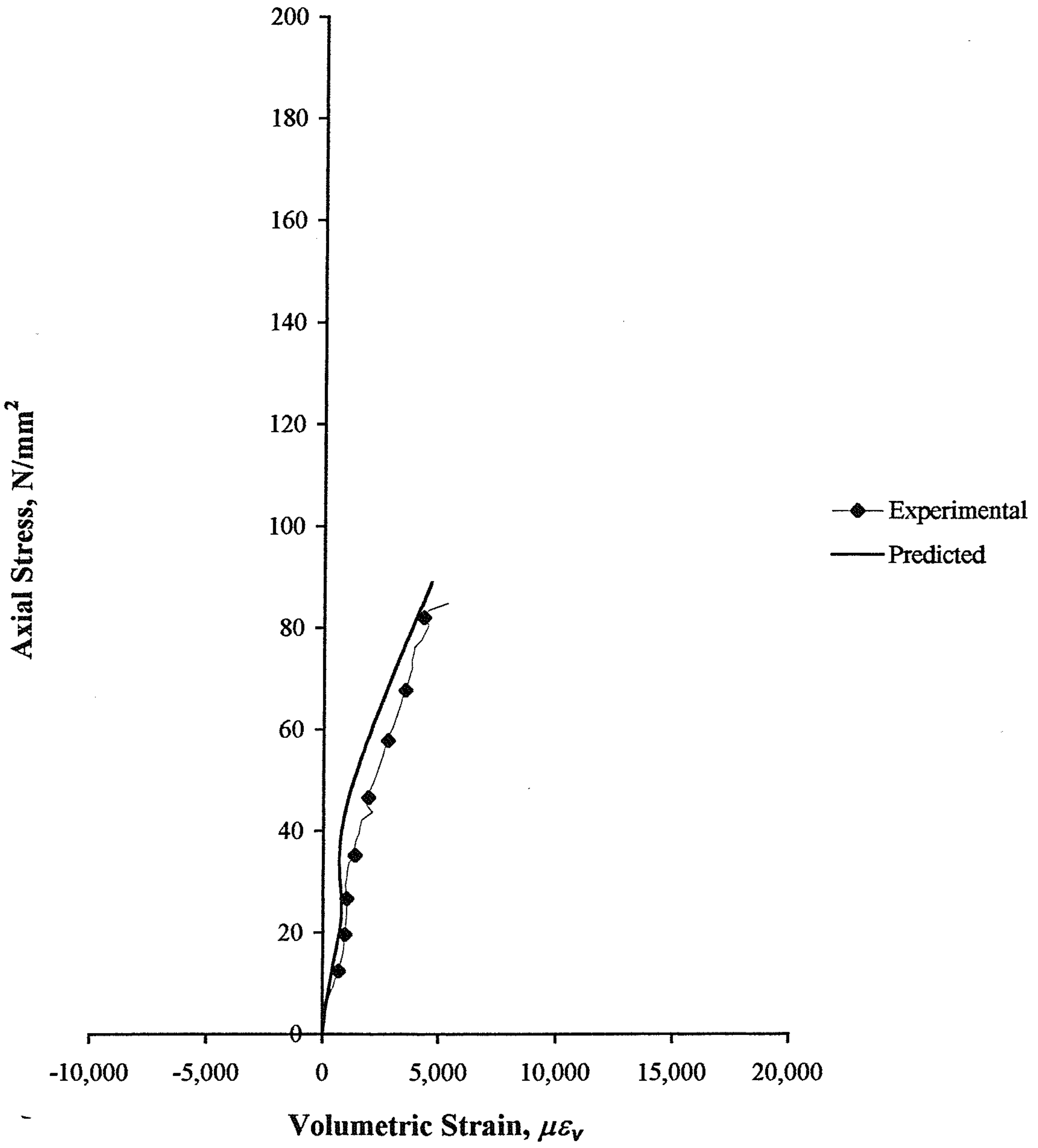



**Figure E.9.** Comparison of the theoretical and experimental stress-volumetric strain curves for the 300 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 86.8 degrees (concrete cube strength = 34.0 N/mm$^2$)

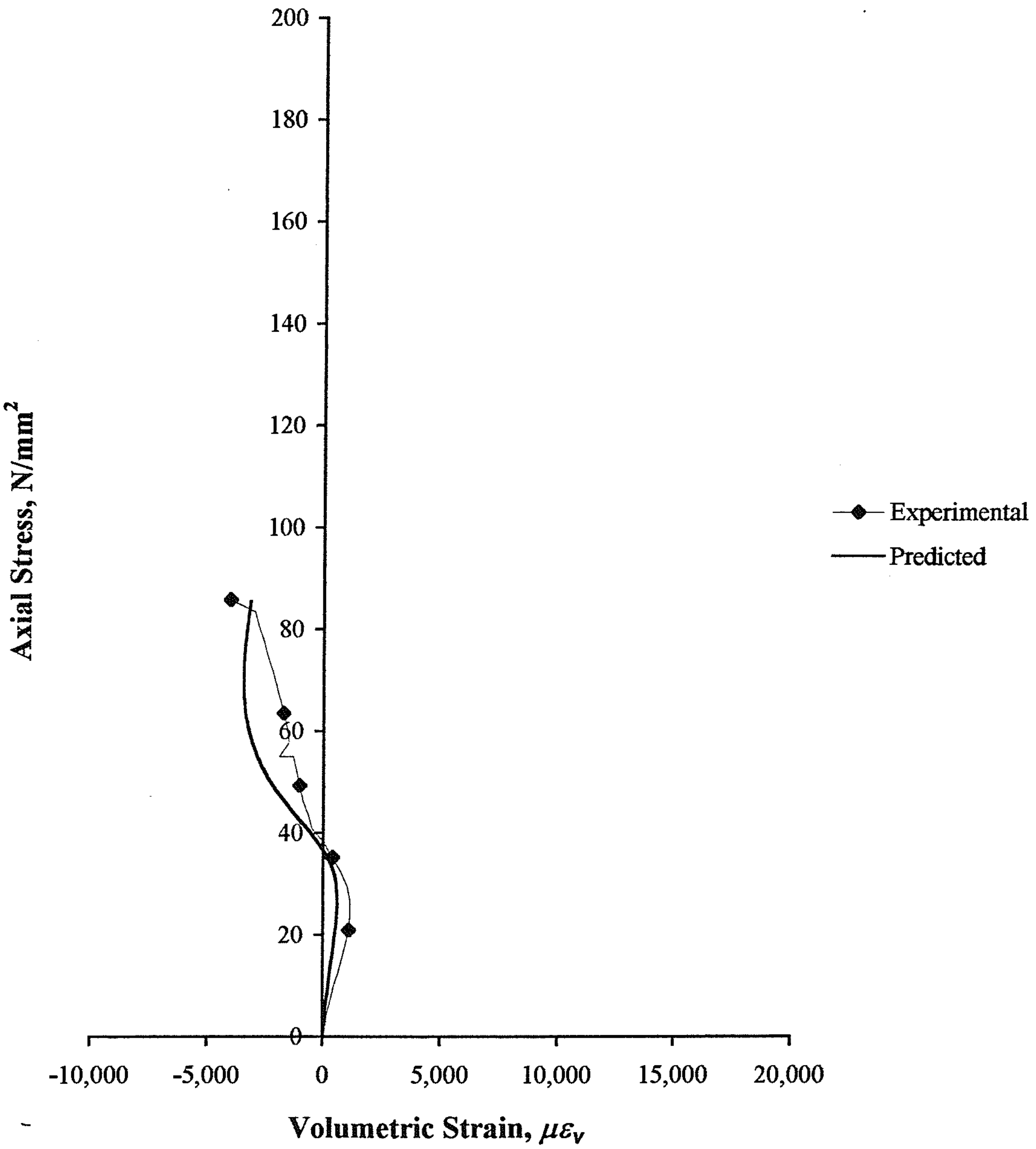



**Figure E.10.** Comparison of the theoretical and experimental stress-volumetric strain curves for the 300 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 86.8 degrees (concrete cube strength = 38.6 N/mm$^2$)

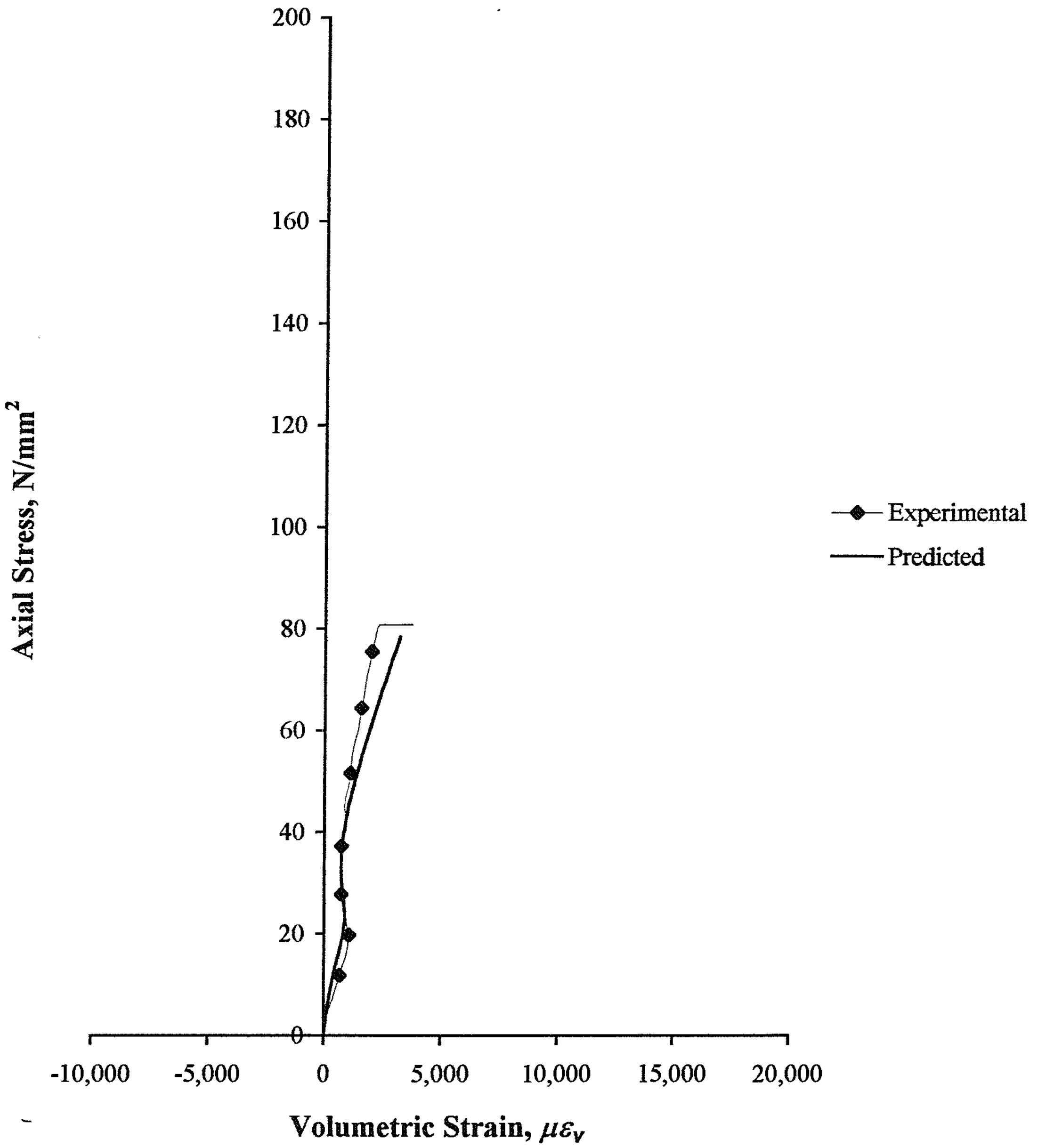



**Figure E.11.** Comparison of the theoretical and experimental stress-volumetric strain curves for the 400 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 87.6 degrees (concrete cube strength = 32.3 N/mm$^2$)

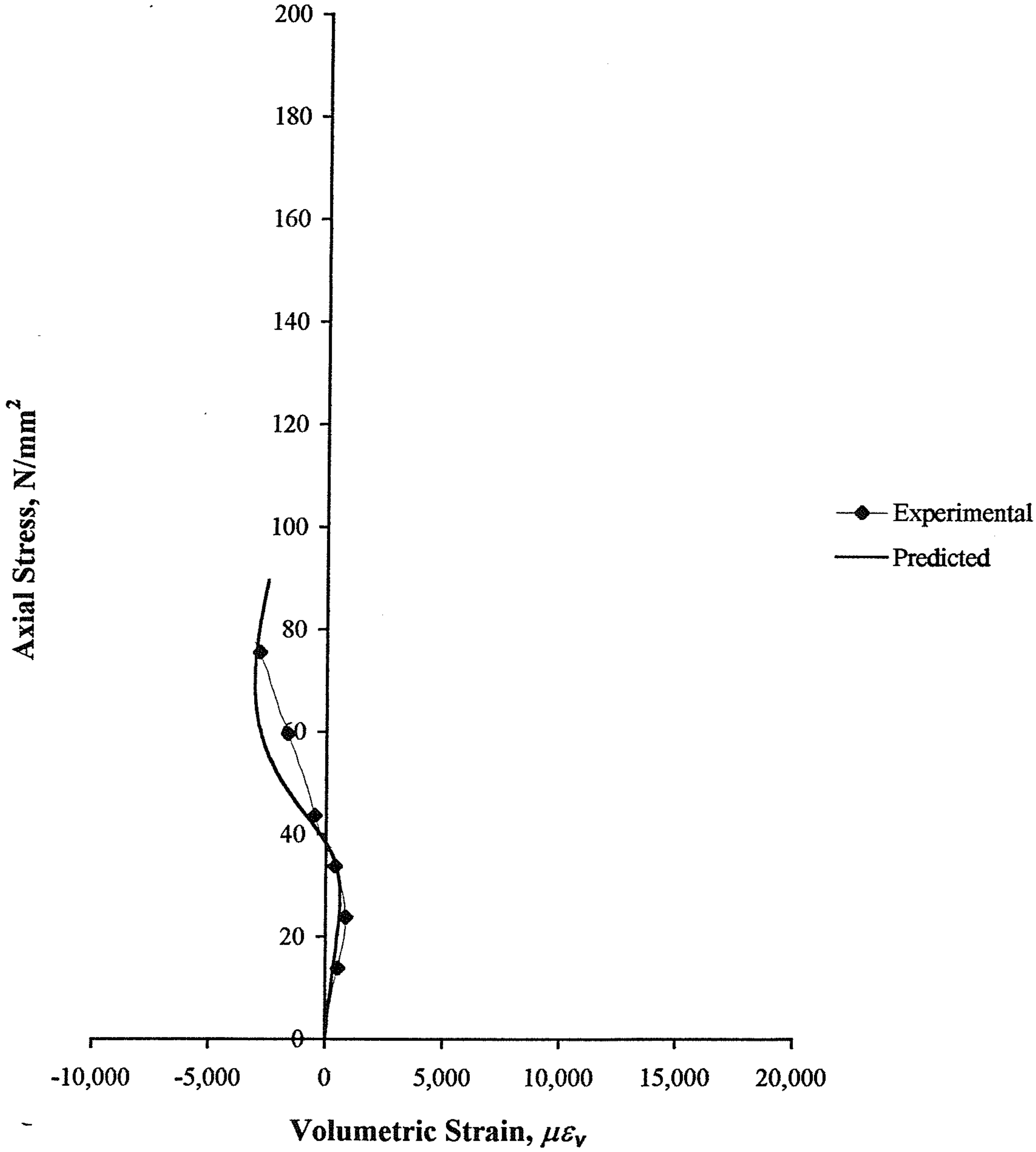



**Figure E.12.** Comparison of the theoretical and experimental stress-volumetric strain curves for the 400 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 87.6 degrees (concrete cube strength = 40.8 N/mm$^2$)

APPENDIX F

# COMPARISON OF THE THEORETICAL AND EXPERIMENTAL STRESS-VOLUMETRIC STRAIN CURVES FOR CONCRETE-FILLED E-GLASS FRP-COMPOSITE STUB COLUMNS WITH A NOMINAL 67½ DEGREE FIBRE ORIENTATION

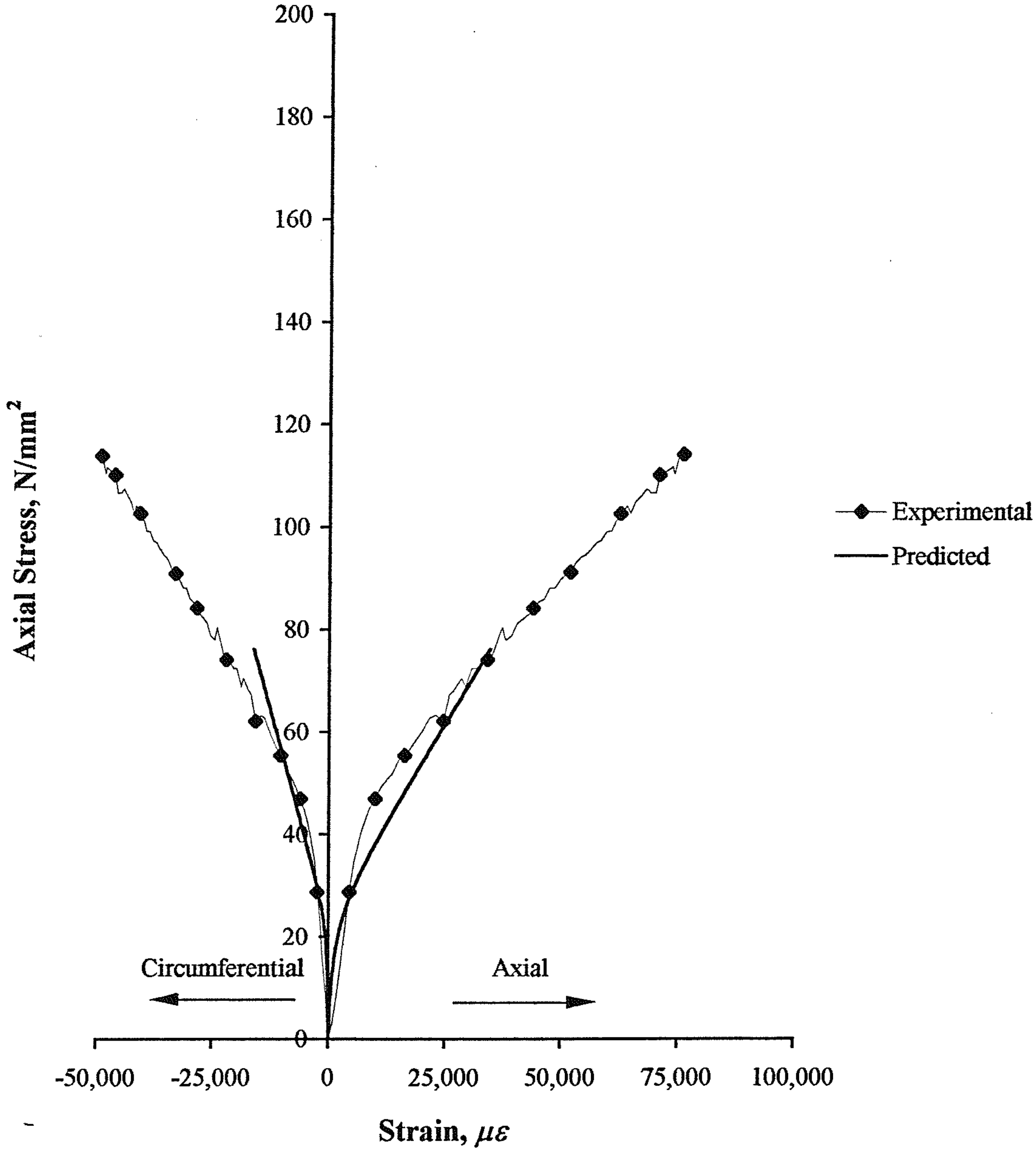



**Figure F.1.** Comparison of the theoretical and experimental stress-strain curves for the 80 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 57.8 degrees (concrete cube strength = 22.6 N/mm$^2$)

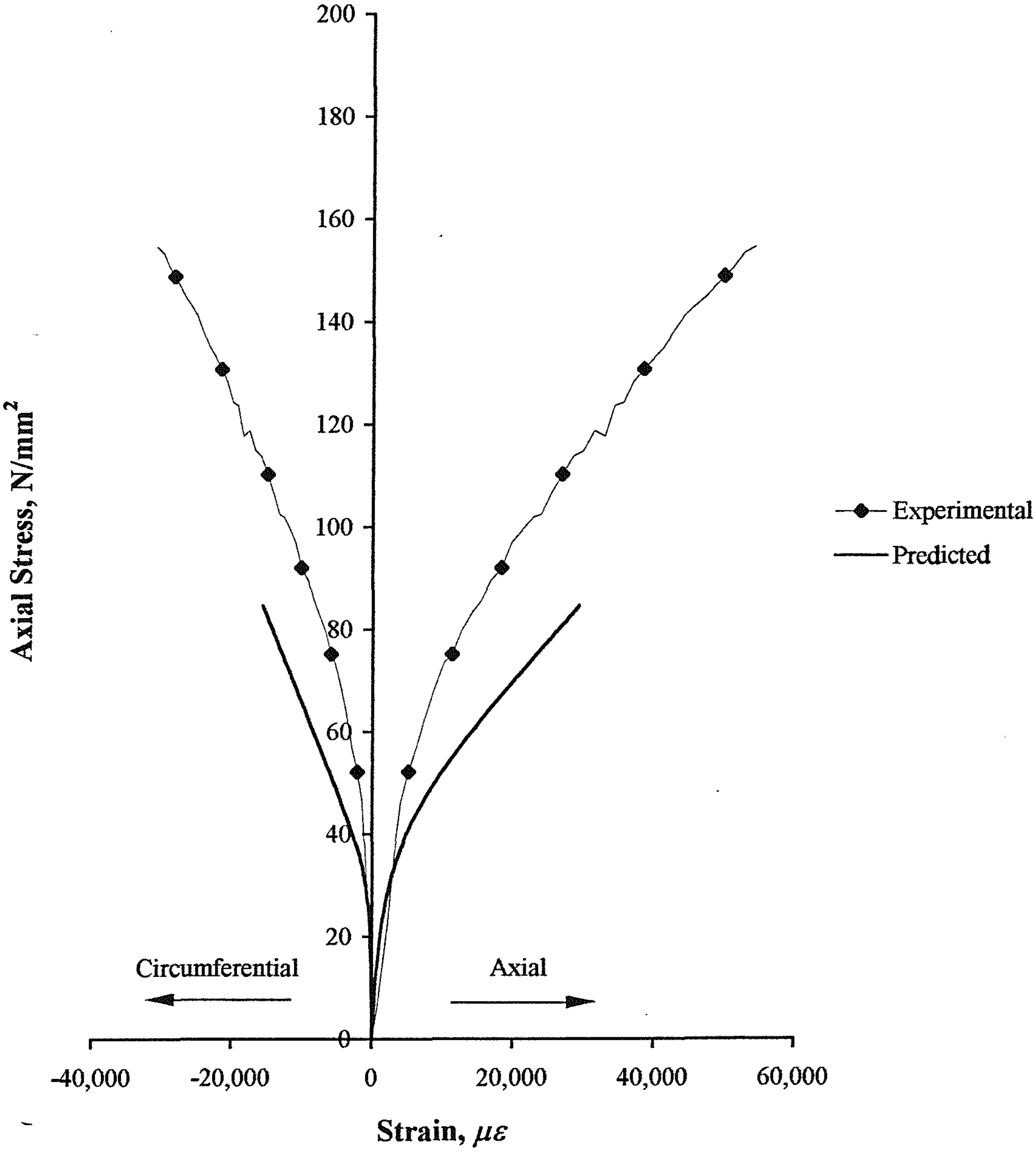



**Figure F.2.** Comparison of the theoretical and experimental stress-strain curves for the 80 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 57.8 degrees (concrete cube strength = 32.8 N/mm$^2$)

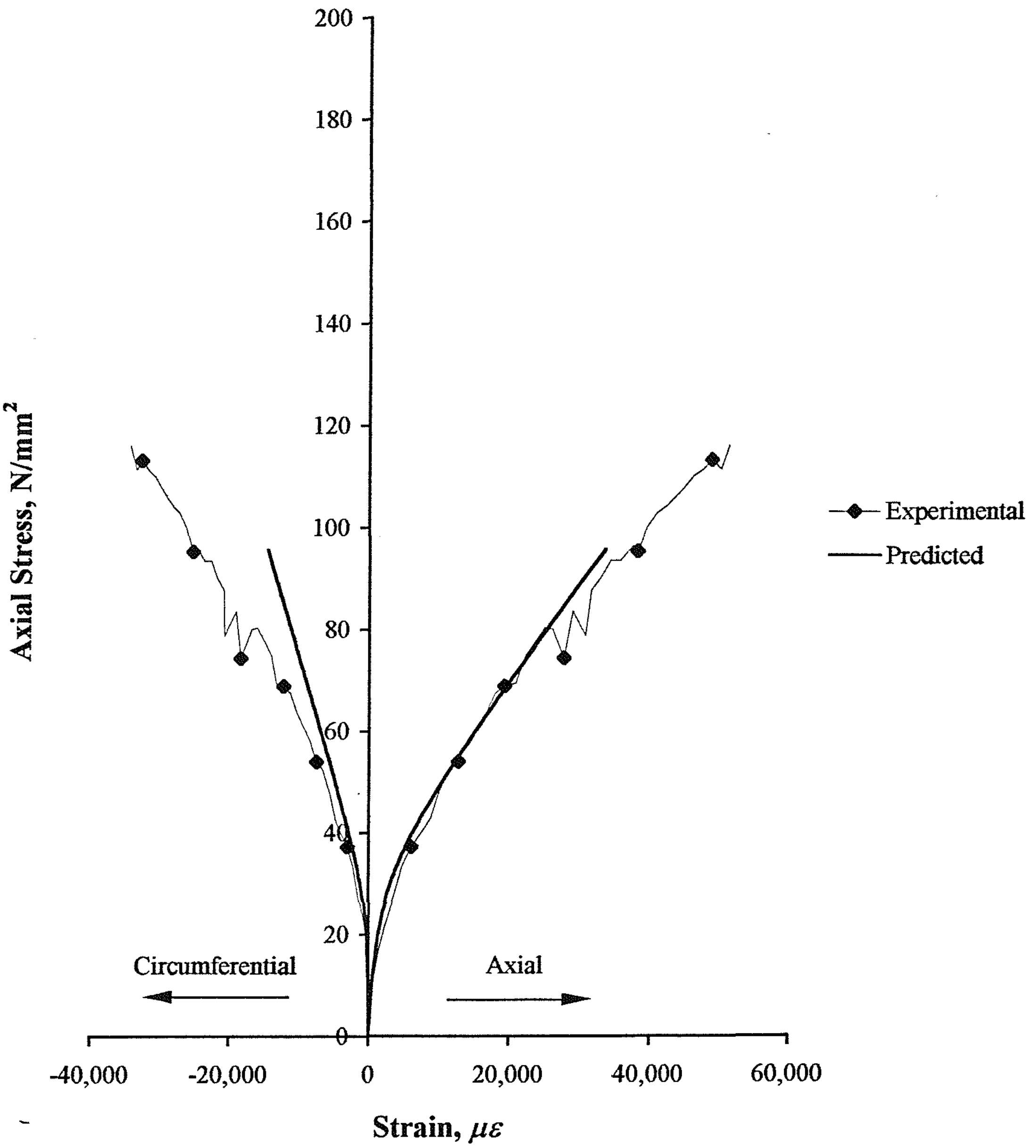



**Figure F.3.** Comparison of the theoretical and experimental stress-strain curves for the 100 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 71.4 degrees (concrete cube strength = 28.2 N/mm$^2$)

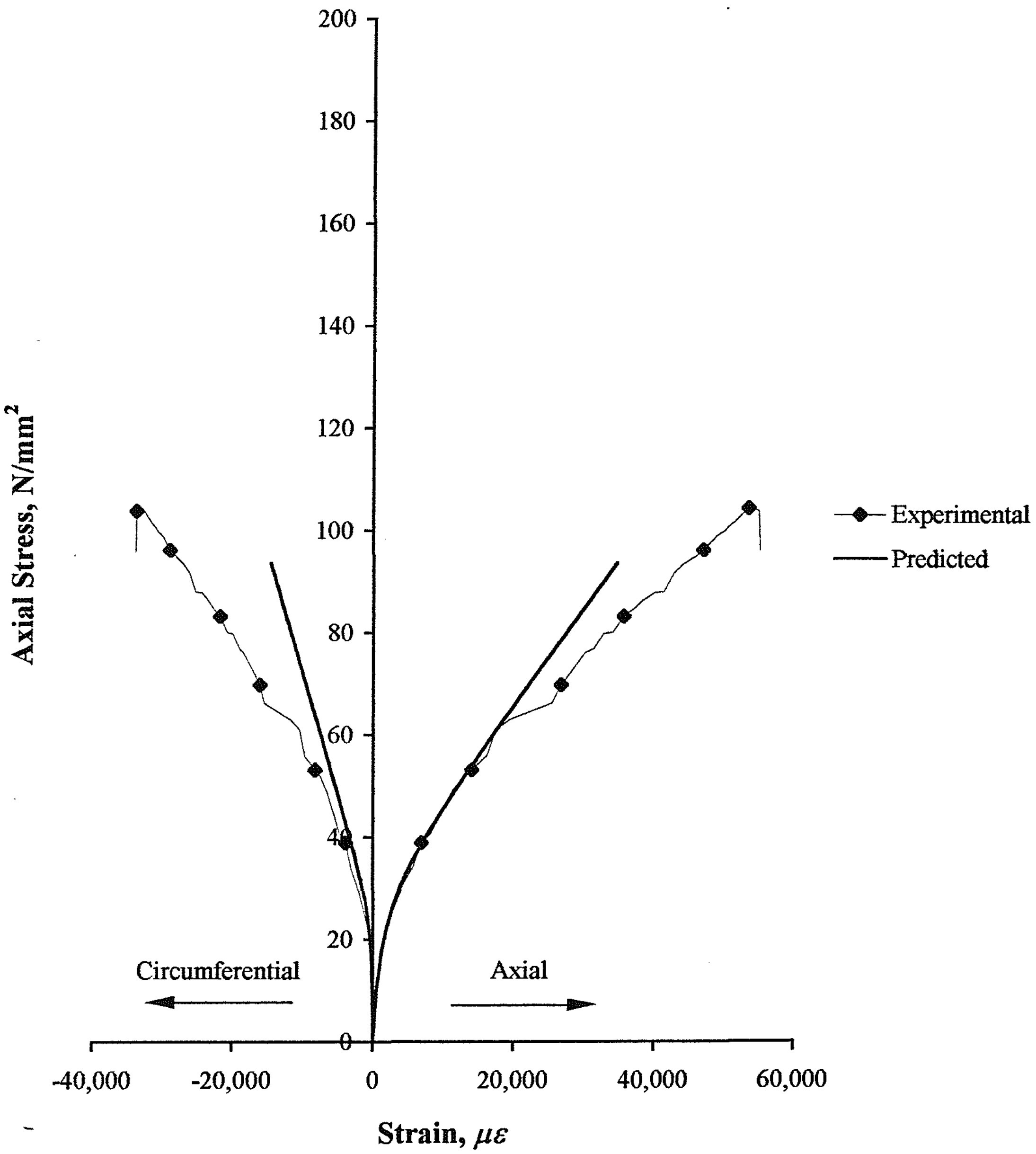



**Figure F.4.** Comparison of the theoretical and experimental stress-strain curves for the 100 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 71.4 degrees (concrete cube strength = 25.6 N/mm$^2$)

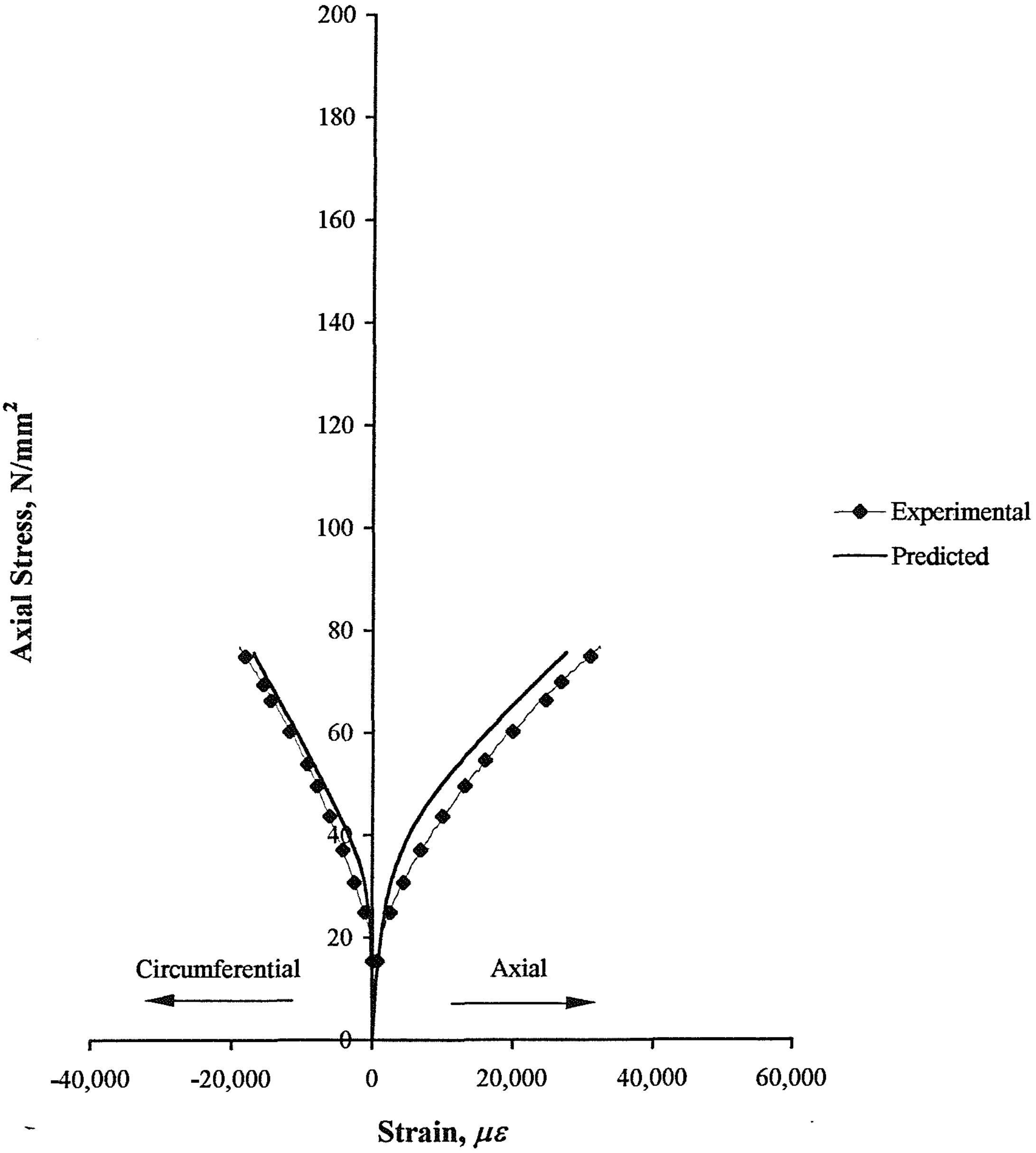



**Figure F.5.** Comparison of the theoretical and experimental stress-strain curves for the 150 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 71.3 degrees (concrete cube strength = 32.7 N/mm$^2$)

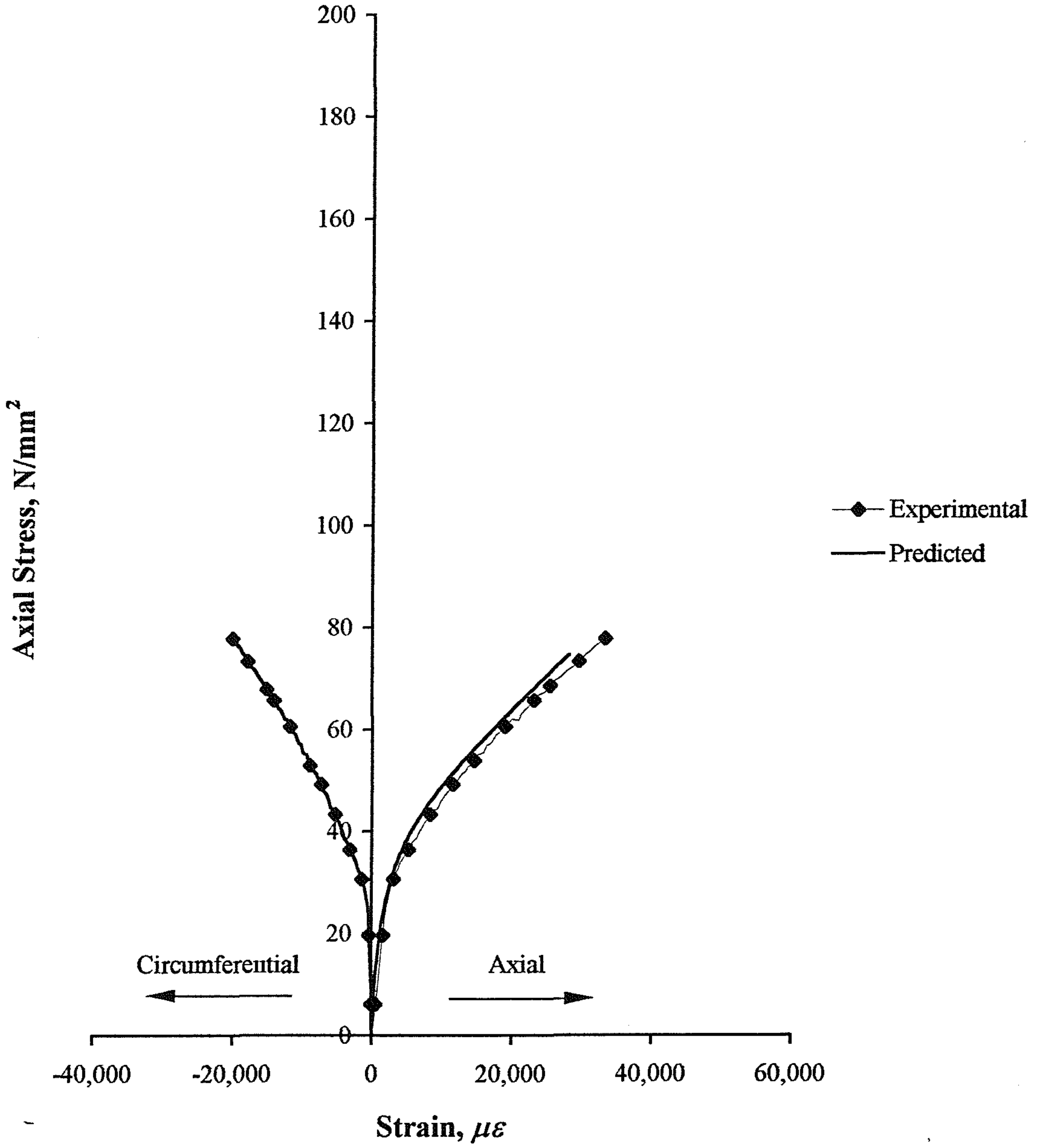



**Figure F.6.** Comparison of the theoretical and experimental stress-strain curves for the 150 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 71.3 degrees (concrete cube strength = 31.7 N/mm$^2$)

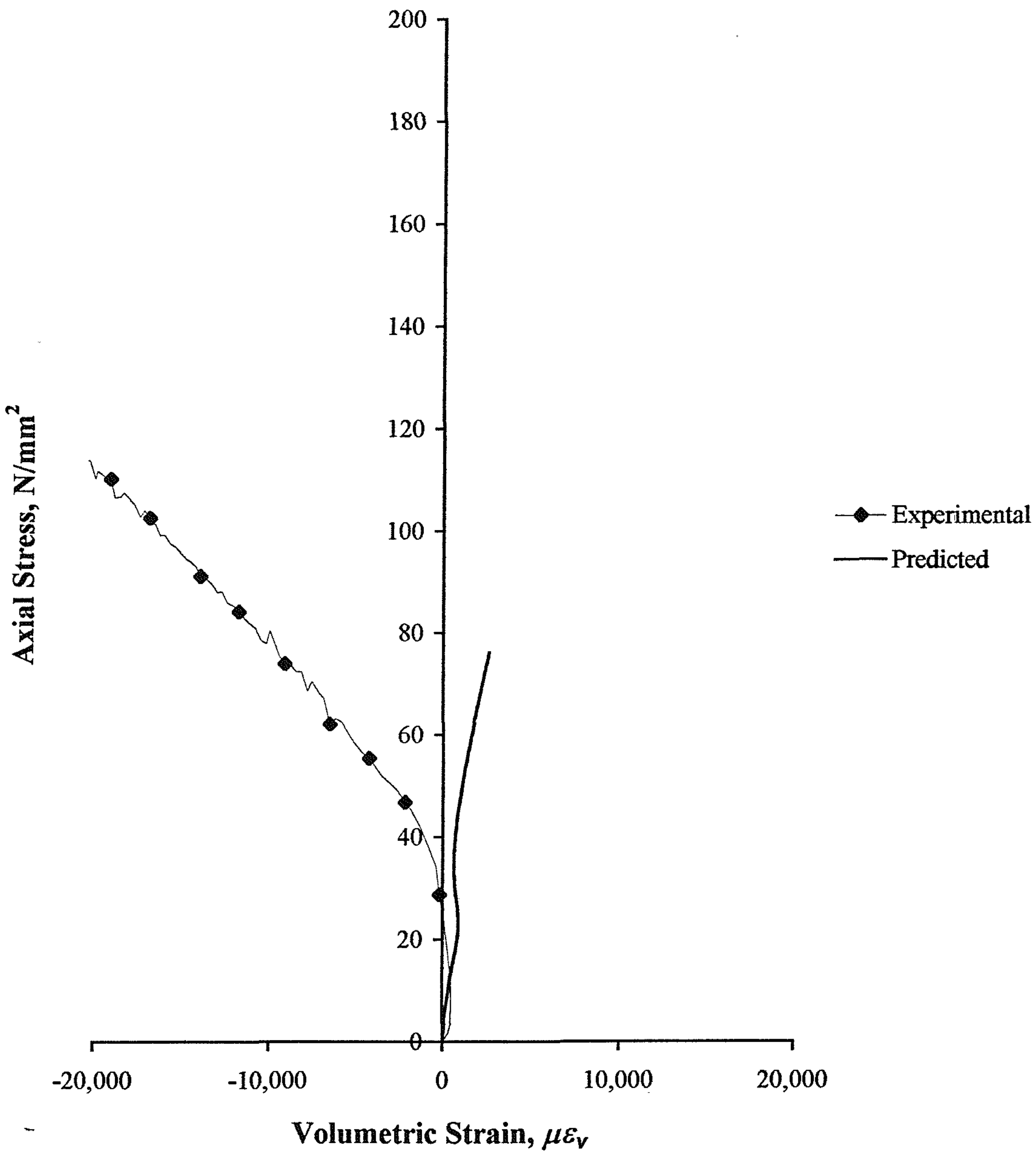



**Figure F.7.** Comparison of the theoretical and experimental stress-volumetric strain curves for the 80 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 57.8 degrees (concrete cube strength = 22.6 N/mm$^2$)

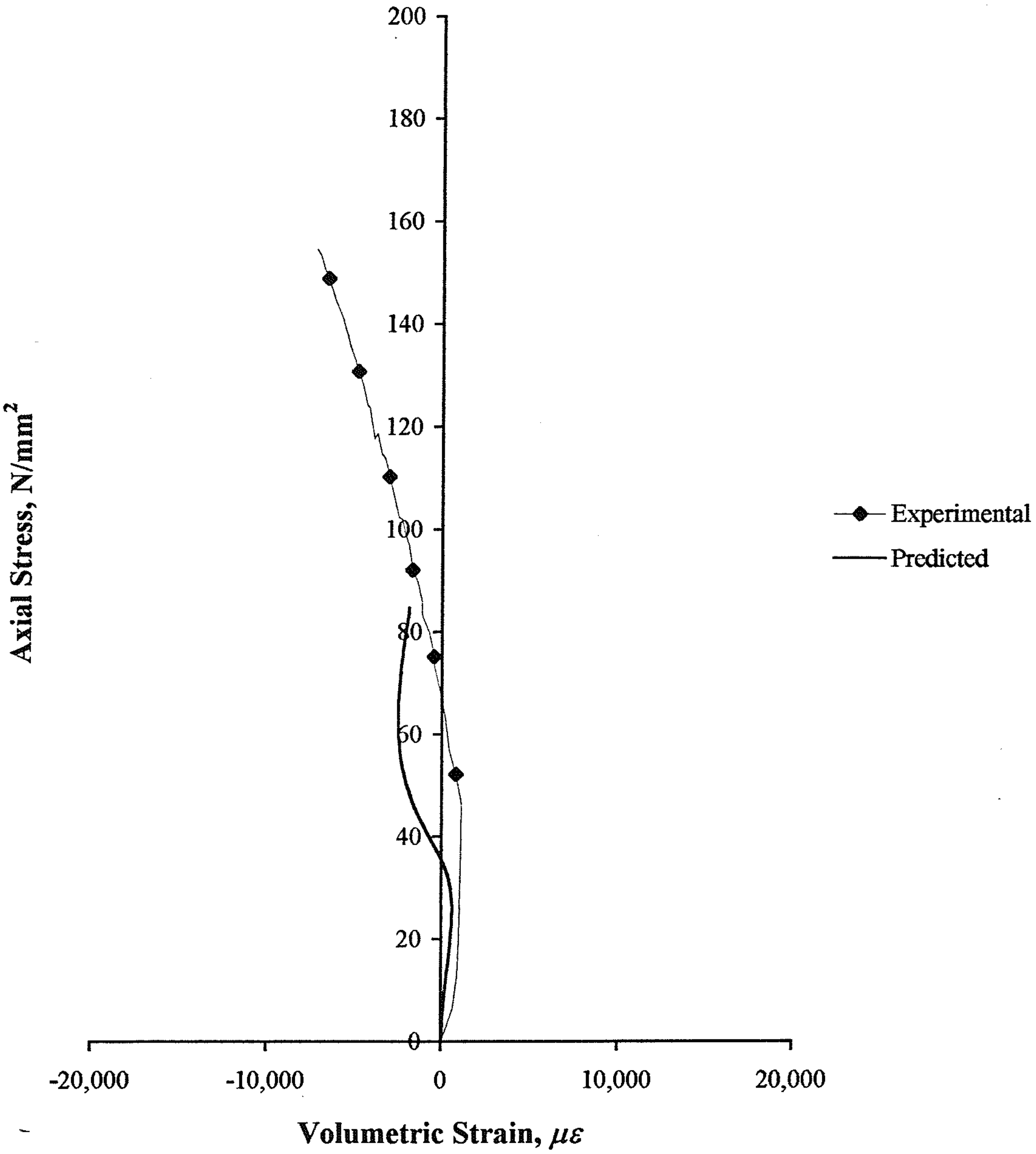



**Figure F.8.** Comparison of the theoretical and experimental stress-volumetric strain curves for the 80 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 57.8 degrees (concrete cube strength = 32.8 N/mm$^2$)

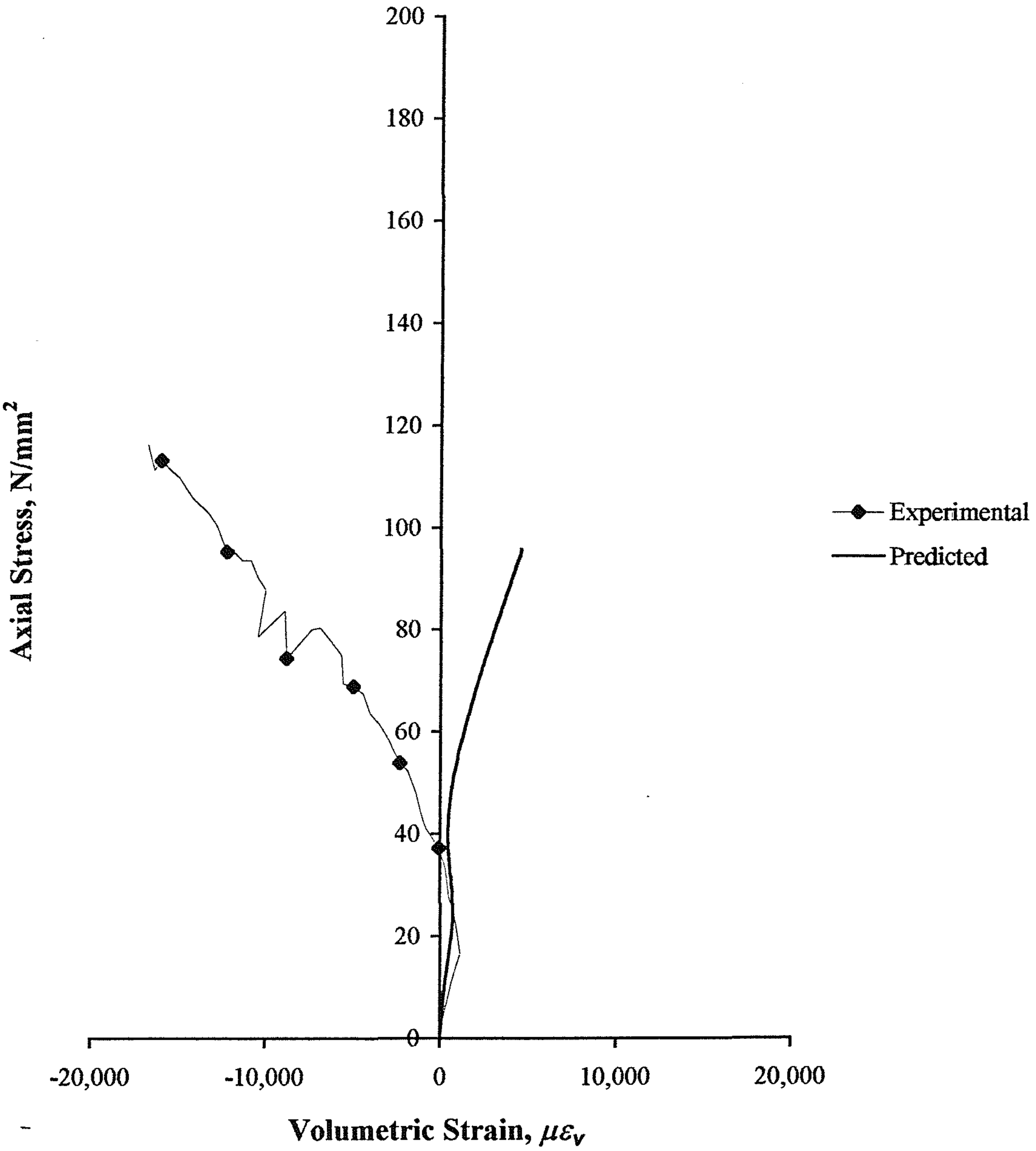



**Figure F.9.** Comparison of the theoretical and experimental stress-volumetric strain curves for the 100 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 71.4 degrees (concrete cube strength = 28.2 N/mm$^2$)

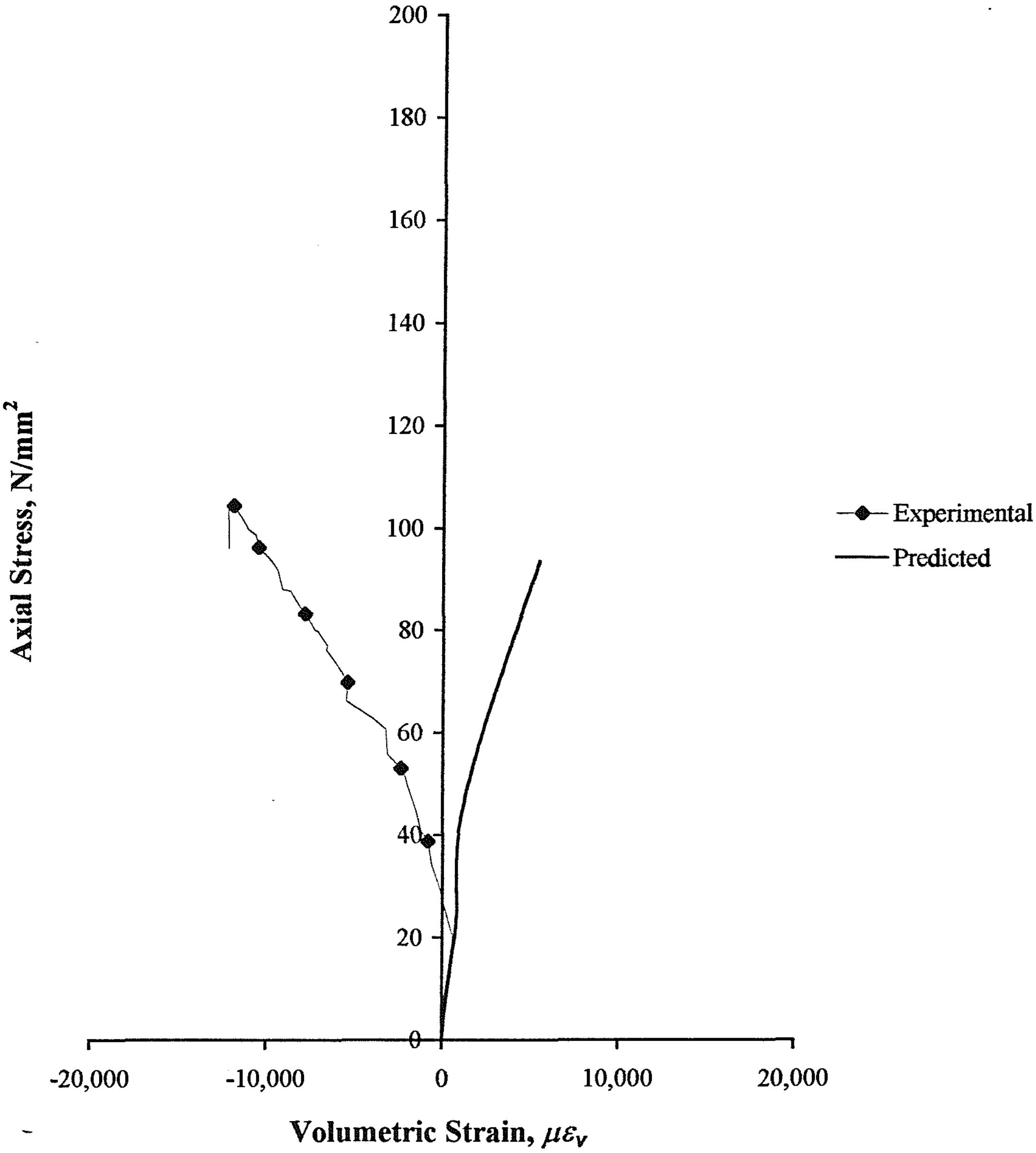



**Figure F.10.** Comparison of the theoretical and experimental stress-volumetric strain curves for the 100 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 71.4 degrees (concrete cube strength = 25.6 N/mm$^2$)

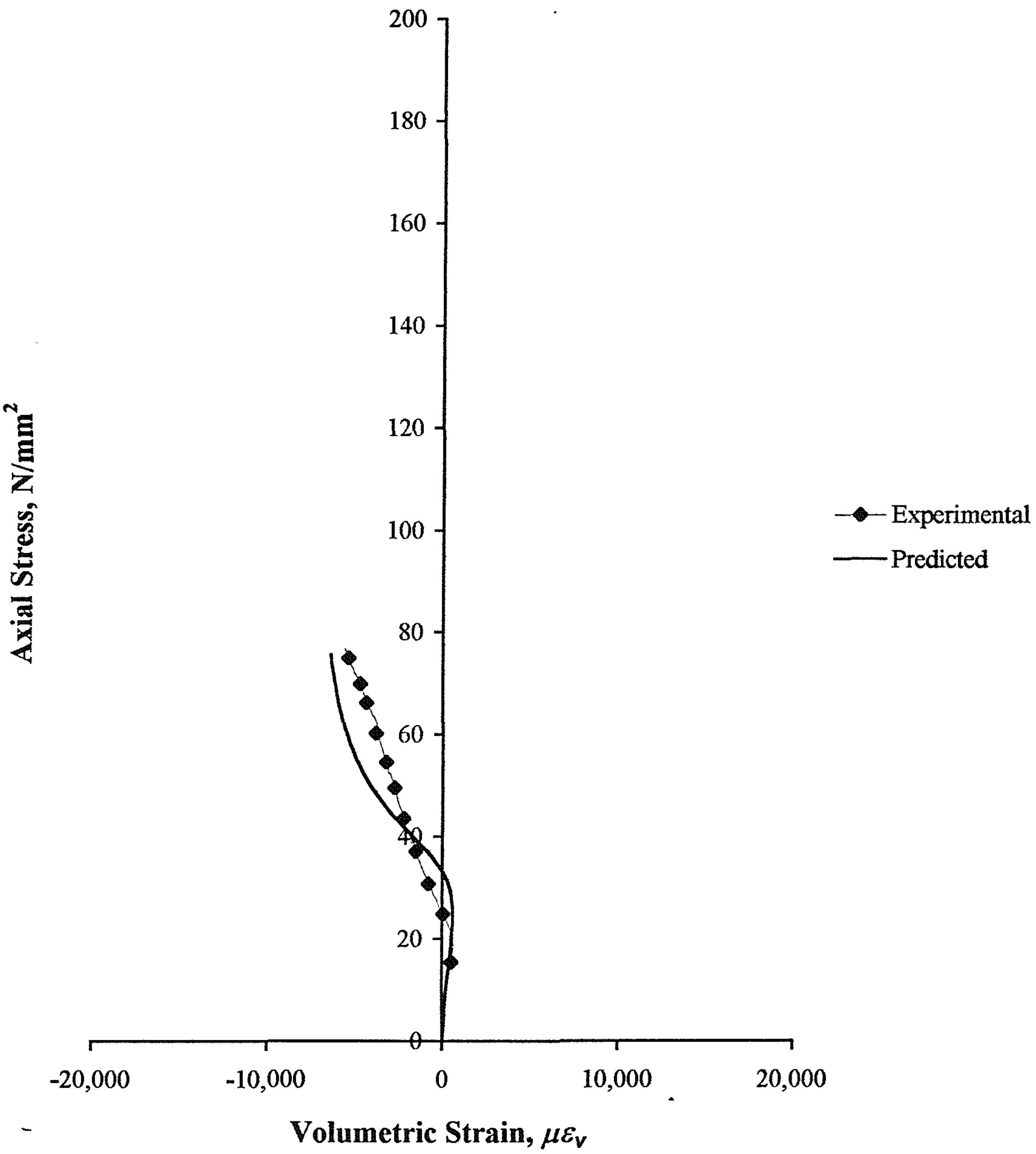



**Figure F.11.** Comparison of the theoretical and experimental stress-volumetric strain curves for the 150 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 71.3 degrees (concrete cube strength = 32.7 N/mm$^2$)

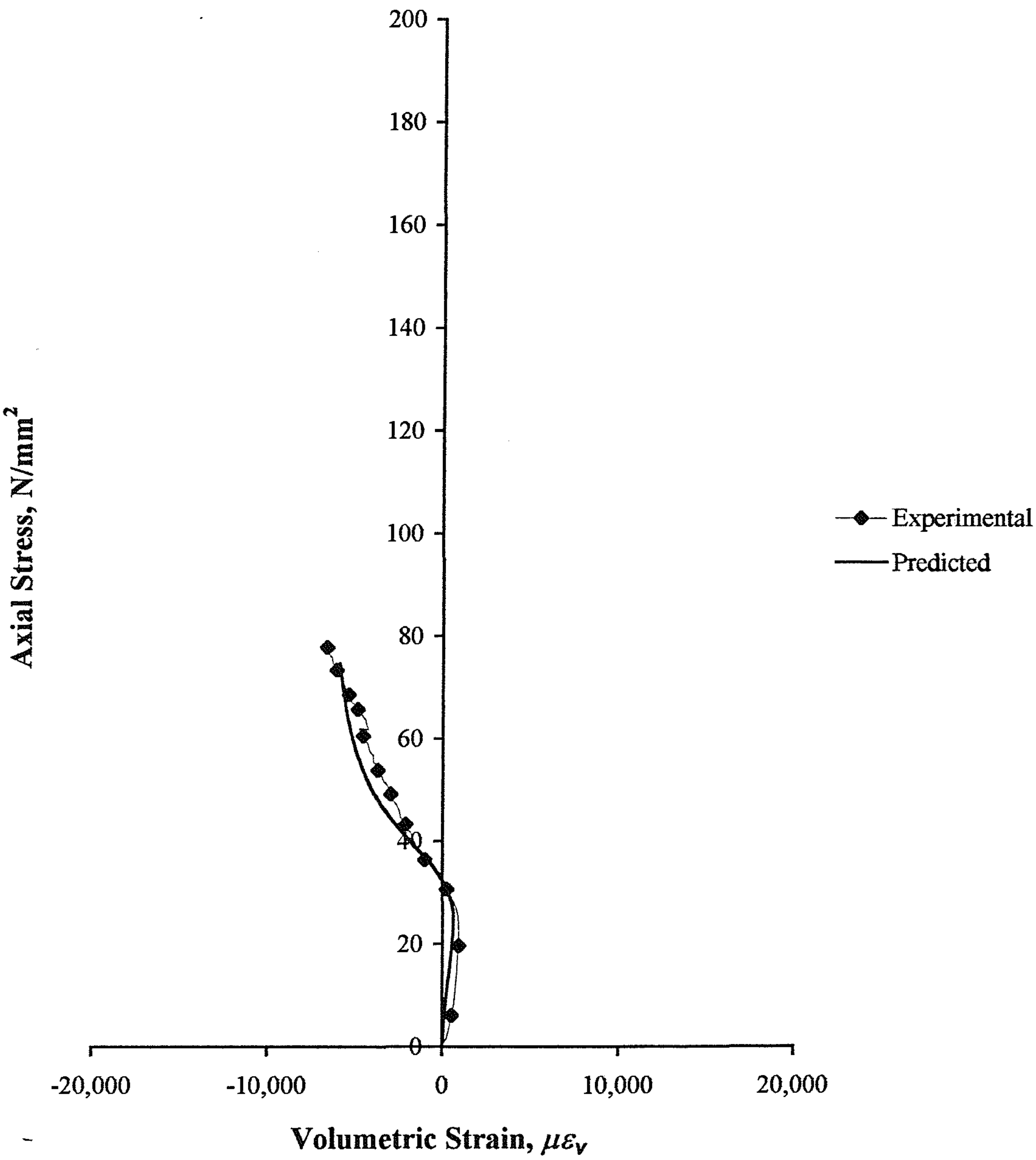



**Figure F.12.** Comparison of the theoretical and experimental stress-volumetric strain curves for the 150 mm diameter concrete-filled stub column confined with E-glass fibres orientated at 71.3 degrees (concrete cube strength = 31.7 N/mm$^2$)

## APPENDIX G

# EXPERIMENTAL LOAD-DEFLECTION CURVES FOR CONCRETE-FILLED E-GLASS FRP-COMPOSITE COLUMNS

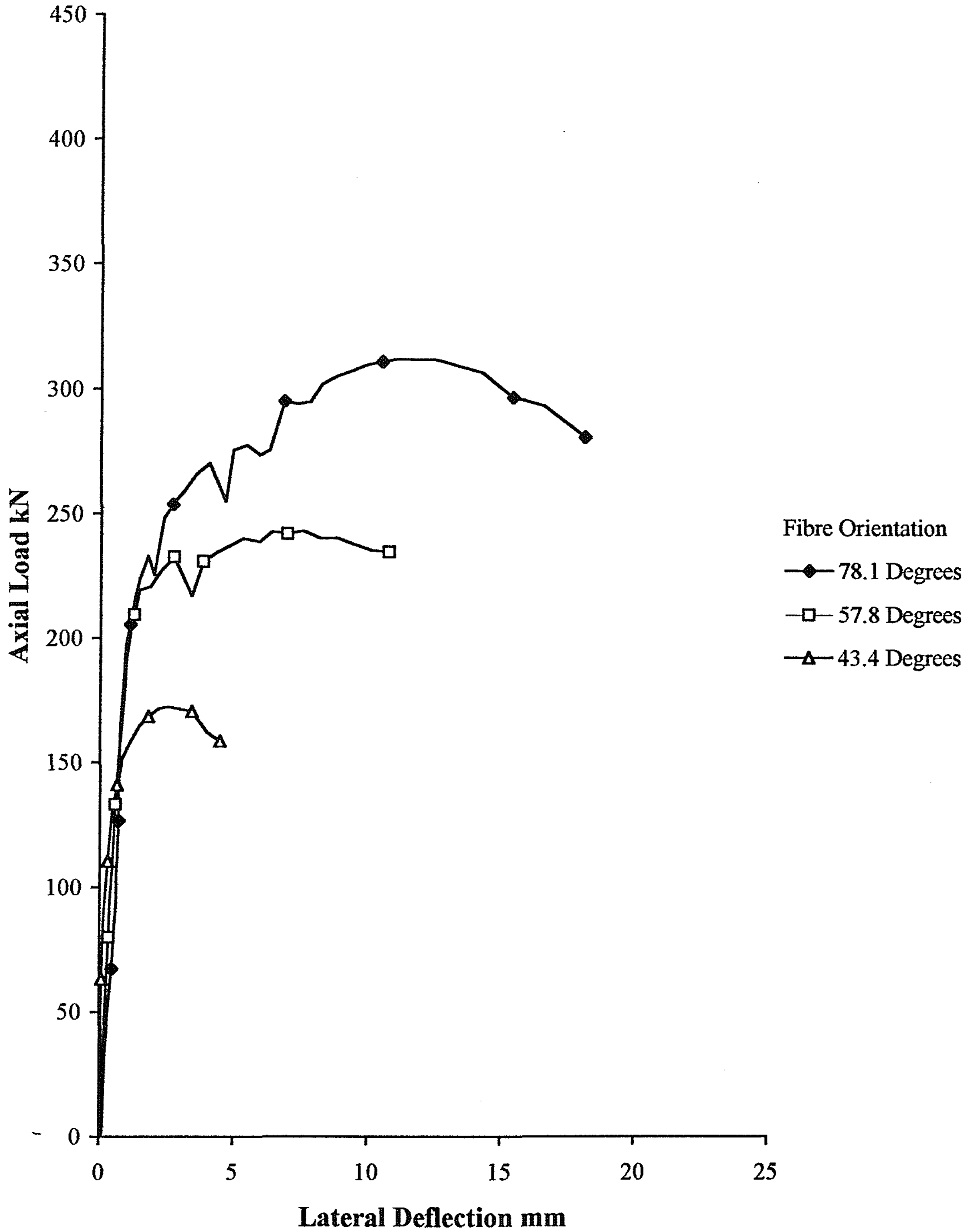



**Figure G.1.** Load-deflection curves for the 80 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 5 (nominal concrete cube strength = 25 N/mm$^2$)

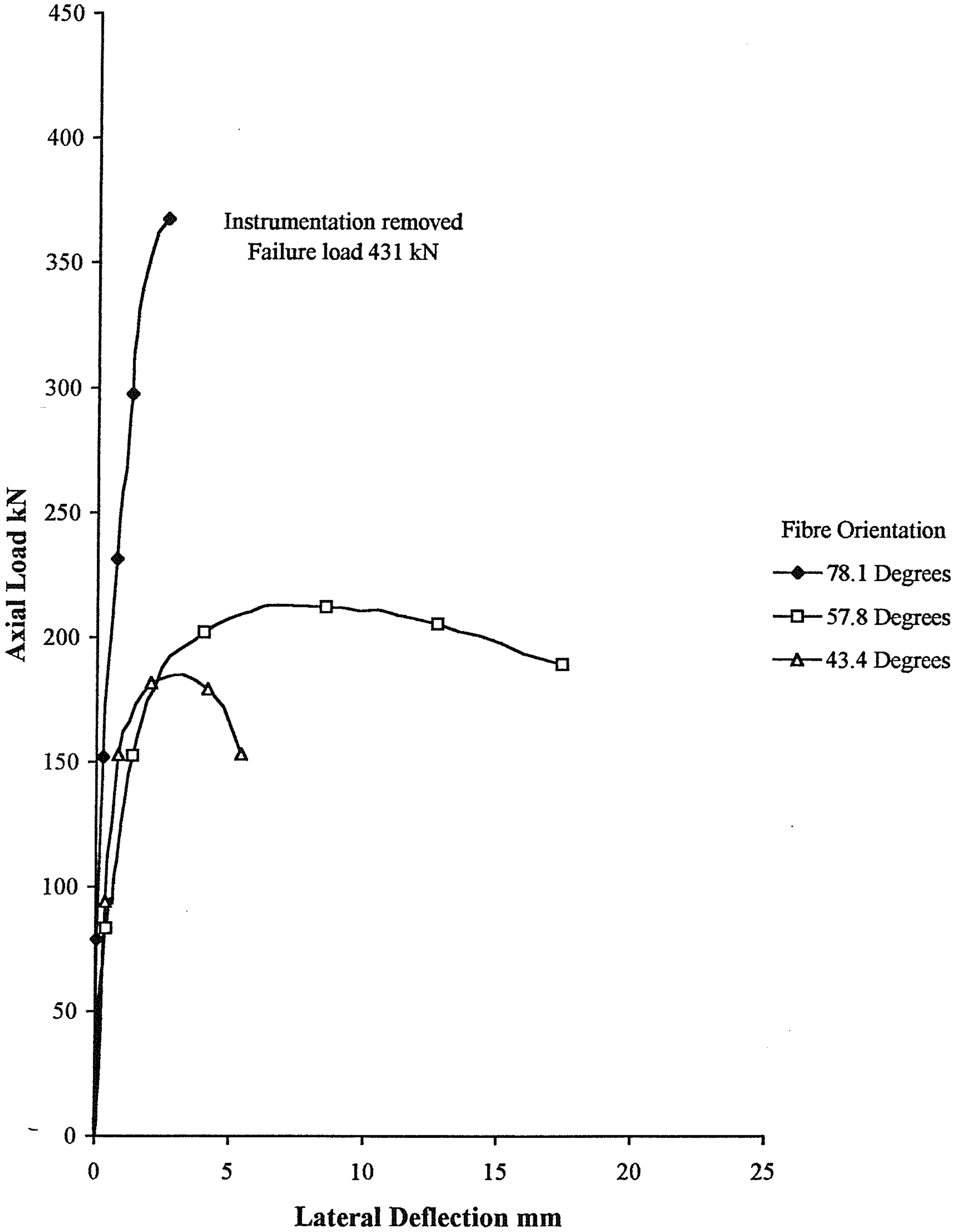



**Figure G.2.** Load-deflection curves for the 80 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 5 (nominal concrete cube strength = 35 N/mm$^2$)

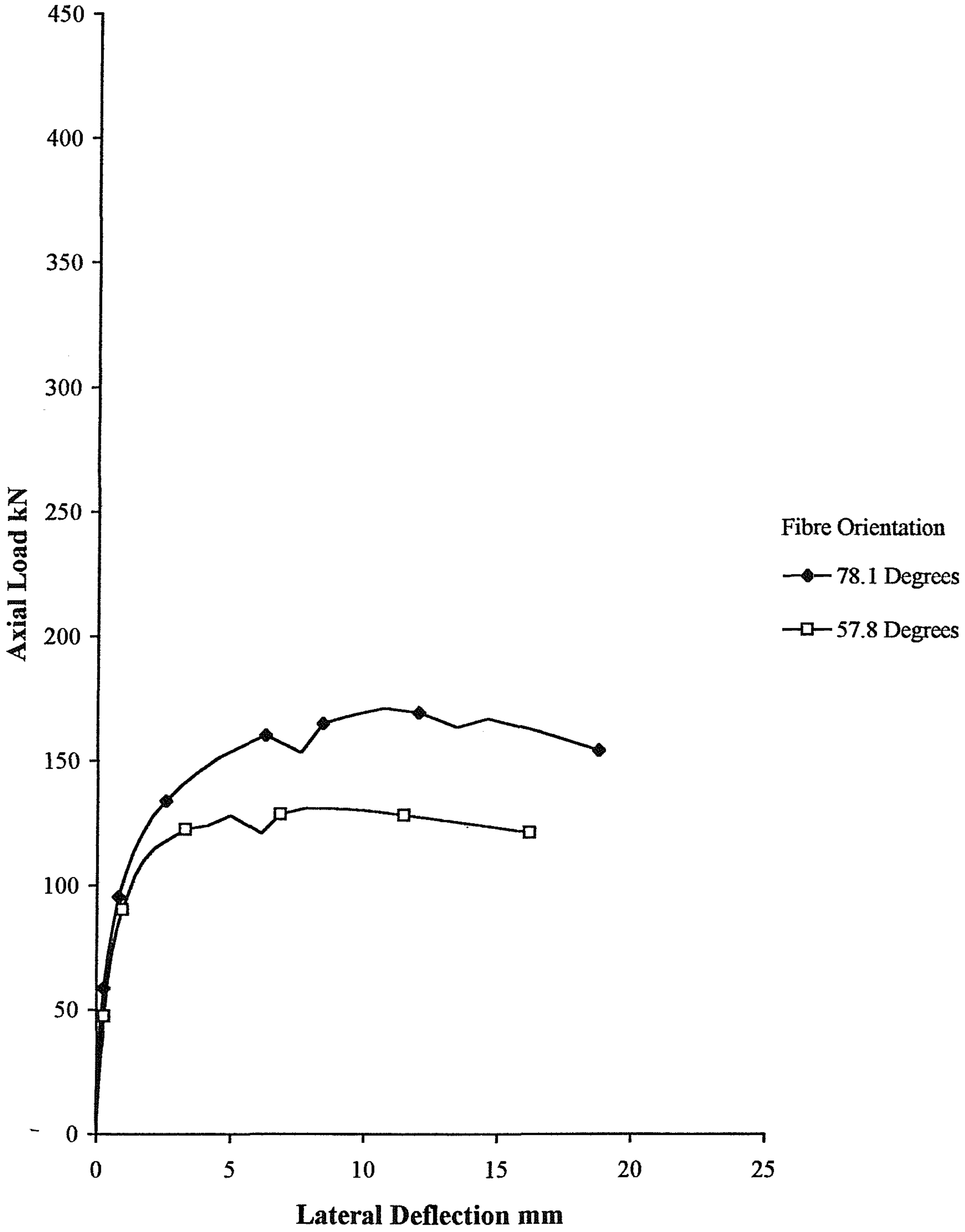



**Figure G.3.** Load-deflection curves for the 80 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 10 (nominal concrete cube strength = 25 N/mm$^2$)

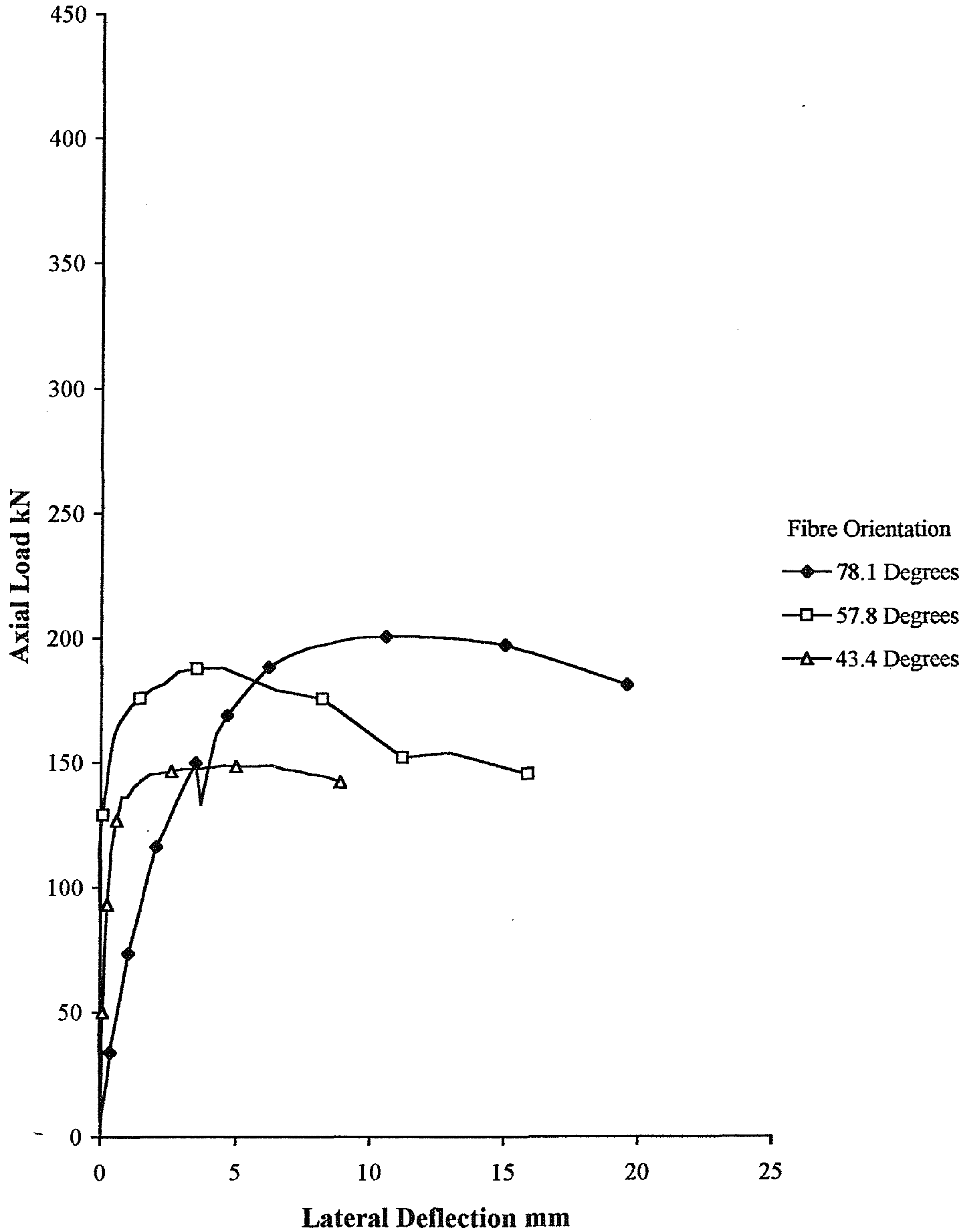



**Figure G.4.** Load-deflection curves for the 80 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 10 (nominal concrete cube strength = 35 N/mm$^2$)

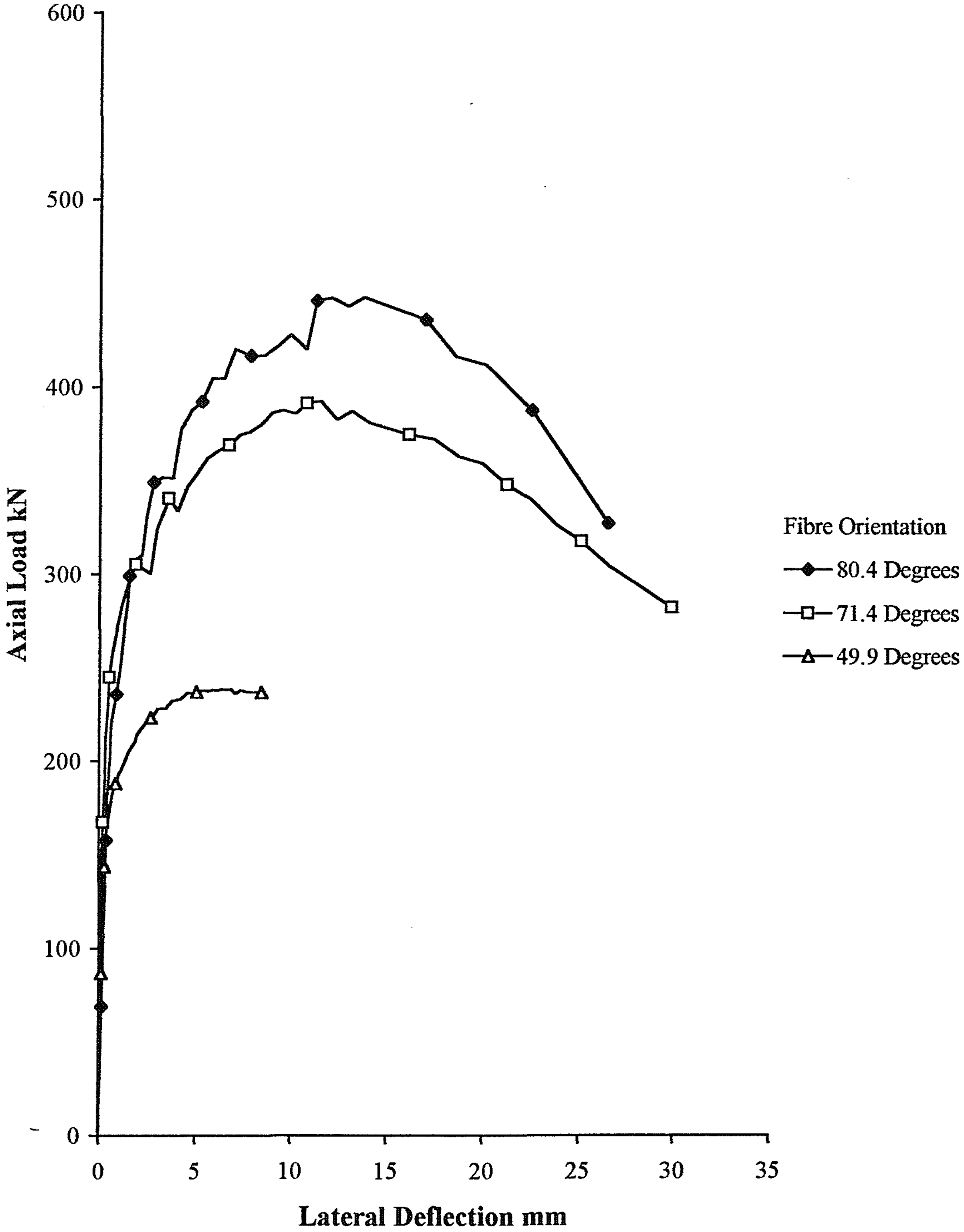



**Figure G.5.** Load-deflection curves for the 100 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 5 (nominal concrete cube strength = 25 N/mm$^2$)

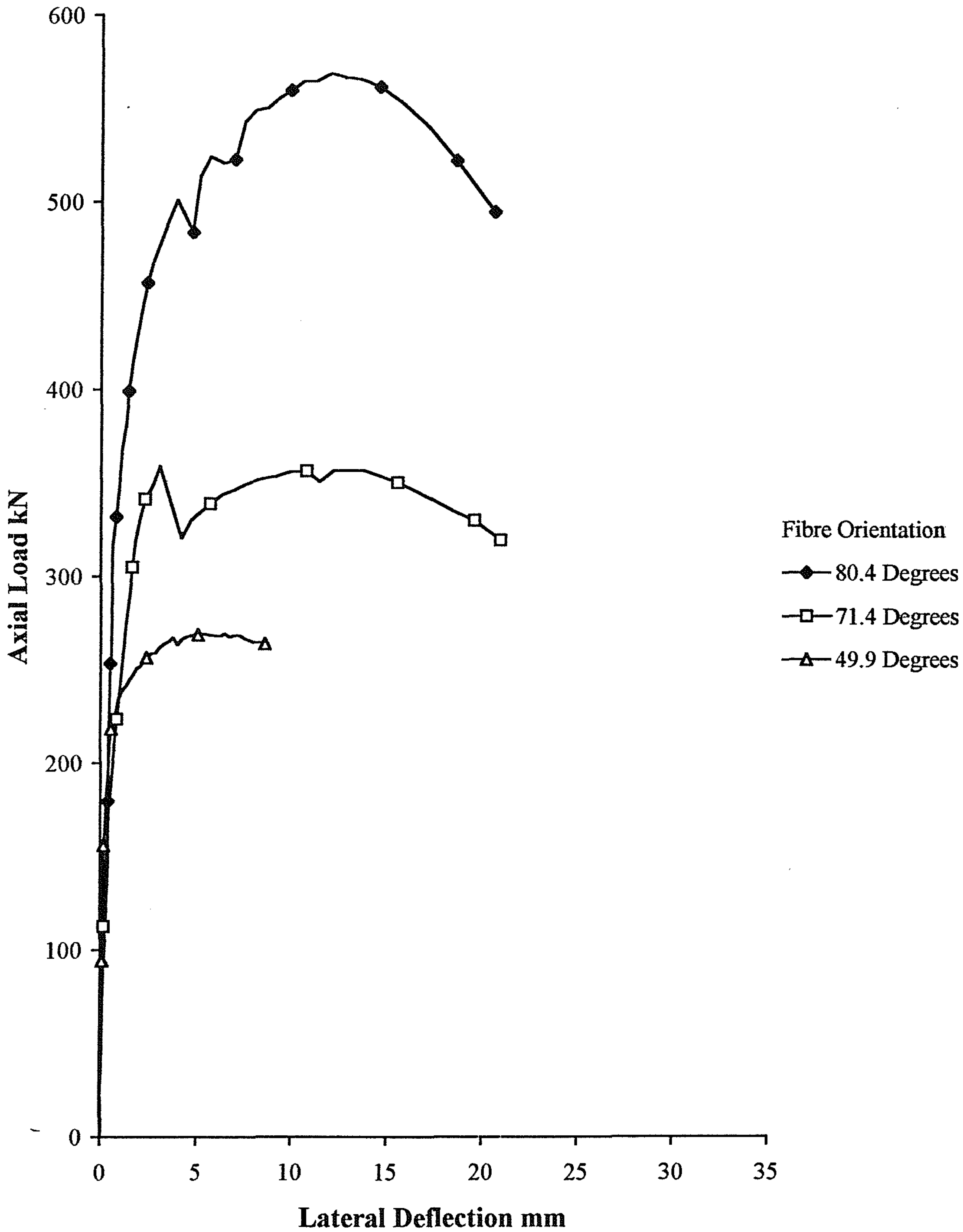



**Figure G.6.** Load-deflection curves for the 100 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 5 (nominal concrete cube strength = 35 N/mm$^2$)

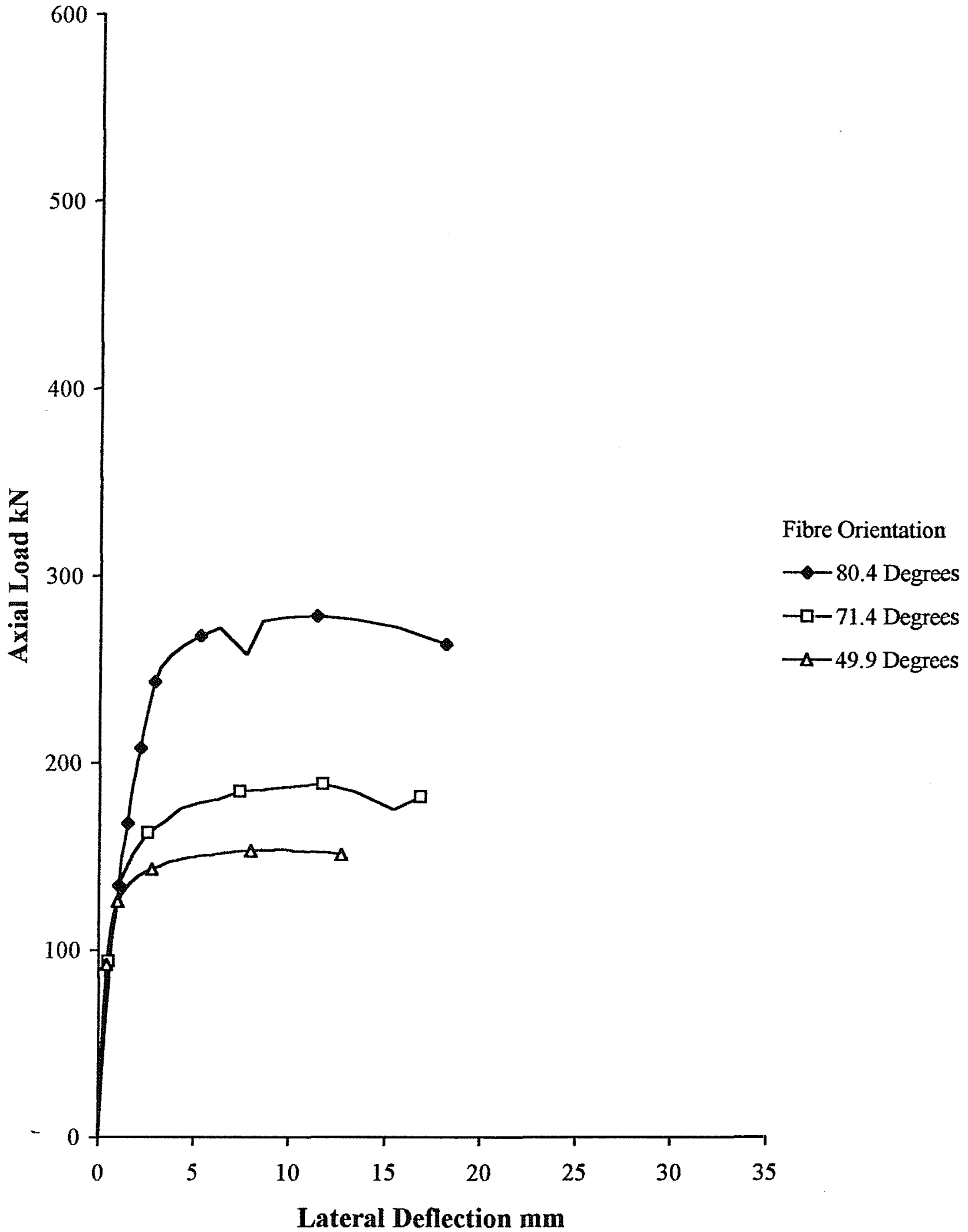



**Figure G.7.** Load-deflection curves for the 100 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 10 (nominal concrete cube strength = 25 N/mm$^2$)

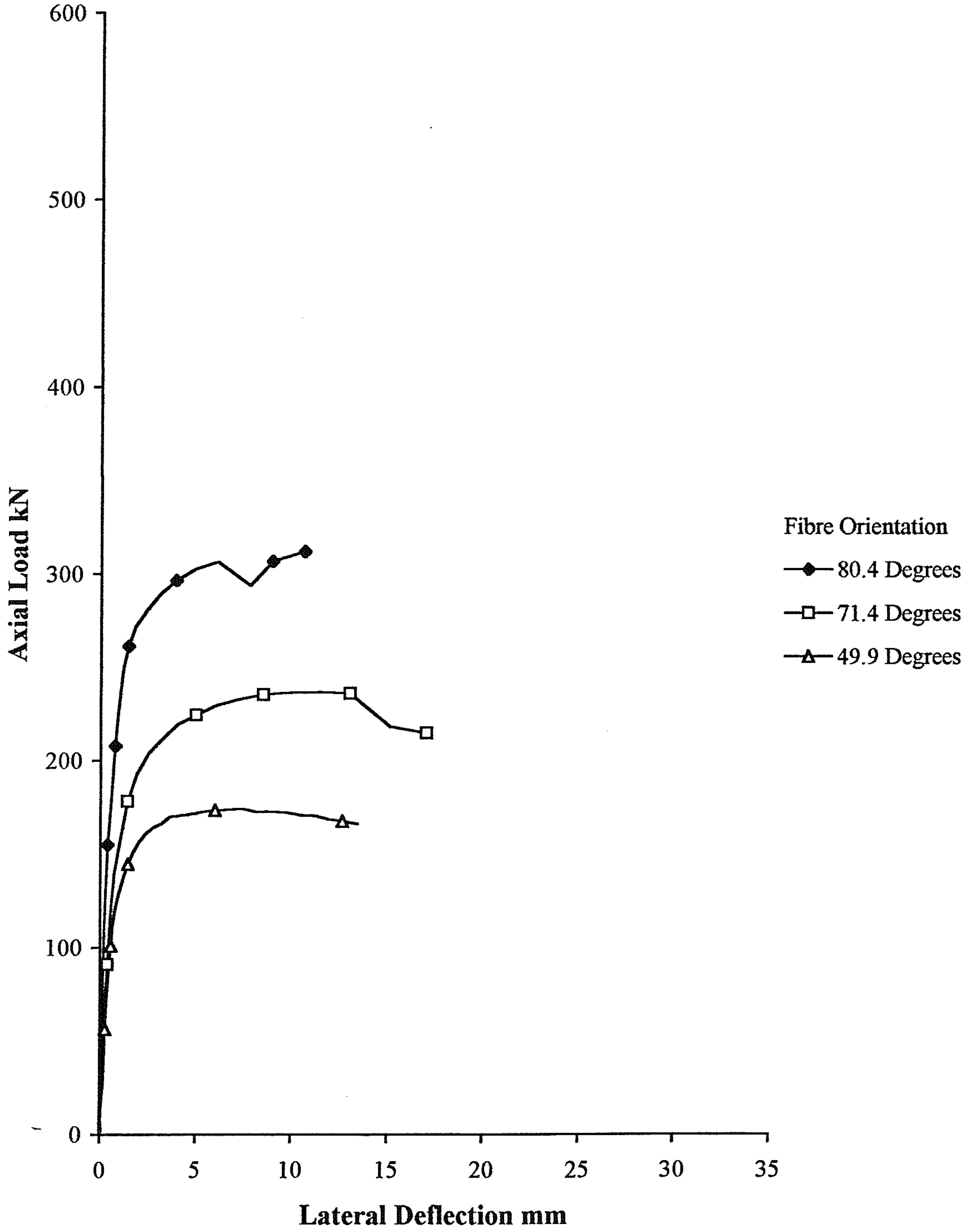



**Figure G.8.** Load-deflection curves for the 100 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 10 (nominal concrete cube strength = 35 $N/mm^2$)

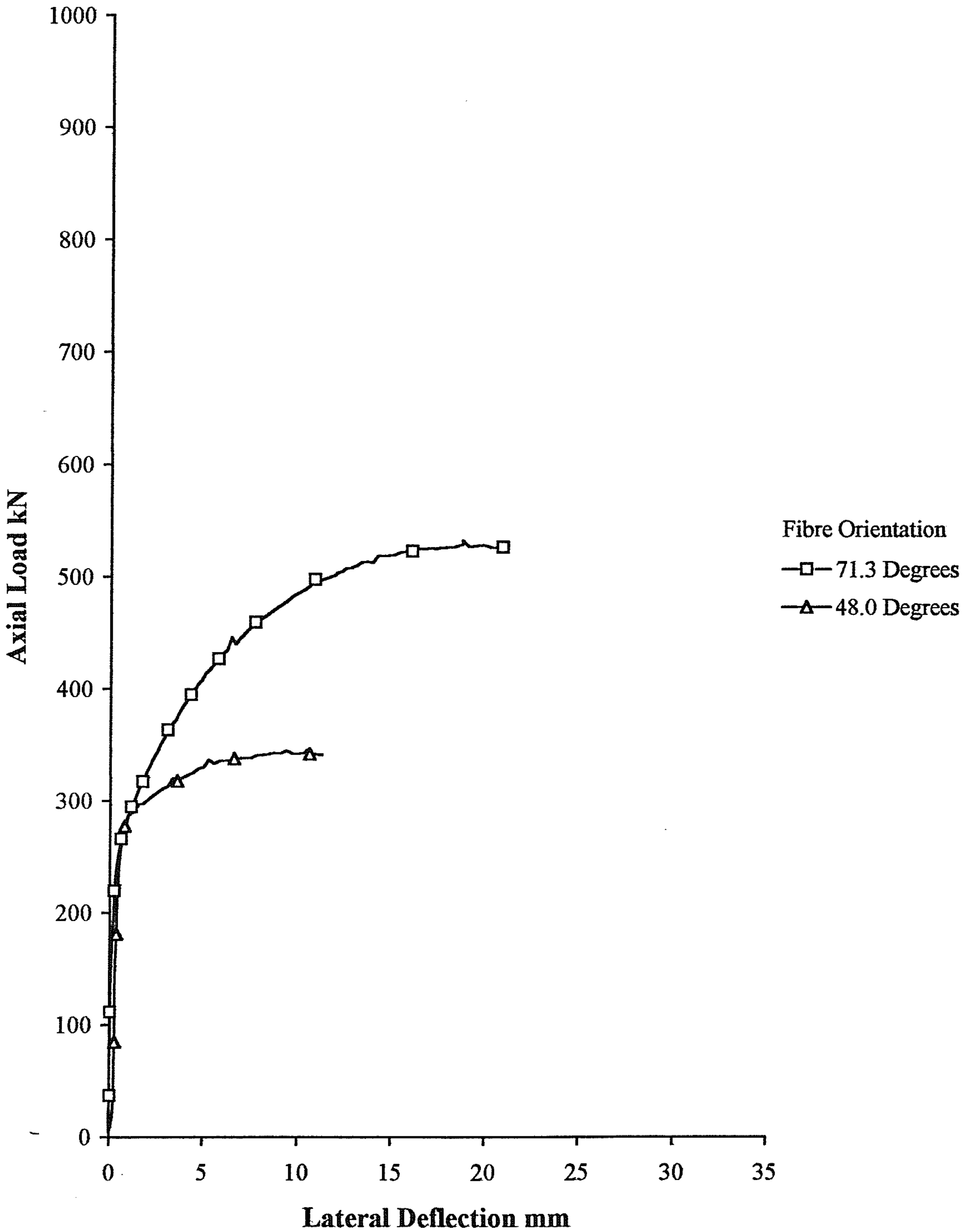



**Figure G.9.** Load-deflection curves for the 150 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 5 (nominal concrete cube strength = 25 N/mm$^2$)

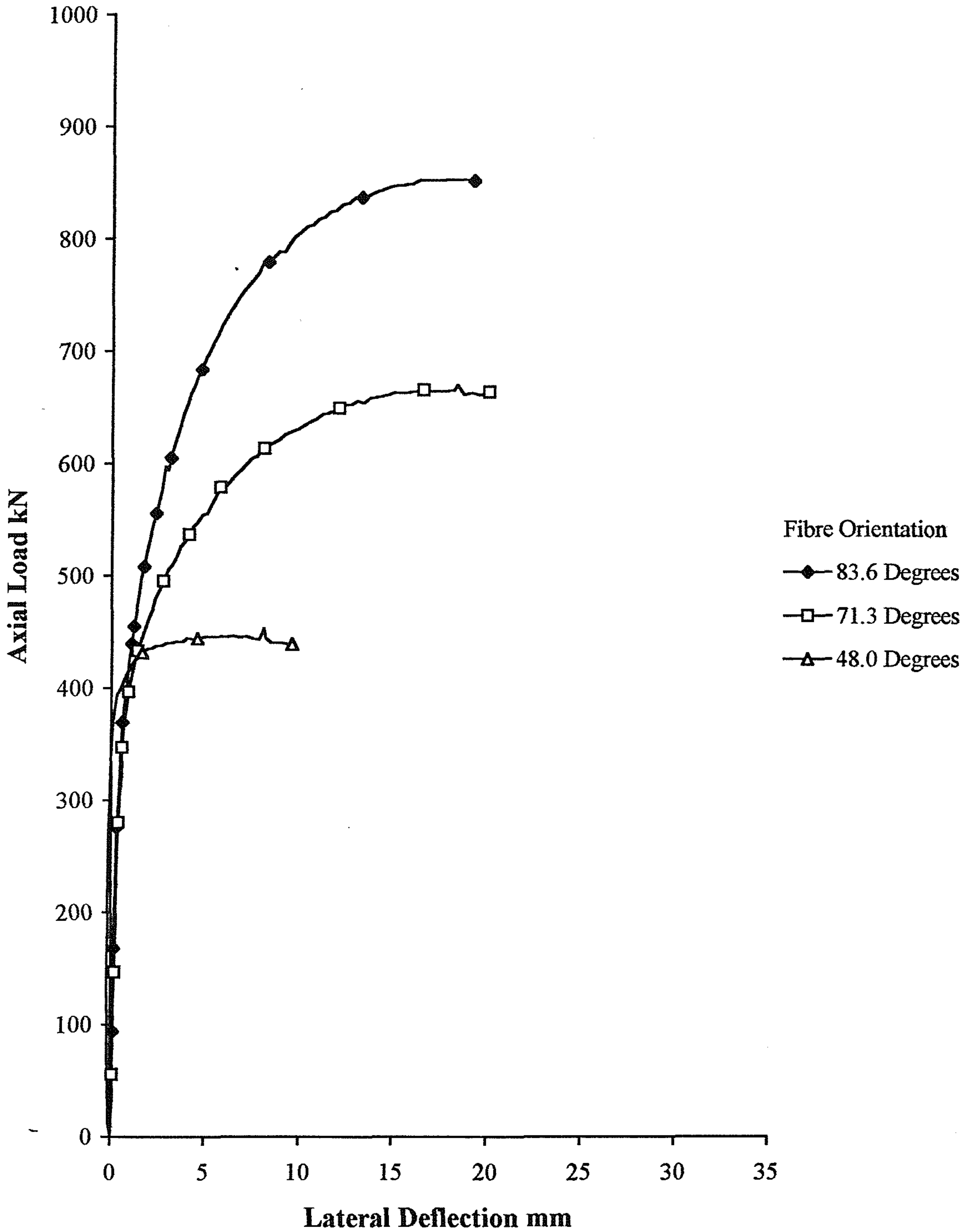



**Figure G.10.** Load-deflection curves for the 150 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 5 (nominal concrete cube strength = 35 N/mm$^2$)

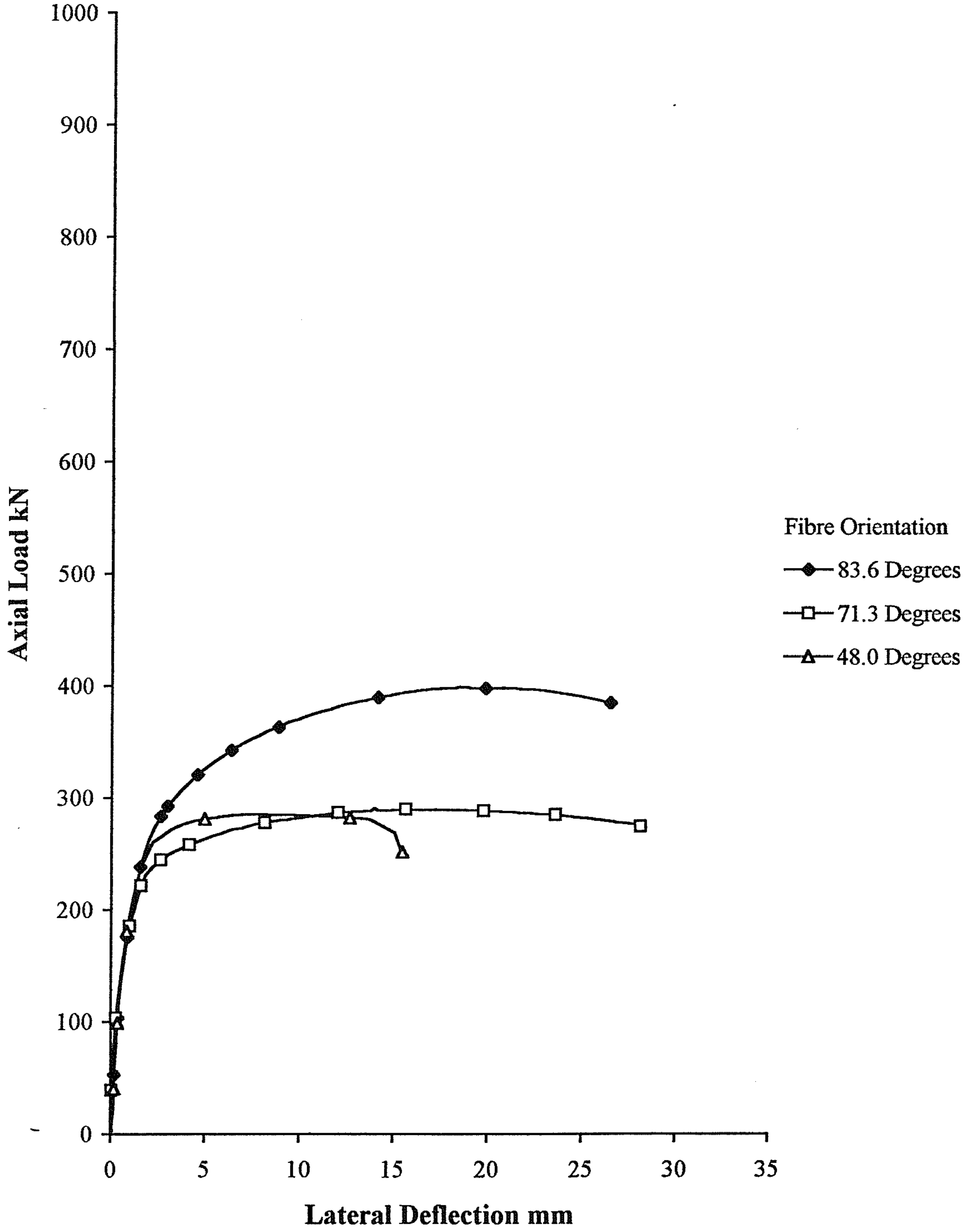



**Figure G.11.** Load-deflection curves for the 150 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 10 (nominal concrete cube strength = 25 $N/mm^2$)

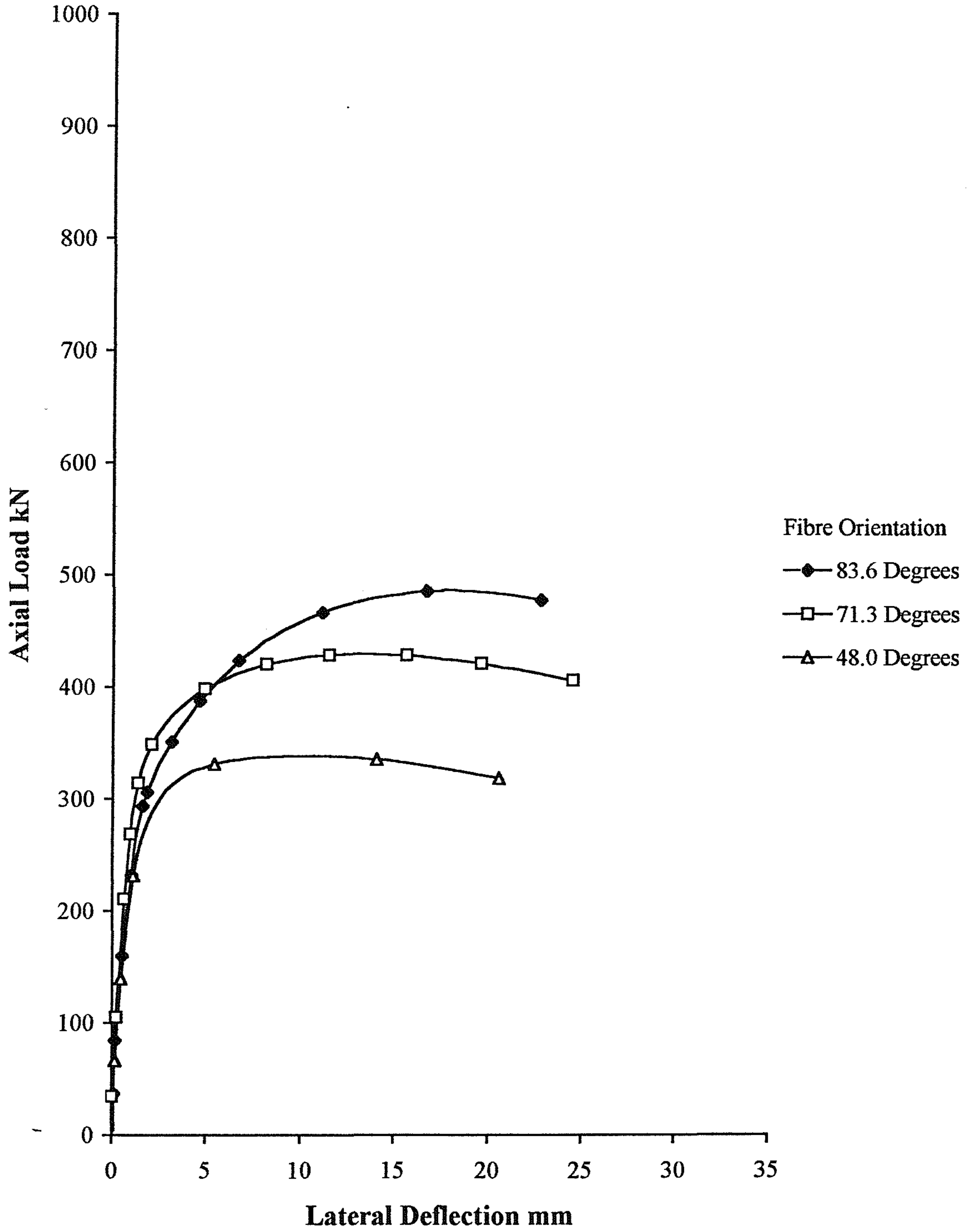



**Figure G.12.** Load-deflection curves for the 150 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 10 (nominal concrete cube strength = 35 N/mm$^2$)

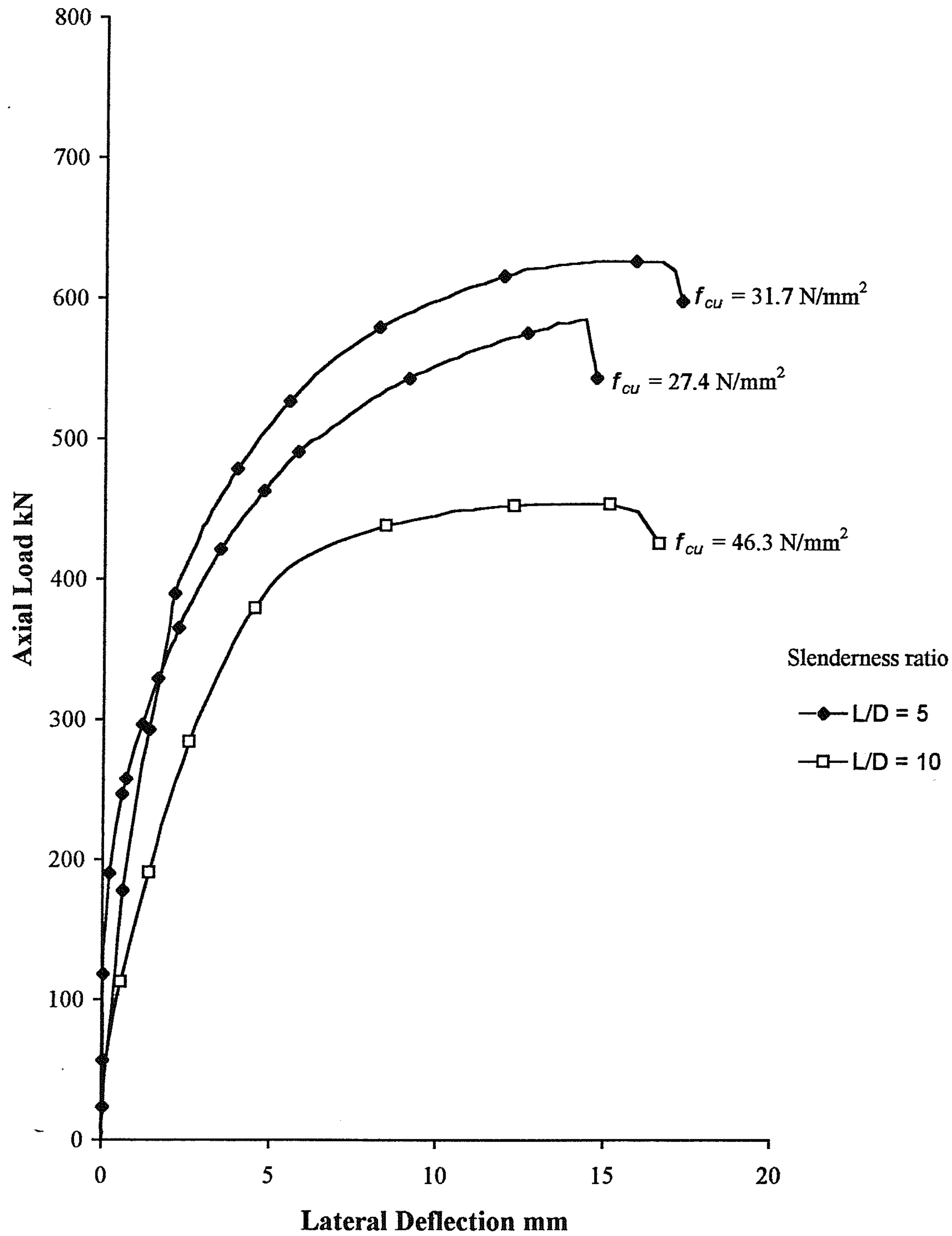



**Figure G.13.** Load-deflection curves for the 125 mm diameter concrete-filled FRP-composite columns confined with E-glass fibres orientated at 82.3 degrees

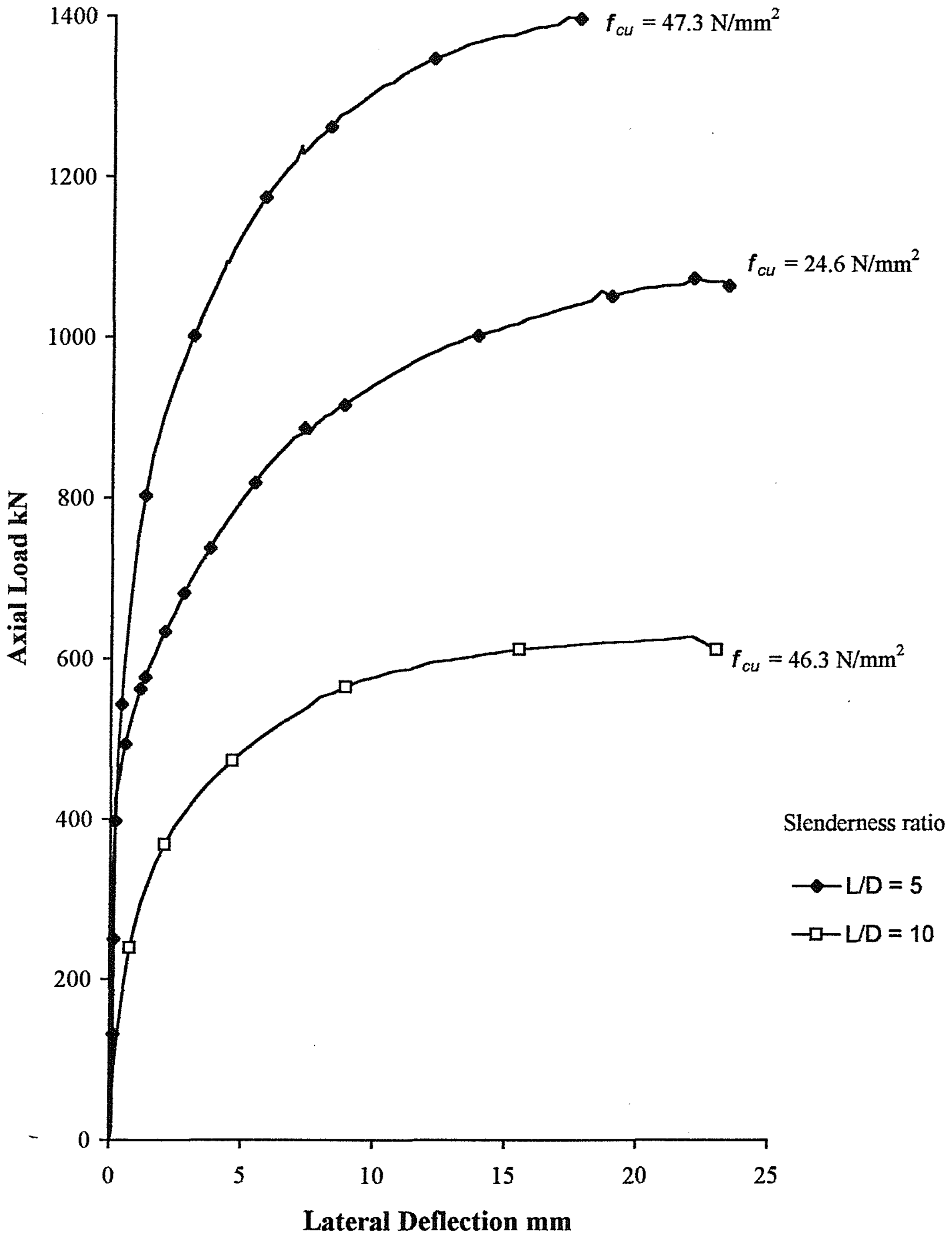



**Figure G.14.** Load-deflection curves for the 200 mm diameter concrete-filled FRP-composite columns confined with E-glass fibres orientated at 85.2 degrees

APPENDIX H

# EXPERIMENTAL LOAD-STRAIN CURVES FOR CONCRETE-FILLED E-GLASS FRP-COMPOSITE COLUMNS

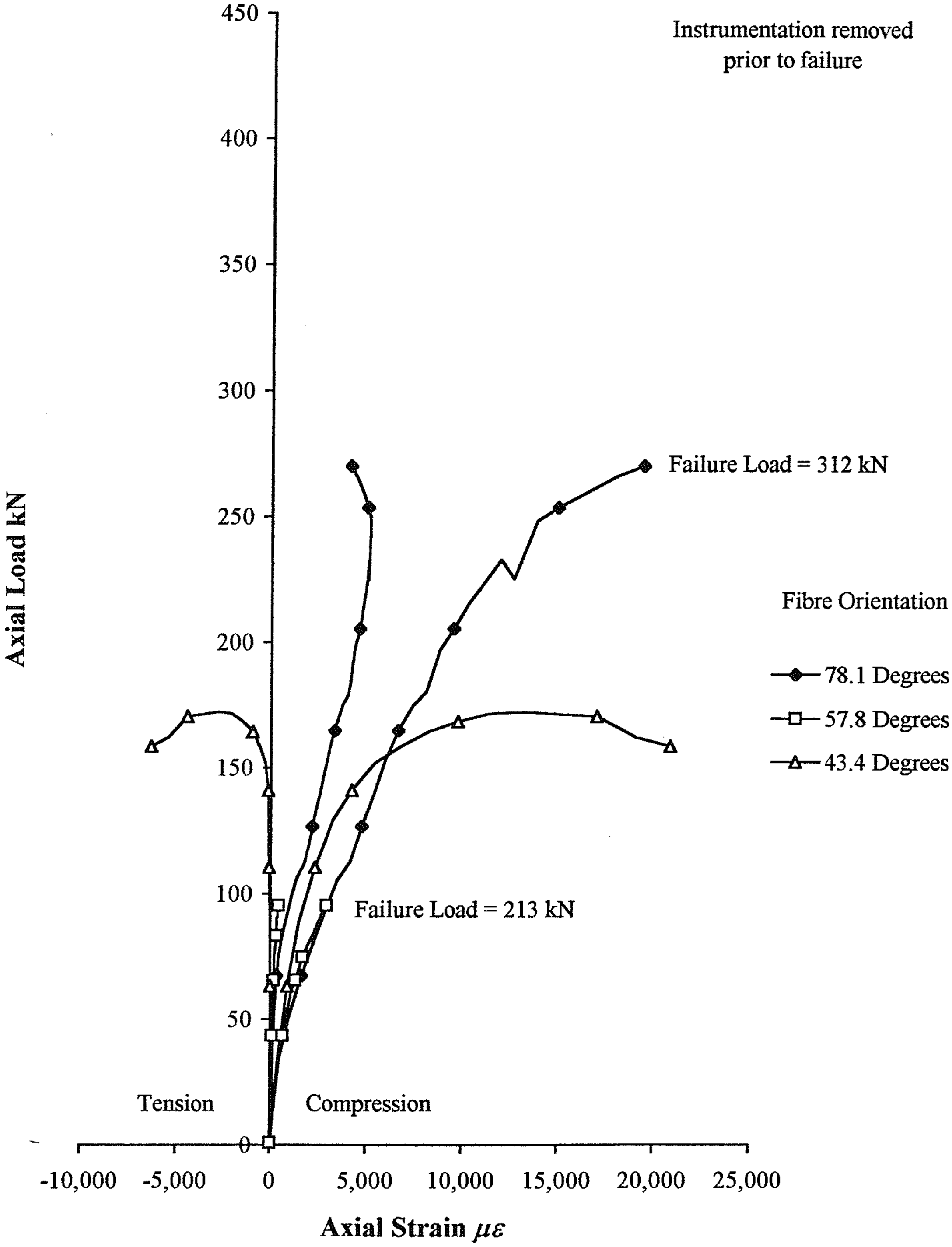



**Figure H.1.** Load-strain curves for the 80 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 5 (nominal concrete cube strength = 25 N/mm$^2$)

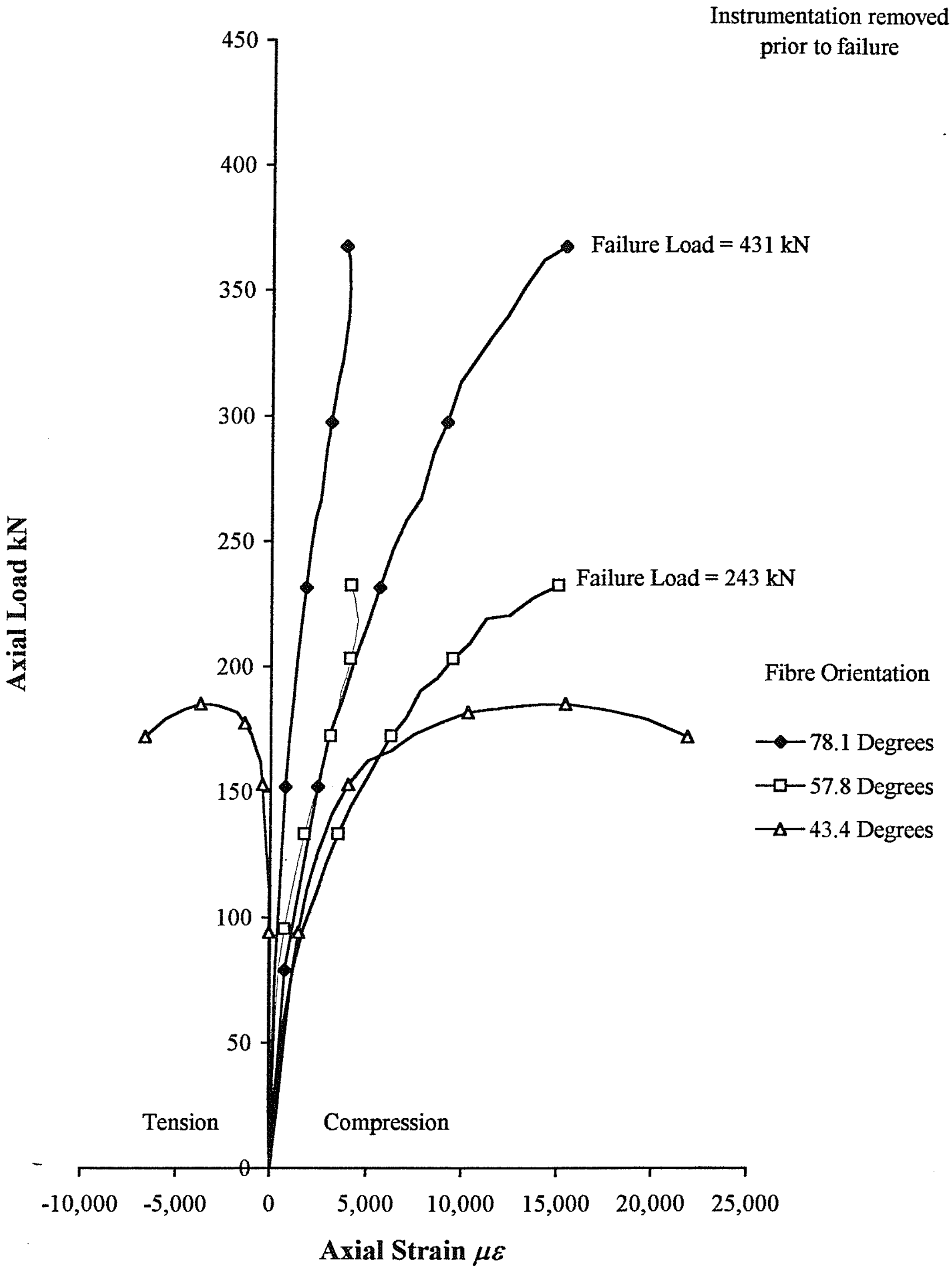



**Figure H.2.** Load-strain curves for the 80 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 5 (nominal concrete cube strength = 35 N/mm$^2$)

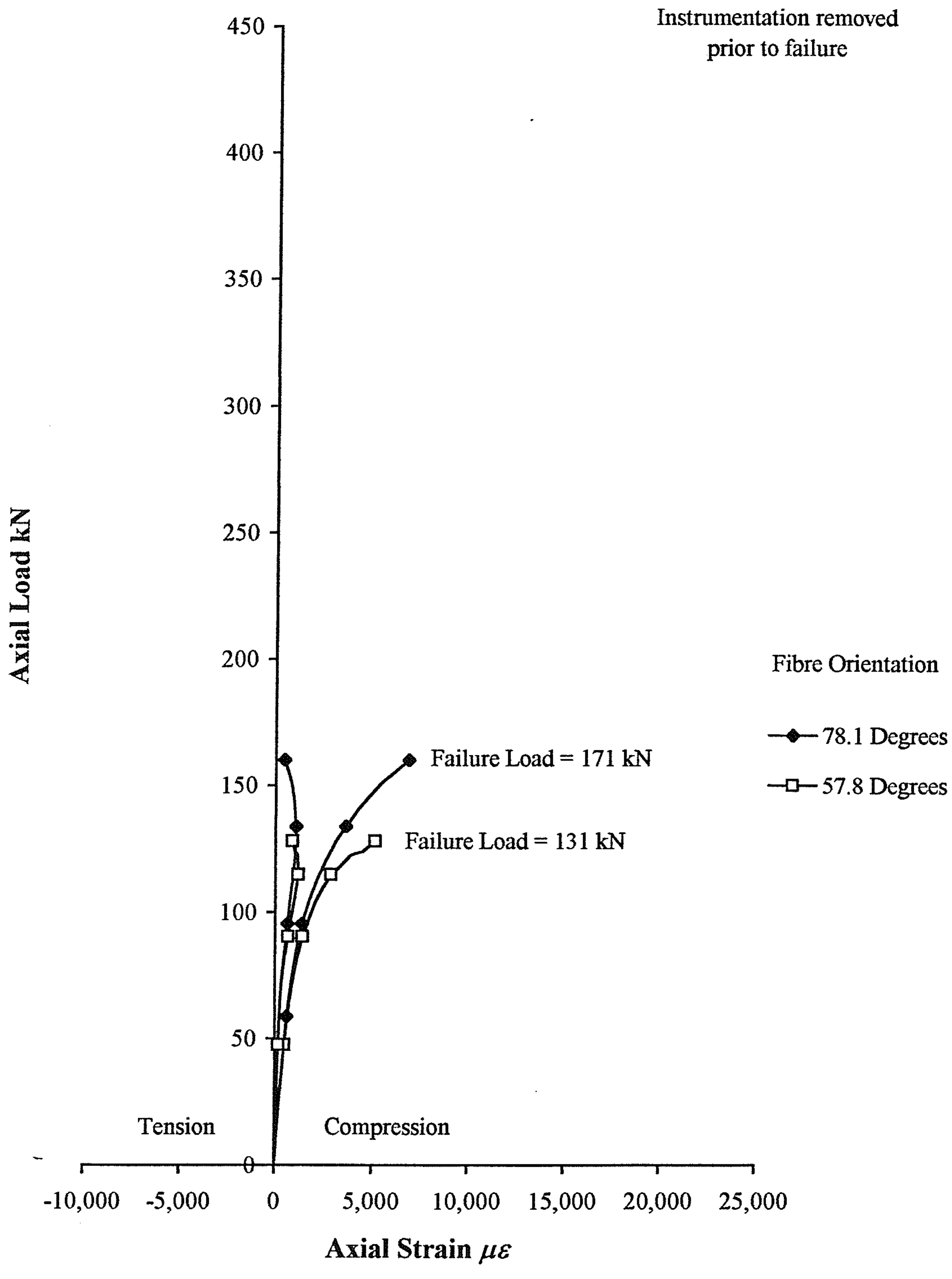



**Figure H.3.** Load-strain curves for the 80 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 10 (nominal concrete cube strength = 25 N/mm$^2$)

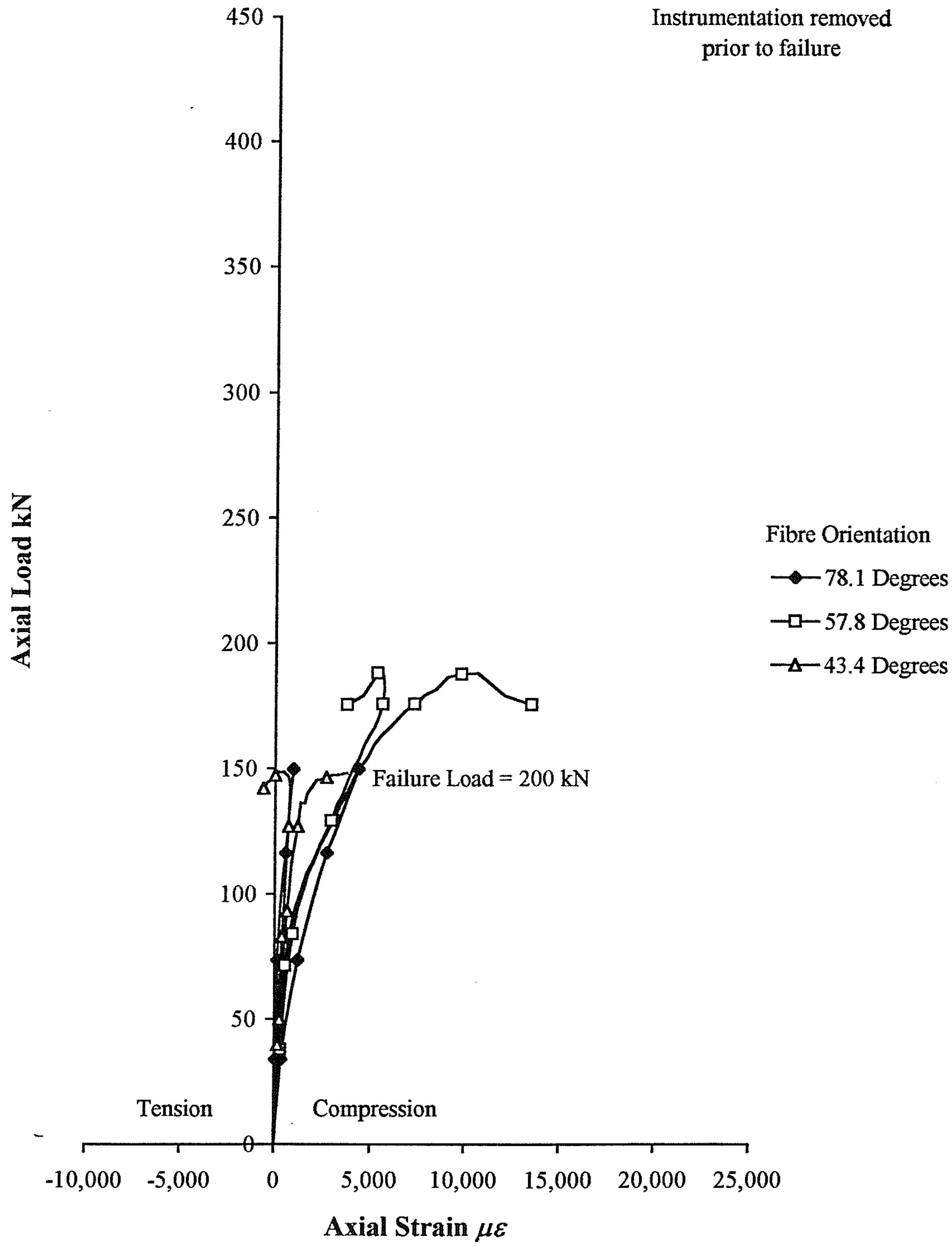



**Figure H.4** Load-strain curves for the 80 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 10 (nominal concrete cube strength = 35 N/mm$^2$)

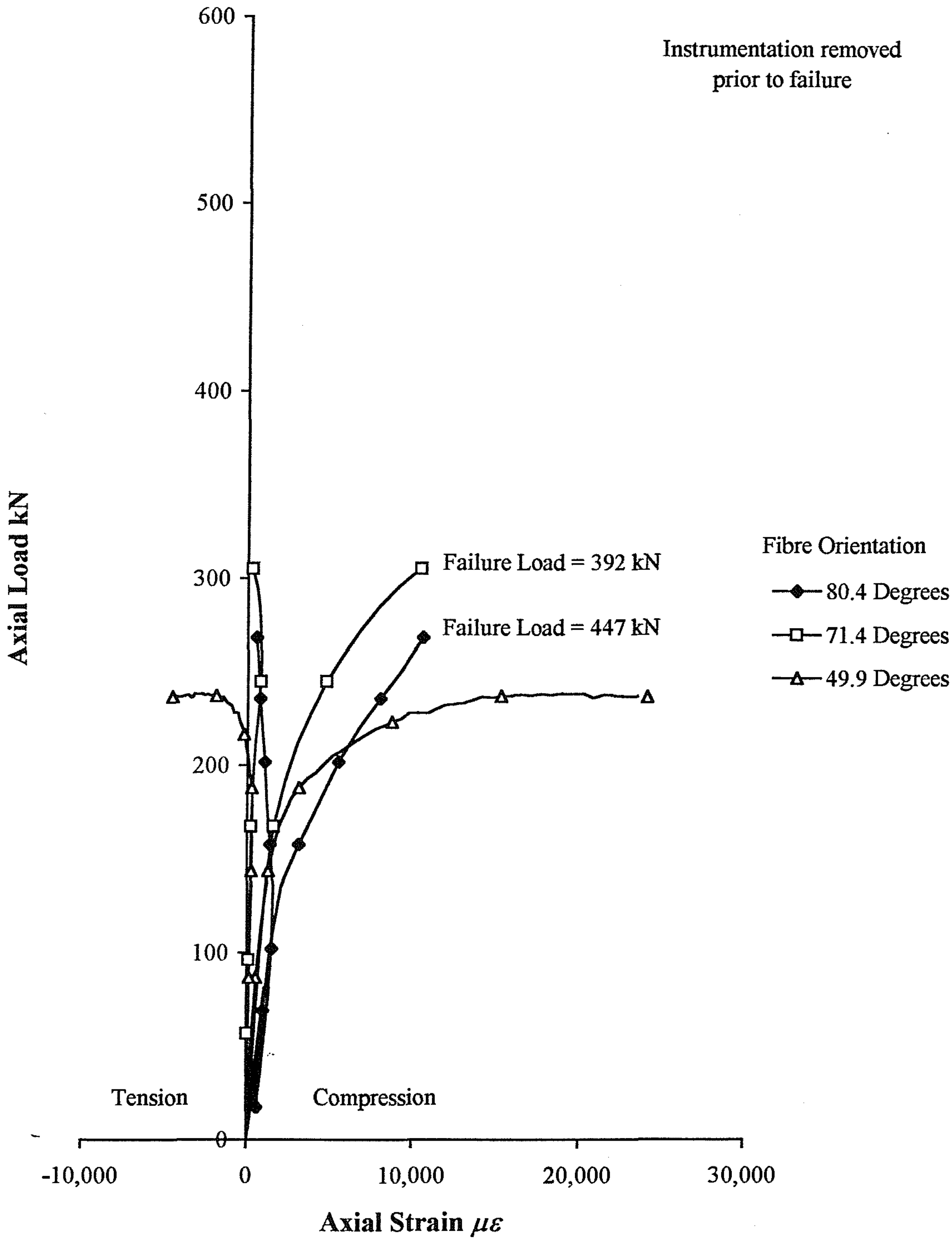



**Figure H.5.** Load-strain curves for the 100 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 5 (nominal concrete cube strength = 25 N/mm$^2$)

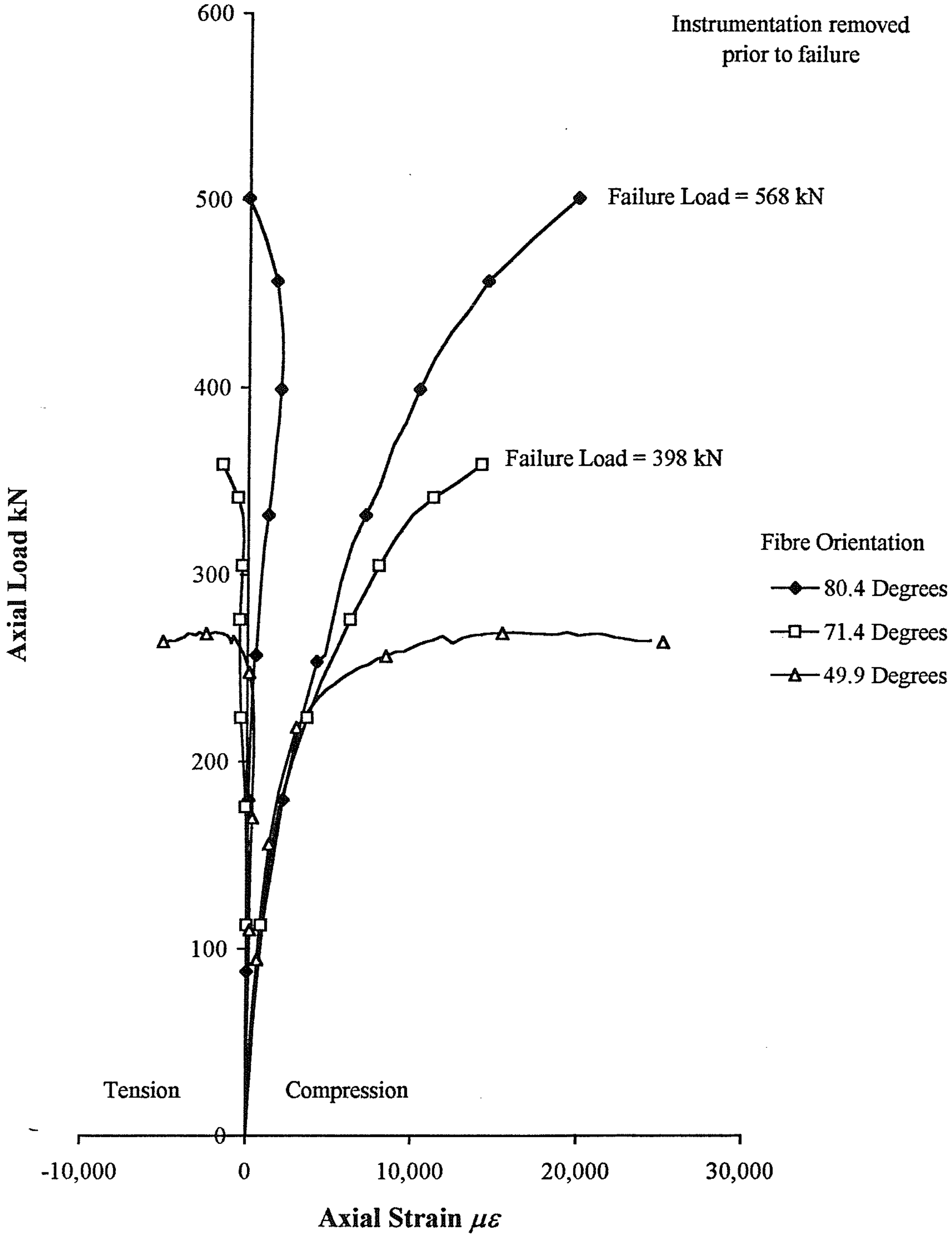



**Figure H.6.** Load-strain curves for the 100 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 5 (nominal concrete cube strength = 35 N/mm$^2$)

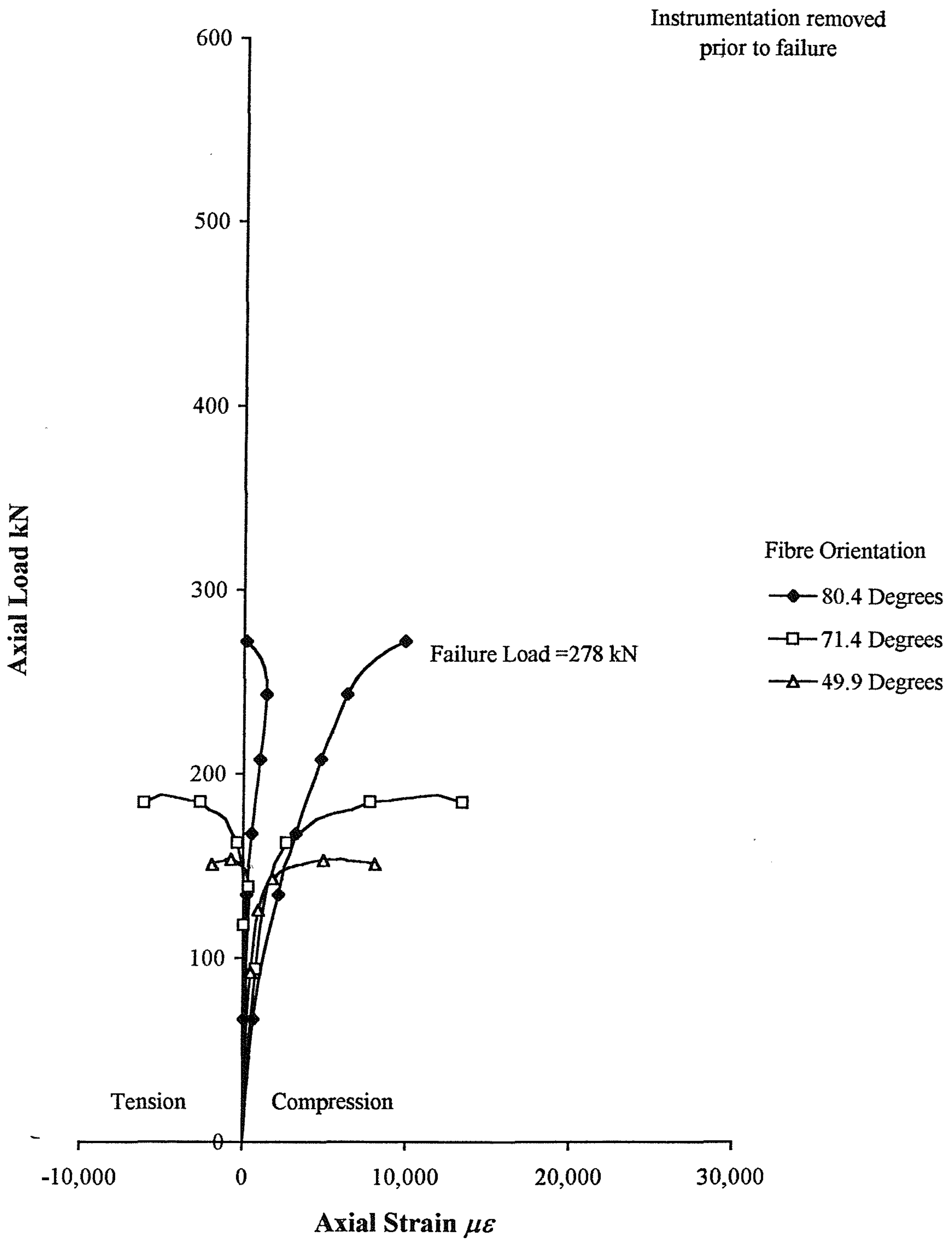



**Figure H.7.** Load-strain curves for the 100 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 10 (nominal concrete cube strength = 25 N/mm$^2$)

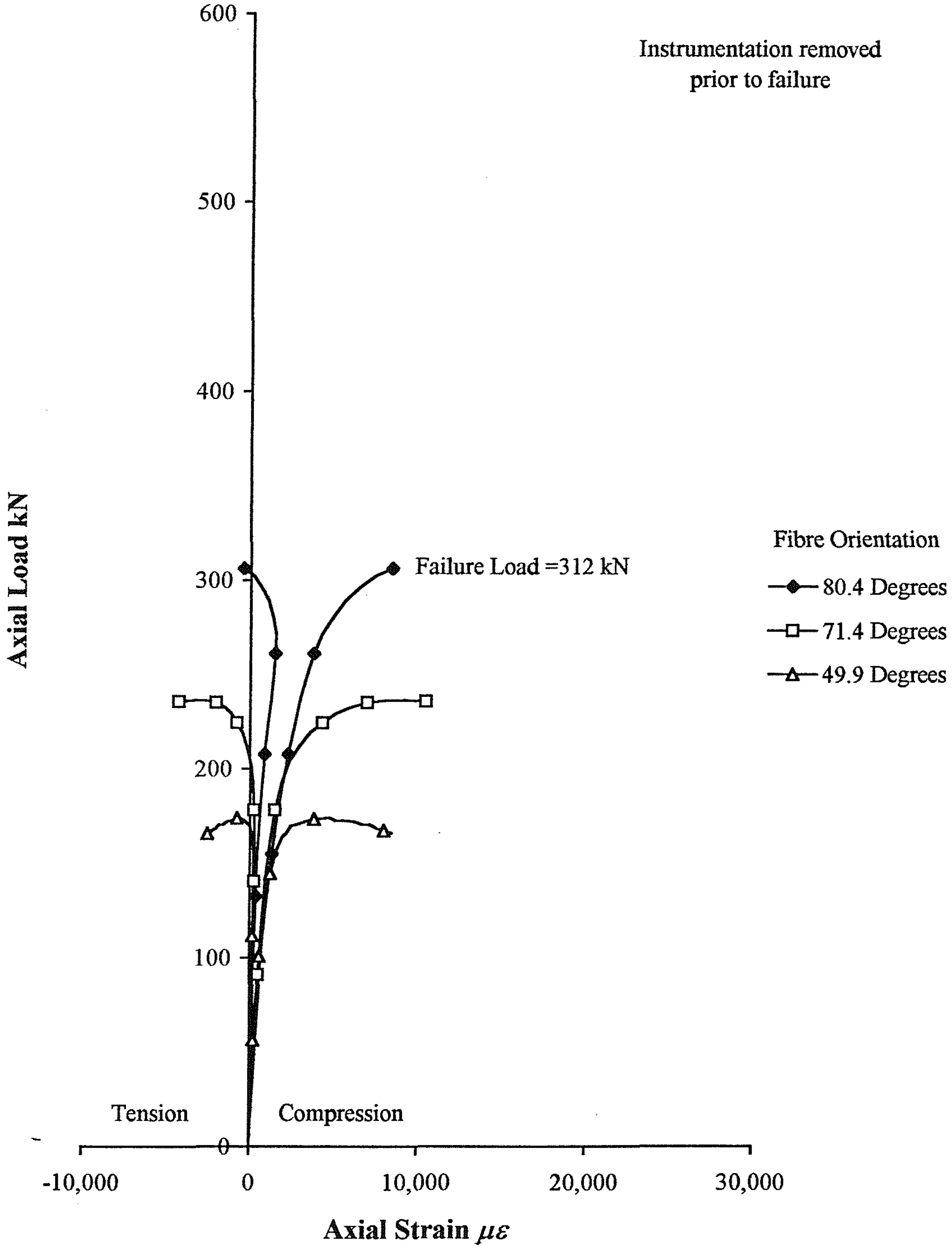



**Figure H.8.** Load-strain curves for the 100 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 10 (nominal concrete cube strength = 35 N/mm$^2$)

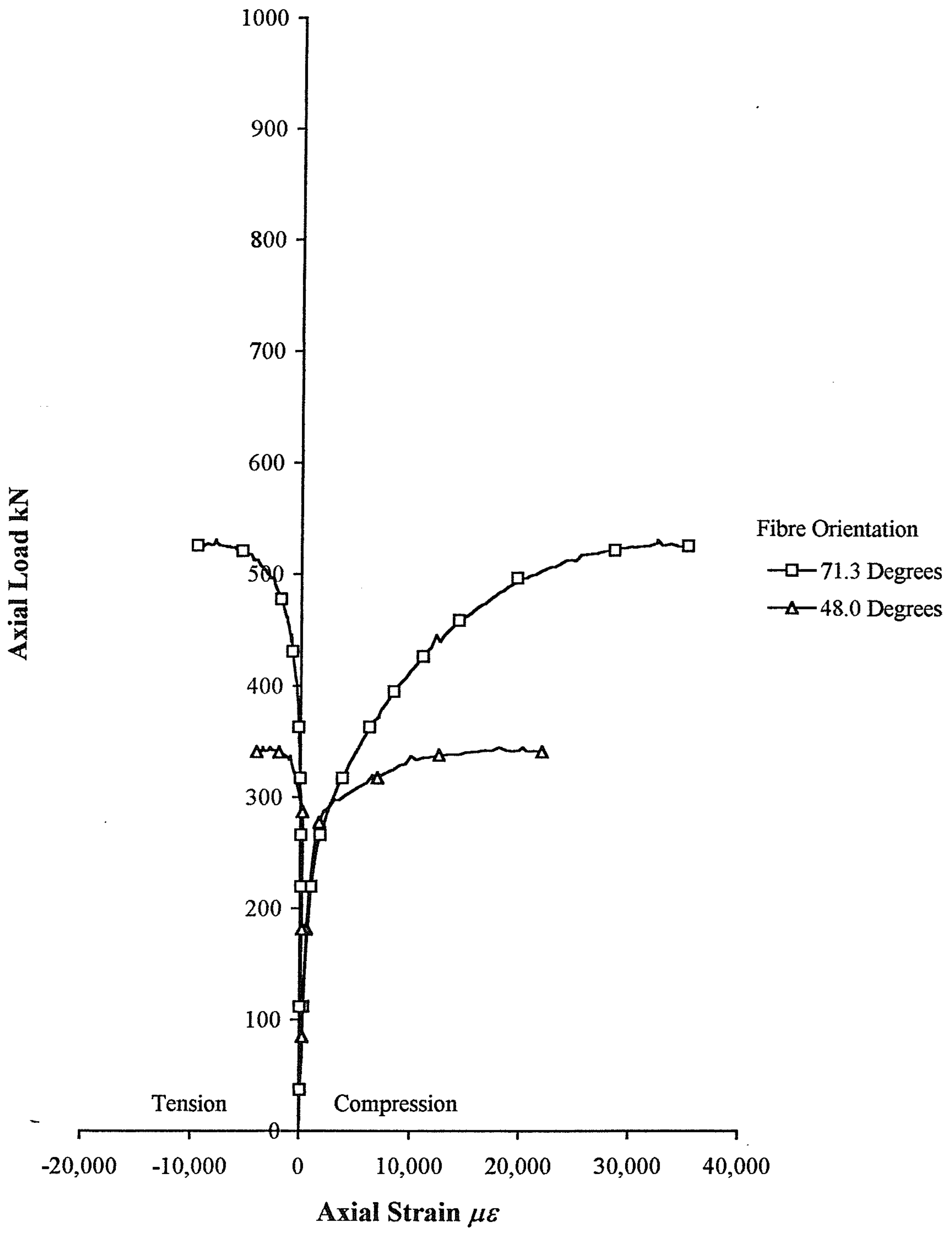



**Figure H.9.** Load-strain curves for the 150 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 5 (nominal concrete cube strength = 25 N/mm$^2$)

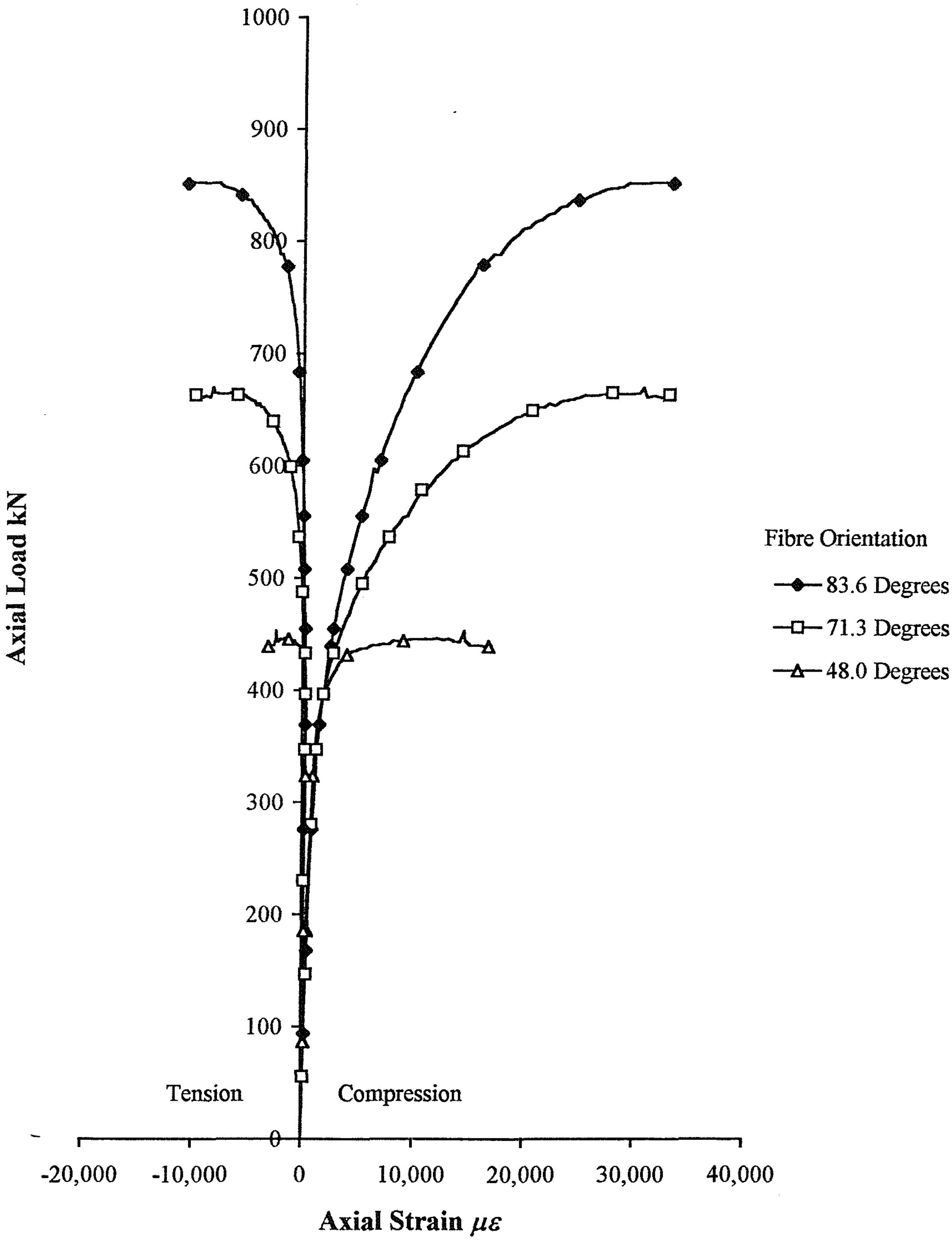



**Figure H.10.** Load-strain curves for the 150 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 5 (nominal concrete cube strength = 35 N/mm$^2$)

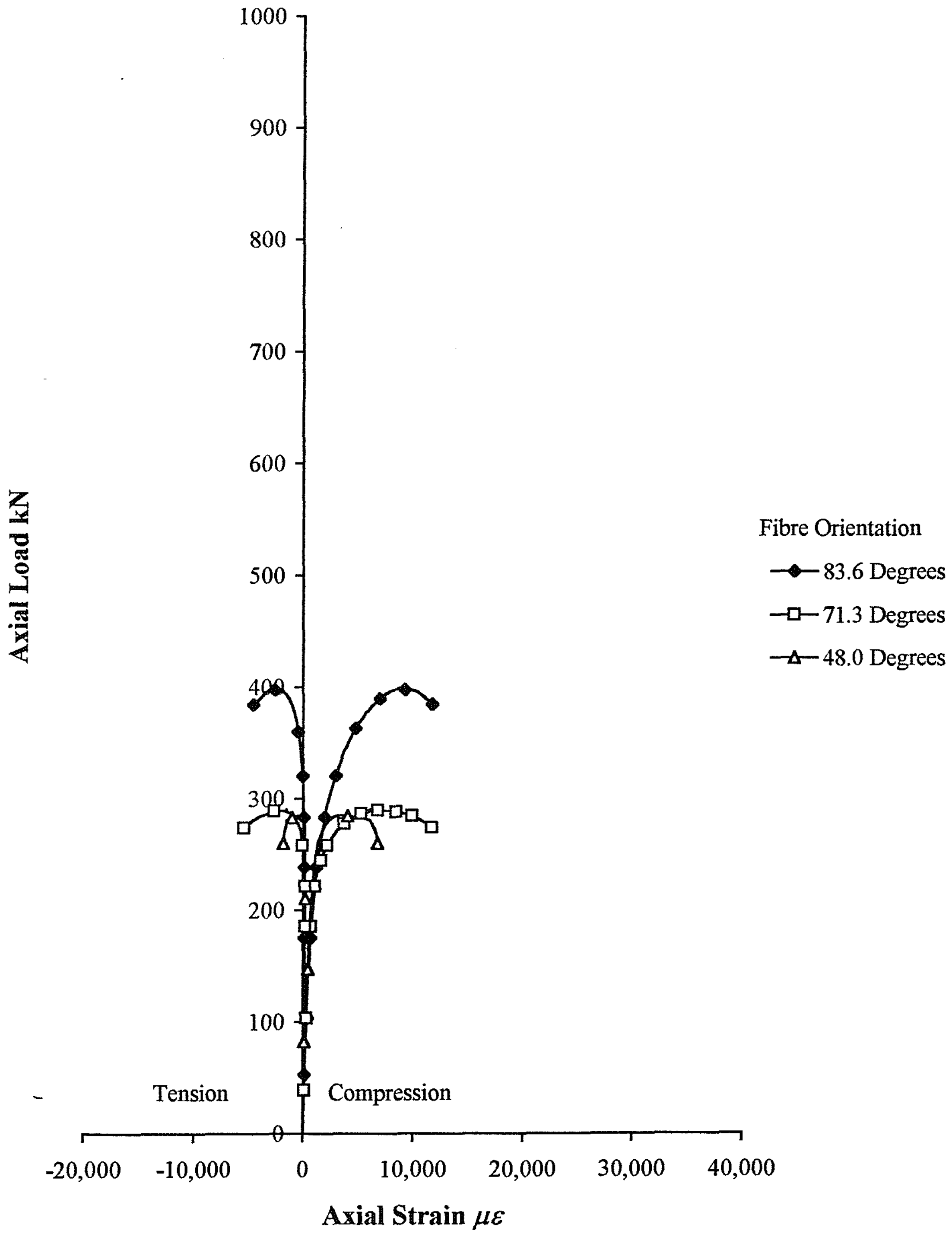



**Figure H.11.** Load-strain curves for the 150 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 10 (nominal concrete cube strength = 25 $N/mm^2$)

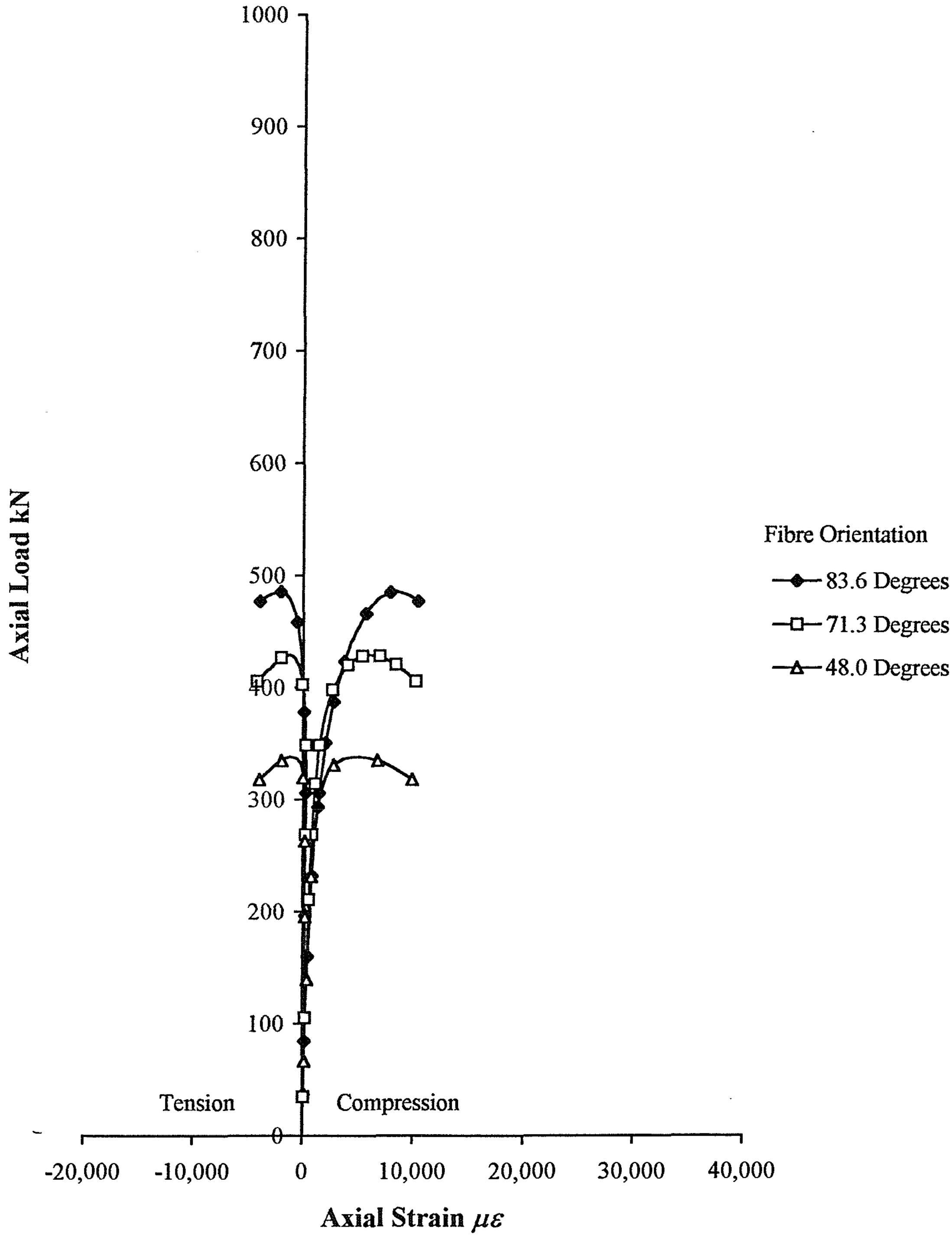



**Figure H.12.** Load-strain curves for the 150 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 10 (nominal concrete cube strength = 35 N/mm$^2$)

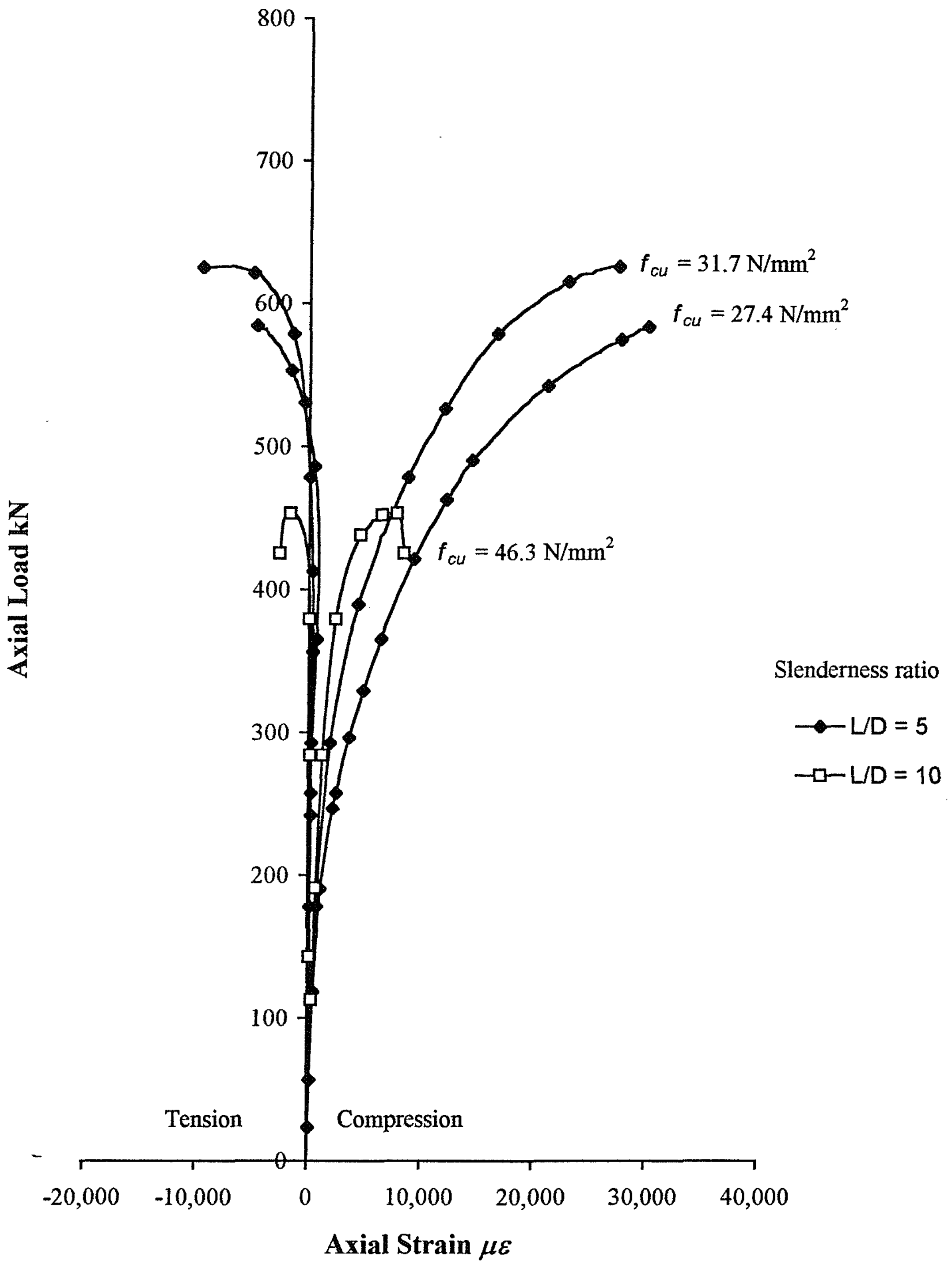



**Figure H.13.** Load-strain curves for the 125 mm diameter concrete-filled FRP-composite columns confined with E-glass fibres orientated at 82.3 degrees

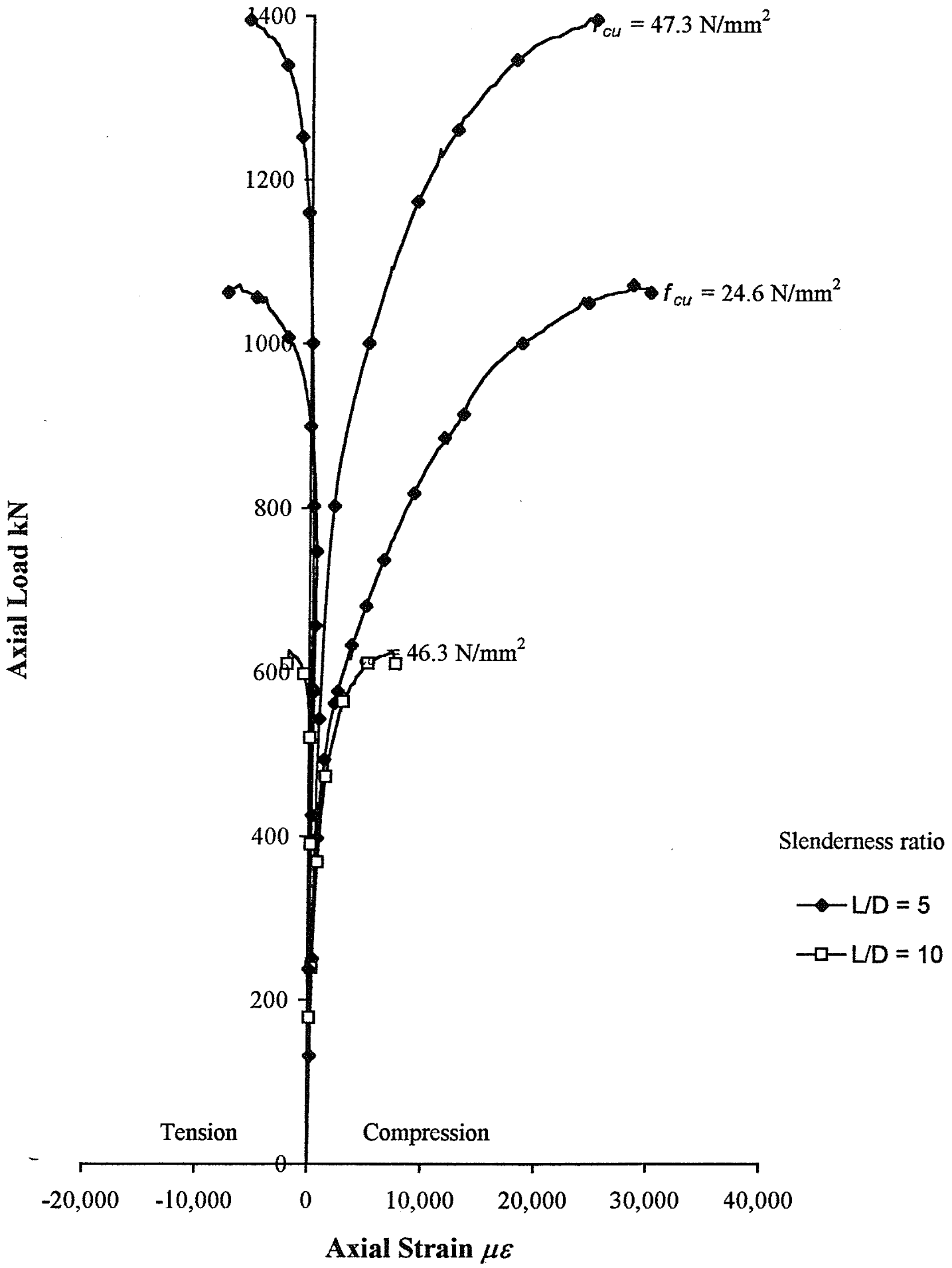



**Figure H.14.** Load-strain curves for the 200 mm diameter concrete-filled FRP-composite columns confined with E-glass fibres orientated at 85.2 degrees

APPENDIX I

# EXPERIMENTAL MOMENT-CURVATURE RELATIONSHIPS FOR CONCRETE-FILLED E-GLASS FRP-COMPOSITE COLUMNS

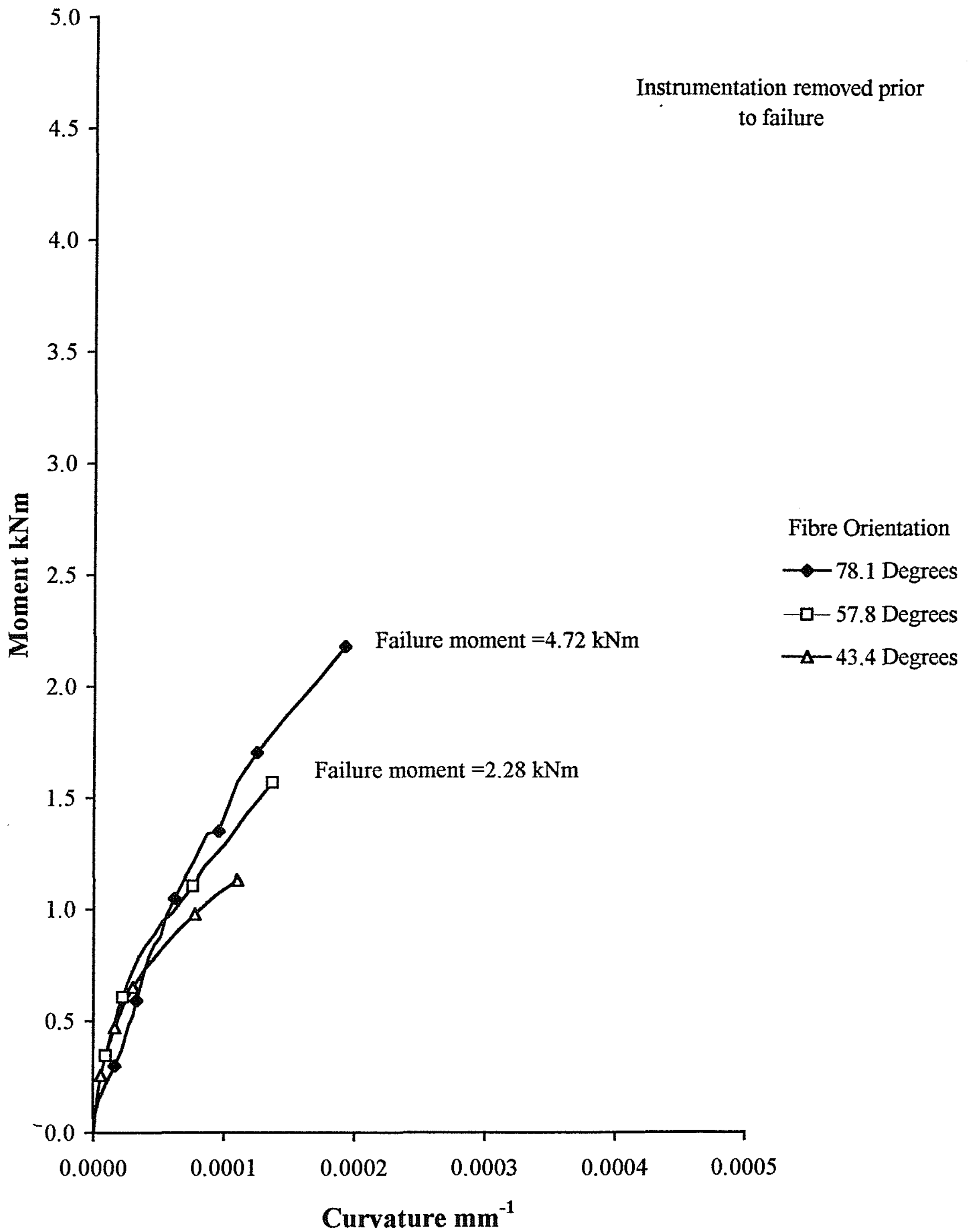



**Figure I.1.** Moment-curvature relationships for the 80 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 5 (nominal concrete cube strength = 25 $N/mm^2$)

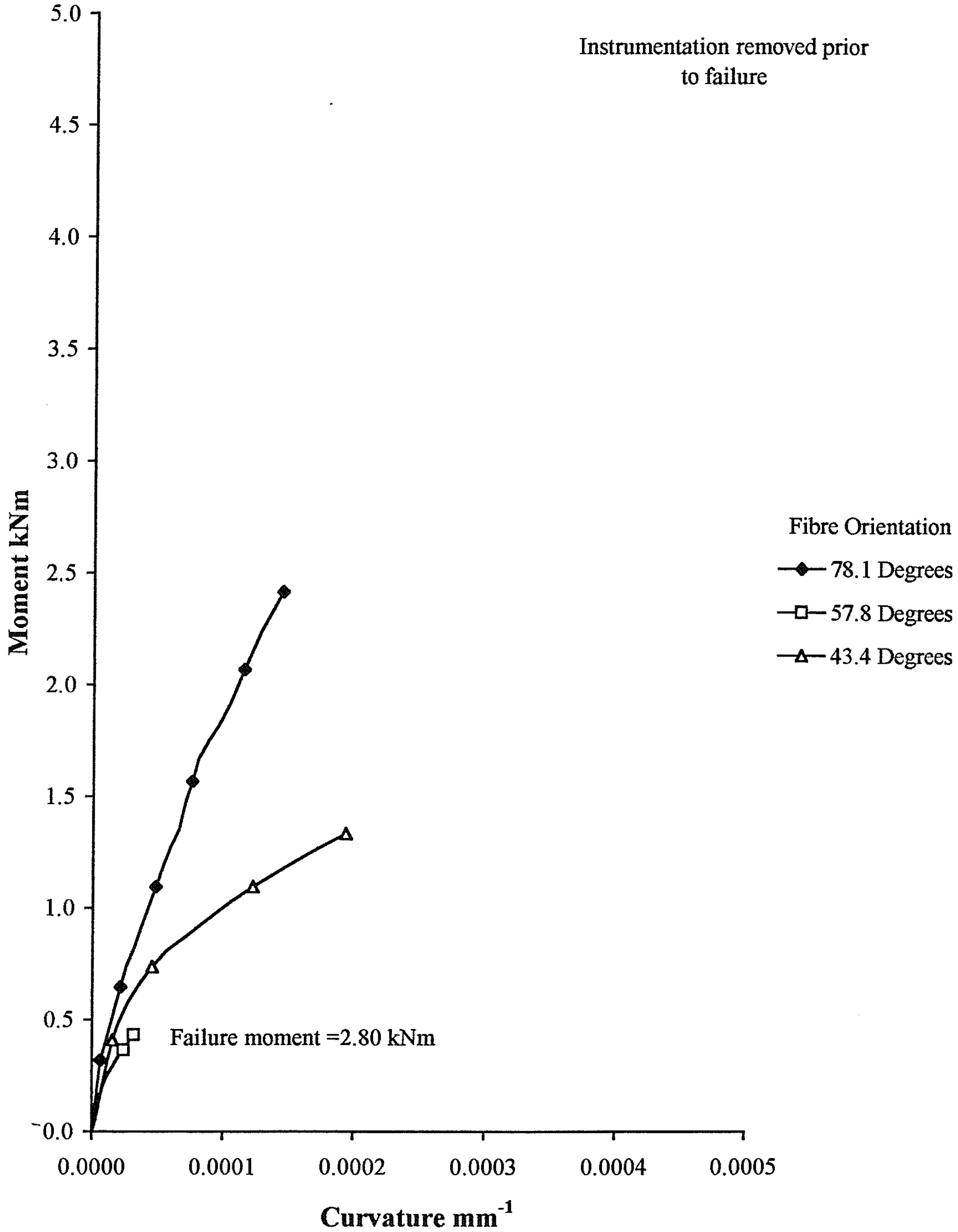



**Figure I.2.** Moment-curvature relationships for the 80 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 5 (nominal concrete cube strength = 35 N/mm$^2$)

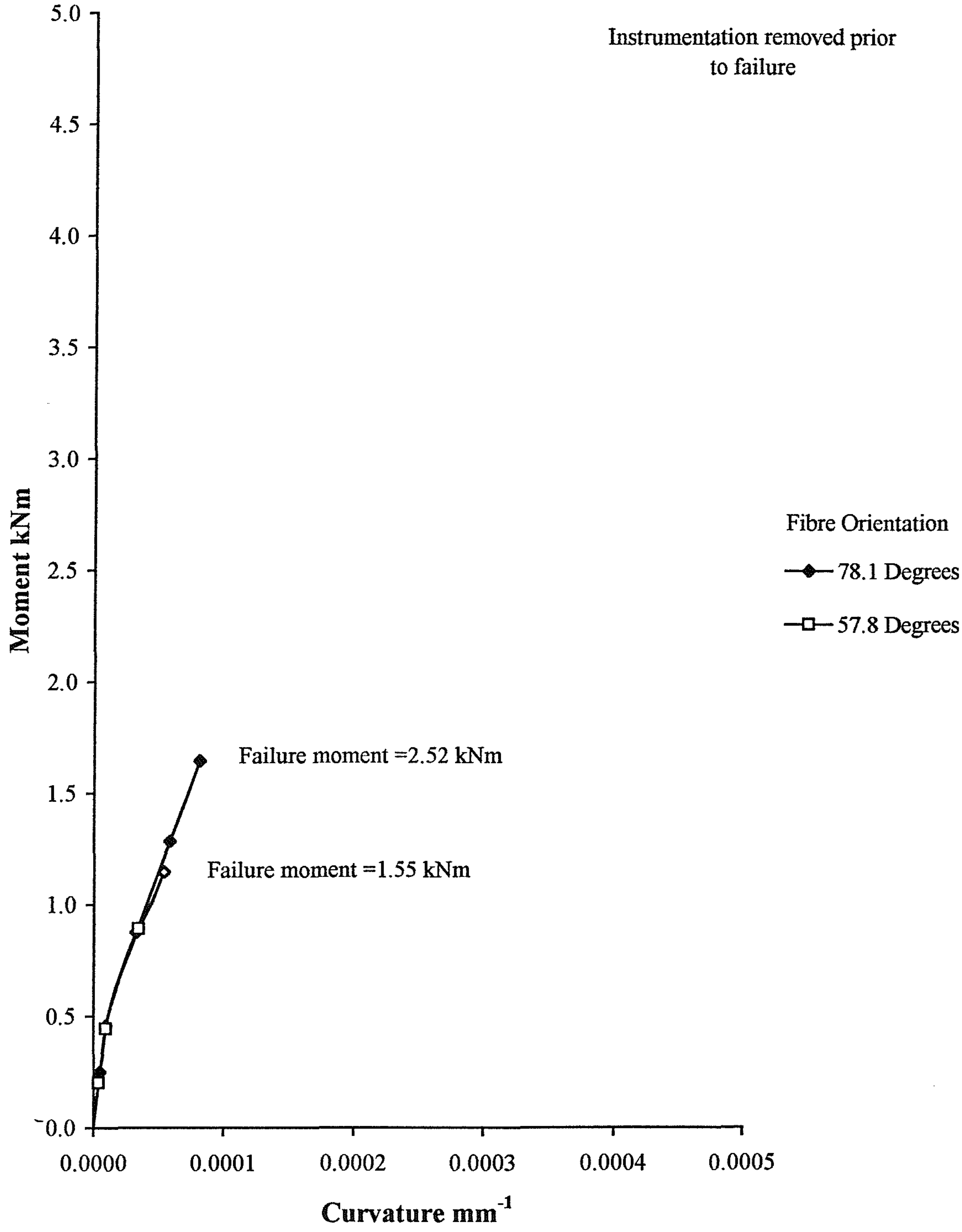



**Figure I.3.** Moment-curvature relationships for the 80 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 10 (nominal concrete cube strength = 25 N/mm$^2$)

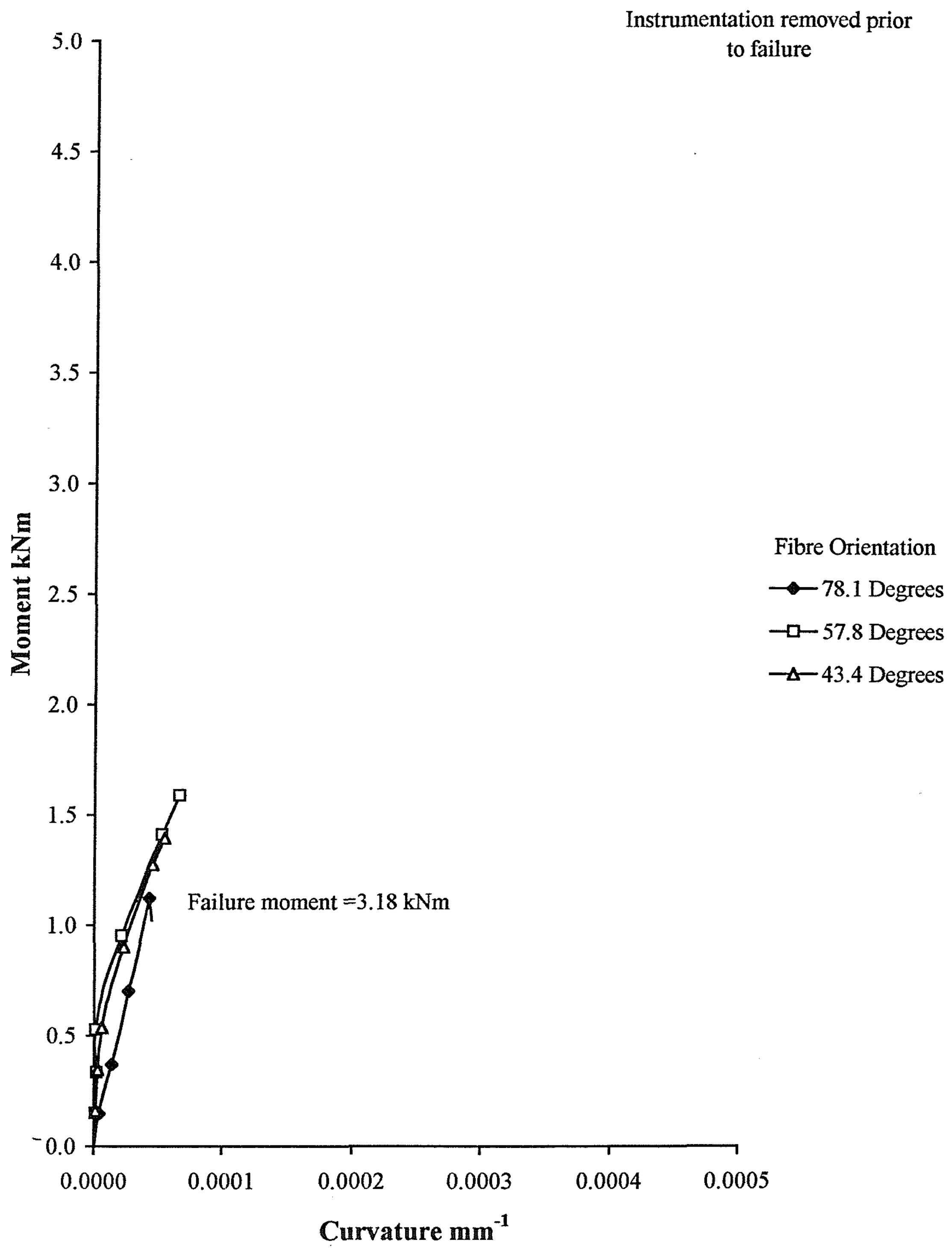



**Figure I.4.** Moment-curvature relationships for the 80 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 10 (nominal concrete cube strength = 35 $N/mm^2$)

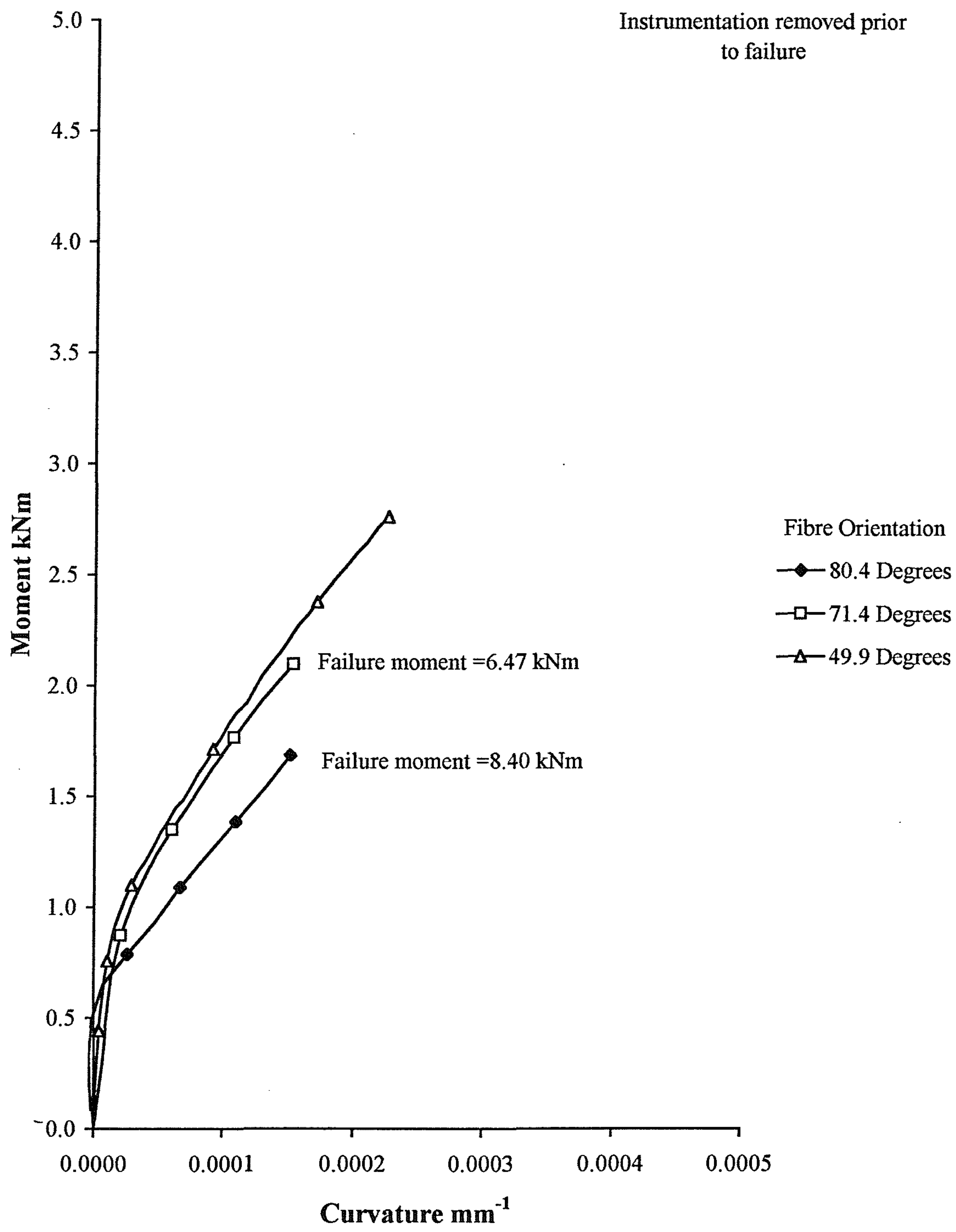



**Figure I.5.** Moment-curvature relationships for the 100 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 5 (nominal concrete cube strength = 25 N/mm$^2$)

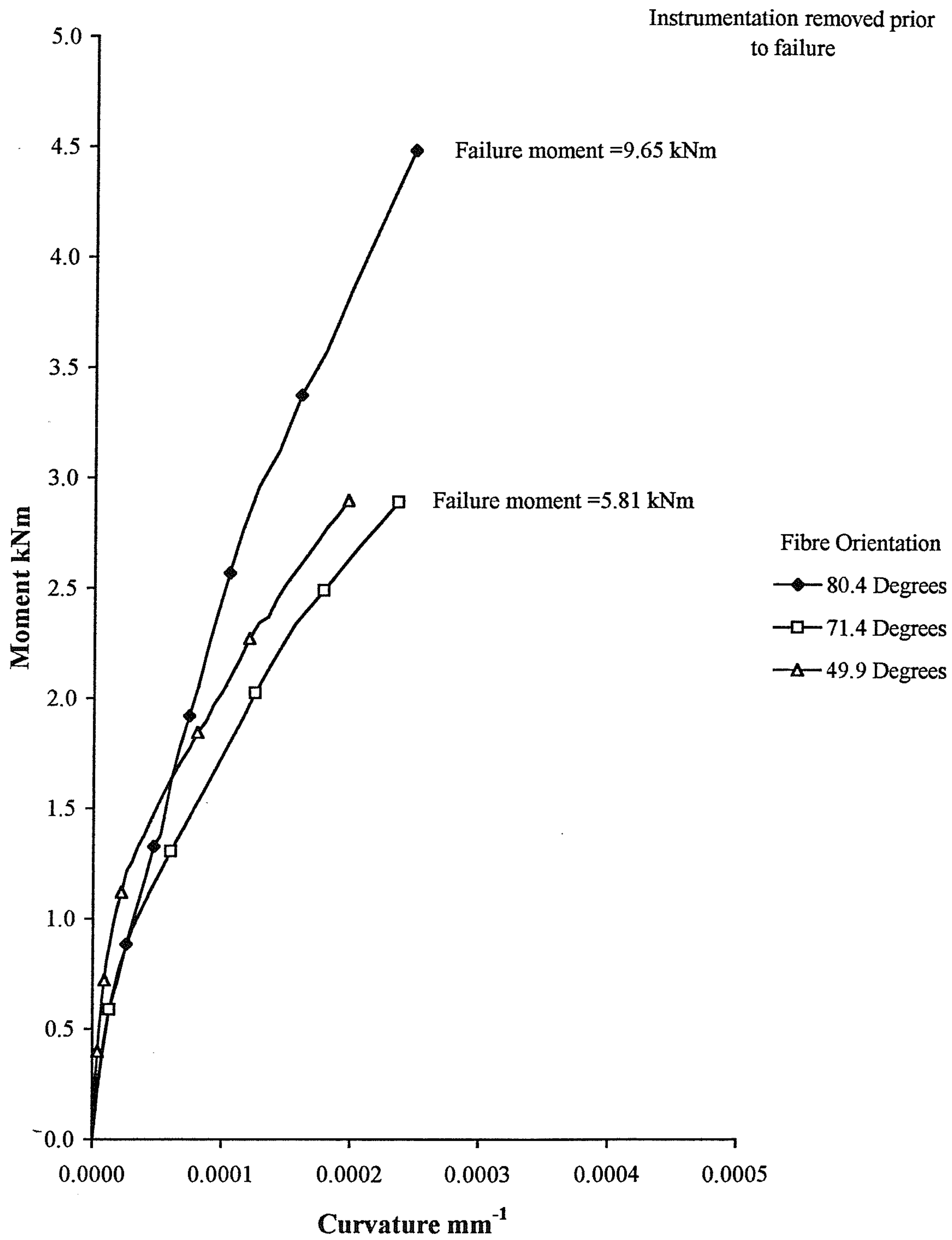



**Figure I.6.** Moment-curvature relationships for the 100 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 5 (nominal concrete cube strength = 35 $N/mm^2$)

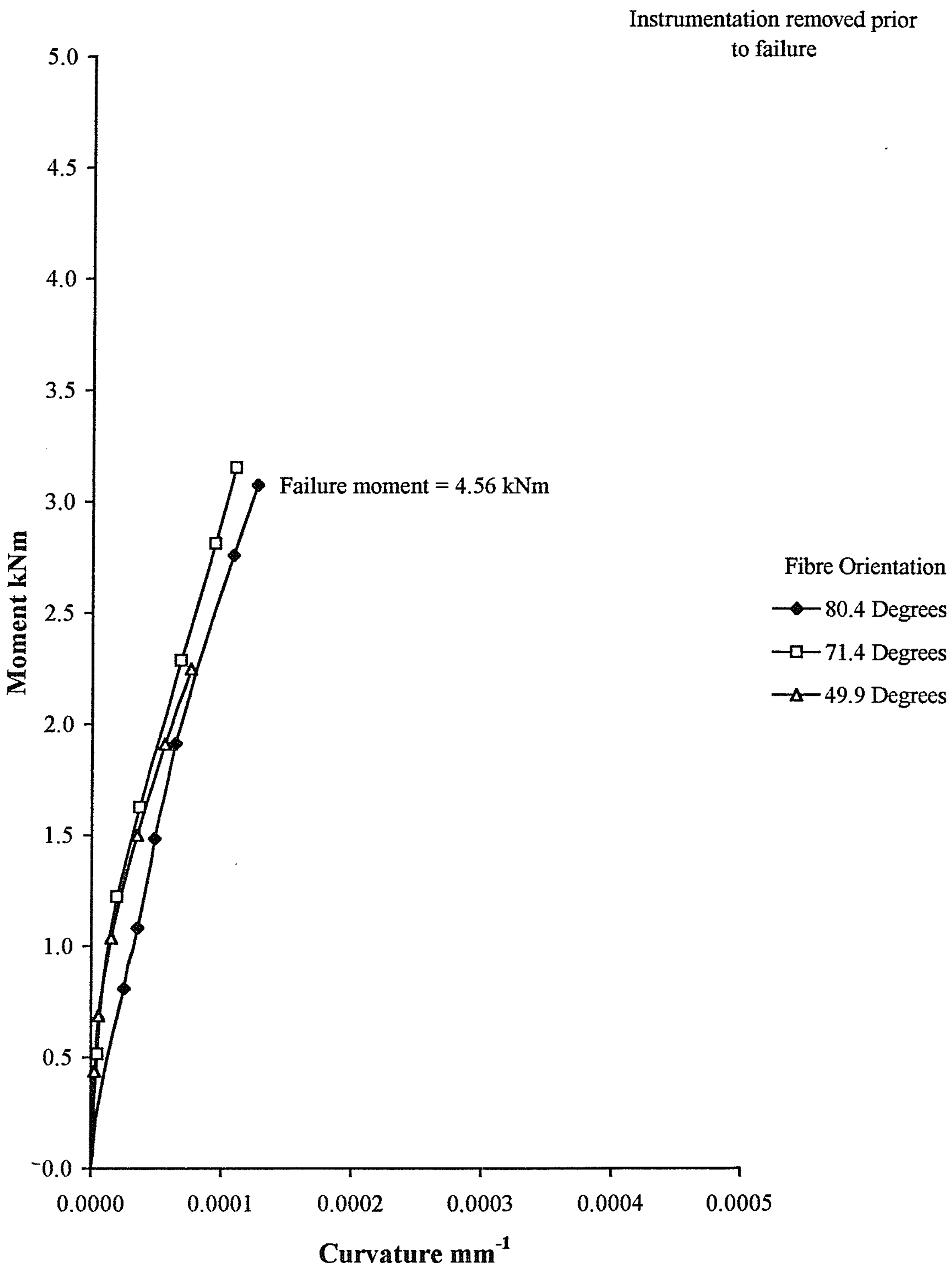



**Figure I.7.** Moment-curvature relationships for the 100 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 10 (nominal concrete cube strength = 25 N/mm$^2$)

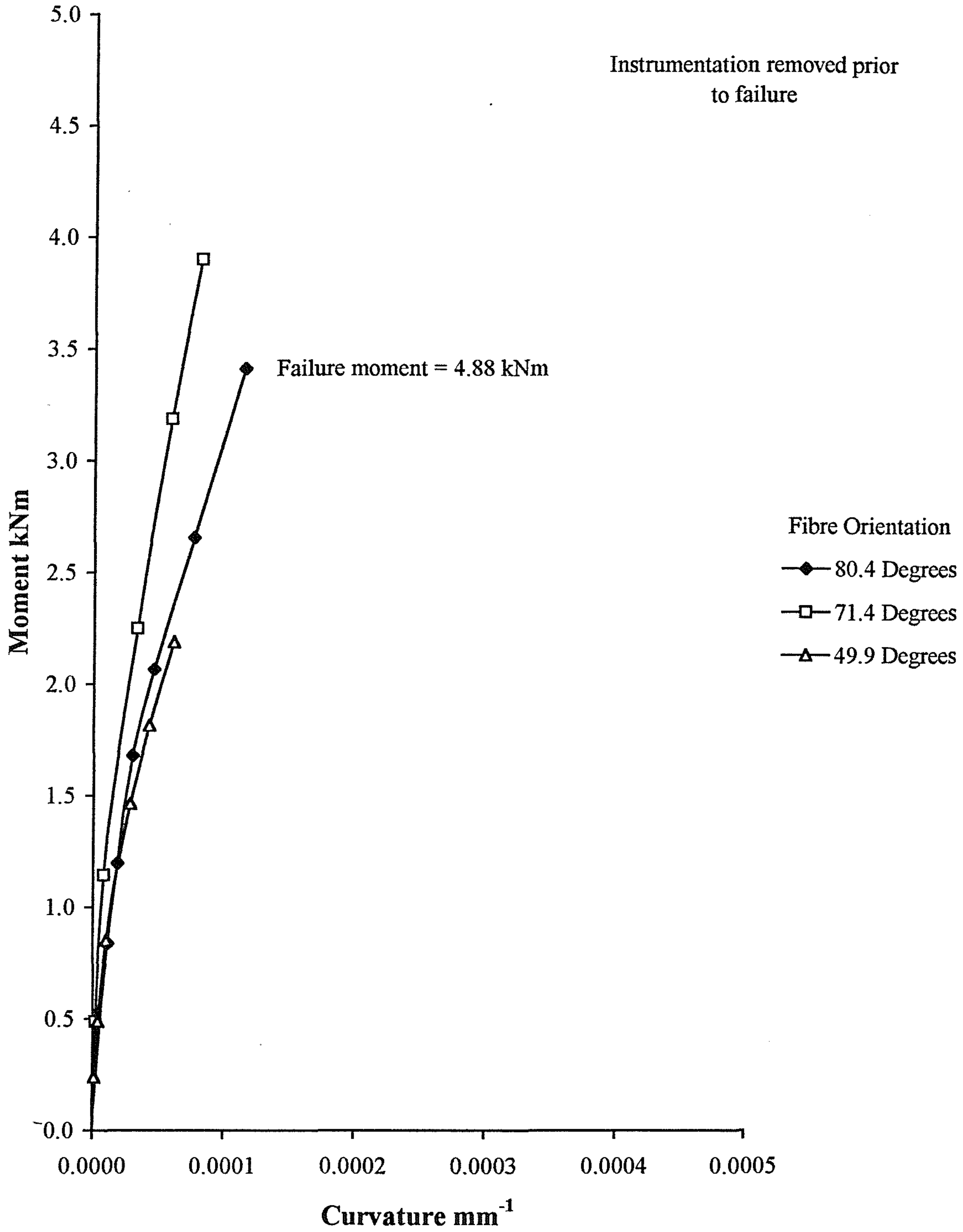



**Figure I.8.** Moment-curvature relationships for the 100 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 10 (nominal concrete cube strength = 35 N/mm$^2$)

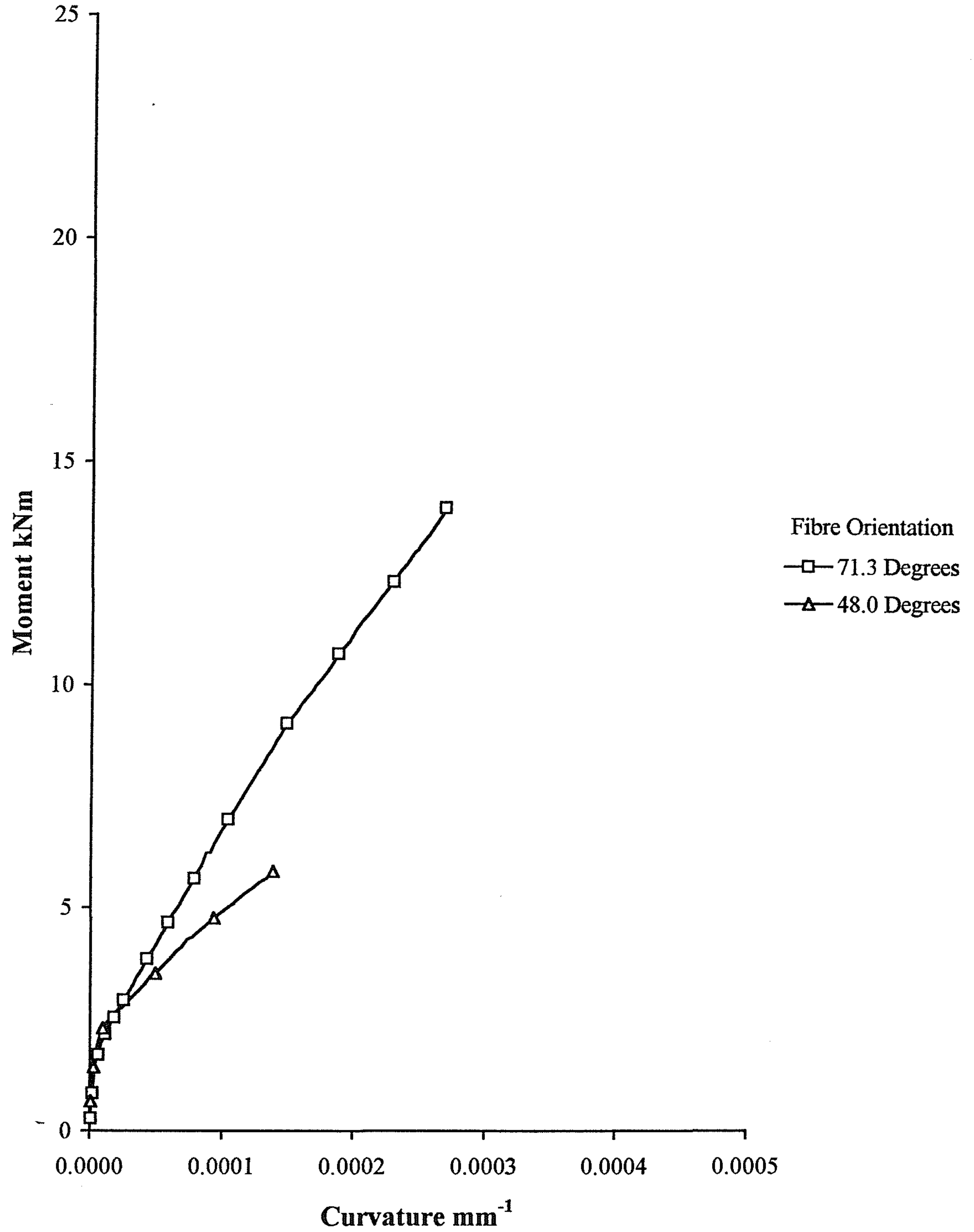



**Figure I.9.** Moment-curvature relationships for the 150 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 5 (nominal concrete cube strength = 25 N/mm$^2$)

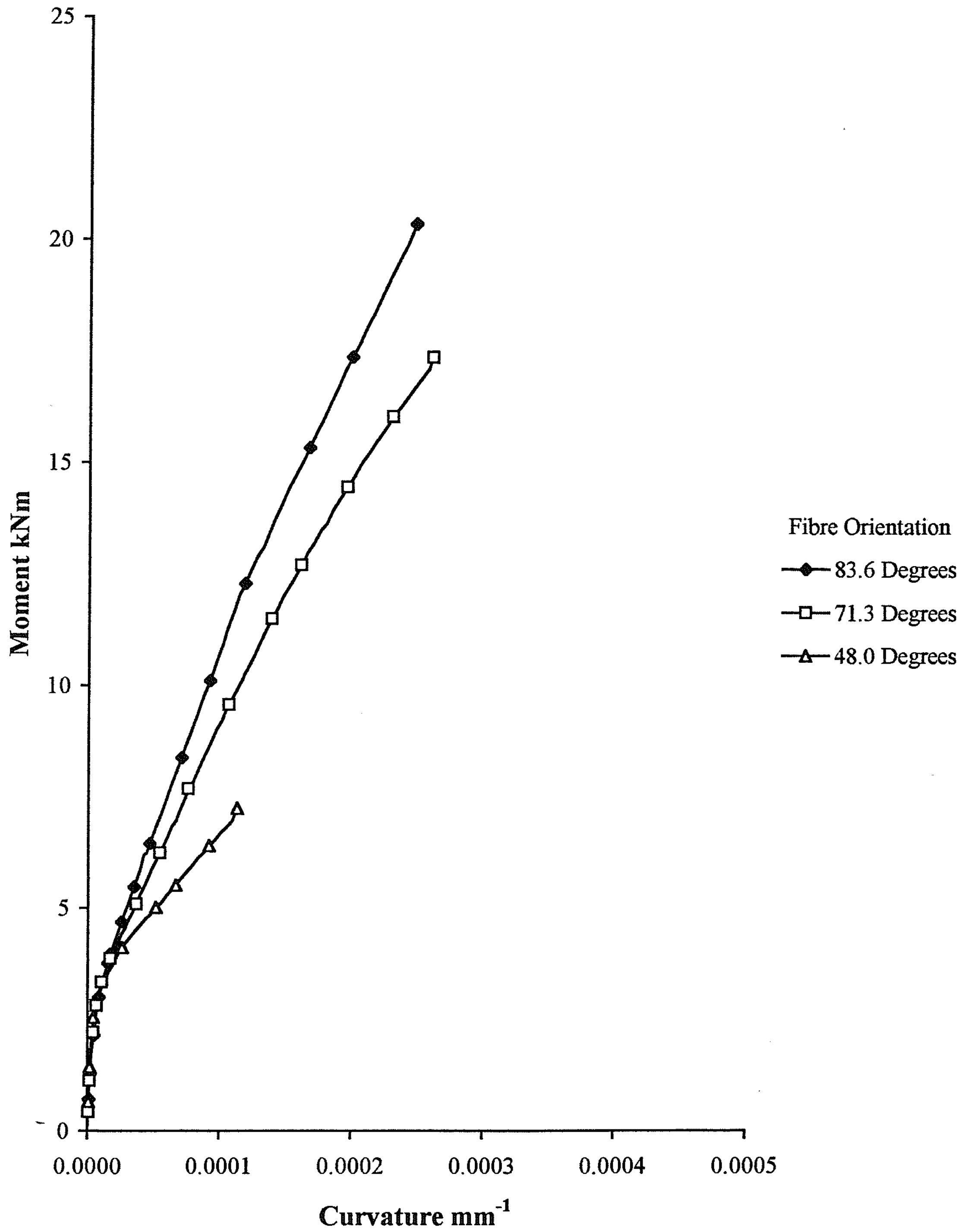



**Figure I.10.** Moment-curvature relationships for the 150 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 5 (nominal concrete cube strength = 35 N/mm$^2$)

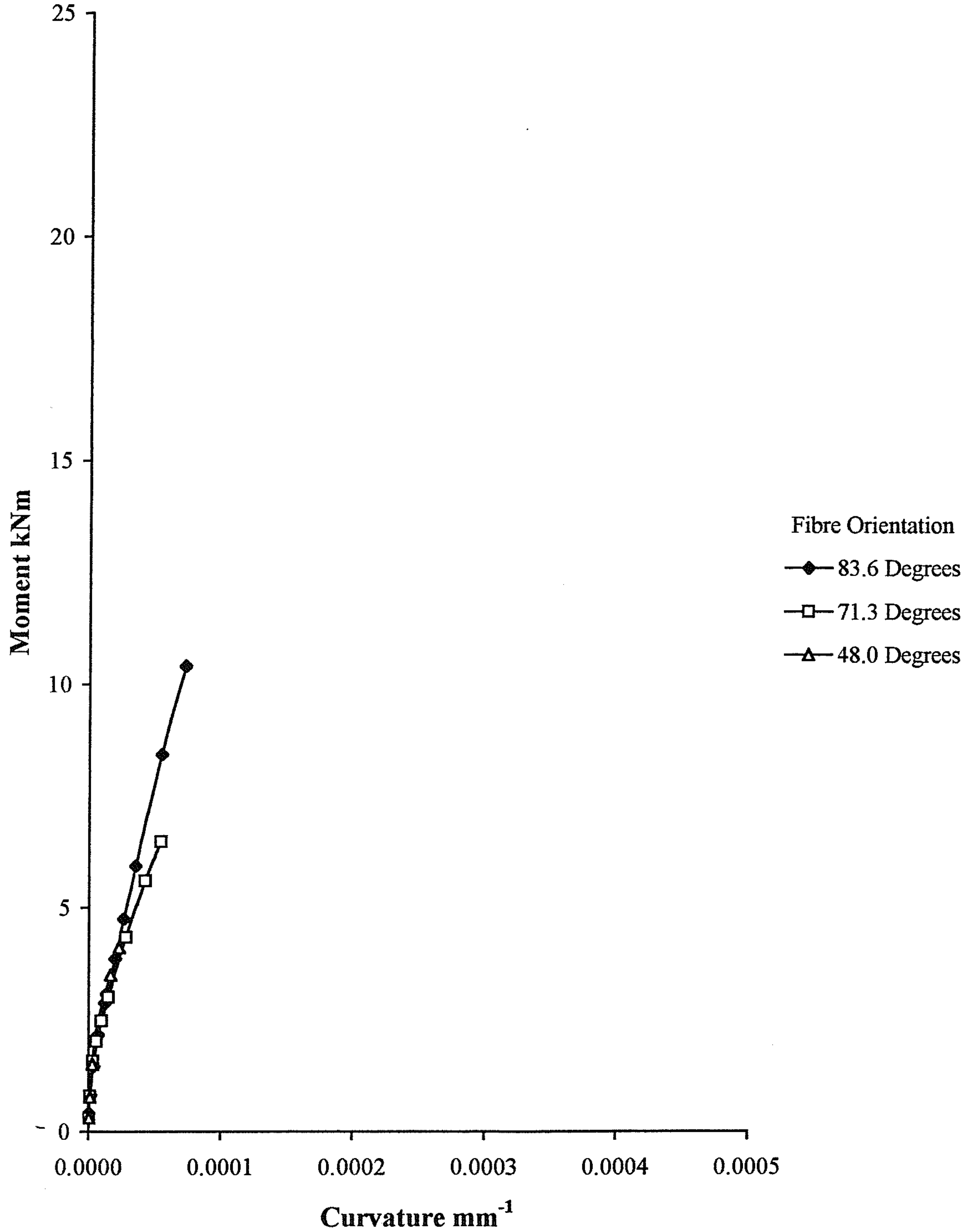



**Figure I.11.** Moment-curvature relationships for the 150 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 10 (nominal concrete cube strength = 25 N/mm$^2$)

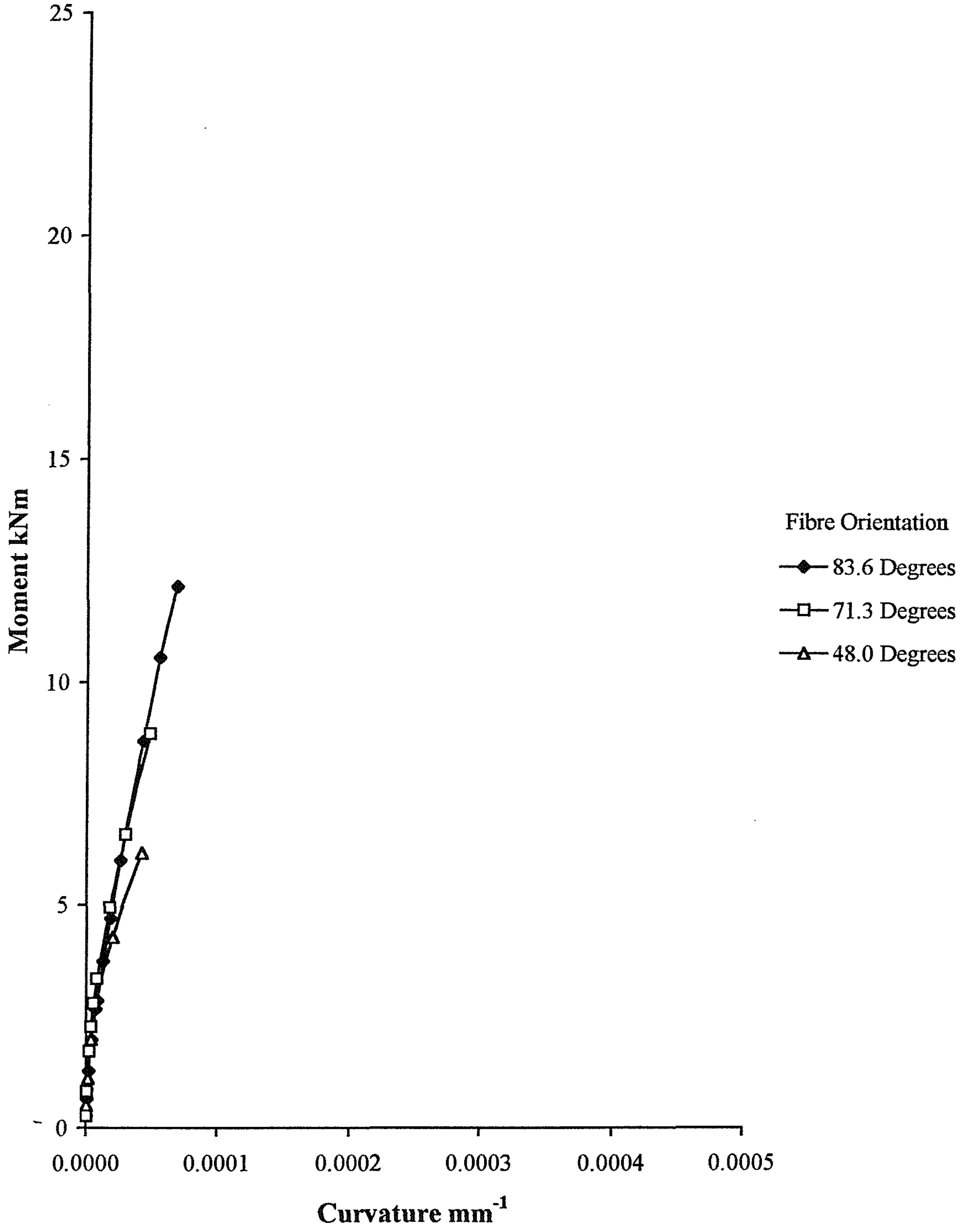



**Figure I.12.** Moment-curvature relationships for the 150 mm diameter concrete-filled FRP-composite columns with a slenderness ratio of 10 (nominal concrete cube strength = 35 N/mm$^2$)

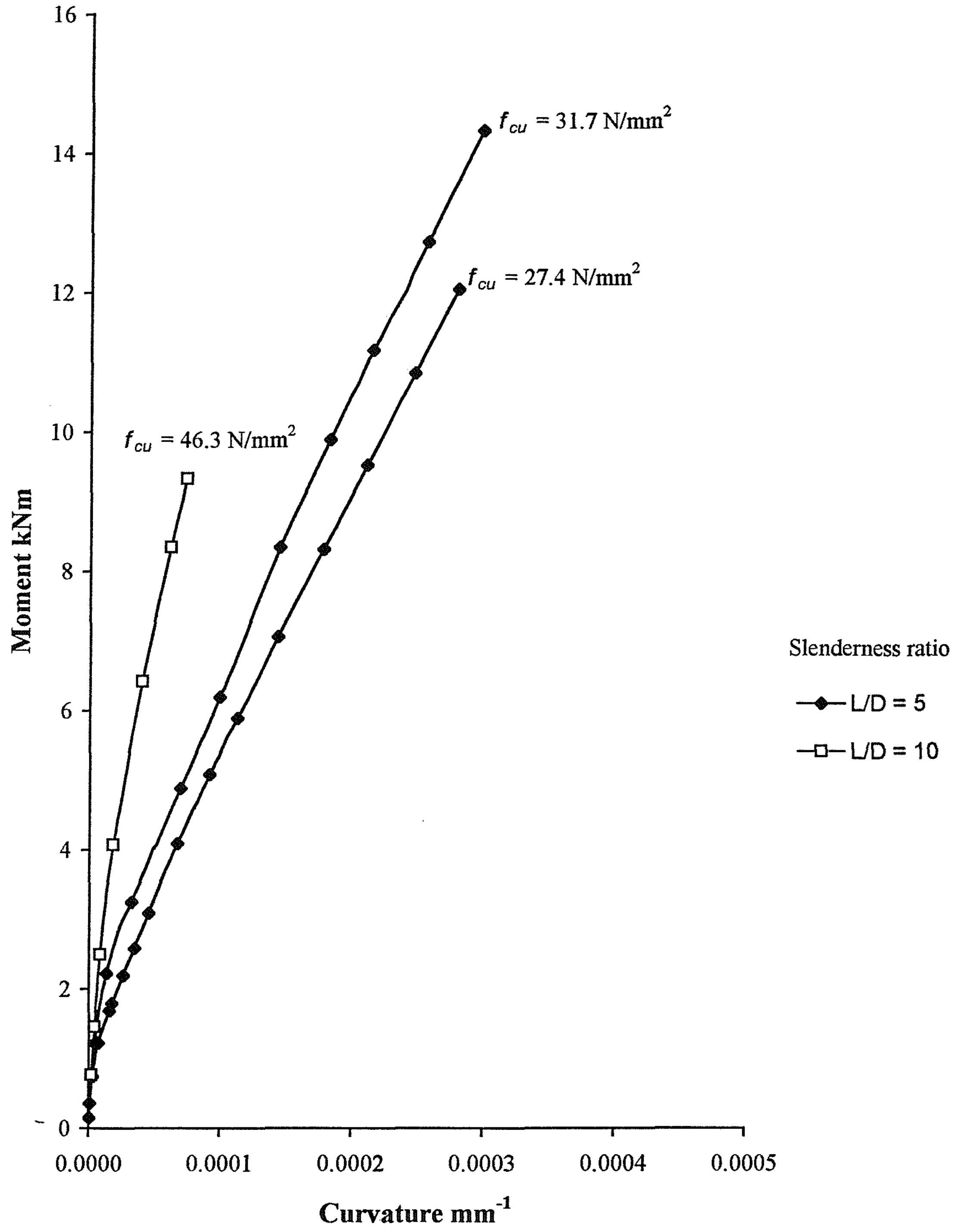



**Figure I.13.** Moment-curvature relationships for the 125 mm diameter concrete-filled FRP-composite columns confined with E-glass fibres orientated at 82.3 degrees

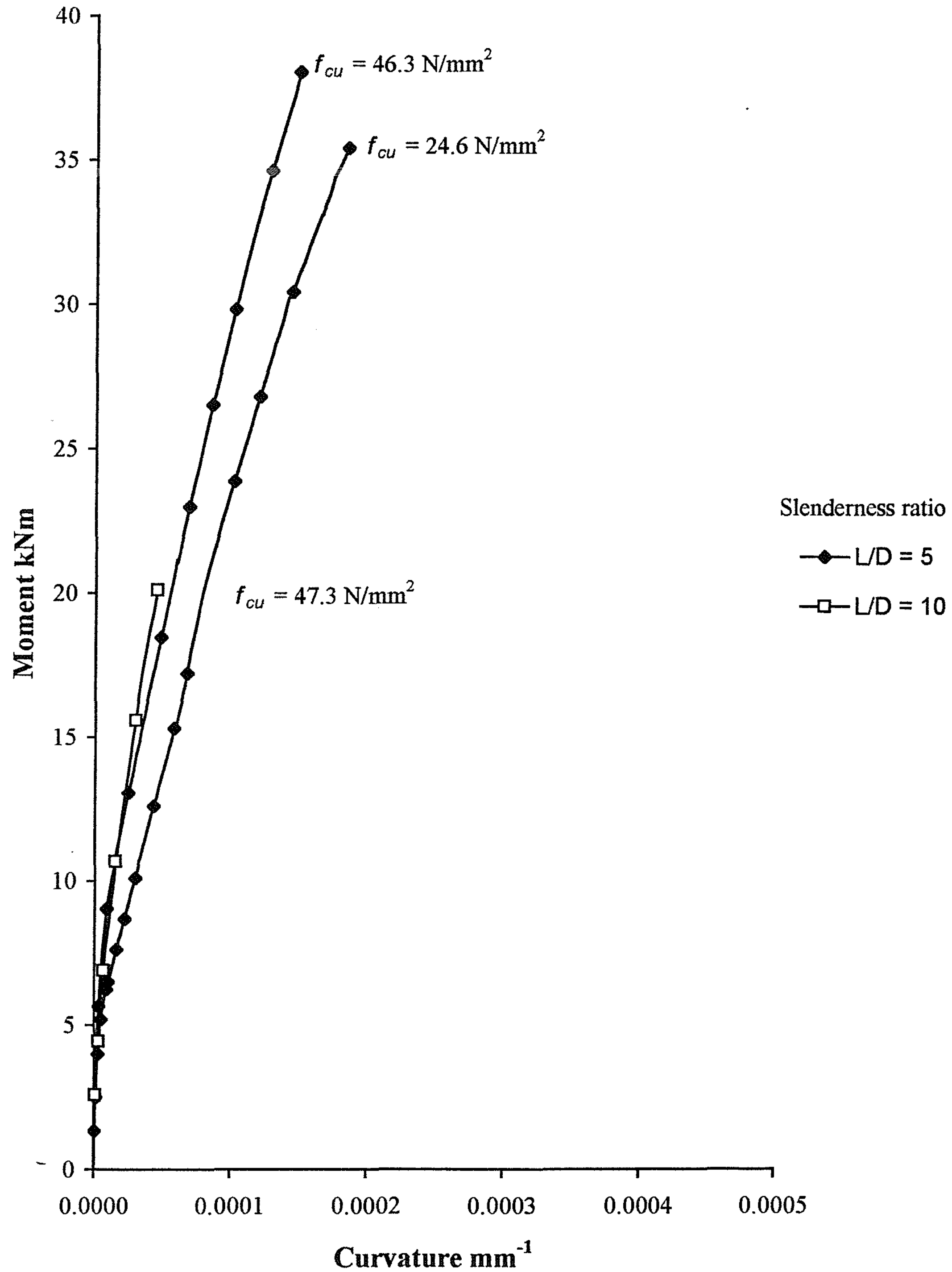



**Figure 1.14.** Moment-curvature relationships for the 200 mm diameter concrete-filled FRP-composite columns confined with E-glass fibres orientated at 85.2 degrees

APPENDIX J

**EXPERIMENTAL LOAD-DEFECTION CURVES FOR CONCRETE-FILLED E-GLASS FRP-COMPOSITE COLUMNS REINFORCED LONGITUDINALLY WITH CARBON FRP-COMPOSITE BARS**

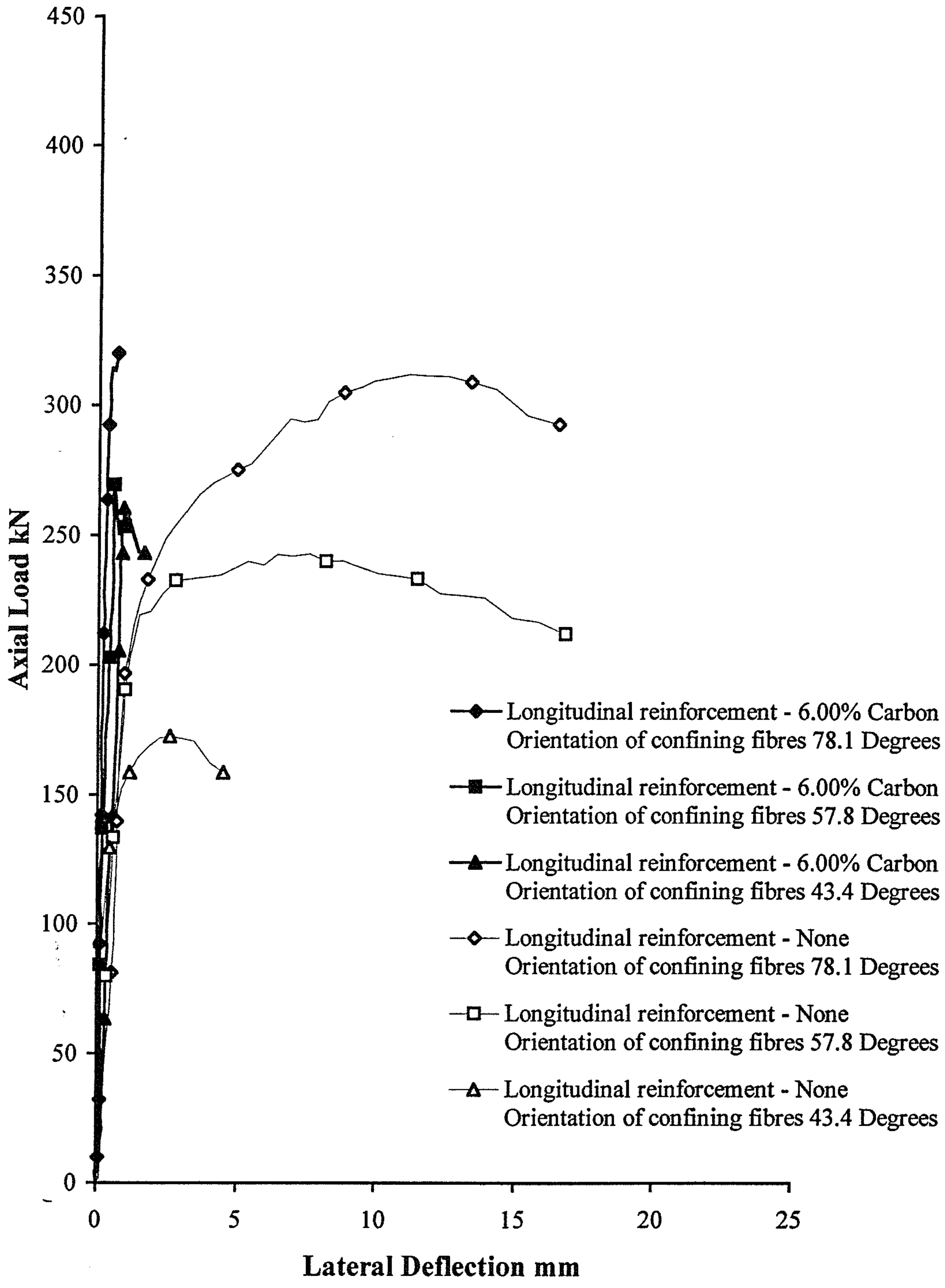



**Figure J.1.** Load-deflection curves for the 80 mm diameter concrete-filled E-glass FRP-composite columns with longitudinal carbon FRP-composite bars (slenderness ratio = 5)

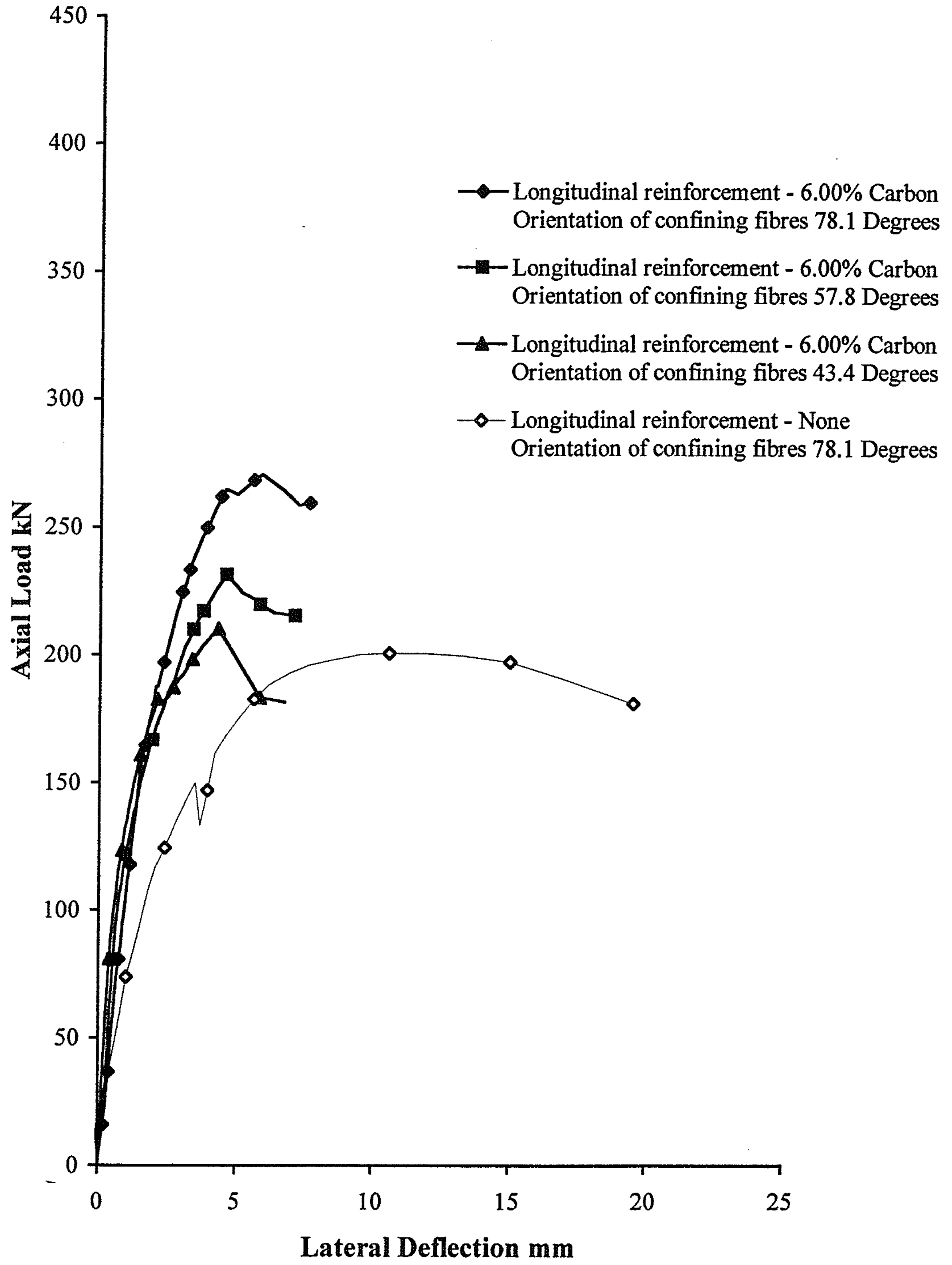



**Figure J.2.** Load-deflection curves for the 80 mm diameter concrete-filled E-glass FRP-composite columns with longitudinal carbon FRP-composite bars (slenderness ratio = 10)

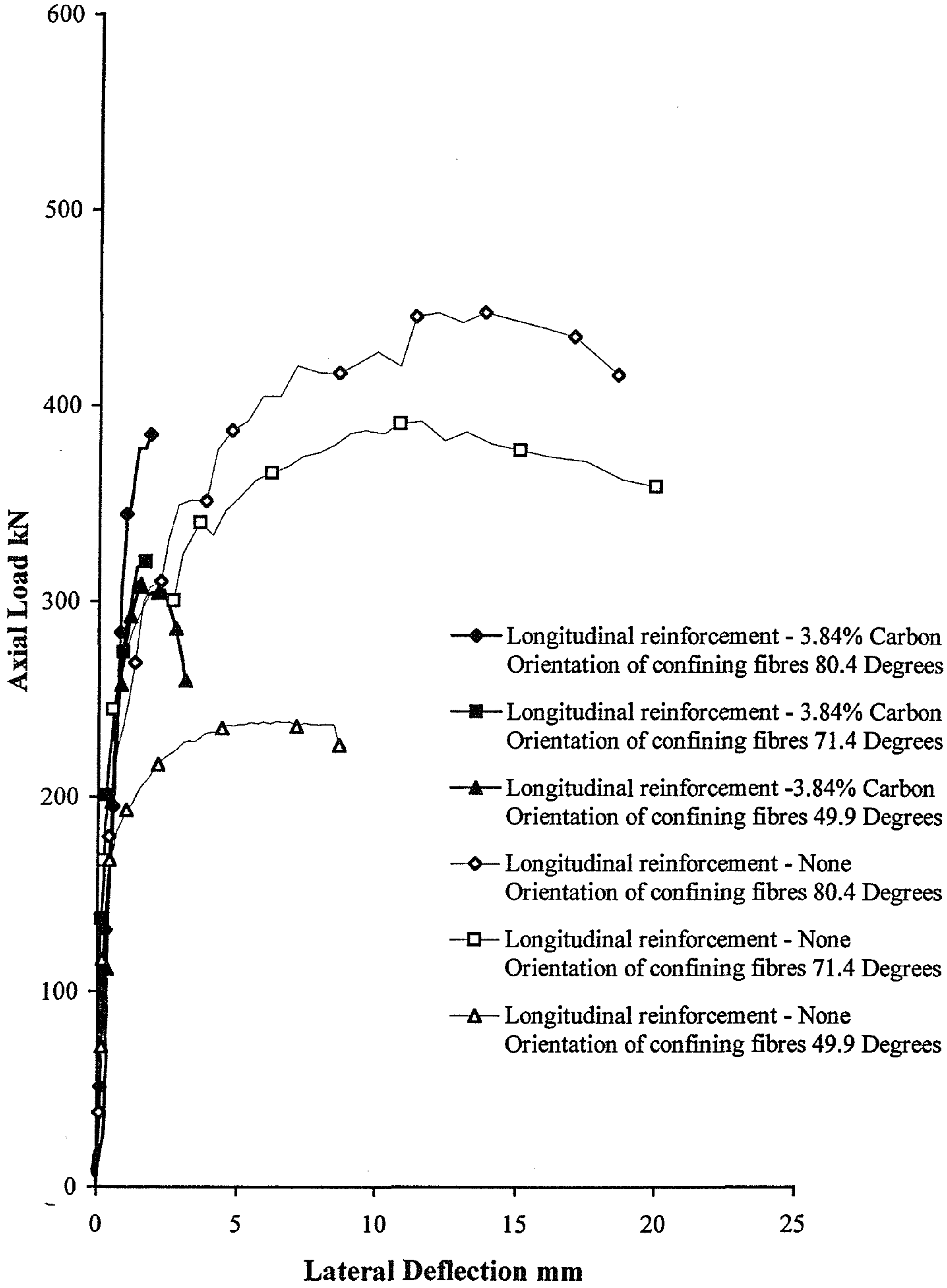



**Figure J.3.** Load-deflection curves for the 100 mm diameter concrete-filled E-glass FRP-composite columns with longitudinal carbon FRP-composite bars (slenderness ratio = 5)

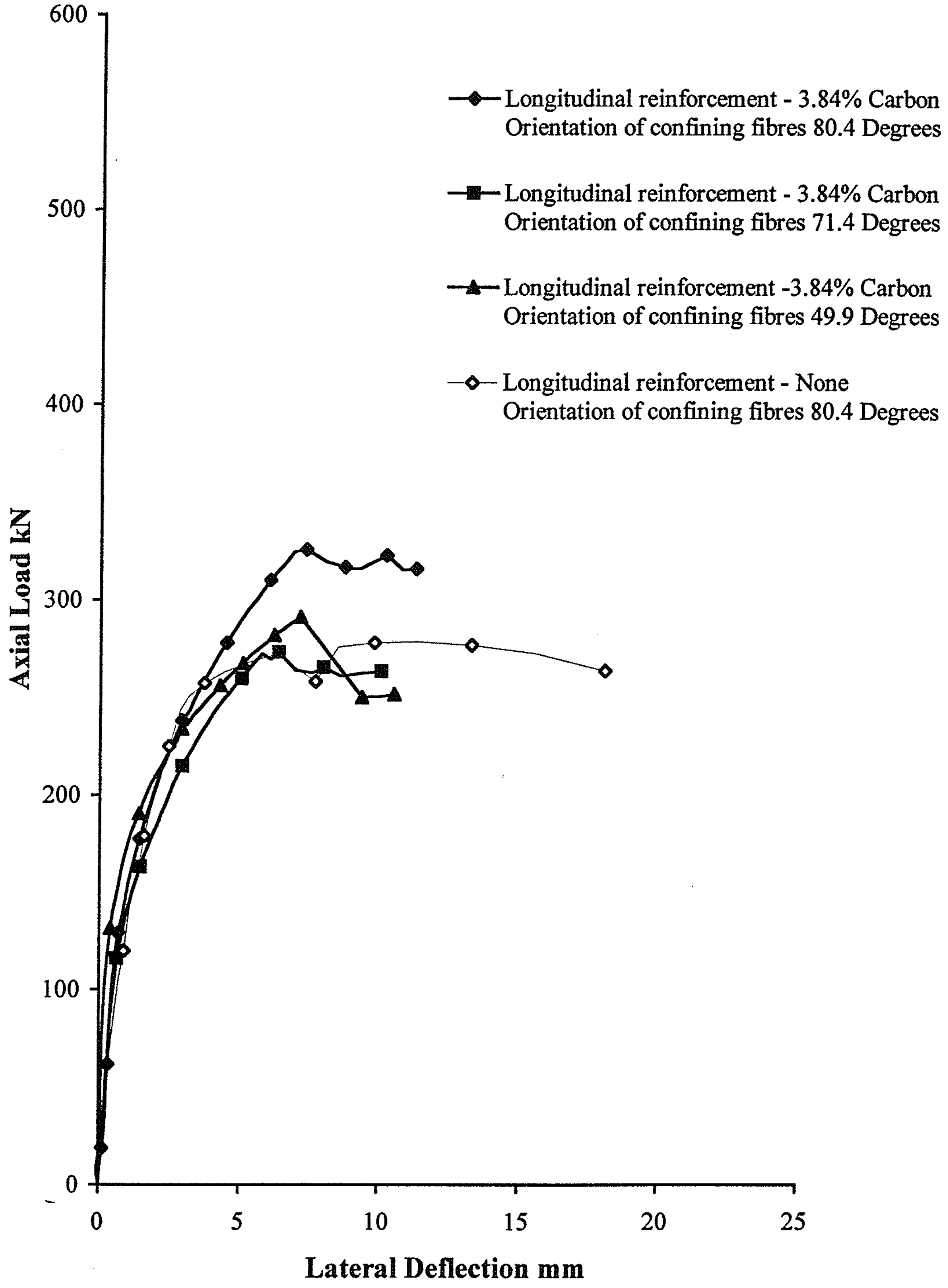



**Figure J.4.** Load-deflection curves for the 100 mm diameter concrete-filled E-glass FRP-composite columns with longitudinal carbon FRP-composite bars (slenderness ratio = 10)

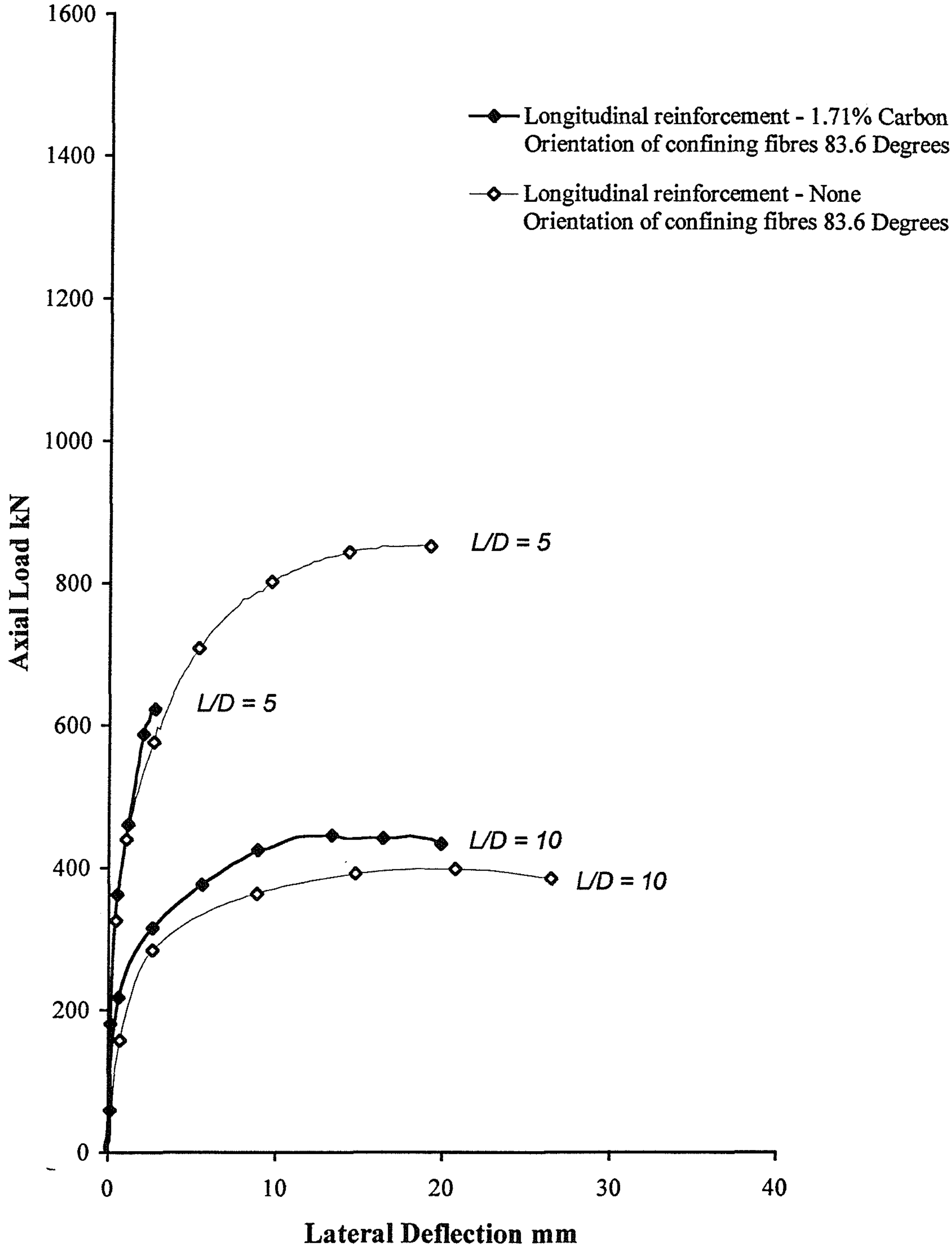



**Figure J.5.** Load-deflection curves for the 150 mm diameter concrete-filled E-glass FRP-composite columns with longitudinal carbon FRP-composite bars

# APPENDIX K

## EXPERIMENTAL LOAD-DEFECTION CURVES FOR CONCRETE-FILLED E-GLASS FRP-COMPOSITE COLUMNS REINFORCED LONGITUDINALLY WITH E-GLASS FRP-COMPOSITE BARS

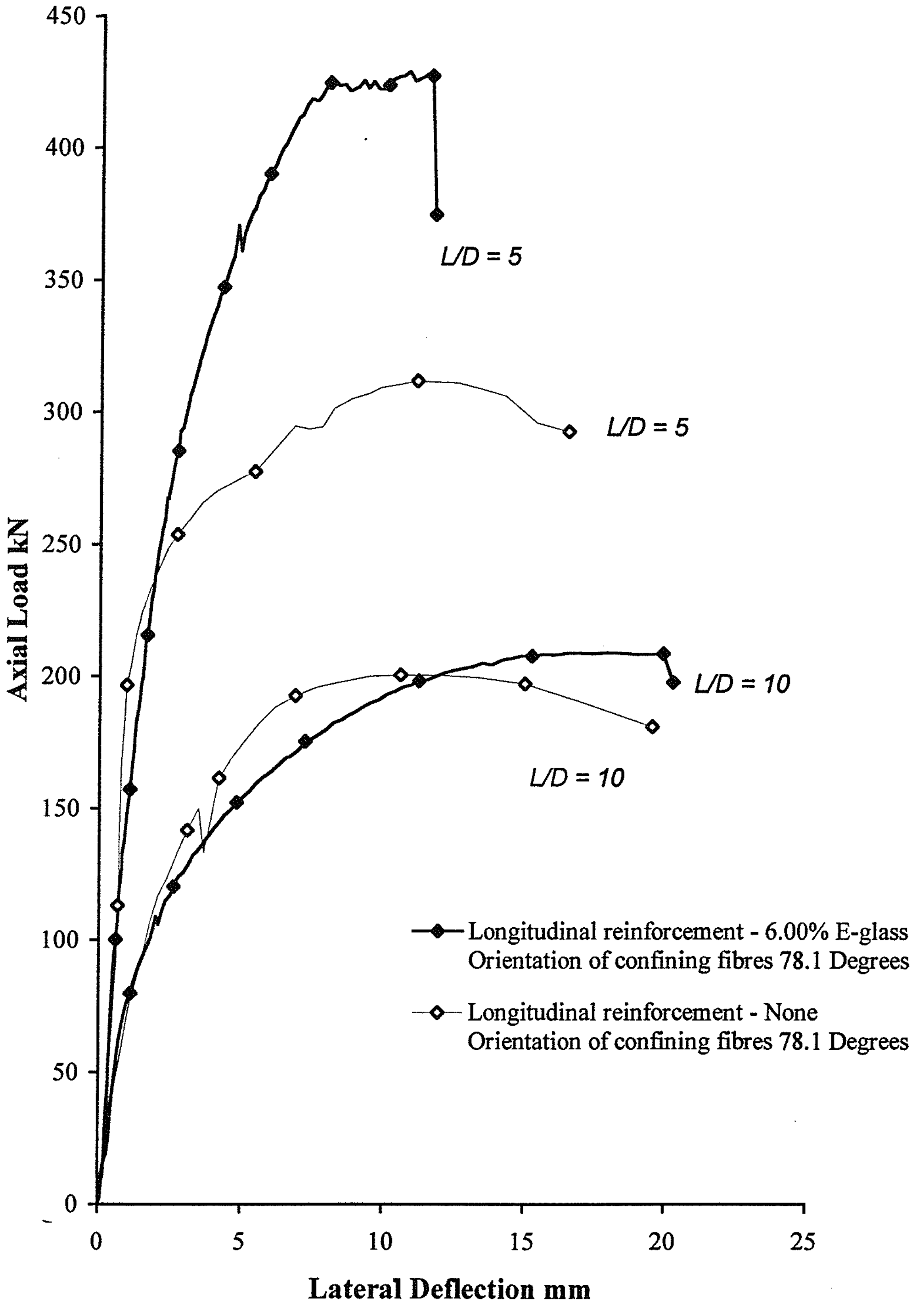



**Figure K.1.** Load-deflection curves for the 80 mm diameter concrete-filled E-glass FRP-composite columns with longitudinal E-glass FRP-composite bars

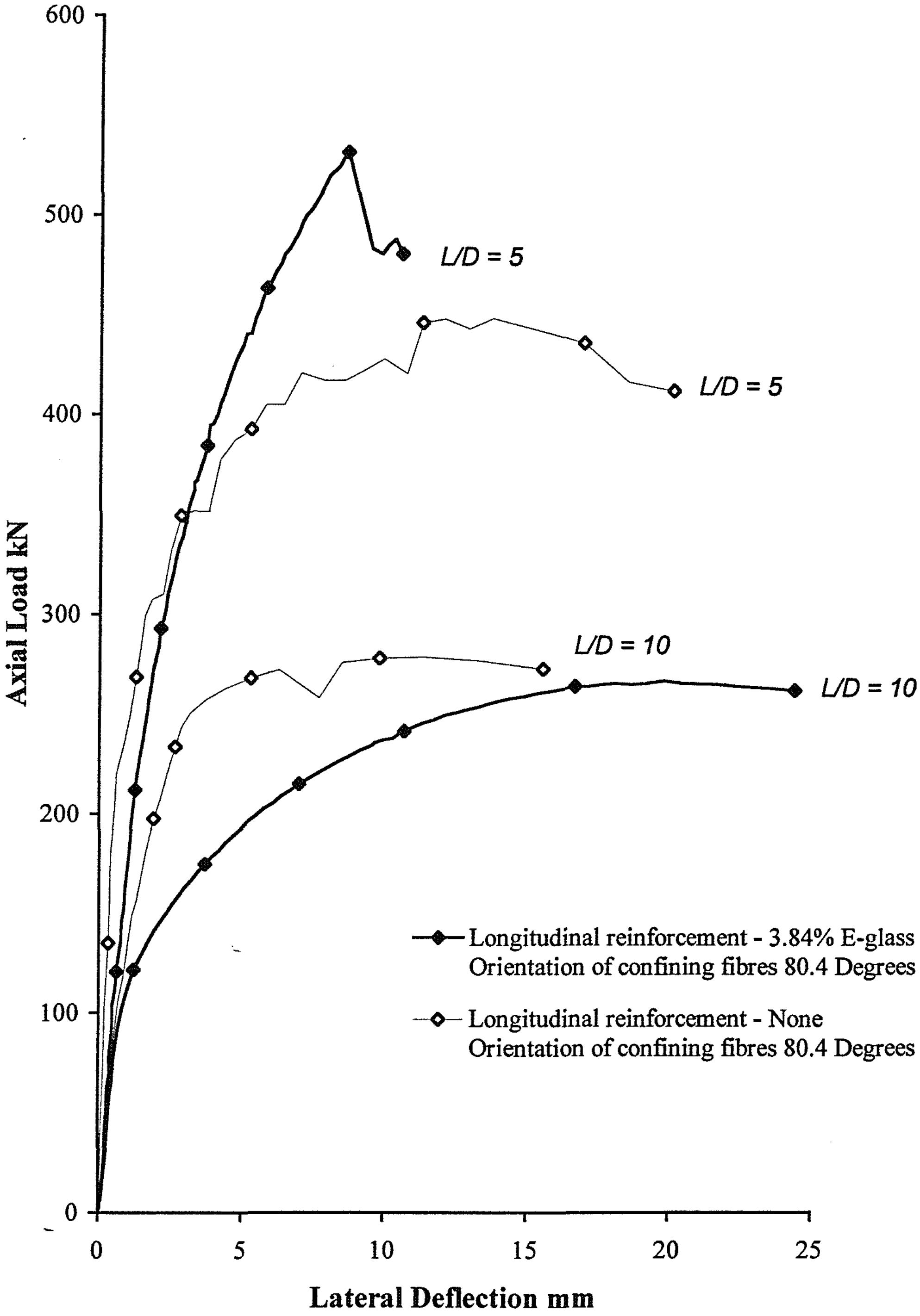



**Figure K.2.** Load-deflection curves for the 100 mm diameter concrete-filled E-glass FRP-composite columns with longitudinal E-glass FRP-composite bars

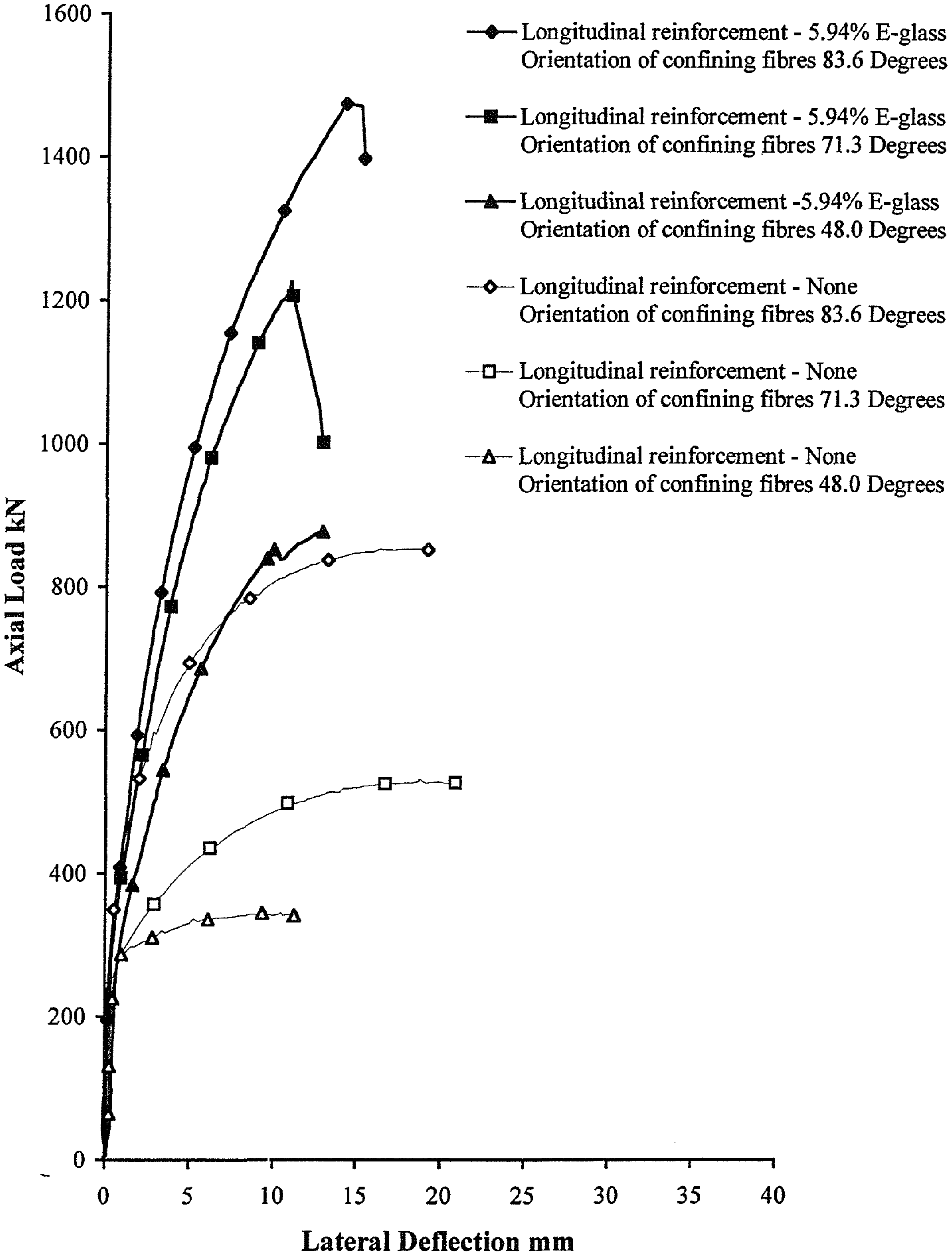



**Figure K.3.** Load-deflection curves for the 150 mm diameter concrete-filled E-glass FRP-composite columns with longitudinal E-glass FRP-composite bars and a slenderness ratio of 5 (nominal concrete cube strength = 25 N/mm$^2$)

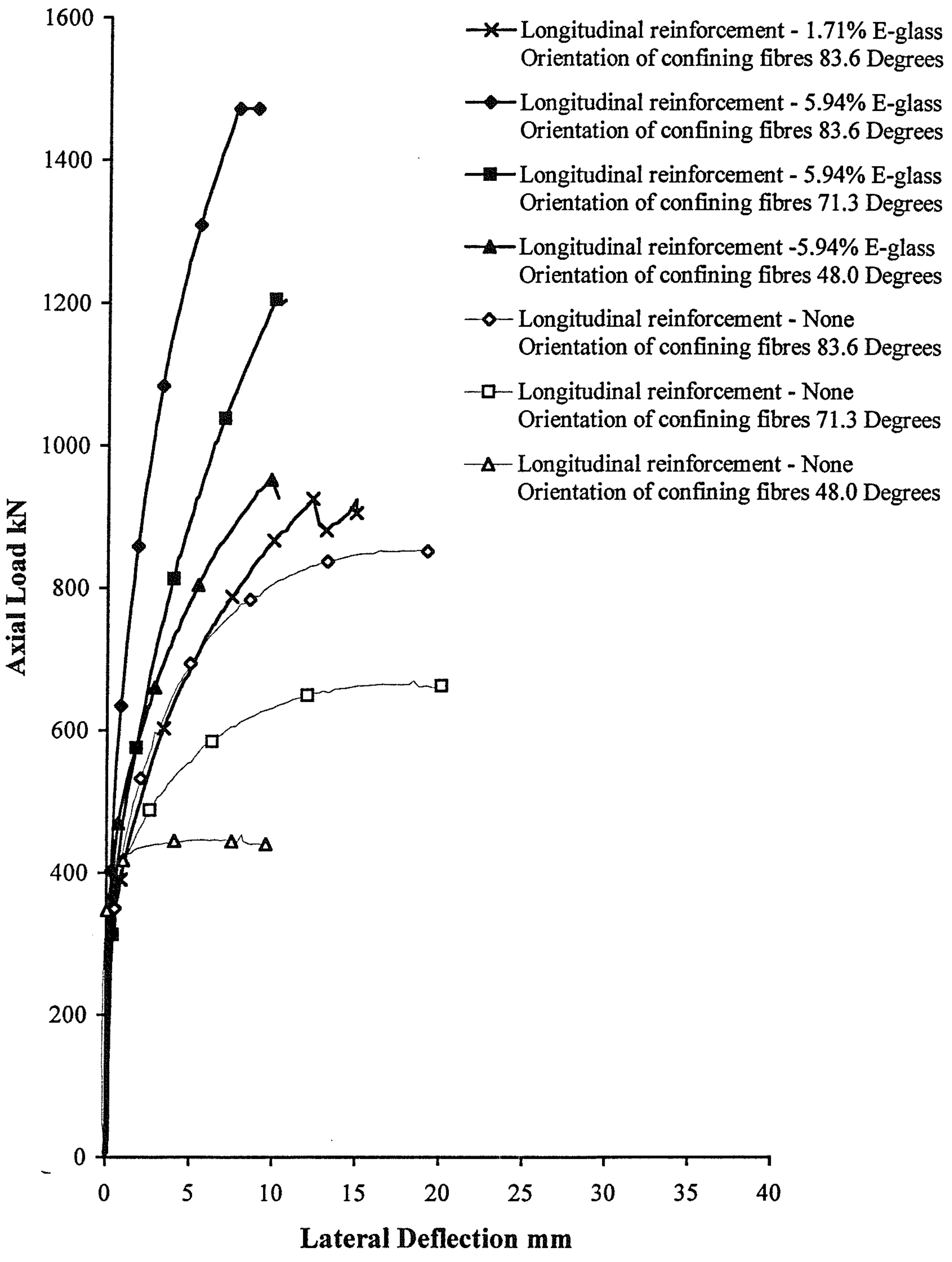



**Figure K.4.** Load-deflection curves for the 150 mm diameter concrete-filled E-glass FRP-composite columns with longitudinal E-glass FRP-composite bars and a slenderness ratio of 5 (nominal concrete cube strength = 35 $N/mm^2$)

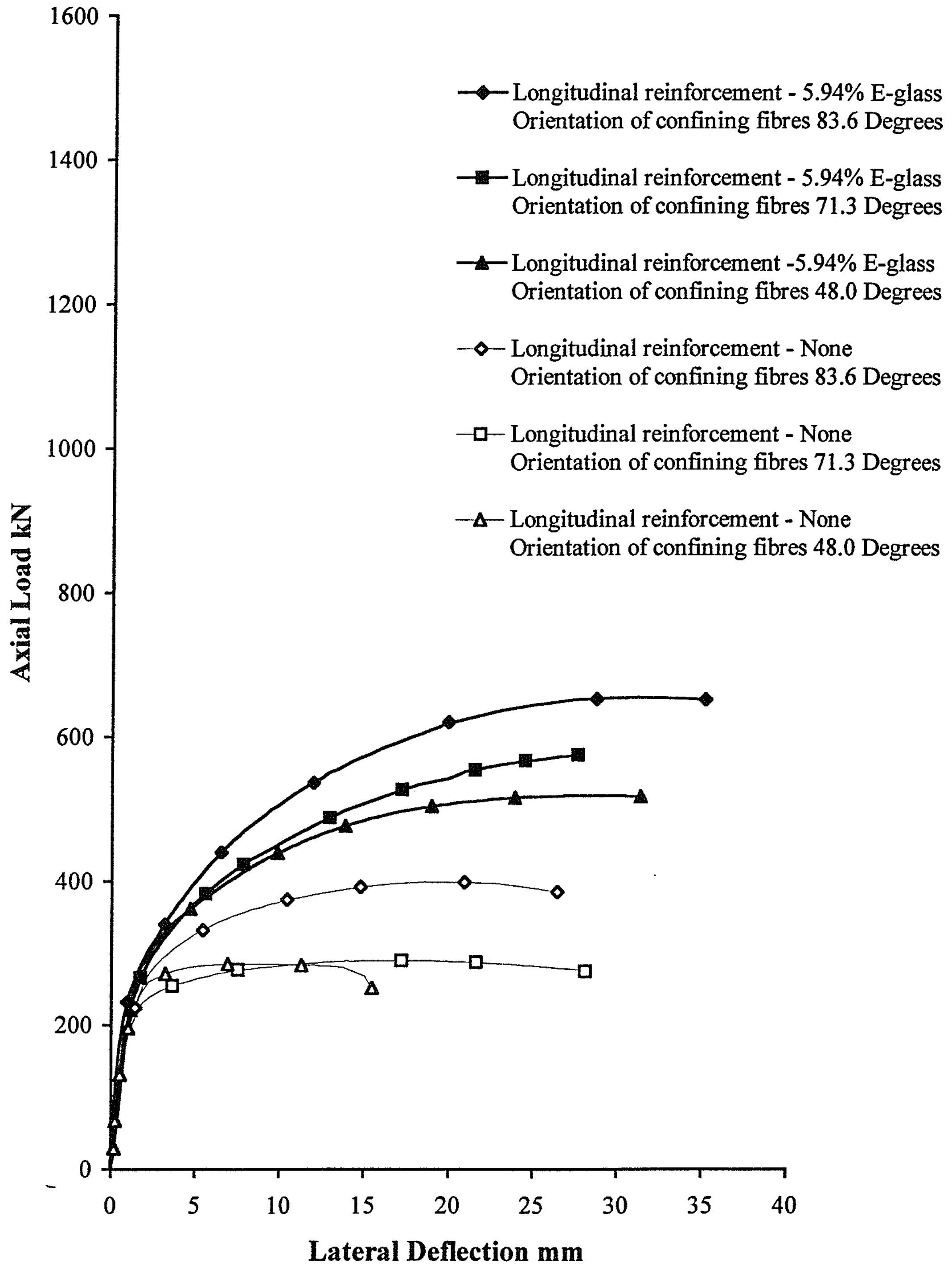



**Figure K.5.** Load-deflection curves for the 150 mm diameter concrete-filled E-glass FRP-composite columns with longitudinal E-glass FRP-composite bars and a slenderness ratio of 10 (nominal concrete cube strength = 25 $N/mm^2$)

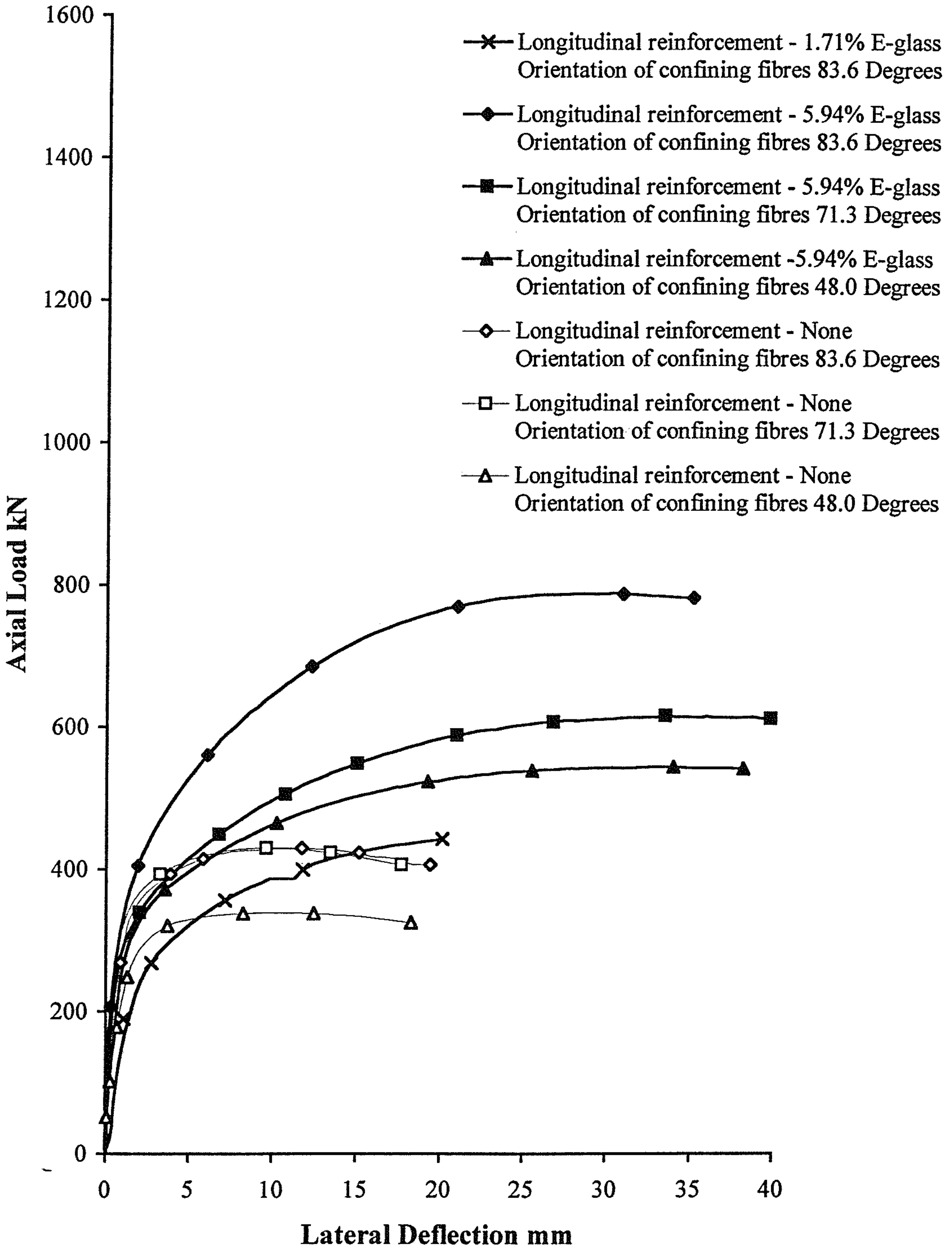



**Figure K.6.** Load-deflection curves for the 150 mm diameter concrete-filled E-glass FRP-composite columns with longitudinal E-glass FRP-composite bars and a slenderness ratio of 10 (nominal concrete cube strength = 35 N/mm$^2$)

APPENDIX L

# EXPERIMENTAL MOMENT-CURVATURE RELATIONSHIPS FOR CONCRETE-FILLED E-GLASS FRP-COMPOSITE COLUMNS REINFORCED LONGITUDINALLY WITH FRP-COMPOSITE BARS

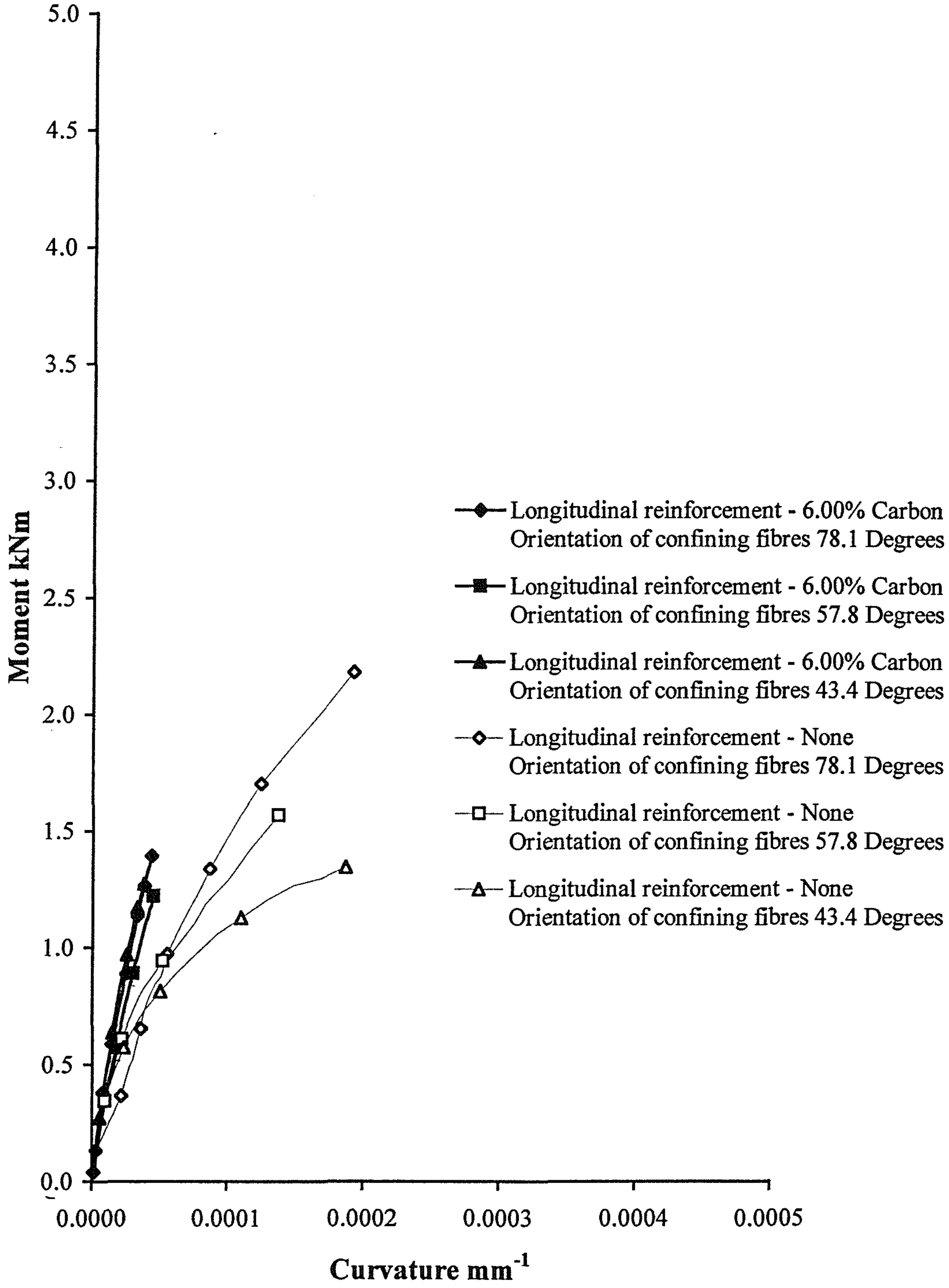



**Figure L.1.** Moment-curvature relationships for the 80 mm diameter concrete-filled E-glass FRP-composite columns, reinforced longitudinally with carbon FRP-composite bars (slenderness ratio = 5)

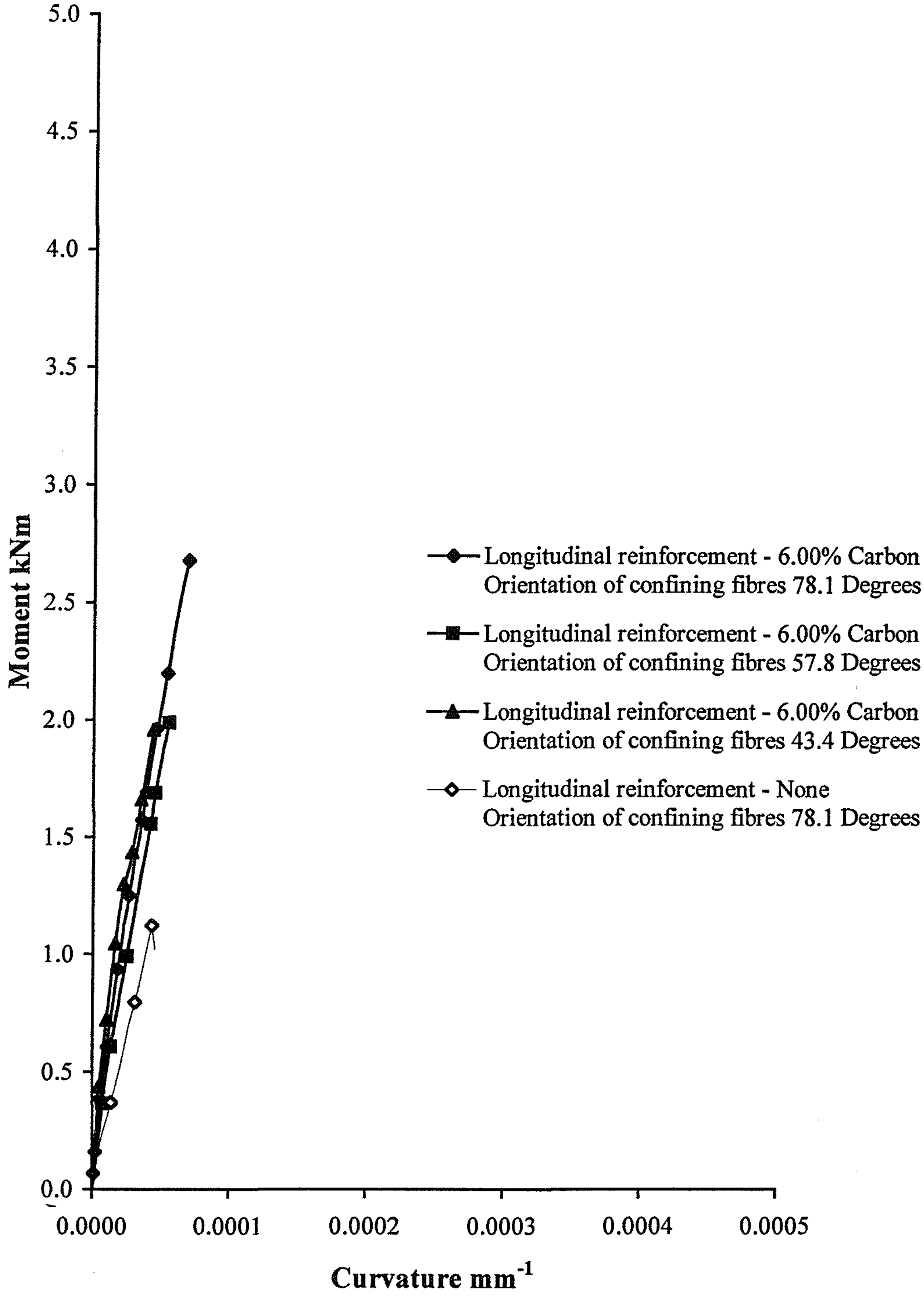



**Figure L.2.** Moment-curvature relationships for the 80 mm diameter concrete-filled E-glass FRP-composite columns, reinforced longitudinally with carbon FRP-composite bars (slenderness ratio = 10)

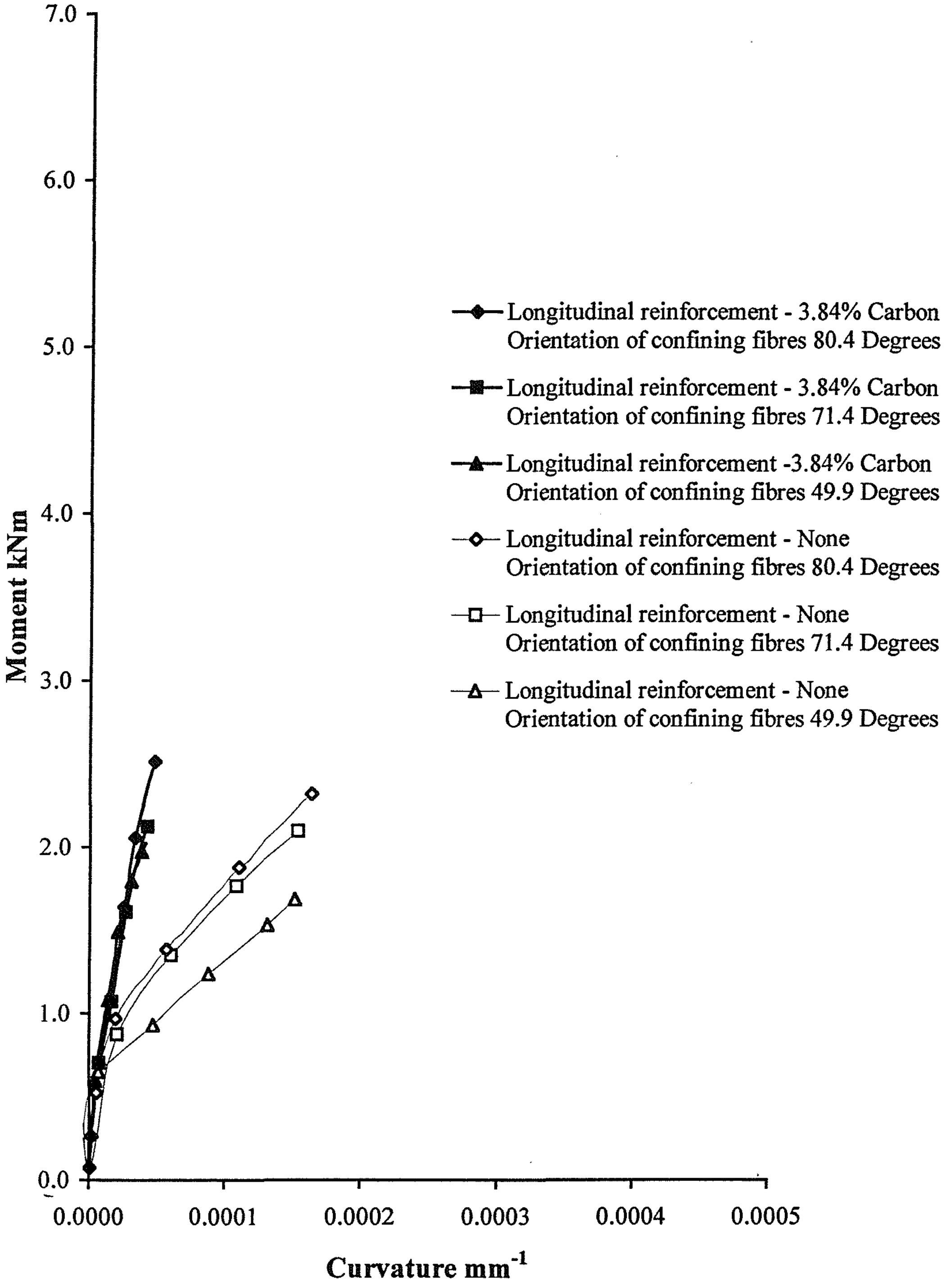



**Figure L.3.** Moment-curvature relationships for the 100 mm diameter concrete-filled E-glass FRP-composite columns, reinforced longitudinally with carbon FRP-composite bars (slenderness ratio = 5)

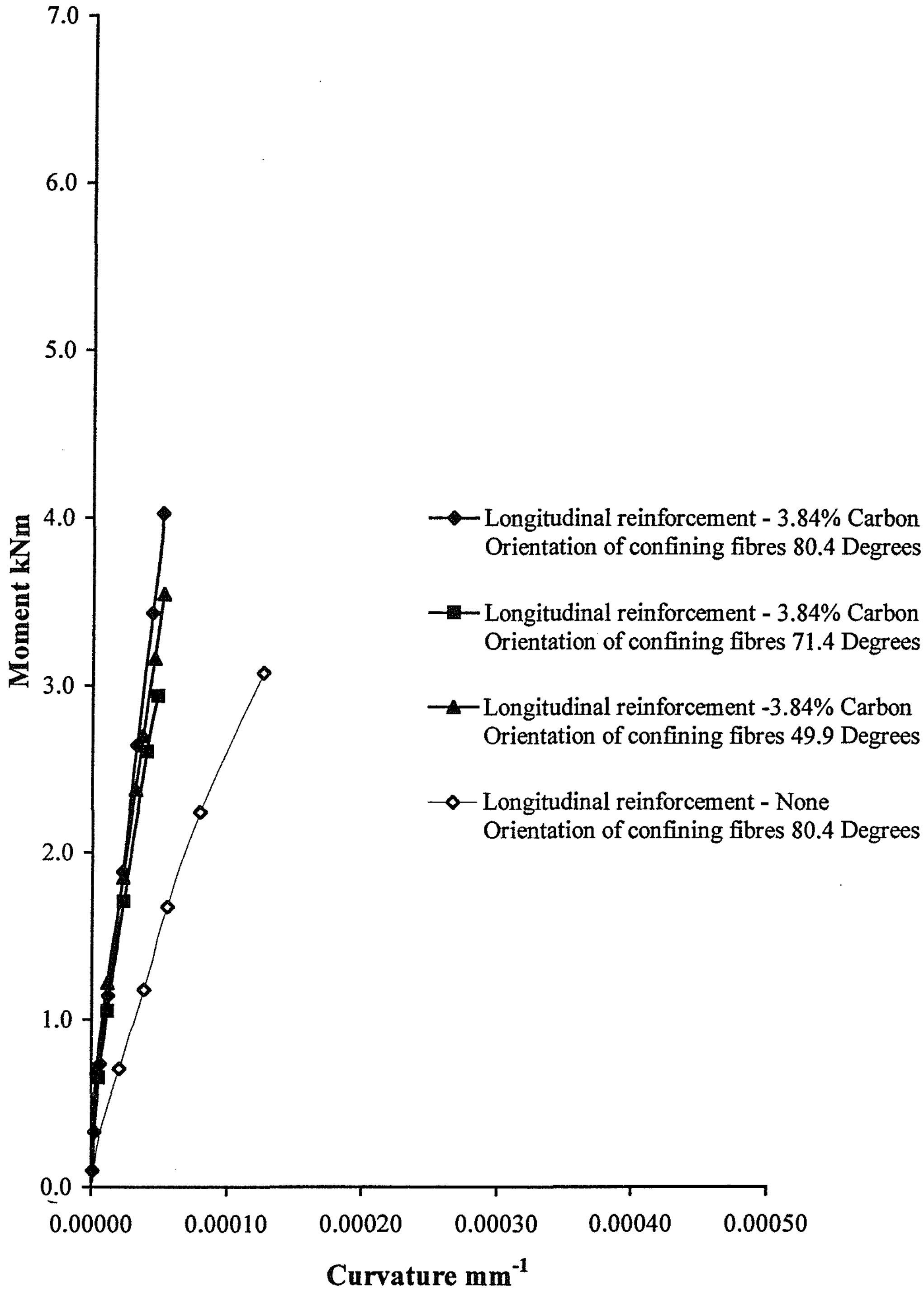



**Figure L.4.** Moment-curvature relationships for the 100 mm diameter concrete-filled E-glass FRP-composite columns, reinforced longitudinally with carbon FRP-composite bars (slenderness ratio = 10)

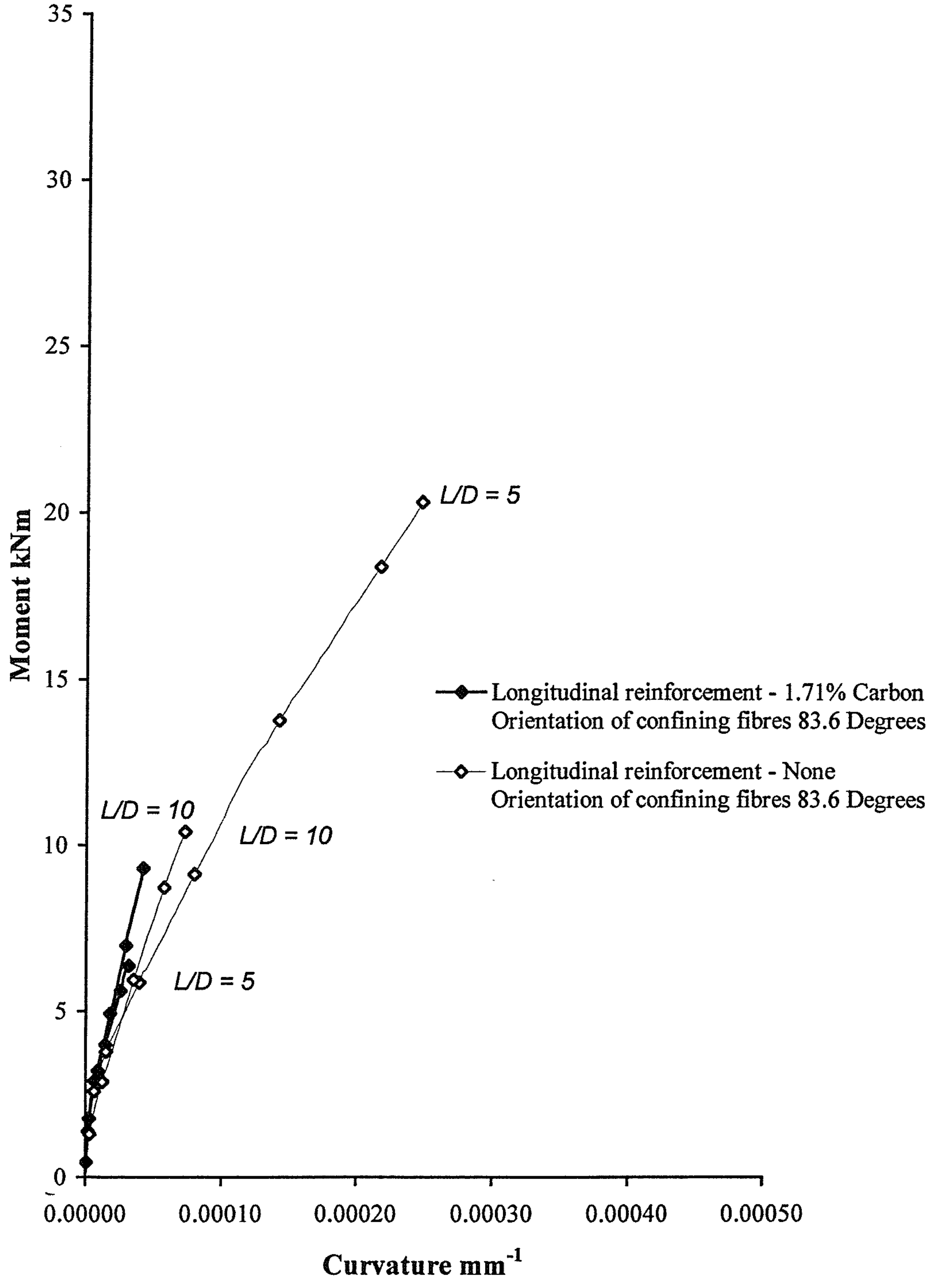



**Figure L.5.** Moment-curvature relationships for the 150 mm diameter concrete-filled E-glass FRP-composite columns, reinforced longitudinally with carbon FRP-composite bars

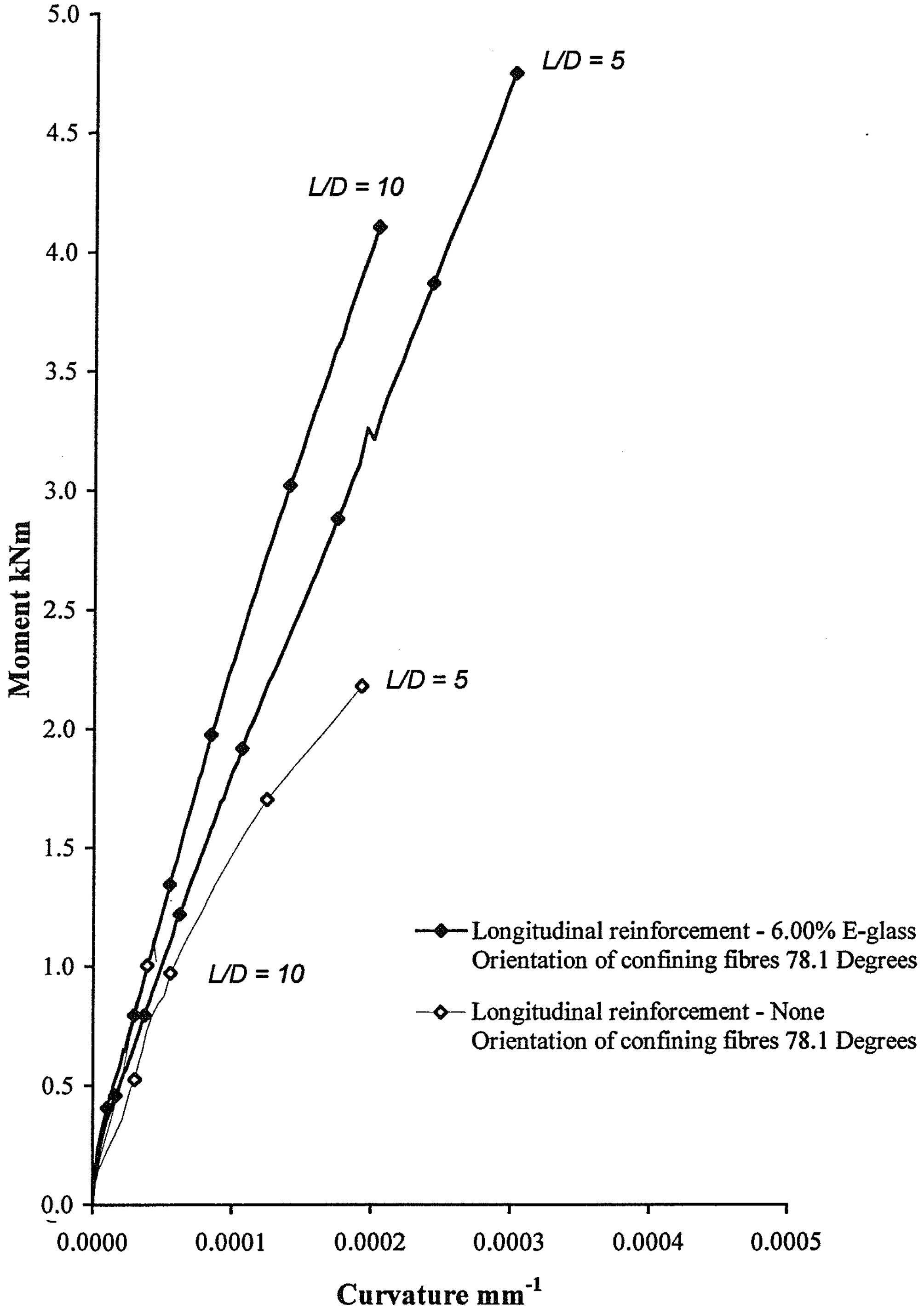



**Figure L.6.** Moment-curvature relationships for the 80 mm diameter concrete-filled E-glass FRP-composite columns, reinforced longitudinally with E-glass FRP-composite bars

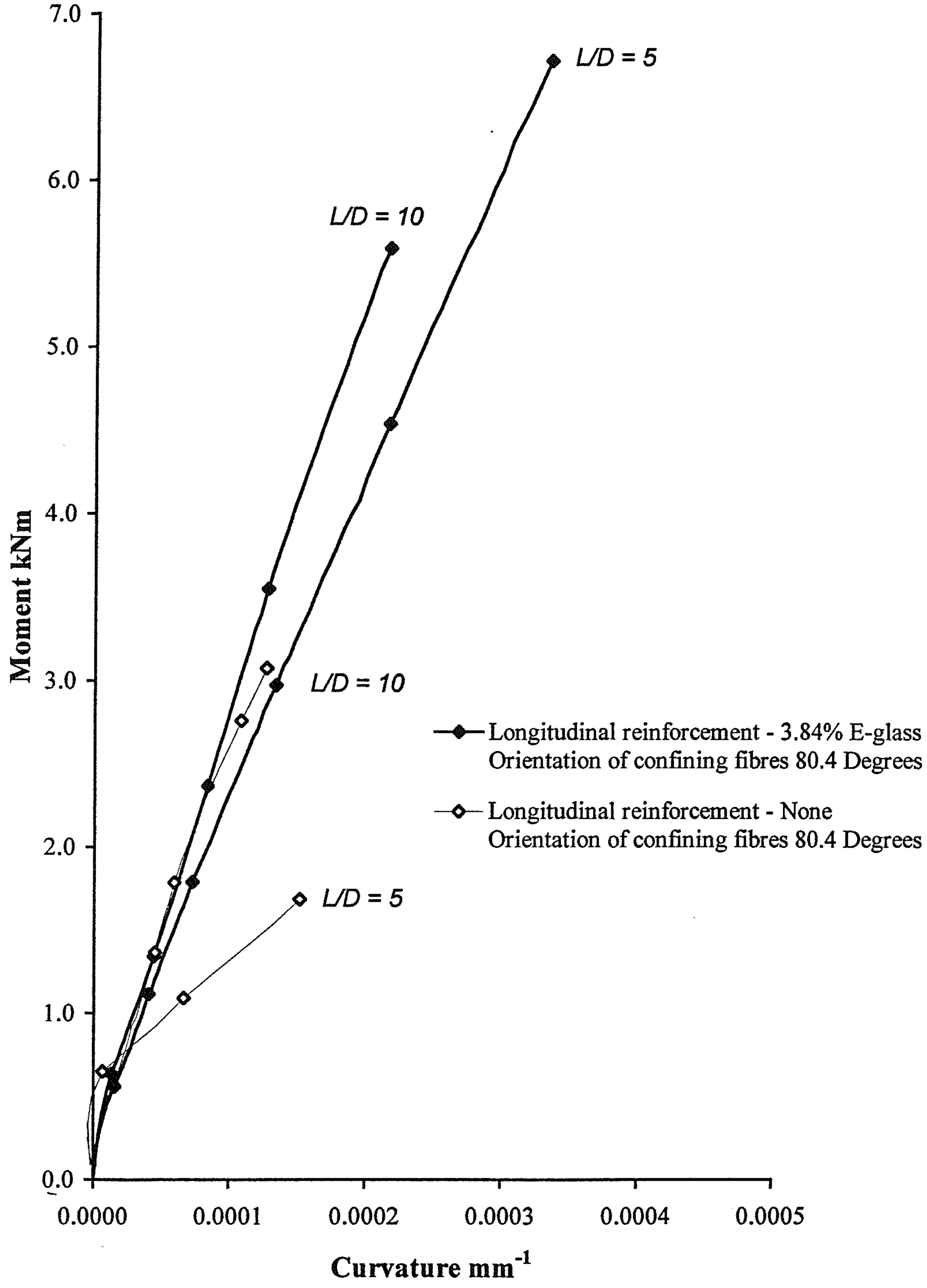



**Figure L.7.** Moment-curvature relationships for the 100 mm diameter concrete-filled E-glass FRP-composite columns, reinforced longitudinally with E-glass FRP-composite bars

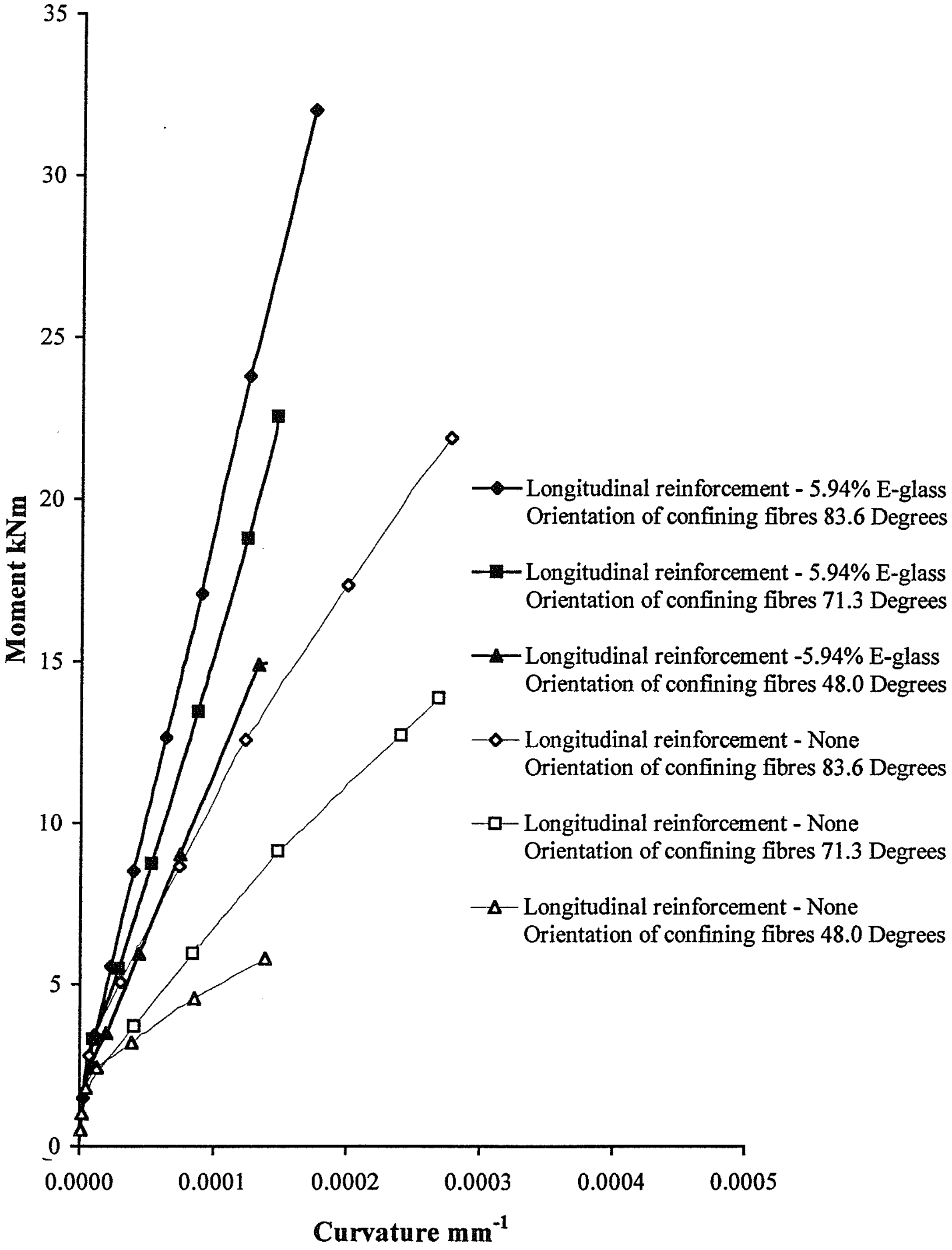



**Figure L.8.** Moment-curvature relationships for the 150 mm diameter concrete-filled E-glass FRP-composite columns, reinforced longitudinally with E-glass FRP-composite bars and a slenderness ratio of 5 (nominal concrete cube strength = 25 $N/mm^2$)

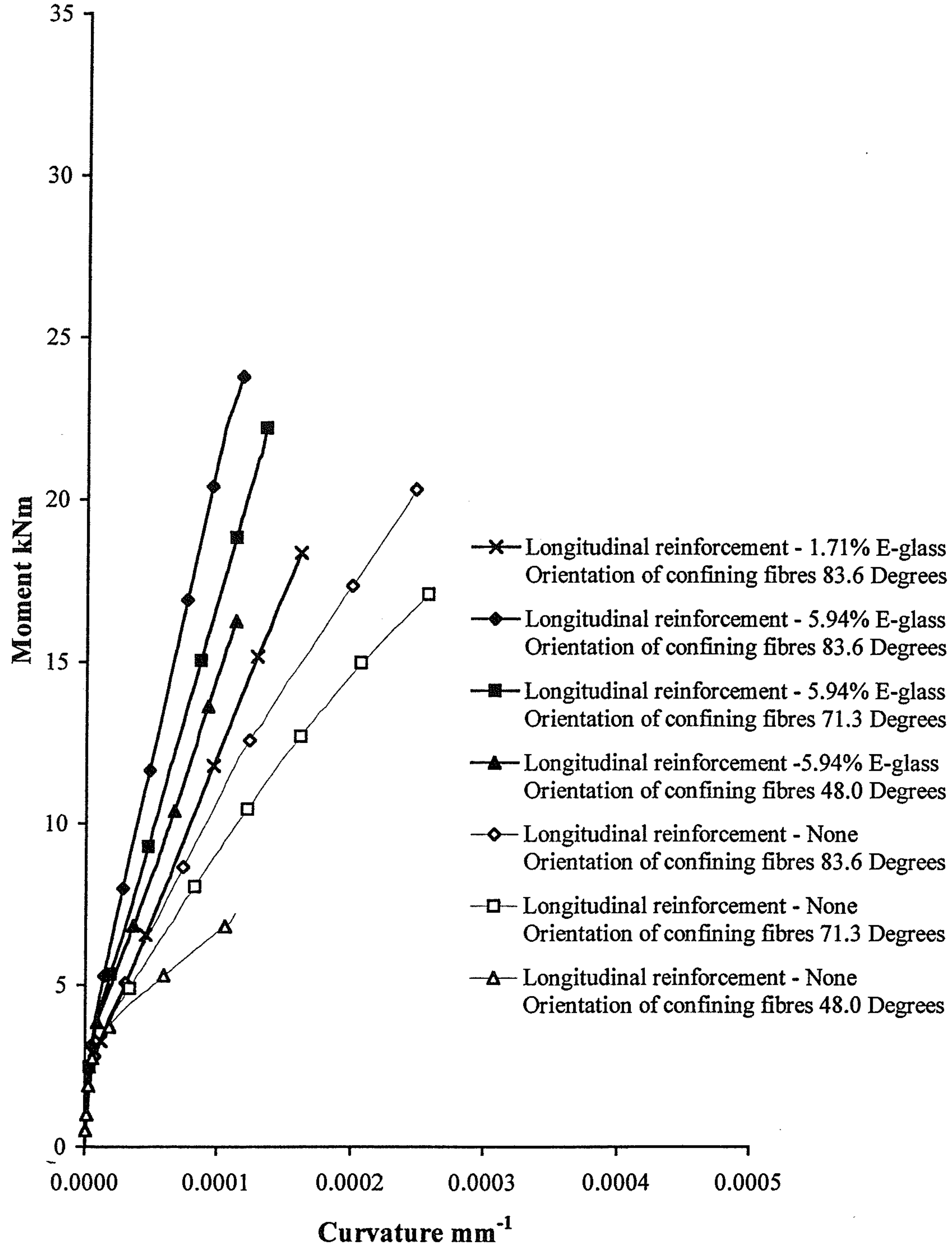



**Figure L.9.** Moment-curvature relationships for the 150 mm diameter concrete-filled E-glass FRP-composite columns, reinforced longitudinally with E-glass FRP-composite bars and a slenderness ratio of 5 (nominal concrete cube strength = 35 N/mm$^2$)

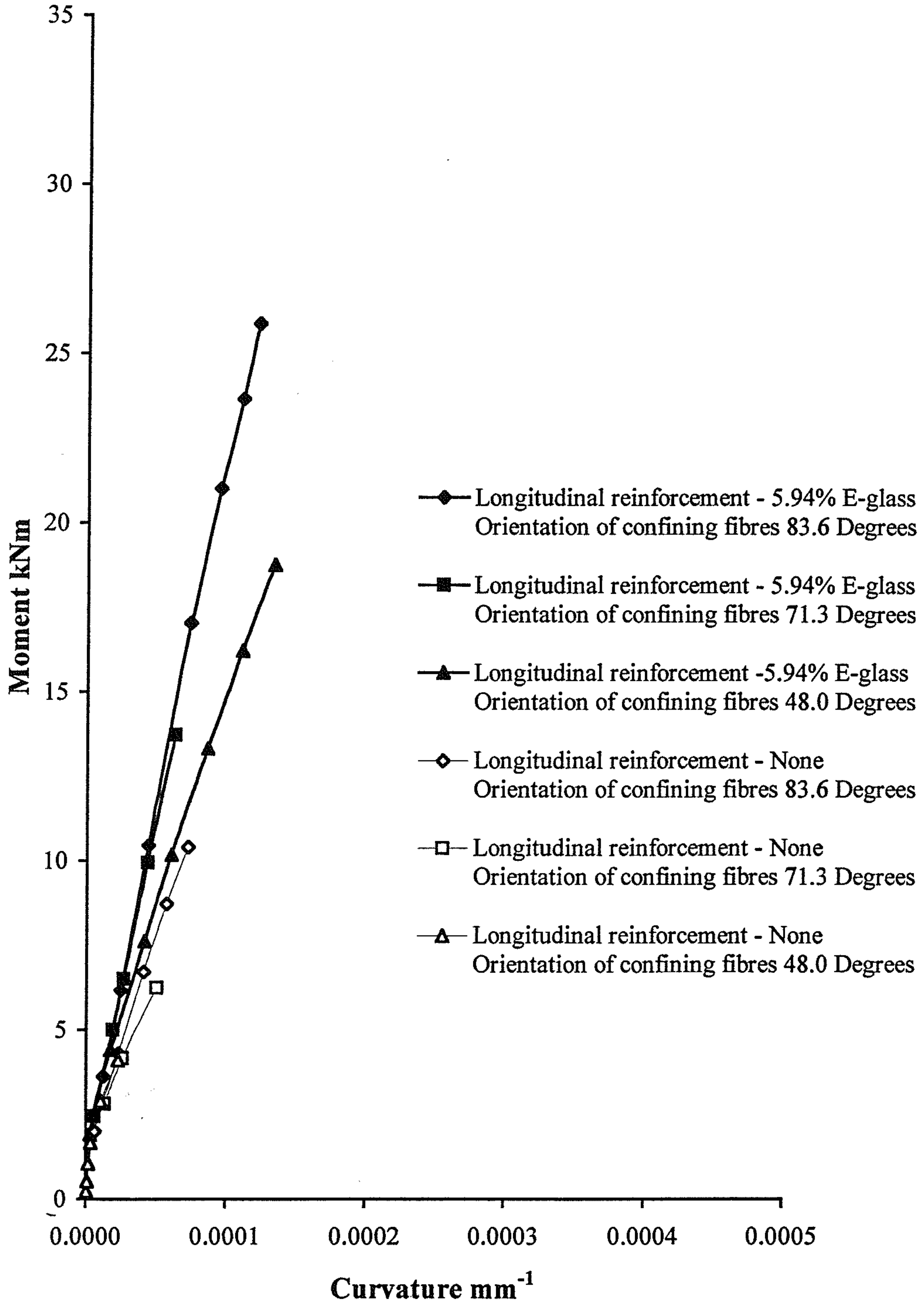



**Figure L.10.** Moment-curvature relationships for the 150 mm diameter concrete-filled E-glass FRP-composite columns, reinforced longitudinally with E-glass FRP-composite bars and a slenderness ratio of 10 (nominal concrete cube strength = 25 N/mm$^2$)

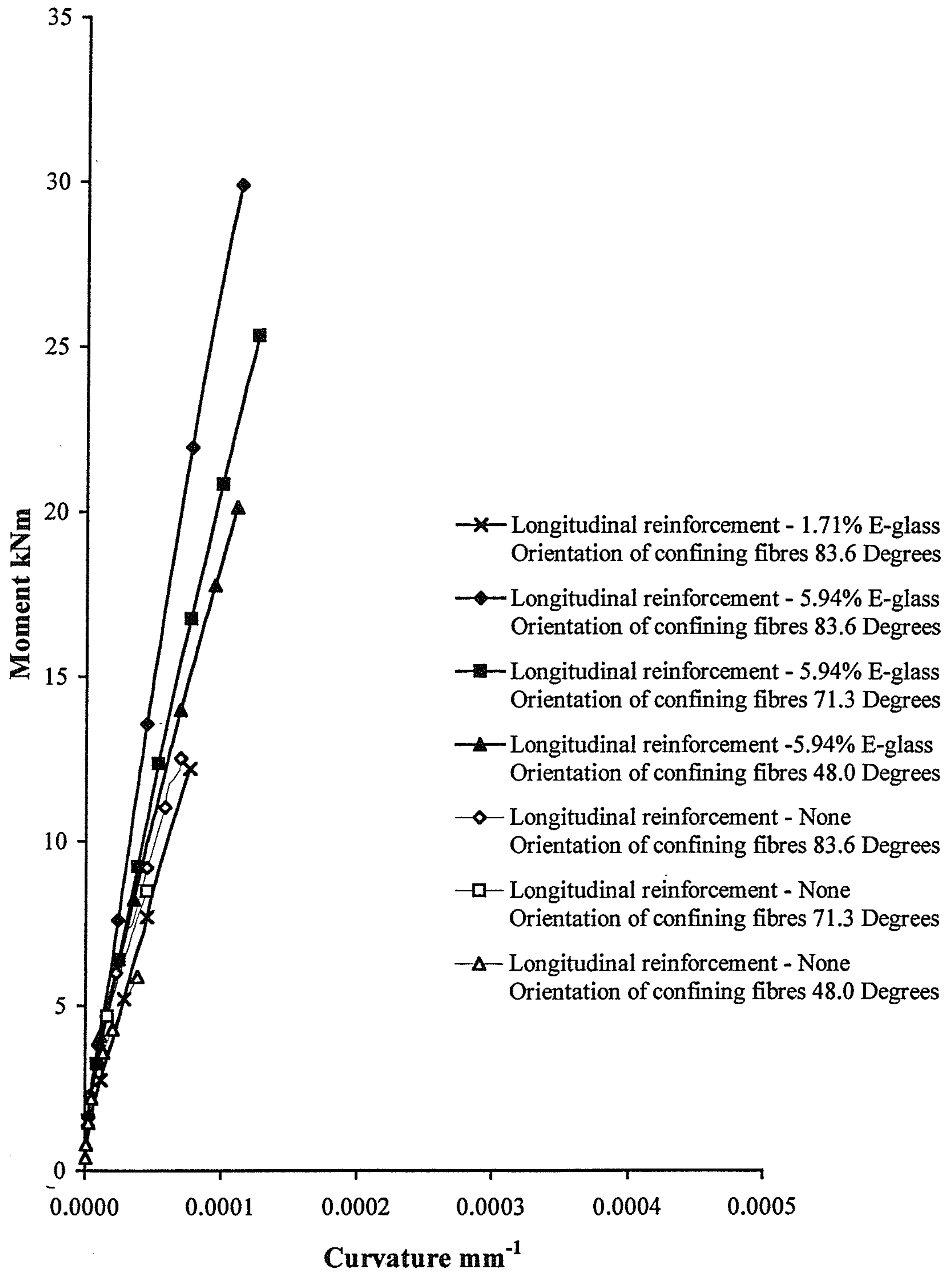



**Figure L.11.** Moment-curvature relationships for the 150 mm diameter concrete-filled E-glass FRP-composite columns, reinforced longitudinally with E-glass FRP-composite bars and a slenderness ratio of 10 (nominal concrete cube strength = 35 N/mm$^2$)

## APPENDIX M

# EXPERIMENTAL LOAD-STRAIN CURVES FOR CONCRETE-FILLED E-GLASS FRP-COMPOSITE COLUMNS REINFORCED LONGITUDINALLY WITH FRP-COMPOSITE BARS

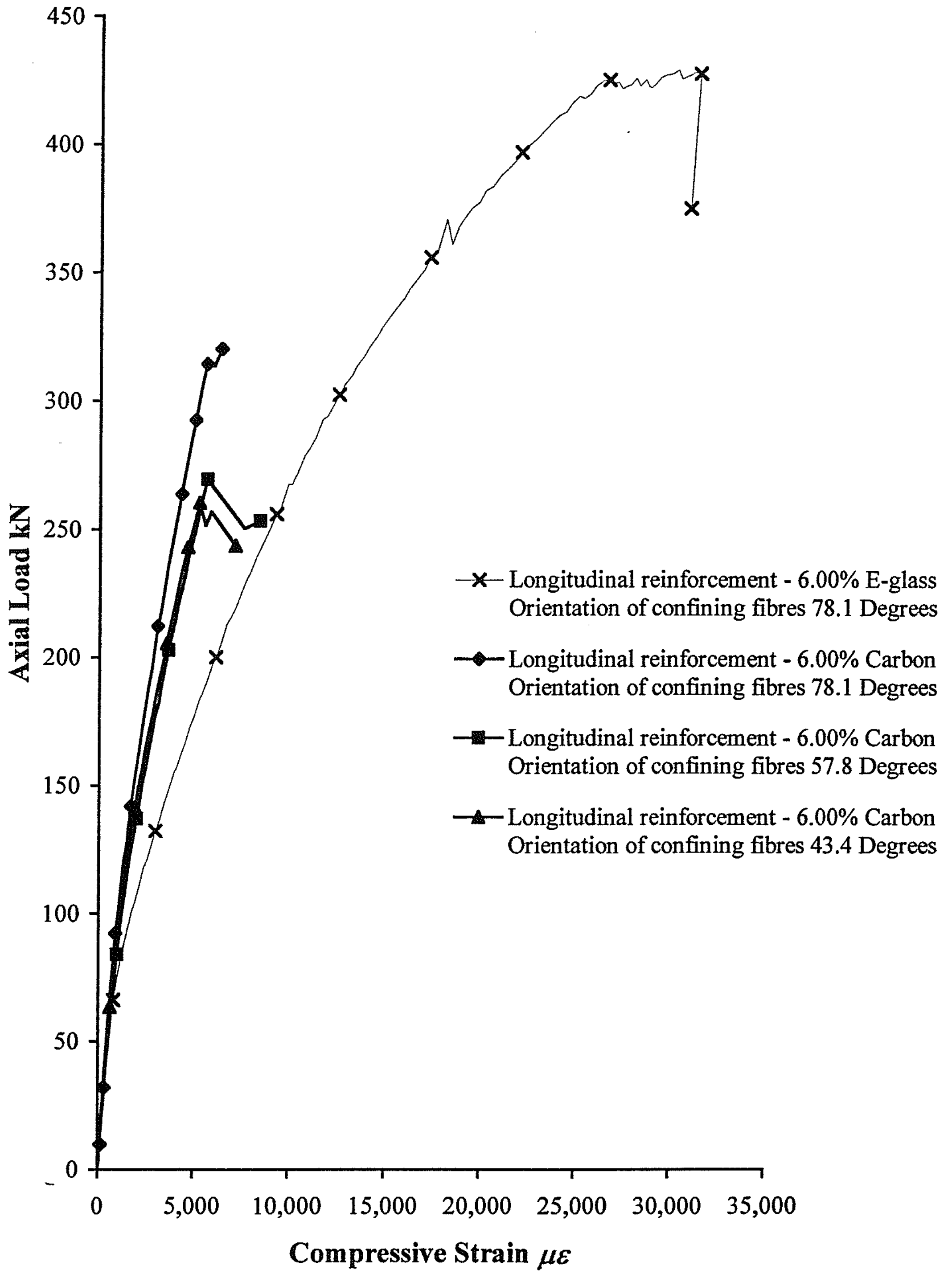



**Figure M.1.** Load-strain curves for the 80 mm diameter concrete-filled E-glass FRP-composite columns, reinforced longitudinally with FRP-composite bars (slenderness ratio = 5)

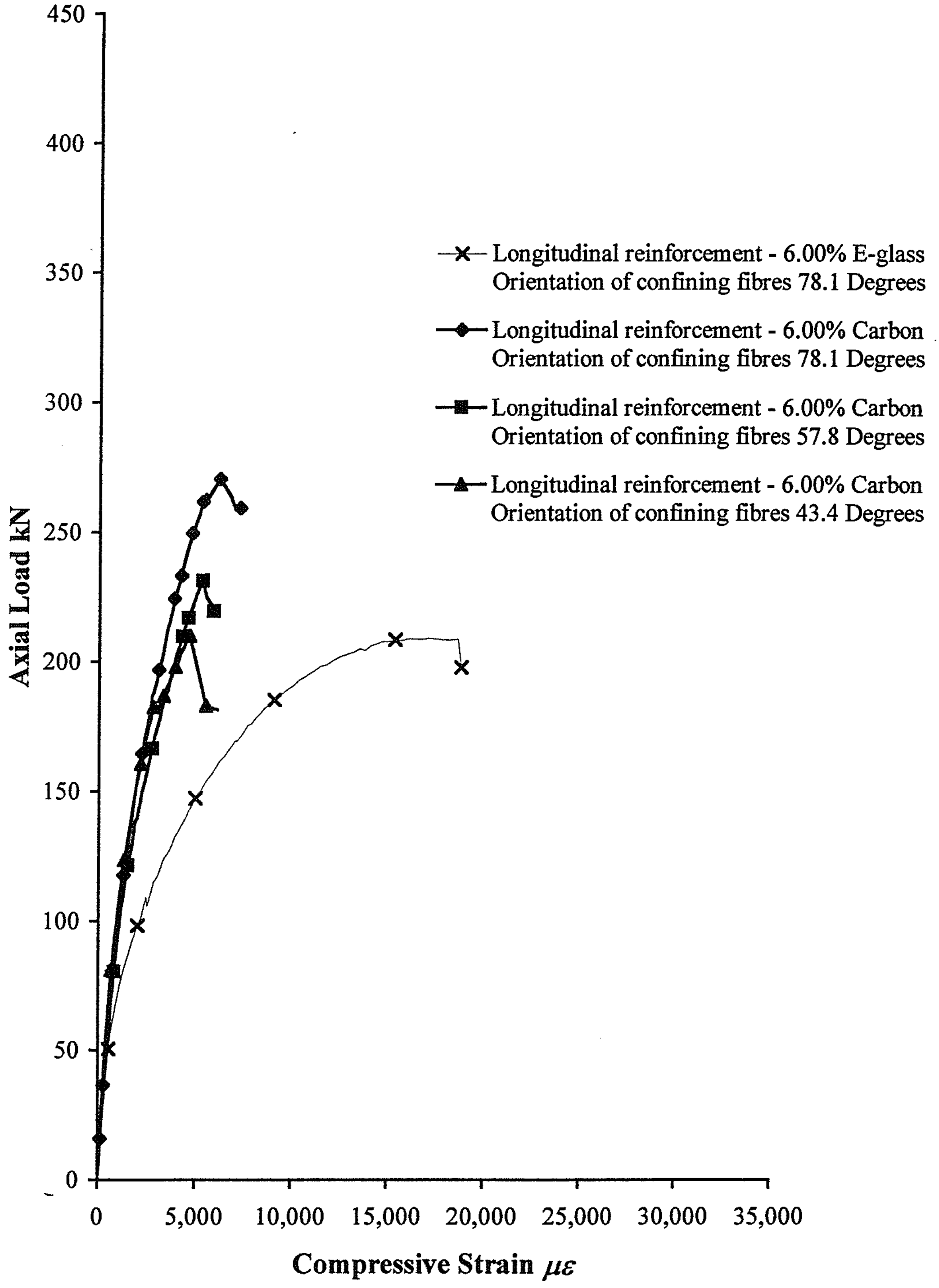



**Figure M.2.** Load-strain curves for the 80 mm diameter concrete-filled E-glass FRP-composite columns, reinforced longitudinally with FRP-composite bars (slenderness ratio = 10)

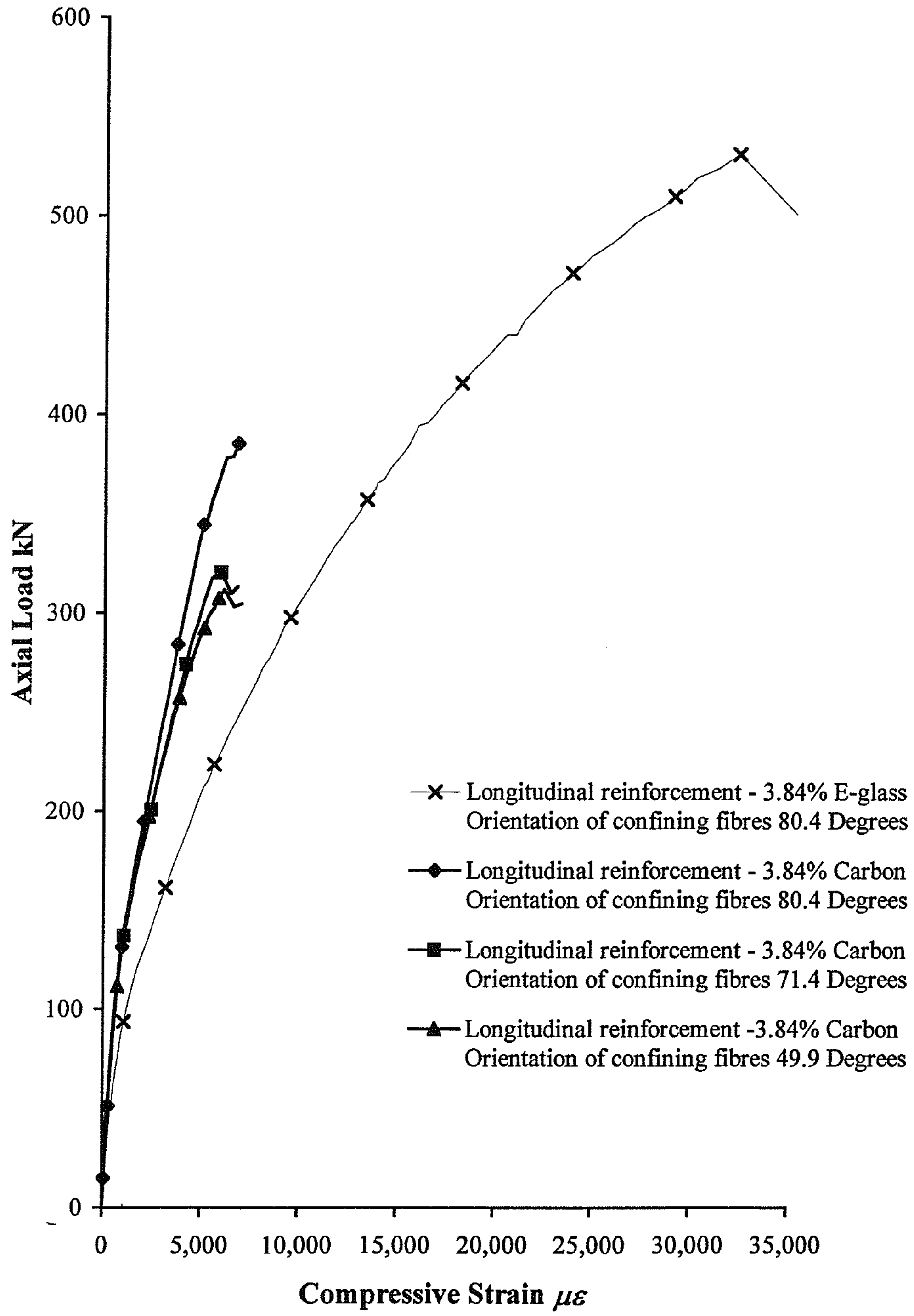



**Figure M.3.** Load-strain curves for the 100 mm diameter concrete-filled E-glass FRP-composite columns, reinforced longitudinally with FRP-composite bars (slenderness ratio = 5)

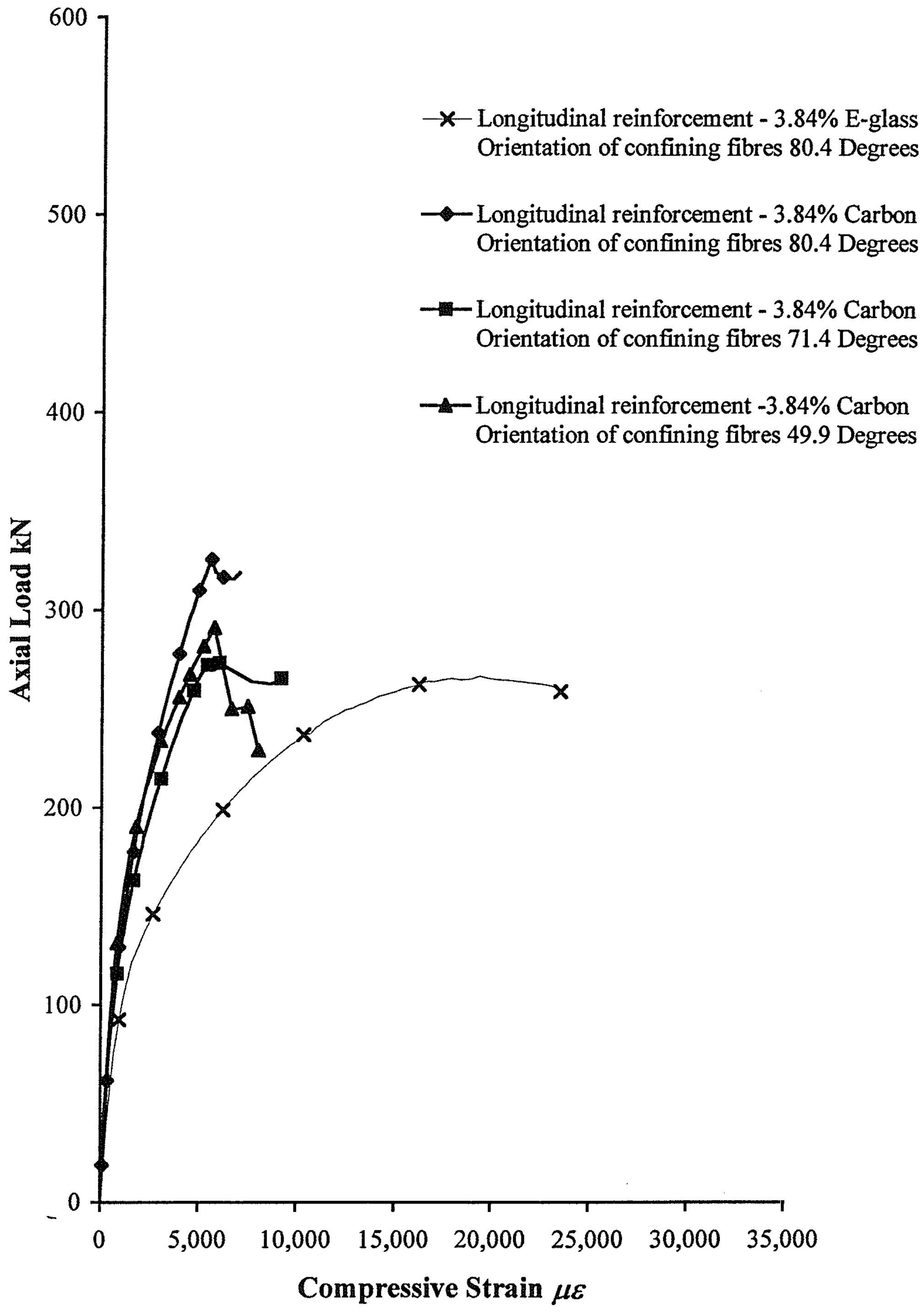



**Figure M.4.** Load-strain curves for the 100 mm diameter concrete-filled E-glass FRP-composite columns, reinforced longitudinally with FRP-composite bars (slenderness ratio = 10)

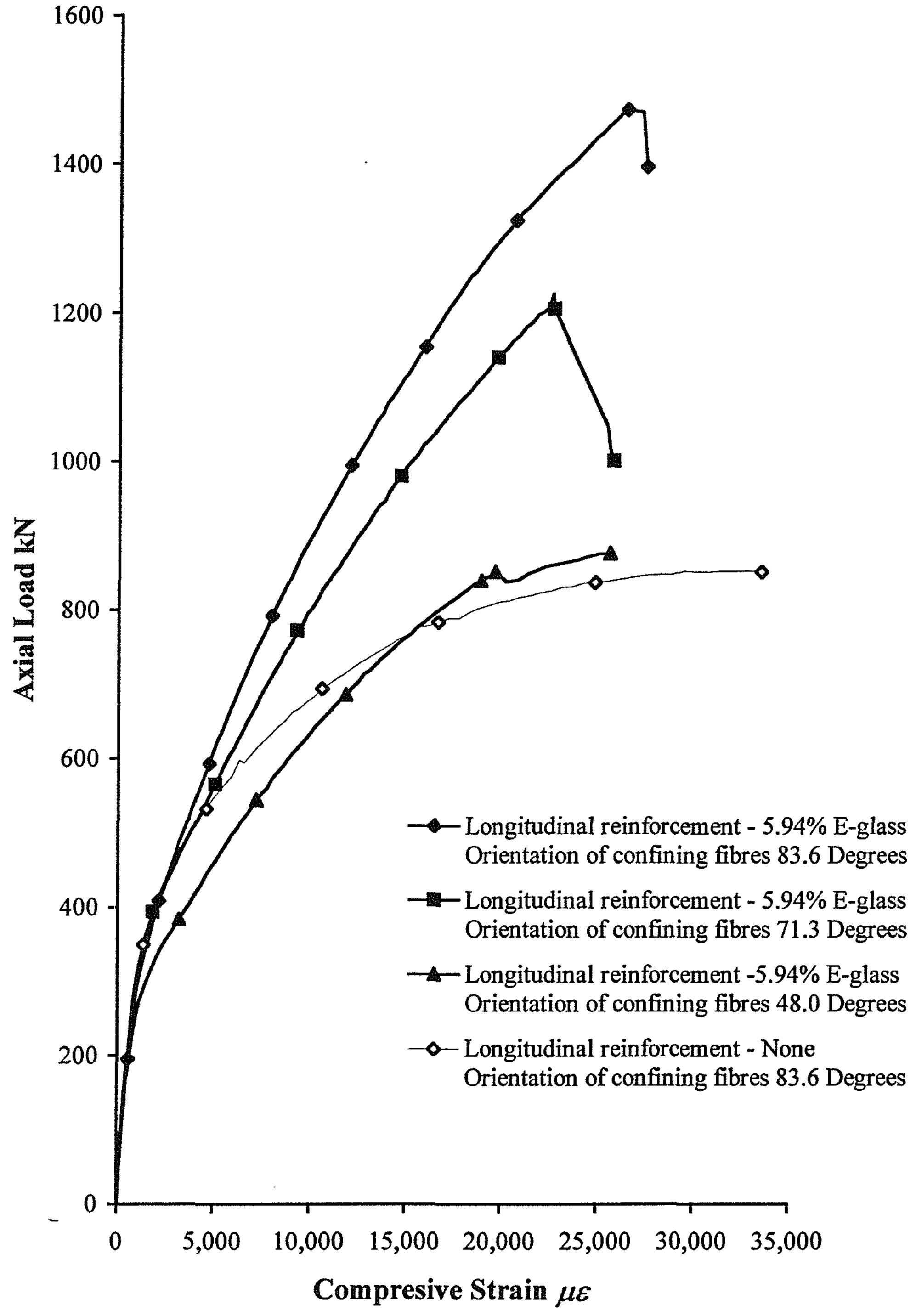



**Figure M.5.** Load-strain curves for the 150 mm diameter concrete-filled E-glass FRP-composite columns, reinforced longitudinally with FRP-composite bars and a slenderness ratio of 5 (nominal concrete cube strength = 25 N/mm$^2$)

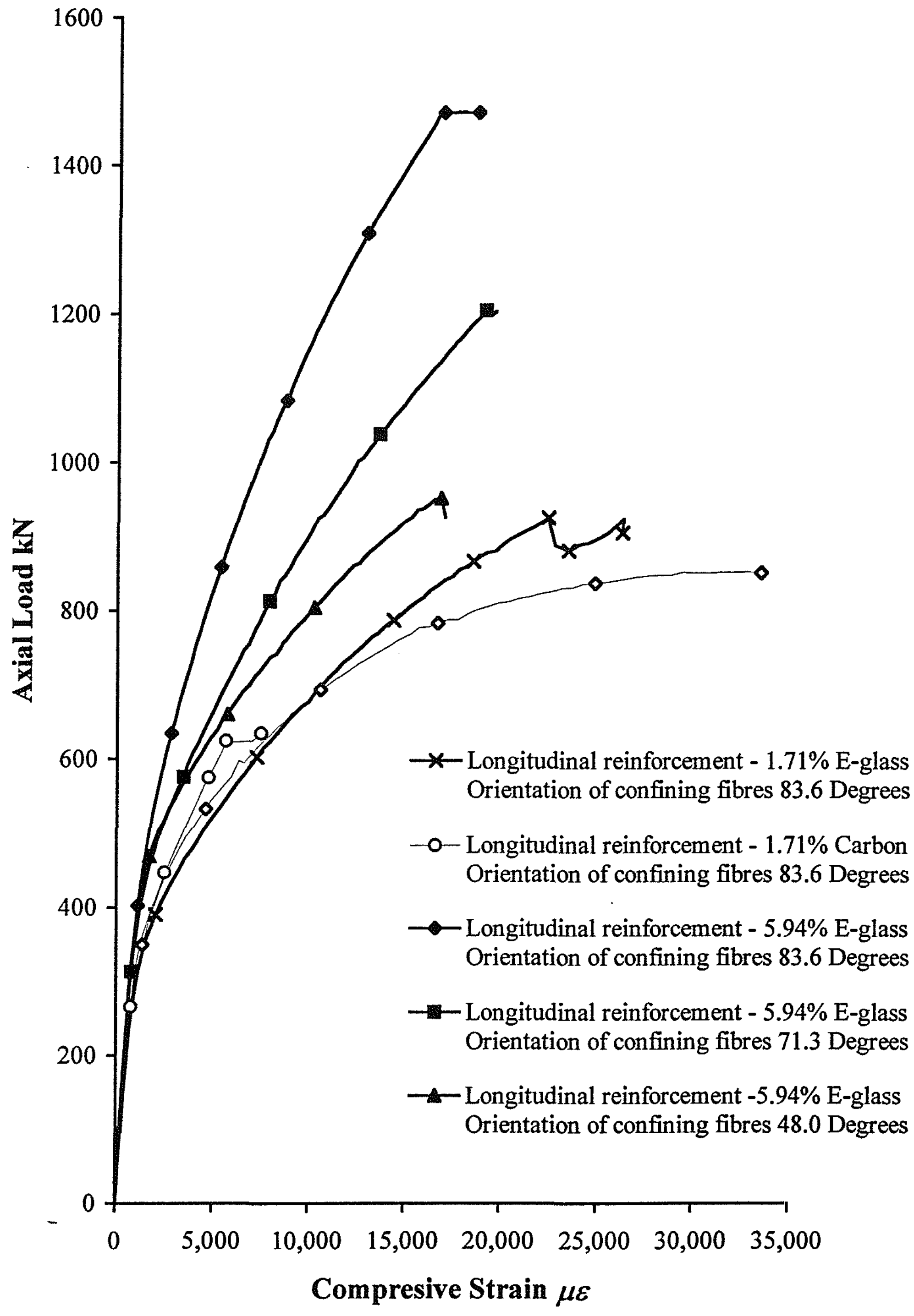



**Figure M.6.** Load-strain curves for the 150 mm diameter concrete-filled E-glass FRP-composite columns, reinforced longitudinally with FRP-composite bars and a slenderness ratio of 5 (nominal concrete cube strength = 35 N/mm$^2$)

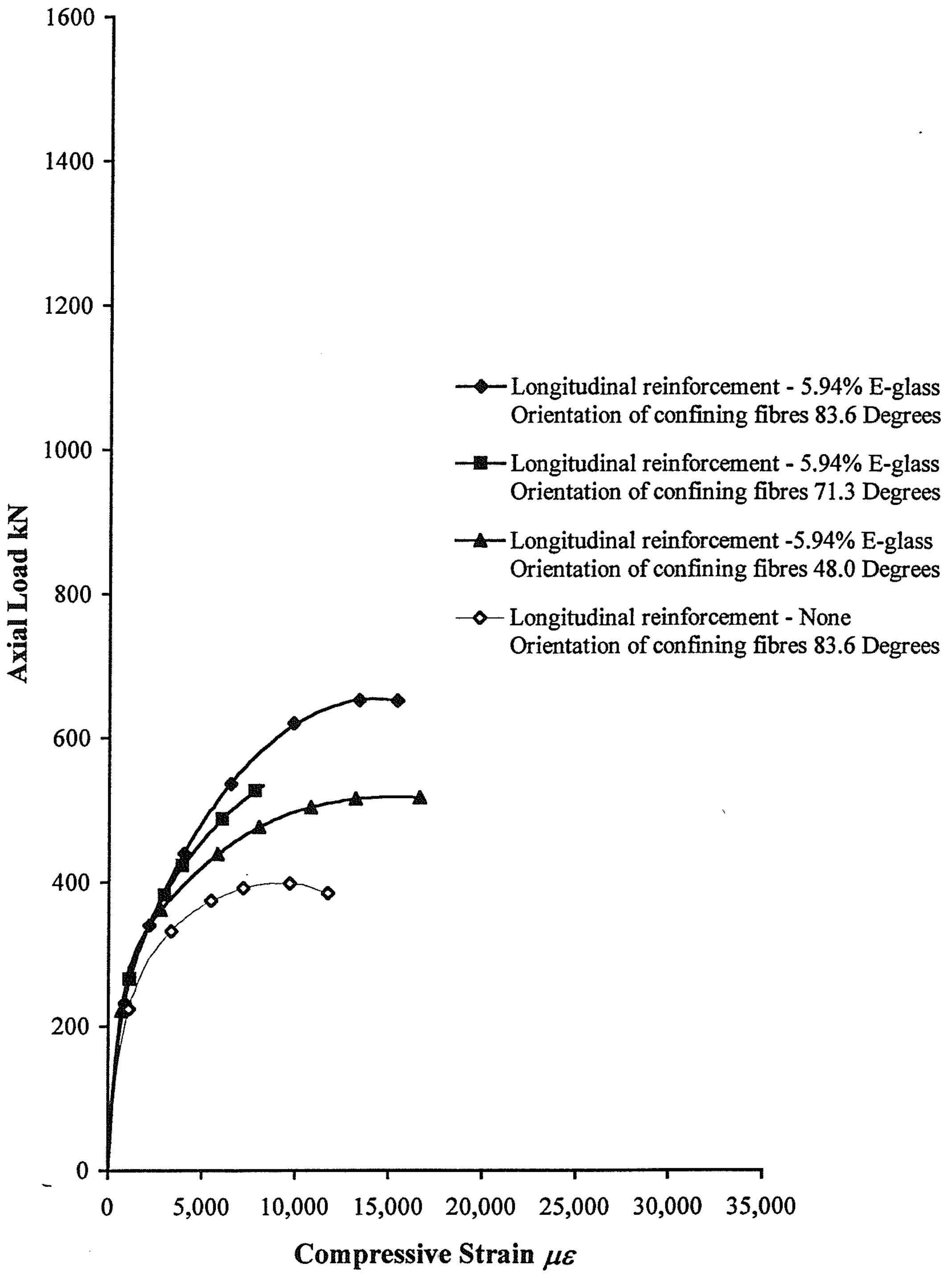



**Figure M.7.** Load-strain curves for the 150 mm diameter concrete-filled E-glass FRP-composite columns, reinforced longitudinally with FRP-composite bars and a slenderness ratio of 10 (nominal concrete cube strength = 25 N/mm$^2$)

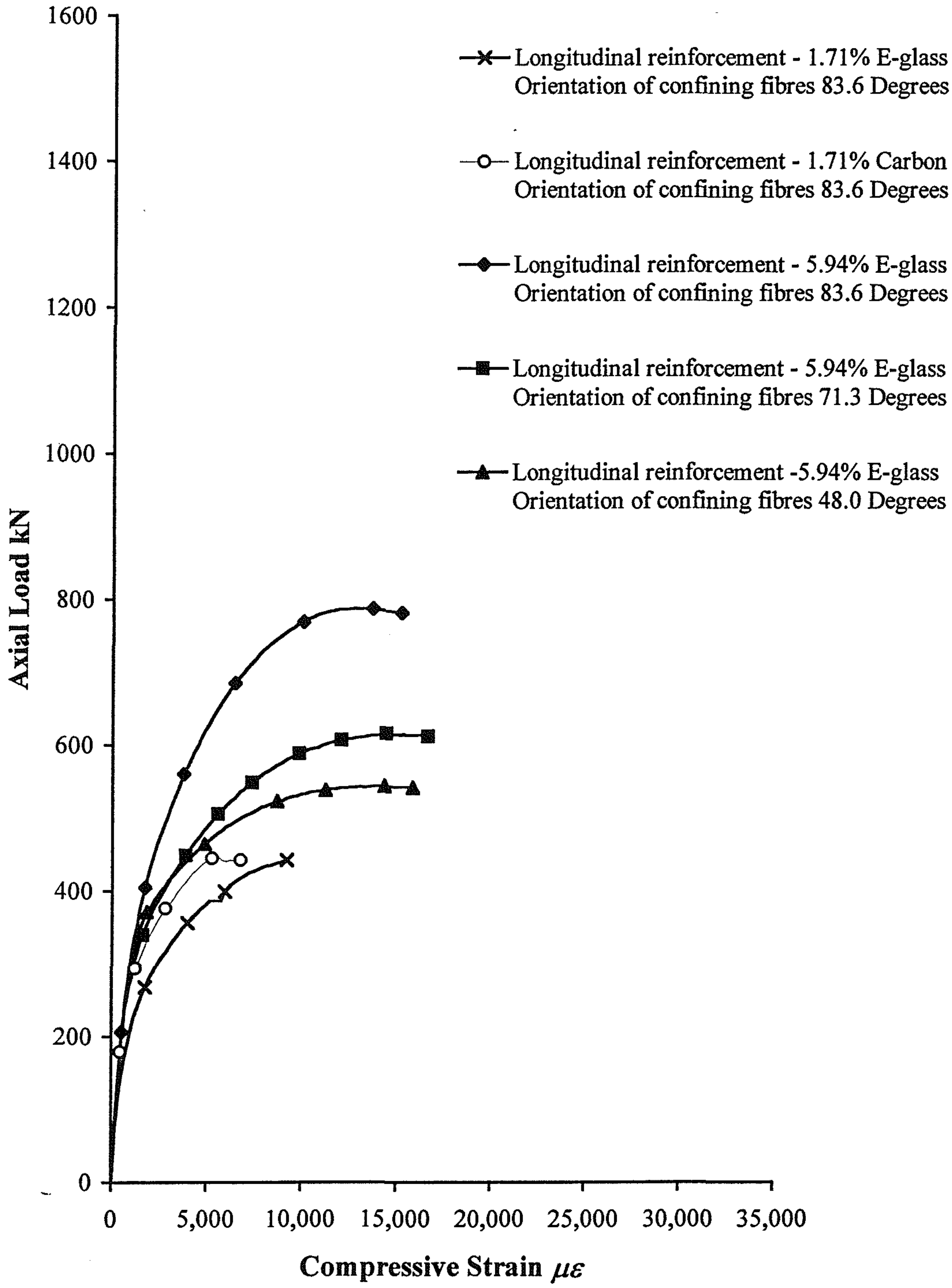



Figure M.8. Load-strain curves for the 150 mm diameter concrete-filled E-glass FRP-composite columns, reinforced longitudinally with FRP-composite bars and a slenderness ratio of 10 (nominal concrete cube strength = 35 N/mm$^2$)