

**ISTANBUL TECHNICAL UNIVERSITY ★ EARTHQUAKE ENGINEERING AND
DISASTER MANAGEMENT INSTITUTE**

CYCLIC BEHAVIOUR OF BARE AND INFILLED STEEL CUSHIONS

M.Sc. THESIS

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Department of Earthquake Engineering

Earthquake Engineering Programme

JANUARY 2015

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JANUARY 2015

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To my family,

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TABLE OF CONTENTS

	<u>Page</u>
FOREWORD	ix
TABLE OF CONTENTS	xi
ABBREVIATIONS	xv
LIST OF TABLES	xvii
LIST OF FIGURES	xix
SUMMARY	xxvii
ÖZET	xxix
1. INTRODUCTION	1
1.1. General	1
1.2. LITERATURE REVIEW	2
1.3. Concept of Parameters Obtained From Experimental Data	6
1.3.1. Energy balance equation	6
1.3.2. Equivalent viscous damping	8
1.3.3. Effective stiffness	8
2. EXPERIMENTAL STUDY	9
2.1. Description of Test Specimens Used In The Experiments.....	9
2.1.1. First group of specimens	9
2.1.2. Second group of specimens.....	10
2.2. Tests Performed On Steel Cushions With Three Different Thicknesses	11
2.3. Different Welding Locations On The Steel Cushions.....	11
2.4. General Types of Performed Tests	11
2.4.1. Uni-axial tests.....	11
2.4.2. Multi-axial tests.....	15
2.5. Summary of Different Types of Performed Tests	15
2.6. Measurement Devices	18
2.6.1. Strain gauges	18
2.6.1.1. Different positions of strain gauges	18
2.6.1.1.1. In cyclic shear tests, bare steel cushions	18
2.6.1.1.2. In monotonic shear test, bare steel cushions	19
2.6.1.1.3. In monotonic axial and cyclic axial tests, bare steel cushions ..	20
2.6.1.1.4. In cyclic shear test, infilled steel cushions	20
2.6.1.1.5. In axial monotonic test, infilled steel cushions	21
2.6.2. Switch box.....	21
2.6.3. Transducers	22
2.6.3.1. Different conditions of using transducers	23
2.6.3.1.1. In uni-axial shear tests.....	23
2.6.3.1.2. In multi-axial tests.....	24
2.6.3.1.3. In uni-axial monotonic or cyclic axial tests	24

3. EXPERIMENTAL RESULTS FROM CYCLIC SHEAR TESTS FOR 8 mm THICKNESS EMPTY STEEL SPECIMEN	27
4. EXPERIMENTAL RESULTS FROM CYCLIC SHEAR LOAD PLUS AXIAL LOAD TESTS.....	29
4.1. Compression Tests For Bare Specimens	29
4.1.1. 8 mm thick specimen.....	29
4.1.1.1. 25 kN axial load	29
4.1.1.2. 50 kN axial load	31
4.1.1.3. 75 kN axial load	34
4.1.2. 5 mm thick specimen.....	36
4.1.2.1. 7.5 kN axial load	36
4.1.2.2. 15 kN axial load	38
4.1.2.3. 25 kN axial load	41
4.1.3. 3 mm thick specimen.....	43
4.1.3.1. 2.5 kN axial load	43
4.1.3.2. 7.5 kN axial load	45
4.1.3.3. 10 kN axial load	48
4.2. Tension Tests For Bare Specimens	50
4.2.1. 8 mm thick specimen.....	50
4.2.1.1. 25 kN axial load	50
4.2.1.2. 50 kN axial load	52
4.2.1.3. 75 kN axial load	55
4.2.2. 5 mm thick specimen.....	57
4.2.2.1. 7.5 kN axial load	57
4.2.2.2. 15 kN axial load	59
4.2.2.3. 25 kN axial load	62
4.2.3. 3 mm thick specimen.....	64
4.2.3.1. 2.5 kN axial load	64
4.2.3.2. 5 kN axial load	66
4.2.3.3. 7.5 kN axial load	69
4.3. Compression Tests For Infilled Specimens.....	71
4.3.1. Cord layered neoprene infilled specimen.....	71
4.3.1.1. 50 kN axial load	71
4.3.1.2. 100 kN axial load	74
4.3.2. FRP layered neoprene infilled specimen.....	76
4.3.2.1. 50 kN axial load	76
4.3.2.2. 100 kN axial load	78
4.3.3. Neoprene infilled specimen.....	81
4.3.3.1. 0 kN axial load	81
4.3.3.2. 50 kN axial load	83
4.3.4. Steel layered neoprene infilled specimen.....	85
4.3.4.1. 50 kN axial load	85
4.3.4.2. 100 kN axial load	88
5. EXPERIMENTAL RESULTS FROM MONOTONIC AXIAL COMPRESSION TESTS	91
5.1. Bare Steel Specimens	91
5.1.1. 3 mm thick specimen.....	91
5.1.2. 5 mm thick specimen.....	93
5.1.3. 8 mm thick specimen.....	94
5.2. Infilled Steel Specimens.....	96

5.2.1. Cord layered neoprene infilling	96
5.2.2. Frp layered neoprene infilling	98
5.2.3. Steel layered neoprene infilling	99
6. COMPARISONS OF TEST RESULTS	103
6.1. Force-Displacement Diagrams	103
6.1.1. Infilled specimens	103
6.1.1.1 Cord layered neoprene specimen	103
6.1.1.2. Frp layered neoprene specimen.....	103
6.1.1.3. Infilled pure neoprene layered specimen	104
6.1.1.4. Steel layered neoprene specimen	104
6.1.1.5. Infilled specimens under 50 kN constant compression load.....	105
6.1.1.6. Infilled specimens under 100 kN constant compression load.....	105
6.1.2. Bare and infilled specimens	106
6.1.2.1. Bare 8 mm specimen vs. cord layered neoprene infilled specimen	106
6.1.2.2. Bare 8 mm specimen vs. frp layered neoprene infilled specimen	107
6.1.2.3. Bare 8 mm specimen vs. steel layered neoprene infilled specimen	107
6.1.2.4. Bare 8 mm specimen vs. cord layered neoprene infilled specimen	108
6.1.2.5. Bare 8 mm specimen vs. frp layered neoprene infilled specimen	108
6.1.2.6. Bare 8 mm specimen vs. pure neoprene infilled specimen.....	109
6.1.2.7. Bare 8 mm specimen vs. steel layered neoprene infilled specimen	109
6.1.2.8. Bare 8 mm specimens vs. frp layered neoprene infilled specimen	110
6.2. Cumulative Energy-Displacement Diagrams.....	110
6.2.1. Bare 8 mm specimen vs. infilled specimens	110
6.2.2. Bare 8 mm specimen vs. infilled specimens	111
6.2.3. Infilled specimens under 50 kN and 100 kN constant compression loads.....	112
6.3. Equivalent Damping-Displacement Diagrams.....	112
6.3.1. Bare 8 mm specimens vs. infilled specimens.....	112
6.3.2. Bare 8 mm specimens vs. infilled specimens.....	113
6.3.3. Infilled specimens under 50 kN and 100 kN constant compression loads.....	113
6.4. Stiffness-Displacement Diagrams	114
6.4.1. Bare 8 mm specimen vs. infilled specimens	114
6.4.2. Bare 8 mm specimen vs. infilled specimens	114
6.4.3. Infilled specimens under 50 kN and 100 kN constant compression loads.....	115
6.5. Envelope Diagrams	115
6.5.1. Bare 8 mm specimen vs. infilled specimens	115
6.5.2. Bare 8 mm specimen vs. infilled specimens	116
6.6. Damping-Stiffness Diagrams	117
6.6.1. Bare 8 mm specimen vs. infilled specimens	117
6.6.2. Bare 8 mm specimen vs. infilled specimens	117
6.7. Ductility Diagrams	118

6.7.1. Bare 8 mm vs. infilled specimens	118
6.7.2. Bare 8 mm specimens vs. infilled specimens.....	118
6.8. Yield Displacement Diagrams.....	119
6.8.1. Bare 8 mm vs. infilled specimens	119
6.8.2. Bare 8 mm specimen vs. infilled specimens	120
6.9. Yield Force Diagrams	120
6.9.1. Bare 8 mm vs. infilled specimens	120
6.9.2. Bare 8 mm specimen vs. infilled specimens	121
6.10. Maximum Force Diagrams.....	121
6.10.1. Bare 8 mm vs. infilled specimens	121
6.10.2. Bare 8 mm specimen vs. infilled specimens	122
6.11. Stiffness Diagrams	122
6.11.1. Bare 8 mm vs. infilled specimens	122
6.11.2. Bare 8 mm vs. infilled specimens	123
6.12. Monotonic Compression Axial Test.....	123
6.12.1. Force-Displacement diagrams.....	123
6.12.1.1. Bare specimens.....	123
6.12.1.2. Bare and infilled specimens	124
6.12.2. Cumulative energy-displacement diagrams	125
6.12.2.1. Bare specimens.....	125
6.12.2.2. Bare and infilled specimens	125
6.12.3. Stiffness diagrams	126
6.12.3.1. Bare specimens.....	126
6.12.3.2. Bare and infilled specimens	126
6.12.4. General comparison between bare and infilled specimens	127
6.13. General Comparison Between Bare And Infilled Specimens Under Cyclic Shear Load Plus Compression Load For 50 KN Compression Load	127
6.14. General Comparison Between Bare And Infilled Specimens Under Cyclic Shear Load Plus Compression Load For 75 KN and 100 KN Compression Loads	128
7. CONCLUSIONS AND RECOMMENDATIONS	129
7.1. Conclusions	129
7.2. Recommendations	131
REFERENCES.....	133
CURRICULUM VITAE	135

ABBREVIATIONS

m	: Mass
u	: Displacement response
$\dot{u}$	: Relative velocity
$\ddot{u}$	: Relative acceleration
$\ddot{u}_g$	: Ground acceleration
c	: Damping coefficient
f_s	: Resisting force
E_K	: Kinetic energy
E_D	: Damping energy
E_A	: Absorbed energy
E_S	: Strain energy
E_P	: Plastic energy
E_I	: Input energy
k	: Elastic stiffness
ζ_{eq}	: Equivalent damping
E_D	: Energy loss
E_{S0}	: Maximum strain energy
K_{eff}	: Effective stiffness
P_{max}	: Maximum target force
P_{min}	: Minimum target force
Δ_{max}	: Maximum target displacement
Δ_{min}	: Minimum target displacement
N+V(+)	: Cyclic shear plus compression axial load
N+V(-)	: Cyclic shear plus tension axial load
ITU	: Istanbul Technical University

LIST OF TABLES

	<u>Page</u>
Table 2.1 : Ratio of displacement amplitudes, FEMA 461 (2007).	12
Table 6.1 : Specimens under 50 KN load in N+V(+) test.	127
Table 6.2 : Specimens under 75 KN and 100 KN loads in N+V(+) test.	128

LIST OF FIGURES

	<u>Page</u>
Figure 1.1 : U-shaped energy dissipaters.	2
Figure 1.2 : Testing O-connector specimens.	2
Figure 1.3 : Pre-WEC system and the used O-connectors.	3
Figure 1.4 : Schematic drawing of a hybrid damper specimen and it's deformed shape.	3
Figure 1.5 : Pipe specimen details.	4
Figure 1.6 : General view of bare pipe specimen under shear test and it's deformed shape after the test.	4
Figure 1.7 : General view of filled pipe specimen under shear test and it's deformed shape after the test.	4
Figure 1.8 : General view of UFP connections and the dissipation mechanism.	5
Figure 1.9 : UFP device in the system and it's force-displacement behavior.	5
Figure 1.10 : Dual-pipe damper device and the framed structure.	6
Figure 1.11 : Testing apparatus and the deformed specimen and it's failure surface.	6
Figure 1.12 : Fixed based SDOF system.	7
Figure 1.13 : Effective stiffness and energy dissipated in a cycle.	8
Figure 2.1 : Bare steel cushion samples.	9
Figure 2.2 : Geometry of the 8 mm thick steel cushion.	9
Figure 2.3 : Two types of 8 mm infilled steel cushion specimens.	10
Figure 2.4 : The location of weldings on the steel cushions.	11
Figure 2.5 : Actuator holder system with the related actuators and closer view of the actuator.	12
Figure 2.6 : Drift based cyclic loading protocol applied to stainless steel cushions.	12
Figure 2.7 : General view of the uni-axial test setup.	13
Figure 2.8 : Drawn sample of the uni-axial test setup.	13
Figure 2.9 : Turned and fixed head of the actuator.	14
Figure 2.10 : Out of plain deformations in the setup.	14
Figure 2.11 : Revisions on test setup.	14
Figure 2.12 : General view of the multi-axial test setup.	15
Figure 2.13 : Axial (cyclic-tension-compression) Test.	16
Figure 2.14 : Cyclic shear plus axial compression test- bare and infilled specimens.	16
Figure 2.15 : Cyclic shear plus axial tension test- bare specimen.	17
Figure 2.16 : Cyclic shear test- bare specimen.	17
Figure 2.17 : Monotonic shear test- bare specimen.	17
Figure 2.18 : Monotonic compression test- infilled specimen.	18
Figure 2.19 : Strain gauge.	18
Figure 2.20 : Locations of the strain gauges.	19

Figure 2.21 : Strain gauge on the inner bottom of specimen.	19
Figure 2.22 : Strain gauges on the outer left and the other side of the specimen.	20
Figure 2.23 : Strain gauges on the outer top and outer bottom of the specimen.....	20
Figure 2.24 : Locations of the strain gauges.	21
Figure 2.25 : Switch box and control room.....	21
Figure 2.26 : Different types of used transducers.	22
Figure 2.27 : Transducers in uni-axial cyclic shear test setup.	23
Figure 2.28 : Transducers in multi-axial test setup.	24
Figure 2.29 : Transducers in uni-axial monotonic test setup.	25
Figure 3.1 : Force-displacement relation from cyclic shear test for 8 mm thickness specimen.....	27
Figure 3.2 : Deformed shapes of the specimen during the test.	28
Figure 3.3 : Cumulative energy-displacement relation for 8 mm thick specimen. ...	28
Figure 3.4 : Equivalent damping-displacement relation for 8 mm thick specimen. .	28
Figure 4.1 : Force-displacement relation from N+V (+) test of 8 mm thick specimen.....	30
Figure 4.2 : Deformed shapes of the specimen during the test.	30
Figure 4.3 : Stiffness-displacement relation for 8 mm thick specimen.....	30
Figure 4.4 : Cumulative energy-displacement relation of 8 mm thick specimen.	31
Figure 4.5 : Equivalent damping-displacement relation of 8 mm thick specimen....	31
Figure 4.6 : Force-displacement relation from N+V (+) test of 8 mm thick specimen.....	32
Figure 4.7 : Deformed shapes of the specimen during the test.	32
Figure 4.8 : Stiffness-displacement Relation for 8 mm thick specimen.	33
Figure 4.9 : Cumulative energy-displacement relation of 8 mm thick specimen.	33
Figure 4.10 : Equivalent damping-displacement relation of 8 mm thick specimen..	33
Figure 4.11 : Force-displacement relation from N+V (+) test of 8 mm thick specimen.	34
Figure 4.12 : Deformed shapes of the specimen during the test.	35
Figure 4.13 : Stiffness-displacement relation for 8 mm thick specimen.....	35
Figure 4.14 : Cumulative energy-displacement relation of 8 mm thick specimen. ..	35
Figure 4.15 : Equivalent damping-displacement relation of 8 mm thick specimen.	36
Figure 4.16 : Force-displacement relation from N+V (+) test of 5 mm thick specimen.	37
Figure 4.17 : Deformed shapes of the specimen during the test.	37
Figure 4.18 : Stiffness-displacement relation for 5 mm thick specimen.....	37
Figure 4.19 : Cumulative energy-displacement relation of 5 mm thick specimen. ..	38
Figure 4.20 : Equivalent damping-displacement relation of 5 mm thick specimen.	38
Figure 4.21 : Force-displacement relation from N+V (+) test of 5 mm thick specimen.	39
Figure 4.22 : Deformed shapes of the specimen during the test.	39
Figure 4.23 : Stiffness-displacement relation for 5 mm thick specimen.....	40
Figure 4.24 : Cumulative energy-displacement relation of 5 mm thick specimen. ..	40
Figure 4.25 : Equivalent damping-displacement relation of 5 mm thick specimen.	40
Figure 4.26 : Force-displacement relation from N+V (+) test of 5 mm thick specimen.	41
Figure 4.27 : Deformed shapes of the specimen during the test.	42

Figure 4.28 : Stiffness-displacement relation for 5 mm thick specimen.	42
Figure 4.29 : Cumulative energy-displacement relation of 5 mm thick specimen. ..	42
Figure 4.30 : Equivalent damping-displacement relation of 5 mm thick specimen.	43
Figure 4.31 : Force-displacement relation from N+V (+) test of 3 mm thick specimen.	44
Figure 4.32 : Deformed shapes of the specimen during the test.	44
Figure 4.33 : Stiffness-displacement relation for 3 mm thick specimen.	44
Figure 4.34 : Cumulative energy-displacement relation of 3 mm thick specimen. ..	45
Figure 4.35 : Equivalent damping-displacement relation of 3 mm thick specimen.	45
Figure 4.36 : Force-displacement relation from N+V (+) test of 3 mm thick specimen.	46
Figure 4.37 : Deformed shapes of the specimen during the test.	46
Figure 4.38 : Stiffness-displacement relation for 3 mm thick specimen.	47
Figure 4.39 : Cumulative energy-displacement relation of 3 mm thick specimen. ..	47
Figure 4.40 : Equivalent damping-displacement relation of 3 mm thick specimen.	47
Figure 4.41 : Force-displacement relation from N+V (+) test of 3 mm thick specimen.	48
Figure 4.42 : Deformed shapes of the specimen during the test.	49
Figure 4.43 : Stiffness-displacement relation for 3 mm thick specimen.	49
Figure 4.44 : Cumulative energy-displacement relation of 3 mm thick specimen. ..	49
Figure 4.45 : Equivalent damping-displacement relation of 3 mm thick specimen.	50
Figure 4.46 : Force-displacement relation from N+V (-) test of 8 mm thick specimen.	51
Figure 4.47 : Deformed shapes of the specimen during the test.	51
Figure 4.48 : Stiffness-displacement relation for 8 mm thick specimen.	51
Figure 4.49 : Cumulative energy-displacement relation of 8 mm thick specimen. ..	52
Figure 4.50 : Equivalent damping-displacement relation of 8 mm thick specimen.	52
Figure 4.51 : Force-displacement relation from N+V (-) test of 8 mm thick specimen.	53
Figure 4.52 : Deformed shapes of the specimen during the test.	53
Figure 4.53 : Stiffness-displacement relation for 8 mm thick specimen.	54
Figure 4.54 : Cumulative energy-displacement relation of 8 mm thick specimen. ..	54
Figure 4.55 : Equivalent damping-displacement relation of 8 mm thick specimen.	54
Figure 4.56 : Force-displacement relation from N+V (-) test of 8 mm thick specimen.	55
Figure 4.57 : Deformed shapes of the specimen during the test.	56
Figure 4.58 : Stiffness-displacement relation for 8 mm thick specimen.	56
Figure 4.59 : Cumulative energy-displacement relation of 8 mm thick specimen. ..	56
Figure 4.60 : Equivalent damping-displacement relation of 8 mm thick specimen.	57
Figure 4.61 : Force-displacement relation from N+V (-) test of 5 mm thick specimen.	58
Figure 4.62 : Deformed shapes of the specimen during the test.	58
Figure 4.63 : Stiffness-displacement relation for 5 mm thick specimen.	58

Figure 4.64 : Cumulative energy-displacement relation of 5 mm thick specimen. ..	59
Figure 4.65 : Equivalent damping-displacement relation of 5 mm thick specimen.	59
Figure 4.66 : Force-displacement relation from N+V (-) test of 5 mm thick specimen.	60
Figure 4.67 : Deformed shapes of the specimen during the test.	60
Figure 4.68 : Stiffness-displacement relation for 5 mm specimen.....	61
Figure 4.69 : Cumulative energy-displacement relation of 5 mm thick specimen. ..	61
Figure 4.70 : Equivalent damping-displacement relation of 5 mm thick specimen.	61
Figure 4.71 : Force-displacement relation from N+V (-) test of 5 mm thick specimen.	62
Figure 4.72 : Deformed shapes of the specimen during the test.	63
Figure 4.73 : Stiffness-displacement relation for 5 mm thick specimen.....	63
Figure 4.74 : Cumulative energy-displacement relation of 5 mm thick specimen. ..	63
Figure 4.75 : Equivalent damping-displacement relation of 5 mm thick specimen.	64
Figure 4.76 : Force-displacement relation from N+V (-) test of 3 mm thick specimen.	65
Figure 4.77 : Deformed shapes of the specimen during the test.	65
Figure 4.78 : Stiffness-displacement relation for 3 mm thick specimen.....	65
Figure 4.79 : Cumulative energy-displacement relation of 3 mm thick specimen. ..	66
Figure 4.80 : Equivalent damping-displacement relation of 3 mm thick specimen.	66
Figure 4.81 : Force-displacement relation from N+V (-) test of 3 mm thick specimen.	67
Figure 4.82 : Deformed shapes of the specimen during the test.	67
Figure 4.83 : Stiffness-displacement relation for 3 mm thick specimen.....	68
Figure 4.84 : Cumulative energy-displacement relation of 3 mm thick specimen. ..	68
Figure 4.85 : Equivalent damping-displacement relation of 3 mm thick specimen.	68
Figure 4.86 : Force-displacement relation from N+V (-) test of 3 mm thick specimen.	69
Figure 4.87 : Deformed shapes of the specimen during the test.	70
Figure 4.88 : Stiffness-displacement relation for 3 mm thick specimen.....	70
Figure 4.89 : Cumulative energy-displacement relation of 3 mm thick specimen. ..	70
Figure 4.90 : Equivalent damping-displacement relation of 3 mm thick specimen.	71
Figure 4.91 : Force-displacement relation from N+V (+) test of cord neoprene layered specimen.	72
Figure 4.92 : Deformed shapes of the specimen during the test.	72
Figure 4.93 : Stiffness-displacement relation for cord neoprene layered specimen.	73
Figure 4.94 : Cumulative energy-displacement relation of cord neoprene layered specimen.	73
Figure 4.95 : Equivalent damping-displacement relation of cord neoprene layered specimen.	73
Figure 4.96 : Force-displacement relation from N+V (+) test of cord neoprene layered specimen.	74
Figure 4.97 : Deformed shapes of the specimen during the test.	75

Figure 4.98 : Stiffness-displacement relation for cord neoprene layered specimen.	75
Figure 4.99 : Cumulative energy-displacement relation of cord neoprene layered specimen.	75
Figure 4.100 : Equivalent damping-displacement relation of cord neoprene layered specimen.	76
Figure 4.101 : Force-displacement relation from N+V (+) test of FRP neoprene layered specimen.	77
Figure 4.102 : Deformed shapes of the specimen during the test.	77
Figure 4.103 : Stiffness-displacement relation of FRP neoprene layered specimen.	77
Figure 4.104 : Cumulative energy-displacement relation of FRP neoprene layered specimen.	78
Figure 4.105 : Equivalent damping-displacement relation of FRP neoprene layered specimen.	78
Figure 4.106 : Force-displacement relation from N+V (+) test of FRP neoprene layered specimen.	79
Figure 4.107 : Deformed shapes of the specimen during the test.	79
Figure 4.108 : Stiffness-displacement relation for FRP neoprene layered specimen.	80
Figure 4.109 : Cumulative energy-displacement Relation of FRP neoprene layered specimen.	80
Figure 4.110 : Equivalent damping-displacement Relation of FRP neoprene layered specimen.	80
Figure 4.111 : Force-displacement relation from N+V (+) test of neoprene infilled specimen.	81
Figure 4.112 : Deformed shapes of the specimen during the test.	82
Figure 4.113 : Stiffness-displacement relation for neoprene infilled specimen.	82
Figure 4.114 : Cumulative energy-displacement relation of neoprene infilled specimen.	82
Figure 4.115 : Equivalent damping-displacement relation of neoprene infilled specimen.	83
Figure 4.116 : Force-displacement relation from N+V (+) test of neoprene infilled specimen.	84
Figure 4.117 : Deformed shapes of the specimen during the test.	84
Figure 4.118 : Stiffness-displacement relation for neoprene infilled specimen.	84
Figure 4.119 : Cumulative energy-displacement relation of neoprene infilled specimen.	85
Figure 4.120 : Equivalent damping-displacement relation of neoprene infilled specimen.	85
Figure 4.121 : Force-displacement relation from N+V (+) test of steel neoprene layered specimen.	86
Figure 4.122 : Deformed shapes of the specimen during the test.	86
Figure 4.123 : Stiffness-displacement relation for steel neoprene layered specimen.	87
Figure 4.124 : Cumulative energy-displacement relation of steel neoprene layered specimen.	87
Figure 4.125 : Equivalent damping-displacement relation of steel neoprene layered specimen.	87

Figure 4.126 : Force-displacement relation from N+V (+) test of steel neoprene layered specimen.....	88
Figure 4.127 : Deformed shapes of the specimen during the test.	89
Figure 4.128 : Stiffness-displacement relation for steel neoprene layered specimen.....	89
Figure 4.129 : Cumulative energy-displacement relation of steel neoprene layered specimen.....	89
Figure 4.130 : Equivalent damping-displacement relation of steel neoprene layered specimen.....	90
Figure 5.1 : Force-displacement relation from monotonic axial test of 3 mm thick specimen.....	91
Figure 5.2 : Deformed shapes of the specimen during the test.	92
Figure 5.3 : Ratio of stiffness-displacement relation for 3 mm thick specimen.	92
Figure 5.4 : Cumulative energy-displacement relation of 3 mm thick specimen.	92
Figure 5.5 : Force-displacement relation from monotonic axial test of 5 mm thick specimen.....	93
Figure 5.6 : Deformed shapes of the specimen during the test.	93
Figure 5.7 : Ratio of stiffness-displacement relation for 5 mm thick specimen.	94
Figure 5.8 : Cumulative energy-displacement relation of 5 mm thick specimen.	94
Figure 5.9 : Force-displacement relation from monotonic axial test of 8 mm thick specimen.....	95
Figure 5.10 : Deformed shapes of the specimen during the test.	95
Figure 5.11 : Ratio of stiffness-displacement relation for 8 mm thick specimen.	95
Figure 5.12 : Cumulative energy-displacement relation of 8 mm thick specimen. ..	96
Figure 5.13 : Force-displacement relation from monotonic axial test of cord neoprene layered specimen.....	96
Figure 5.14 : Deformed shapes of the specimen during the test.	97
Figure 5.15 : Ratio of stiffness-displacement relation for cord neoprene layered specimen.	97
Figure 5.16 : Cumulative energy-displacement relation of cord neoprene layered specimen.	97
Figure 5.17 : Force-displacement relation from monotonic axial test of FRP neoprene layered specimen.....	98
Figure 5.18 : Deformed shapes of the specimen during the test.	98
Figure 5.19 : Ratio of stiffness-displacement relation for FRP neoprene layered specimen.	99
Figure 5.20 : Cumulative energy-displacement relation of FRP neoprene layered specimen.	99
Figure 5.21 : Force-displacement relation from monotonic axial test of steel neoprene layered specimen.....	100
Figure 5.22 : Deformed shapes of the specimen during the test.	100
Figure 5.23 : Ratio of stiffness-displacement relation for steel neoprene layered specimen.	100
Figure 5.24 : Cumulative energy-displacement relation of steel neoprene layered specimen.	101
Figure 6.1 : Force-displacement relation from N+V (+) test of cord neoprene layered specimen.	103
Figure 6.2 : Force-displacement relation from N+V (+) test of FRP neoprene layered specimen.	104

Figure 6.3 : Force-displacement relation from N+V (+) test of neoprene infilled specimen.	104
Figure 6.4 : Force-displacement relation from N+V (+) test of steel neoprene layered specimen.	105
Figure 6.5 : Force-displacement relation from N+V (+) test of infilled specimens.	105
Figure 6.6 : Force-displacement relation from N+V (+) test of infilled specimens.	106
Figure 6.7 : Force-displacement relation from N+V (+) test of infilled and bare specimens.	106
Figure 6.8 : Force-displacement relation from N+V (+) test of infilled and bare specimens.	107
Figure 6.9 : Force-displacement relation from N+V (+) test of infilled and bare specimens.	107
Figure 6.10 : Force-displacement relation from N+V (+) test of infilled and bare specimens.	108
Figure 6.11 : Force-displacement relation from N+V (+) test of infilled and bare specimens.	108
Figure 6.12 : Force-displacement relation from N+V (+) test of infilled and bare specimens.	109
Figure 6.13 : Force-displacement relation from N+V (+) test of infilled and bare specimens.	109
Figure 6.14 : Force-displacement relation from N+V (+) test of infilled and bare specimens.	110
Figure 6.15 : Cumulative energy-displacement relation from N+V (+) test of infilled and bare specimens.	111
Figure 6.16 : Cumulative energy-displacement relation from N+V (+) test of infilled and bare specimens.	111
Figure 6.17 : Cumulative energy-displacement relation from N+V (+) test of infilled specimens.	112
Figure 6.18 : Equivalent damping-displacement relation from N+V (+) test of infilled and bare specimens.	113
Figure 6.19 : Equivalent damping-displacement relation from N+V (+) test of infilled and bare specimens.	113
Figure 6.20 : Equivalent damping-displacement relation from N+V (+) test of infilled specimens.	114
Figure 6.21 : Ratio of stiffness-displacement relation from N+V (+) test for infilled and bare specimens.	114
Figure 6.22 : Ratio of stiffness-displacement relation from N+V (+) test for infilled and empty specimens.	115
Figure 6.23 : Ratio of stiffness-displacement relation from N+V (+) test for infilled specimens.	115
Figure 6.24 : Ratio of peak strength to yield strength for infilled and bare specimens from N+V (+) test.	116
Figure 6.25 : Ratio of peak strength to yield strength for infilled and bare specimens from N+V (+) test.	116
Figure 6.26 : Stiffness-damping relation from N+V (+) test for infilled and bare specimens.	117
Figure 6.27 : Stiffness-damping relation from N+V (+) test for infilled and bare specimens.	118

Figure 6.28 : Ductility amounts from N+V (+) test for infilled and bare specimens.	118
Figure 6.29 : Ductility amounts from N+V (+) test for infilled and bare specimens.	119
Figure 6.30 : Yield displacement amount from N+V (+) test for infilled and bare specimens.	119
Figure 6.31 : Yield displacement amount from N+V (+) test for infilled and bare specimens.	120
Figure 6.32 : Yield force amount from N+V (+) test for infilled and bare specimens.	120
Figure 6.33 : Yield force amount from N+V (+) test for infilled and bare specimens.	121
Figure 6.34 : Maximum force amount from N+V (+) test for infilled and bare specimens.	121
Figure 6.35 : Maximum force amount from N+V (+) test for infilled and bare specimens.	122
Figure 6.36 : Stiffness amount from N+V (+) test for infilled and bare specimens.	122
Figure 6.37 : Stiffness amount from N+V (+) test for infilled and bare specimens.	123
Figure 6.38 : Force-displacement relation from monotonic axial test of bare specimens.	124
Figure 6.39 : Force-displacement relation from monotonic axial test of infilled and bare specimens.	124
Figure 6.40 : Cumulative energy-displacement relation from monotonic axial test of bare specimens.	125
Figure 6.41 : Cumulative energy-displacement relation from monotonic axial test of infilled and bare specimens.	125
Figure 6.42 : Ratio of stiffness-displacement relation from monotonic axial test of bare specimens.	126
Figure 6.43 : Ratio of stiffness-displacement relation from monotonic axial test of infilled and bare specimens.	126

CYCLIC BEHAVIOUR OF BARE AND INFILLED STEEL CUSHIONS

SUMMARY

Cladding panels that are assumed as non-structural parts of pre-cast structures contribute to increase the lateral stiffness of the structure during an earthquake.

Testing new practical energy dissipative devices called steel cushions is a part of a research project named SAFECLADDING, that has been initiated with the collaboration of European Union universities such as Politecnico di Milano, University of Ljubljana, National Technical University of Athens and Istanbul Technical University.

These steel cushions are being used in different locations of cladding panels such as panel to foundation, panel to panel, panel to frame connections.

One of the most important advantages of these steel cushions is that they could stand the damage of earthquake and could be replaced easily without any damage to the main parts of the system such as panels and the frame after every imposed earthquake.

These specimens have different kinds such as *Empty* types with the thicknesses of 3, 5 and 8 mm and *Infilled* types with different filled resistance materials.

The infilled specimens have better energy dissipation capacity than empty ones and because of using resistance material inside the specimen they could better carry the weight of the cladding panels and then it is more practical to use them at panel to foundation connections.

In order to check the performance of these Infilled specimens four different filled resistance materials are being used inside these specimens with the names of Cord, FRP, Neoprene and Steel layered.

Many uni-axial and multi-axial tests been carried out at the Istanbul Technical University laboratory to obtain the performance of these steel specimens and finally the below results obtained:

The amount of degradation in stiffness decreases by using infilled material inside the specimen but the amounts of energy dissipation capacity and also the maximum amount of shear force increases by using infilled material inside the specimen.

Furthermore among the infilled specimens the amount of maximum force increases by increasing the amount of compression axial load.

BOŞ VE İÇİ DOLU ÇELİK YASTIKLARIN ÇEVİRİMSEL DAVRANIŞI

ÖZET

Ön döküm yapıların yapısal olmayan parçaları sayılan cephe paneller, bir deprem sırasında yapının yatay rijitliğine katkıda bulunur.

Çelik yastık adı verilen yeni, pratik enerji sönümleyici birleşim araçları SAFECLADDING adlı araştırma projesinin parçasıdır. Bu çelik yastıklar, panel temel, panel panel, panel çerçeve bağlantısını sağlamada kullanılabilir.

Bu çelik yastıkların en önemli avantajlarından biri, depremin hasarına dayanabilmeleri ve maruz kalınan her deprem sonrasında paneller ve çerçeve gibi sistemin ana parçalarına hasar gelmeksizin kolaylıkla değiştirilebilmeleridir.

Çelik yastıklar 3, 5 ve 8 mm kalınlığındaki boş tipler ve farklı malzemelerle doldurulmuş içi dolu tipler olarak iki farklı türdedir.

İçi dolu yastıklar boş olanlardan daha iyi bir enerji tüketme kapasitesine sahiptir ve dolgu malzemesi kullanılmasından dolayı cephe panellerinin ağırlığını taşıyabilirler.

Farklı dolgu türlerini incelemek üzere yastıkların içine kumaş, FRP, çelik ve neopren doldurulmuştur.

Çelik yastıkların performansını öğrenmek için istanbul teknik üniversitesi'nde tek eksenli ve çok eksenli pek çok test yapılmış ve sonuçta aşağıdaki bulgular elde edilmiştir:

Dolgulu çelik yastıklarda mukavemetteki düşme miktarı azalır, enerji tüketme kapasitesi ve kesme dayanımı artar.

Yine içi dolu yastıklarda kopma dayanımı eksenel yükün artırılmasıyla artar.

1. INTRODUCTION

1.1. General

Several structural and non-structural elements such as columns, pre-fabricated beams and cladding panels that are located at the outside of the structures form the pre-cast structures.

During an earthquake the cladding panels basically act as stiffening elements while they are assumed as non-structural parts of the pre-cast structures and they contribute to increase the initial stiffness of the structure.

Various mechanisms through the panel to panel and panel to structure connections should dissipate the excessive energy imposed to the structure, and regular types of connection could not handle this issue.

A research project named SAFECLADDING has been done and a portion of this project is consisted of testing a new practical energy dissipative device called steel cushions. Steel cushions in the precast constructions are being used in the panel to foundation, panel to panel, panel to frame connections. The related part of this project has been done in the Structural and Earthquake Engineering Laboratory of ITU.

These devices stand the damage of earthquake and could be replaced after every imposed earthquake, without any damage to the main parts of the system such as panels or the frame.

In order to explore the energy dissipation capacity and the hysteretic behavior of the steel specimens many uni-axial and multi-axial cyclic tests were performed.

In safe cladding project at the ITU laboratory total number of 70 tests carried out on the empty specimens with the thicknesses of 3, 5 and 8mm and on the infilled steel specimens with the thicknesses of only 8 mm using Cord, FRP, Neoprene and Steel infilling materials to achieve their performed behaviour.

1.2. LITERATURE REVIEW

In order to determine the earthquake behavior of energy dissipaters many studies have been carried out, some of them are as follows:

A series of experiments to find out the inelastic flexural deformation capacity of the U-Shaped energy dissipating shear connectors Figure 1.1, has been carried out and as a result the energy dissipation capacity of the whole system increases as these U-Shaped connectors bend and unbend, (Shultz et al, 1996).

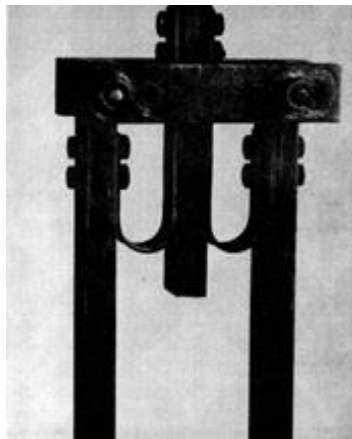


Figure 1.1 : U-shaped energy dissipaters.

Another type of most practical and suitable shear connectors are (O-connector) systems Figure 1.2, that have been used in (Pre-WEC) precast wall systems Figure 1.3, they have excellent force-displacement responses and also provide stable and reliable response with sufficient energy dissipation provided to the used (Pre-WEC) system, (Henry et.al, 2008).

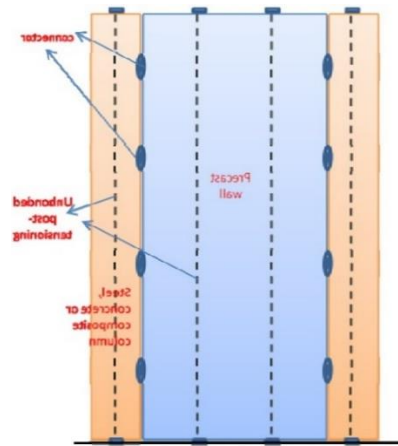


Test setup

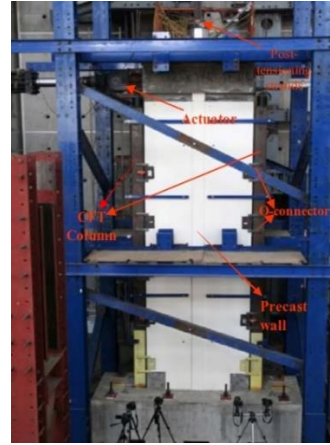


Fractured O-connectors

Figure 1.2 : Testing O-connector specimens.



Test setup



System concept

Figure 1.3 : Pre-WEC system and the used O-connectors.

In the following study, a hybrid damper consisting of high damping rubber and U-shaped steel dampers is proposed to improve the seismic performance of reinforced concrete shear wall systems, Figure 1.4.

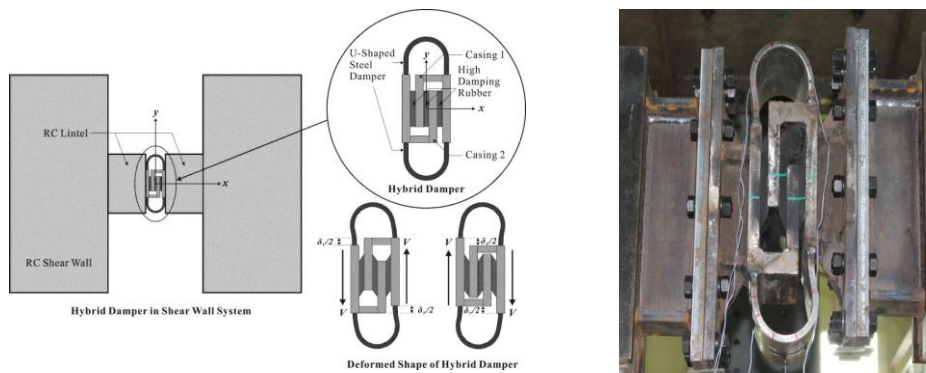


Figure 1.4 : Schematic drawing of a hybrid damper specimen and it's deformed shape.

The results obtained from the experiment indicated that this hybrid energy dissipative device minimized damages to the structural elements with concentrating plastic hinges into the devices and also increased energy dissipation capacity of the whole system, (Joon Kim et.al, 2008).

The purpose of the following experiment is to examine the behavior of O-shaped steel pipes Figure 1.5, in the case of bare Figure 1.6, and filled Figure 1.7, with concrete as a possible hysteretic damper. For this purpose, the steel pipe is tested under cyclic and monotonic shear force between two rigid plates, (Maleki and Bagheri, 2010).

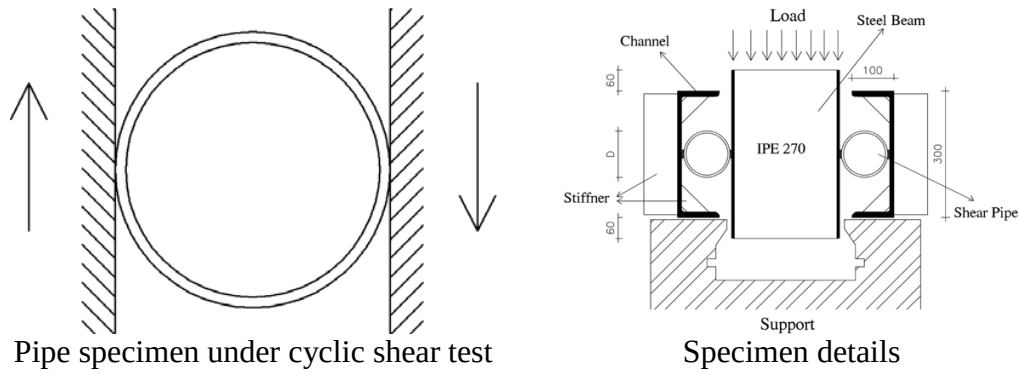


Figure 1.5 : Pipe specimen details.



General view of the bare steel pipe under shear test



Typical deformed shape of bare steel pipe specimen

Figure 1.6 : General view of bare pipe specimen under shear test and it's deformed shape after the test.



General view of the filled steel pipe under shear test



Typical deformed shape of filled steel pipe specimen

Figure 1.7 : General view of filled pipe specimen under shear test and it's deformed shape after the test.

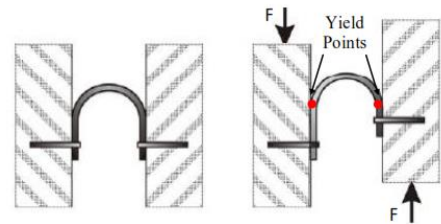
The tests showed that O-shaped pipes filled with concrete fail in a non-ductile manner due to crushing of concrete under shear loading but the pipe itself remains undamaged and also cyclic shear tests on bare steel pipes provides an excellent energy dissipation capacity.

The results showed that the O-Shaped bare steel pipes are capable of absorbing a great amount of energy under a severe cyclic shear loading with a stable hysteretic behavior, (Maleki and Bagheri, 2010).

U-shaped flexural plate dissipaters (UFPs) Figure 1.8, are formed by heating mild steel plates and bending a section around a fixed radius to form a U shape. They have successfully been used in several structural dissipation systems Figure 1.9.



UFP connections before (left) and after (right) being tested

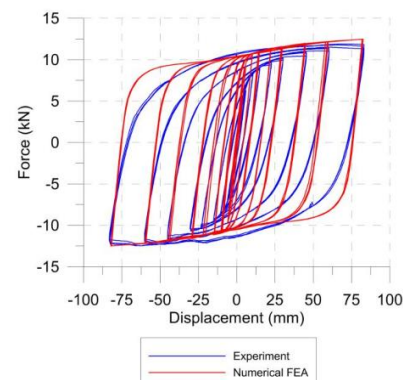


UFP dissipation mechanism

Figure 1.8 : General view of UFP connections and the dissipation mechanism.



UFP device between two timber shear walls



Force-displacement behavior of UFP device

Figure 1.9 : UFP device in the system and it's force-displacement behavior.

The results of an experimental and numerical investigation into UFP cladding connections showed they have great potential as passive energy dissipation devices. They dissipate earthquake energy that would otherwise result in damage to the structure. They are also able to limit maximum displacements in a structure, and could reduce potential damage to other non-structural components, (Baird and Palermo, 2013).

Another study is about a new passive earthquake energy dissipative device called the dual-pipe damper (DPD), the device consists of two pipes welded at selected locations and loaded in shear, they are used in some types of installations in the framed structures Figure 1.10. The testing apparatus and also the deformed shape of the specimens and the failure surface are shown in Figure 1.11, (Maleki and Mahjoubi, 2013).

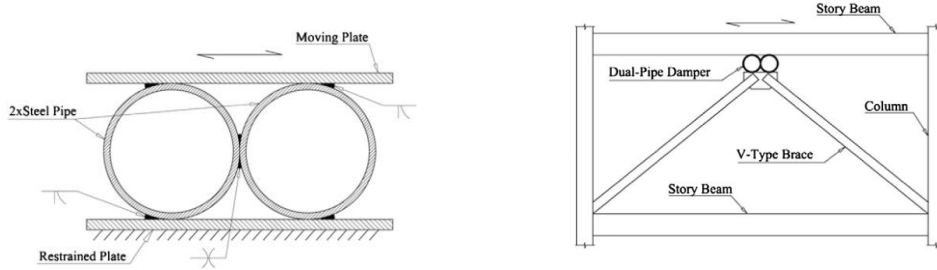


Figure 1.10 : Dual-pipe damper device and the framed structure.



Testing apparatus



Deformed shape
specimens



Specimen failure surface

Figure 1.11 : Testing apparatus and the deformed specimen and it's failure surface.

The above system is a light-weight inexpensive and simple to build system and has a large deformation capacity with high amount of ductility that absorbs significant amount of energy, (Maleki and Mahjoubi, 2013).

1.3. Concept of Parameters Obtained From Experimental Data

1.3.1. Energy balance equation

The energy-balance equation can be derived by directly integrating the equation of motion with respect to the response of the system illustrated in Figure 1.12, (Uang and Bertero, 1990).

$$\int m\ddot{u}(t)du + \int c\dot{u}(t)du + \int f_s du = -\int m\ddot{u}_g(t)du \quad (1.1)$$

where m is the mass of the structure, $\ddot{u}$ is the relative acceleration, c is the damping coefficient, u is the displacement response, $\dot{u}$ is the relative velocity, f_s is the resisting force and $\ddot{u}_g$ is the ground acceleration. Response of the system (u) is taken relative to the ground level (fixed-based system) instead of absolute values for the sake of simple representation, Figure 1.12.

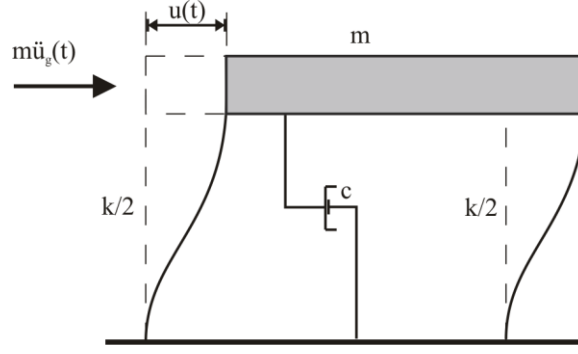


Figure 1.12 : Fixed based SDOF system.

The terms on left hand side of Equation (1.1) represent the energy mechanisms of the structure, kinetic (E_K), damping (E_D) and absorbed (E_A) energies. Right-hand side of the equation represents total input energy (E_I) that is imposed to the structure. Thus,

$$E_K + E_D + E_A = E_I \quad (1.2)$$

The absorbed energy (E_A) term also includes strain (E_S) and plastic (E_P) energies caused by elastic and inelastic response of the system, respectively. It is expressed as,

$$E_A = E_S + E_P \quad (1.3)$$

Thus, the final form of the energy balance equation becomes

$$E_K + E_D + (E_S + E_P) = E_I \quad (1.4)$$

The elastic strain energy (E_S) is calculated by using the elastic stiffness (k) of the system as follows;

$$E_S = \frac{u^2(t)}{2k} \quad (1.5)$$

The energy dissipated by the inelastic displacements can be determined by calculating the area of the closed loop of the force-displacement relationship, (Wong and Yang, 2002). However, the plastic energy can also be calculated by subtracting the kinetic, damping and elastic energies from the input energy as expressed in equation (1.6).

$$E_P = E_I - (E_K + E_D + E_S) \quad (1.6)$$

1.3.2. Equivalent viscous damping

Damping in actual structures is usually represented by equivalent viscous damping, the most common method for defining equivalent viscous damping is to equate the energy dissipated in a vibration cycle of the actual structure and an equivalent viscous system.

The amount of equivalent damping could be obtained from the below formula:

$$\zeta_{eq} = \frac{1}{4\pi} \frac{E_D}{E_{S0}} \quad (1.7)$$

Where E_D is the amount of energy loss and E_{S0} is the amount of maximum strain energy in a cycle of harmonic vibration.

1.3.3. Effective stiffness

The amount of effective stiffness could be obtained from the below formula:

$$K_{eff} = \frac{|P_{max}| - |P_{min}|}{|\Delta_{max}| - |\Delta_{min}|} \quad (1.8)$$

Where P_{max} and P_{min} are the maximum and minimum amounts of target forces respectively and Δ_{max} and Δ_{min} are the maximum and minimum amounts of target displacements respectively, Figure 1.13.

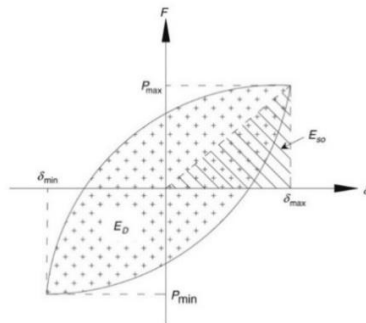


Figure 1.13 : Effective stiffness and energy dissipated in a cycle.

2. EXPERIMENTAL STUDY

2.1. Description of Test Specimens Used In The Experiments

2.1.1. First group of specimens

The first group consists of bare steel cushions that are available in three alternative thicknesses of 3, 5 and 8 mm. Bare specimens consist of two U-Shaped portions from mild steel that are welded to each other properly, Figure 2.1.

In these specimens there are two holes in two opposite sides of the specimens and the diameters of the holes are 29 mm for 8 mm cushion and 20 mm for 3 and 5 mm thickness cushions, respectively. The specimens are connected to the testing setup via these holes by two bolts.

The geometries of the 8 mm thick specimen is shown in Figure 2.2.



Figure 2.1 : Bare steel cushion samples.

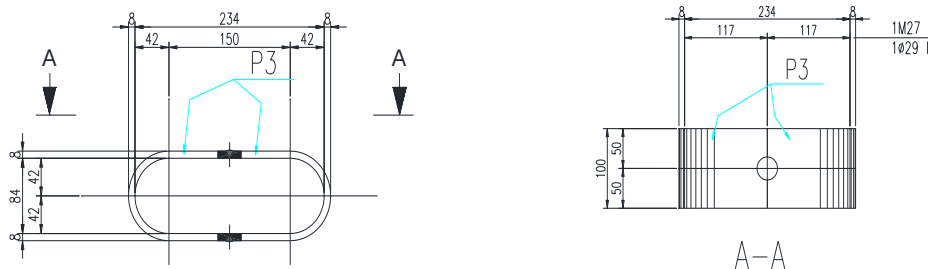


Figure 2.2 : Geometry of the 8 mm thick steel cushion.

2.1.2. Second group of specimens

The second group consists of infilled cushions in only 8 mm thickness but available in four different types namely:

- 1) Cord Layered Infilling.
- 2) FRP Layered Infilling.
- 3) Pure Neoprene Infilling.
- 4) Steel Layered Infilling.

There is a difference between preparation of infilled and bare specimens and it is that during manufacturing infilled specimens a bolt is welded to the specimen and there is a hole in the other side of it and it's inner empty space is filled with special resistance materials, Figure 2.3. Also it should be mentioned that the steel plates inside the infilled steel layered specimen have 3 mm thickness each.

These specimens are connected to the testing setup by twisting one side and fixing the other side.



8 mm infilled steel layered specimen

8mm infilled FRP layered specimen

Figure 2.3 : Two types of 8 mm infilled steel cushion specimens.

It should be mentioned that in testing both bare and infilled steel cushions, thicknesses of the specimens and the loading direction are the most important parameters.

2.2. Tests Performed On Steel Cushions With Three Different Thicknesses

- 1) 3 mm thick specimens
- 2) 5 mm thick specimens
- 3) 8 mm thick specimens

2.3. Different Welding Locations On The Steel Cushions

- 1) Location of the welding is at the center of the straight part.
- 2) Location of the welding is at the top of the straight part.
- 3) Location of the welding is at the middle of the straight part, Figure 2.4.

Based on the previous experiments it was obtained that the welding location at the center of the straight part is the best condition.

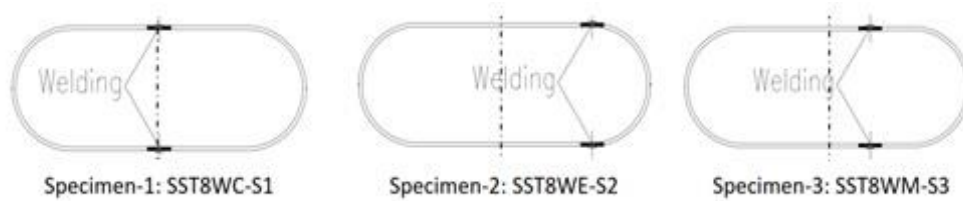


Figure 2.4 : The location of weldings on the steel cushions.

2.4. General Types of Performed Tests

2.4.1. Uni-axial tests

In performing the uni-axial shear tests, one actuator is being used that is one of the most important parts of the test setup. In uni-axial test setup actuator is used for applying vertical cyclic or monotonic load based on the loading protocol.

General view of the actuator holder system and the connected actuators is shown in Figure 2.5. The general view of the uni-axial test setup has been presented in Figure 2.7 and the detailed dimensions are given in Figure 2.8. The specimens bolted to the test setup are shown in the drawing. In this drawing the actuator is shown in two different positions, however at the same time only one of tests (uni-axial shear or axial) can be made.



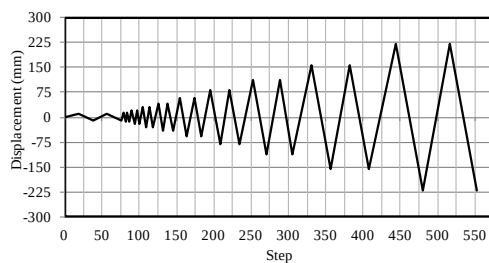
Figure 2.5 : Actuator holder system with the related actuators and closer view of the actuator.

In order to perform the tests a testing protocol has been created and is applied by the actuator. The protocol is based on the expected ultimate drift and it is selected from FEMA 461. The applied target displacements in the protocol is obtained by multiplying specimen height of 100 mm in its vertical axis and 250 mm in its lateral axis by “ a_i/a_{10} ” ratios to consider the expected deformability of the specimen, Table 2.1.

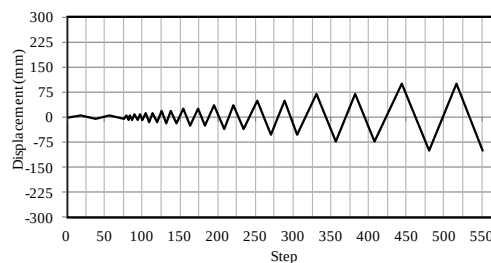
As an example, for cyclic shear and axial tests there are ten distinct displacement targets in the protocol and for each of the displacements two full cycles are performed, a complete loading protocol is shown in Figure 2.6.

Table 2.1 : Ratio of displacement amplitudes, FEMA 461 (2007).

step	1	2	3	4	5	6	7	8	9	10
a_i/a_{10}	0.048	0.068	0.095	0.133	0.186	0.260	0.364	0.510	0.714	1.000



Cyclic shear test loading protocol



Cyclic axial test loading protocol

Figure 2.6 : Drift based cyclic loading protocol applied to stainless steel cushions.



Figure 2.7 : General view of the uni-axial test setup.

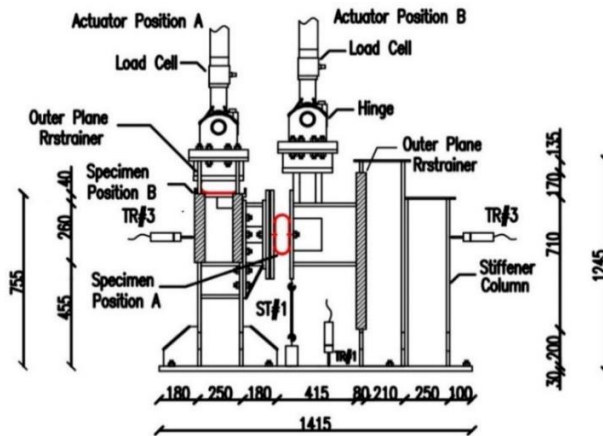


Figure 2.8 : Drawn sample of the uni-axial test setup.

It should be mentioned that at the first steps of uni-axial tests some problems appeared, when the actuator applied the axial load it's loading head turned and to fix the problem a new method was applied that was using four restrainers that made the actuator's head to move straightly vertical, the head of the actuator before and after the restrains is shown in Figure 2.9.

Also there were some out-of plain deformations in the setup shown in Figure 2.10, but after performing some revisions the problem was fixed, one of these revision on test setup was welding some restraints along the reaction column for preventing the movement and the other one was positioning longer restraining steel plates along the steel beam and steel cushion connection, these revisions are shown in Figure 2.11.



Turning head before using restrains



Using four restrains to make the head fixed

Figure 2.9 : Turned and fixed head of the actuator.



Figure 2.10 : Out of plain deformations in the setup.

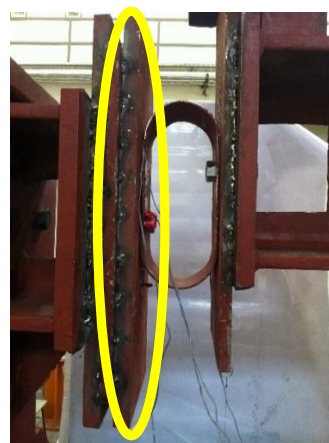


Figure 2.11 : Revisions on test setup.

2.4.2. Multi-axial tests

It is necessary to carry out the multi-axial tests as there are load coupling for the *panel to panel* and *panel to beam* or *panel to column* connections. The multi-axial test will be carried out by applying constant tension or compression forces and reversed drift based displacement cycles. In multi-axial test setup one of the actuators was used for applying vertical cyclic or monotonic load just like the uni-axial test and the other actuator was used for applying constant tension or compression loads during the test, the general view of the multi-axial test setup is shown in Figure 2.12.



Figure 2.12 : General view of the multi-axial test setup.

Several uni-axial tests such as axial tests (Cyclic axial and Monotonic axial), shear tests (Cyclic shear and Monotonic shear) and also several multi-axial tests that is a combination of shear test and axial test have been done on two types of specimens.

2.5. Summary of Different Types of Performed Tests

- 1) Axial cyclic, tension, compression tests carried out on bare steel cushions, Figure 2.13.
- 2) Cyclic shear plus axial compression tests performed on bare and infilled steel cushions, Figure 2.14.
- 3) Cyclic shear plus axial tension tests performed on bare steel cushions, Figure 2.15.
- 4) Cyclic shear tests performed on bare steel cushions, Figure 2.16.
- 5) Monotonic shear tests carried out on bare steel cushions, Figure 2.17.
- 6) Monotonic compression tests performed on infilled steel cushions, Figure 2.18.

Cyclic Axial Tests (9 tests)	
a) 3mm	[cyclic, compression, tension]
b) 5mm	[cyclic, compression, tension]
c) 8mm	[cyclic, compression, tension]

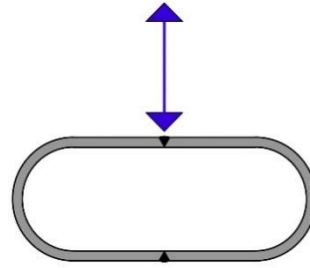


Figure 2.13 : Axial (cyclic-tension-compression) Test.

Cyclic Shear plus Axial test (28 tests)	
Bare Specimens (Two series been done)	
a) 3mm	[compression]
b) 5mm	[compression]
c) 8mm	[compression]
Infilled Specimens	
a) 8mm Neopren Infilled	
b) 8mm Cord Layered	
c) 8mm FRP Layered	
d) 8mm Steel Layered	

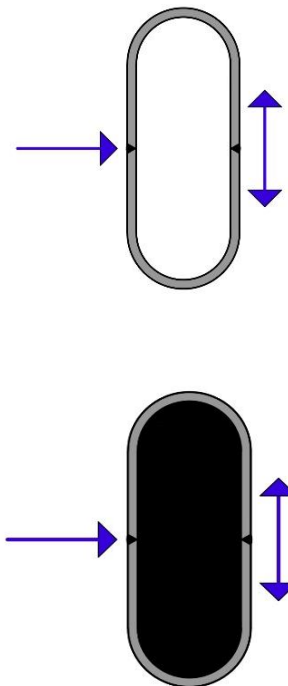


Figure 2.14 : Cyclic shear plus axial compression test- bare and infilled specimens.

Cyclic Shear plus Axial Test
(19 tests)

Bare Specimens
(Two series been done)

- a) 3mm [tension]
- b) 5mm [tension]
- c) 8mm [tension]

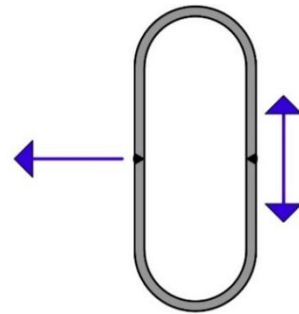


Figure 2.15 : Cyclic shear plus axial tension test- bare specimen.

Cyclic Shear Test
(16 tests)

Bare Specimens

- a) 3mm
- b) 5mm
- c) 8mm

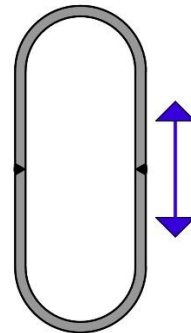


Figure 2.16 : Cyclic shear test- bare specimen.

Monotonic Shear Test
(3 tests)

Bare Specimens

- a) 3mm
- b) 5mm
- c) 8mm

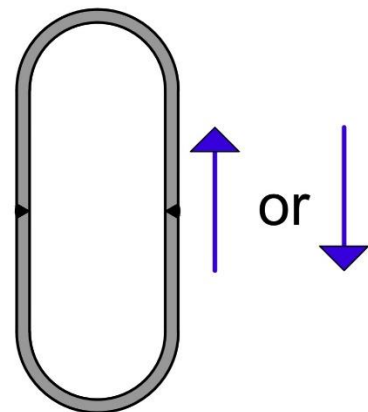


Figure 2.17 : Monotonic shear test- bare specimen.

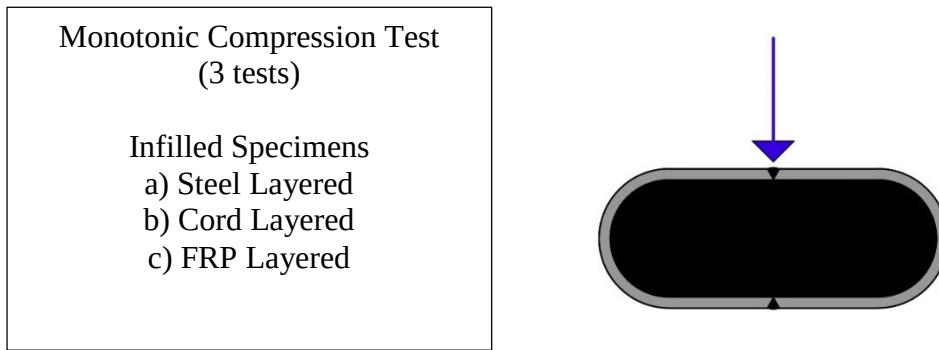


Figure 2.18 : Monotonic compression test- infilled specimen.

2.6. Measurement Devices

2.6.1. Strain gauges

To measure the strains on the specimens several strain gauges were used depending on the specimen type and the performed test, Figure 2.19.



Figure 2.19 : Strain gauge.

2.6.1.1. Different positions of strain gauges

2.6.1.1.1. In cyclic shear tests, bare steel cushions

Four strain gauges have been used, Figure 2.20.

- 1) On the outer top part of the specimen
- 2) On the inner top part of the specimen
- 3) On the inner bottom part of the specimen
- 4) On the outer bottom part of the specimen

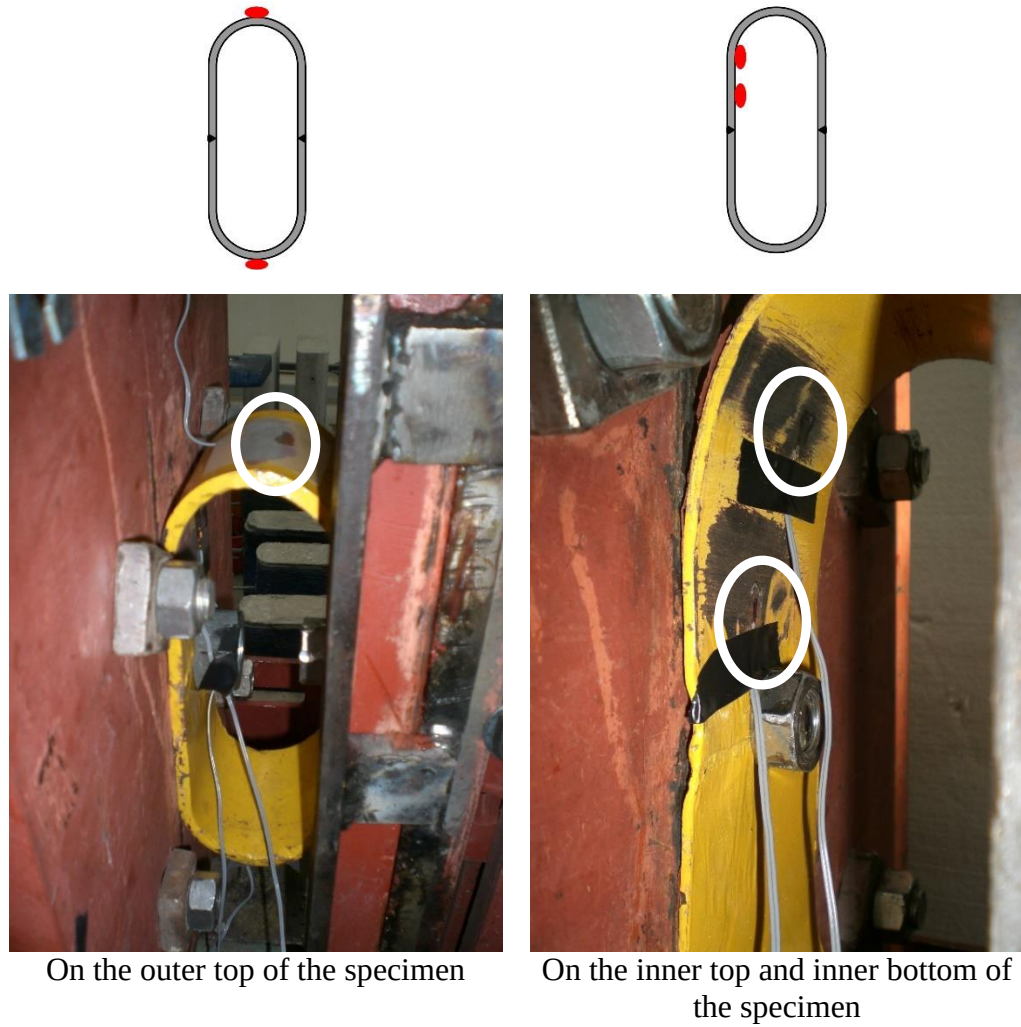


Figure 2.20 : Locations of the strain gauges.

2.6.1.1.2. In monotonic shear test, bare steel cushions

Only one strain gauge on the inner bottom side of the specimen has been used, Figure 2.21.

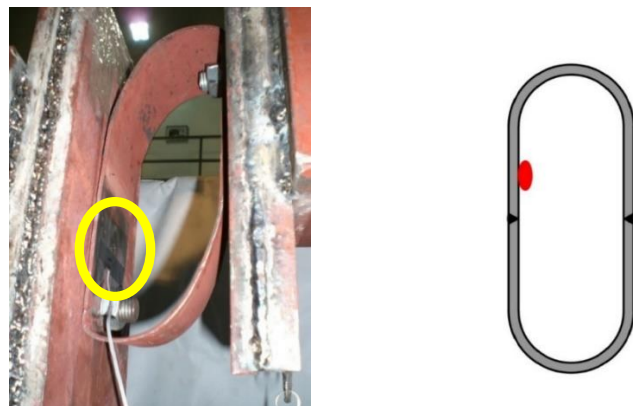


Figure 2.21 : Strain gauge on the inner bottom of specimen.

2.6.1.1.3. In monotonic axial and cyclic axial tests, bare steel cushions

Two strain gauges have been used, Figure 2.22.

- 1) On the outer left side of the specimen
- 2) On the outer right side of the specimen

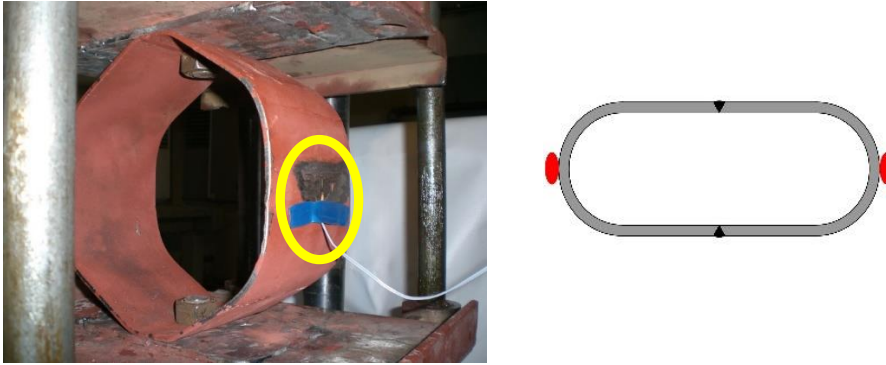


Figure 2.22 : Strain gauges on the outer left and the other side of the specimen.

2.6.1.1.4. In cyclic shear test, infilled steel cushions

Two strain gauges have been used, Figure 2.23.

- 1) On the outer top part of the specimen
- 2) On the outer bottom part of the specimen



Figure 2.23 : Strain gauges on the outer top and outer bottom of the specimen.

2.6.1.1.5. In axial monotonic test, infilled steel cushions

Two strain gauges have been used, Figure 2.24.

- 1) On the outer left side of the specimen
- 2) On the outer right side of the specimen



On the outer left side of the specimen



On the outer right side of the specimen

Figure 2.24 : Locations of the strain gauges.

2.6.2. Switch box

The switch box shown in Figure 2.25, is a link between the testing setup and the control room. One end of the strain gauge cables are connected to this tool to convey the captured strain's information to the computer, as well as the transducers are connected to the switch box to measure the displacements.



Switch box



Control room of the laboratory

Figure 2.25 : Switch box and control room.

2.6.3. Transducers

To measure various displacement components, different types of transducers, Figure 2.26, are used in the tests. They are:

- a) 25 mm transducer
- b) 50 mm transducer
- c) 100 mm transducer
- d) String transducer



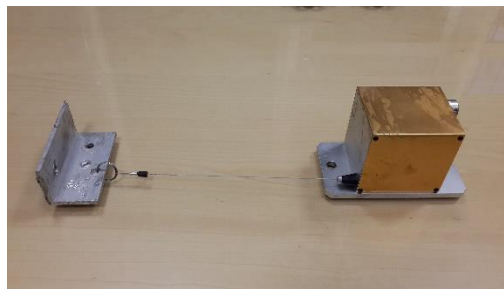
25 mm transducer



50 mm transducer



100 mm transducer



String transducer

Figure 2.26 : Different types of used transducers.

2.6.3.1. Different conditions of using transducers

2.6.3.1.1. In uni-axial shear tests

Four transducers have been used, Figure 2.27.

- a) One 25 mm transducer is positioned at the left side of the testing setup to measure the rotation or any small movement at that part of the test setup.
- b) One 25 mm transducer is positioned at the right side of the testing setup to measure the rotation or any small movement at that part of the test setup.
- c) One 25 mm transducer is used at the middle of the test setup to measure any small uplifting in the setup during the test.
- d) One string transducer is connected to the bottom of the moving plate to measure the vertical displacement.



Figure 2.27 : Transducers in uni-axial cyclic shear test setup.

2.6.3.1.2. In multi-axial tests

Three transducers have been used, Figure 2.28.

- a) One 50 mm transducer is positioned at the left bottom side of the compression plate to measure possible rotation of that part of the plate.
- b) One 50 mm transducer is used at the right top side of the compression plate to measure possible rotation of that part of the plate.
- c) One 25 mm transducer is located at the top of the compression plate to measure the uplifting of the plate.

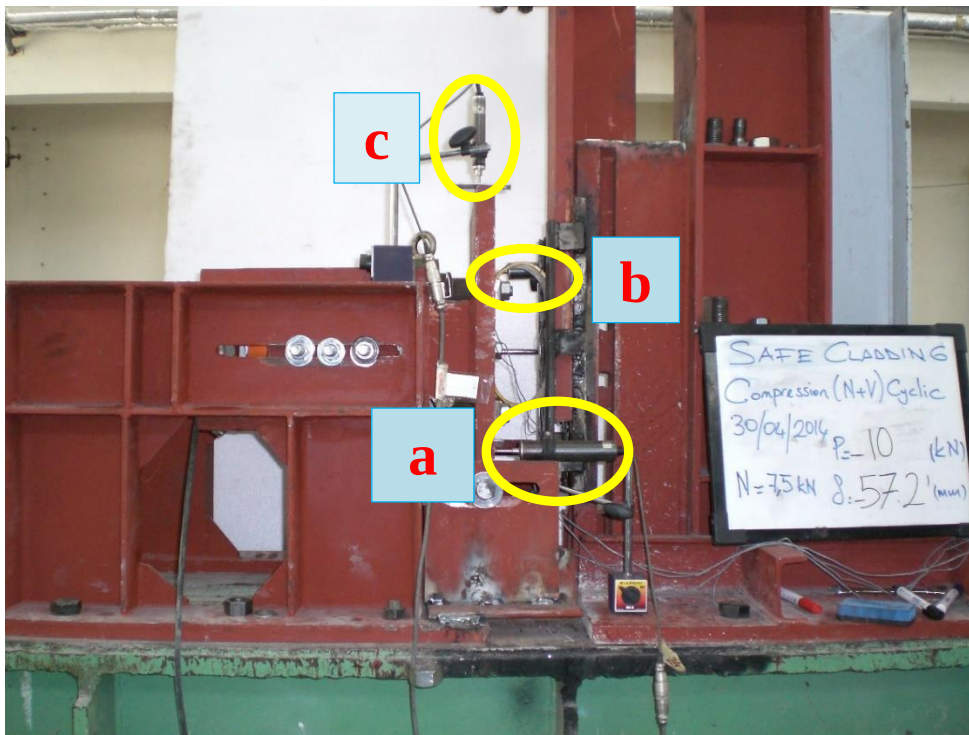


Figure 2.28 : Transducers in multi-axial test setup.

2.6.3.1.3. In uni-axial monotonic or cyclic axial tests

Two transducers have been used, Figure 2.29.

- a) One 50 mm transducer is used at the left side of the plate to measure the rotation of the loading actuator.
- b) One 50 mm transducer is used at the right side of the plate to measure the rotation of the loading actuator.

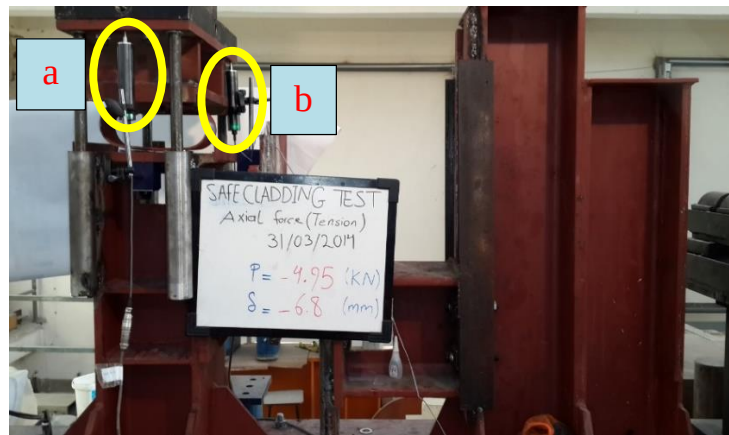


Figure 2.29 : Transducers in uni-axial monotonic test setup.

3. EXPERIMENTAL RESULTS FROM CYCLIC SHEAR TESTS FOR 8 mm THICKNESS EMPTY STEEL SPECIMEN

Totally four similar cyclic shear tests were carried out on 8 mm thick specimen. The force displacement relation is presented in Figure 3.1.

From cyclic shear tests, the 8 mm thickness steel specimen has a nominal strength of 33 kN, and also a maximum displacement capacity of 220 mm. The ultimate compression strength of the 8 mm thick specimen is 100 kN. Based on the strain gauges measurements obtained from four tests the yielding is calculated about 11.039 mm. The specimen has a symmetric behavior under cyclic shear test.

Big cracks were observed at the final steps of the test that started on the welding area and the specimen was near to rupture but it did not completely ruptured.

The partially deformed shape of 8 mm specimen during the test and also the ultimate deformed shape of that specimen at the ultimate steps is presented in Figure 3.2.

The amount of the cumulative energy or simply the area enclosed by hysteresis loops for 8 mm thick specimen under cyclic shear that is obtained from four similar tests is equal to 160000 kN.mm, Figure 3.3.

Equivalent damping obtained from the cyclic shear test of 8 mm thick cushions is about 49 percent, Figure 3.4.

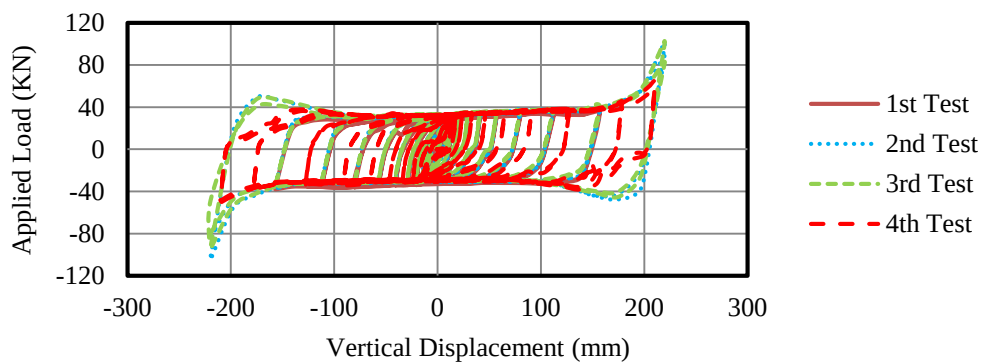


Figure 3.1 : Force-displacement relation from cyclic shear test for 8 mm thickness specimen.

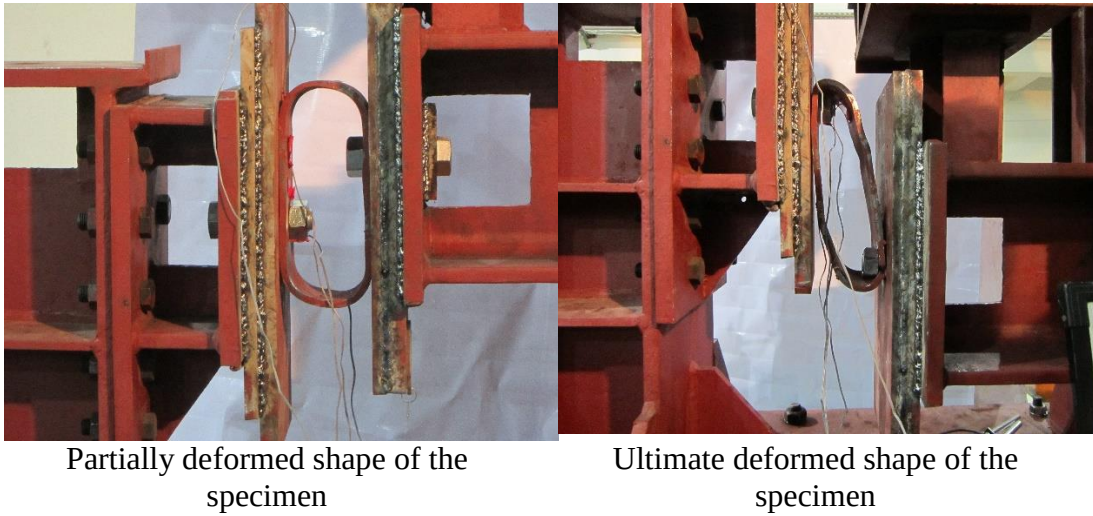


Figure 3.2 : Deformed shapes of the specimen during the test.

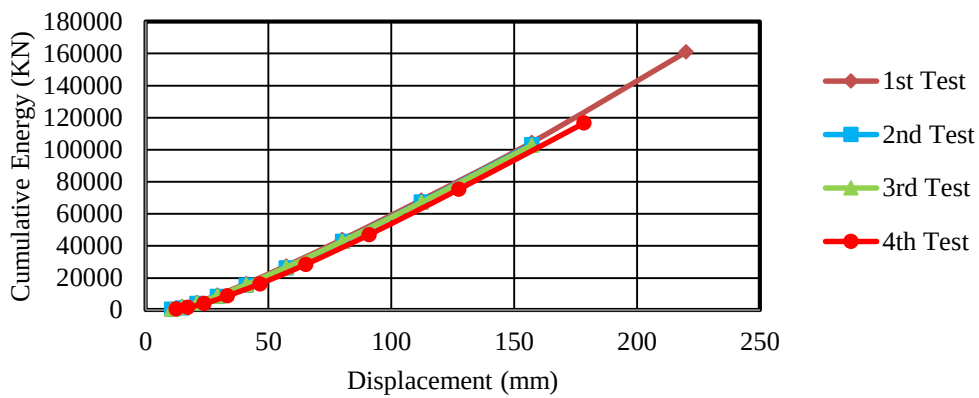


Figure 3.3 : Cumulative energy-displacement relation for 8 mm thick specimen.

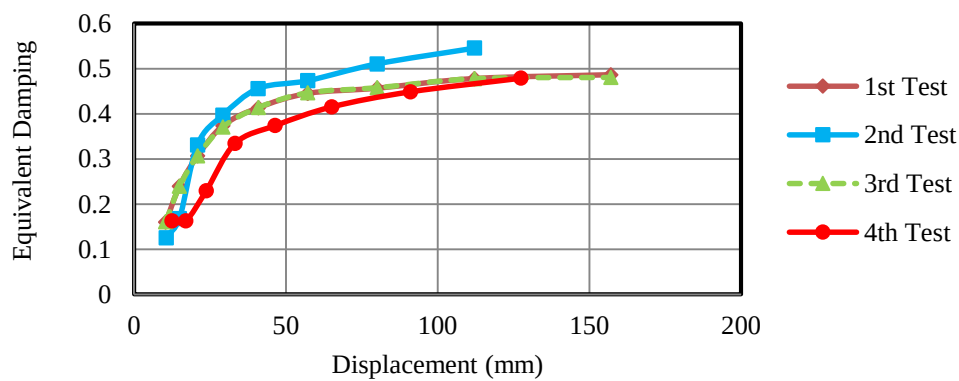


Figure 3.4 : Equivalent damping-displacement relation for 8 mm thick specimen.

4. EXPERIMENTAL RESULTS FROM CYCLIC SHEAR LOAD PLUS AXIAL LOAD TESTS

Two types of multi axial tests are carried out on three types of specimens with the thicknesses of 3 mm, 5 mm and 8 mm.

The first test is cyclic shear load plus compression axial load stands for N+V(+) and the second test is cyclic shear load plus tension axial load stands for N+V(-) test.

4.1. Compression Tests For Bare Specimens

4.1.1. 8 mm thick specimen

4.1.1.1. 25 kN axial load

Two similar N+V(+) tests were carried out on 8 mm thick specimen for 25 kN compression axial load. Cycles obtained from the tests are presented in Figure 4.1.

8 mm thick steel specimen has a nominal strength of 31.7 kN from first test and 31.5 kN from second test, as well as a maximum displacement capacity of 200 mm. The ultimate compression strength of 8 mm thick specimen is 54 kN. Based on the obtained strain gauges measurements from two tests, the average yielding displacement is calculated as 12.75 mm. The specimen has a symmetric behavior.

Some cracks are observed at the final steps of the test. The second specimen ruptured at the end of the test.

The partially deformed shape of the specimen and the ultimate deformed shape are presented in Figure 4.2.

The stiffness of the specimen at the beginning of the test is about 3 kN/mm while it is calculated as 0.22 kN/mm at the end of the test, Figure 4.3.

The cumulative energy which is calculated as the enclosed area of force-displacement curve is equal to 156000 kN.mm, Figure 4.4.

The ultimate equivalent damping calculated from the tests is about 49 percent, Figure 4.5.

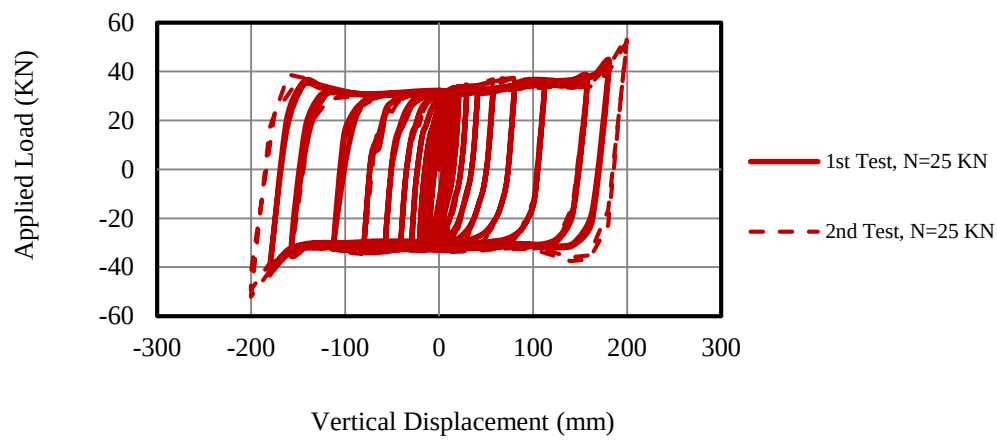
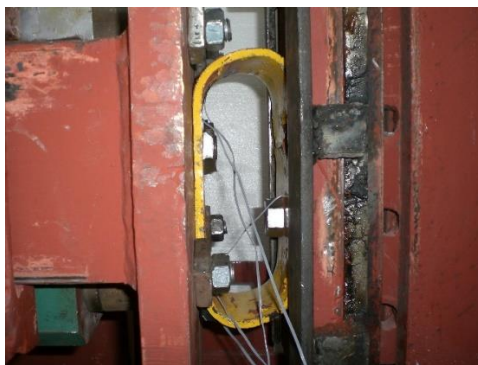
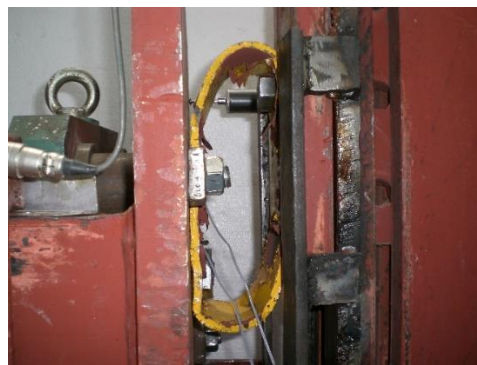


Figure 4.1 : Force-displacement relation from N+V (+) test of 8 mm thick specimen.



Partially deformed shape of the specimen



Ultimate deformed shape of the specimen

Figure 4.2 : Deformed shapes of the specimen during the test.

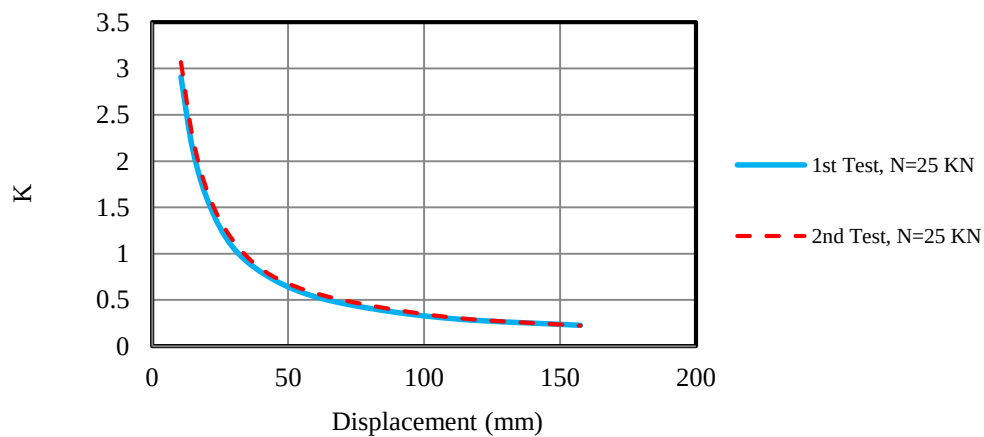


Figure 4.3 : Stiffness-displacement relation for 8 mm thick specimen.

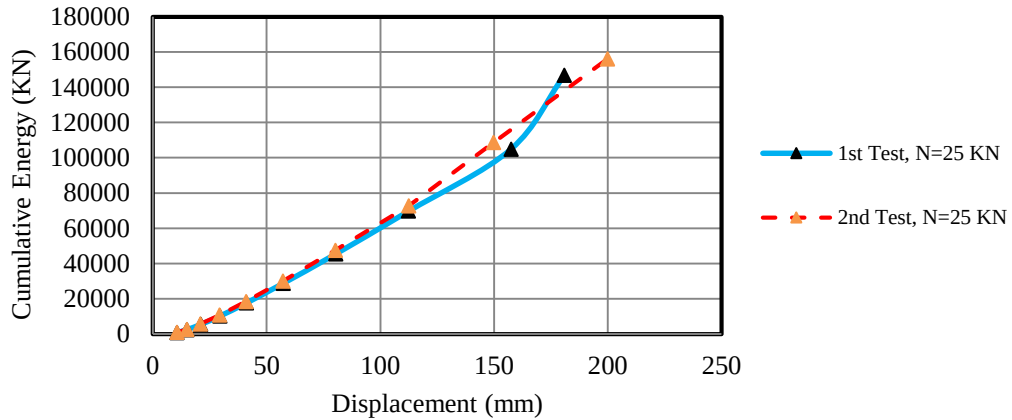


Figure 4.4 : Cumulative energy-displacement relation of 8 mm thick specimen.

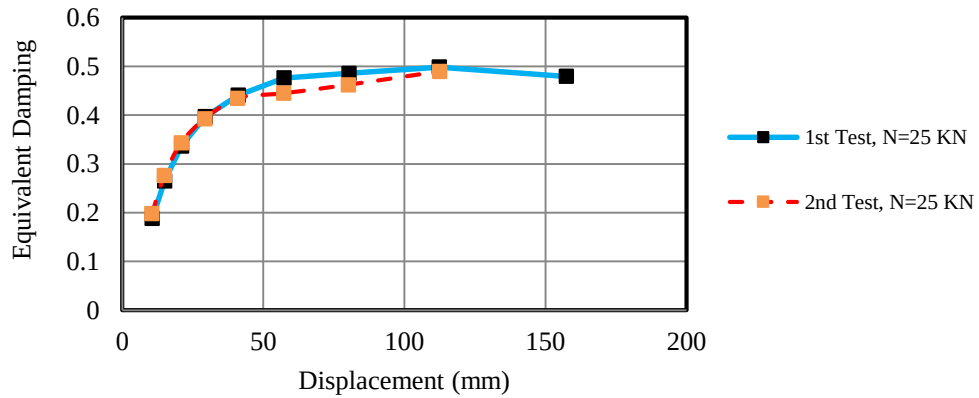


Figure 4.5 : Equivalent damping-displacement relation of 8 mm thick specimen.

4.1.1.2. 50 kN axial load

Two similar N+V(+) tests were carried out on 8 mm thick specimen for 50 kN compression axial load. Cycles obtained from the tests are presented in Figure 4.6.

8 mm thick steel specimen has a nominal strength of 44 kN from first test and 35 kN from second test, as well as a maximum displacement capacity of 200 mm. The ultimate compression strength of 8 mm thick specimen is 38 kN. Based on the obtained strain gauges measurements from two tests, the average yielding displacement is calculated as 10.52 mm. The specimen has a symmetric behavior.

Some cracks are observed at the final steps of the test. The first specimen ruptured at the end of the test.

The partially deformed shape of the specimen and the ultimate deformed shape are presented in Figure 4.7.

The stiffness of the specimen at the beginning of the test is about 2.89 kN/mm while it is calculated as 0.22 kN/mm at the end of the test, Figure 4.8.

The cumulative energy which is calculated as the enclosed area of force-displacement curve is equal to 168000 kN.mm, Figure 4.9.

The ultimate equivalent damping calculated from the tests is about 55 percent, Figure 4.10.

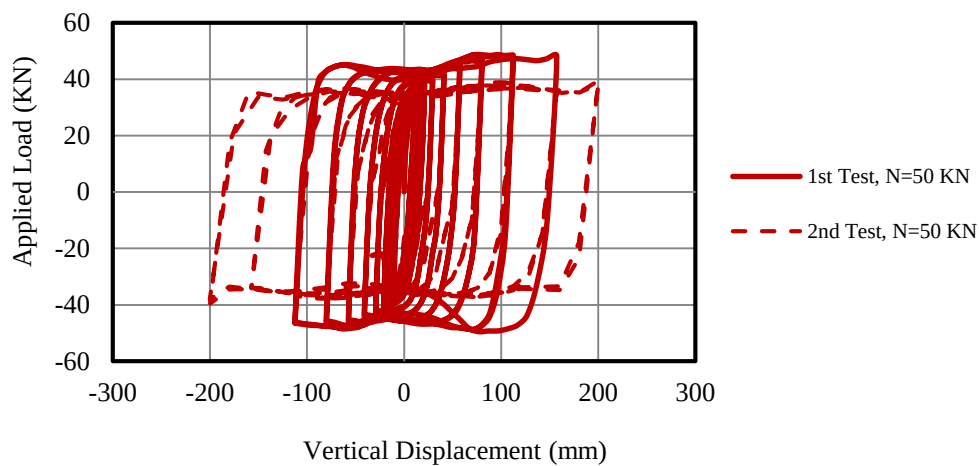
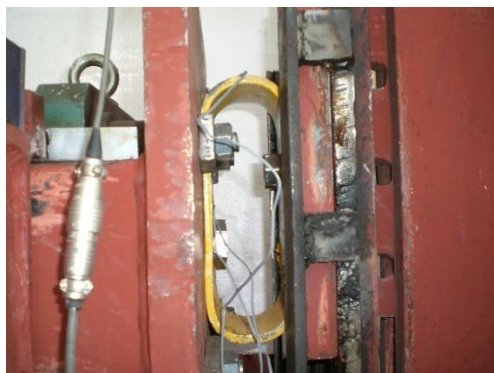
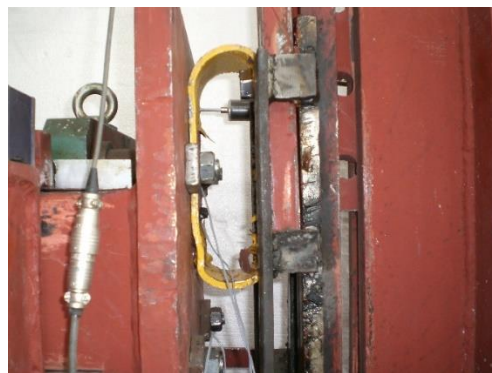


Figure 4.6 : Force-displacement relation from N+V (+) test of 8 mm thick specimen.



Partially deformed shape of the specimen



Ultimate deformed shape of the specimen

Figure 4.7 : Deformed shapes of the specimen during the test.

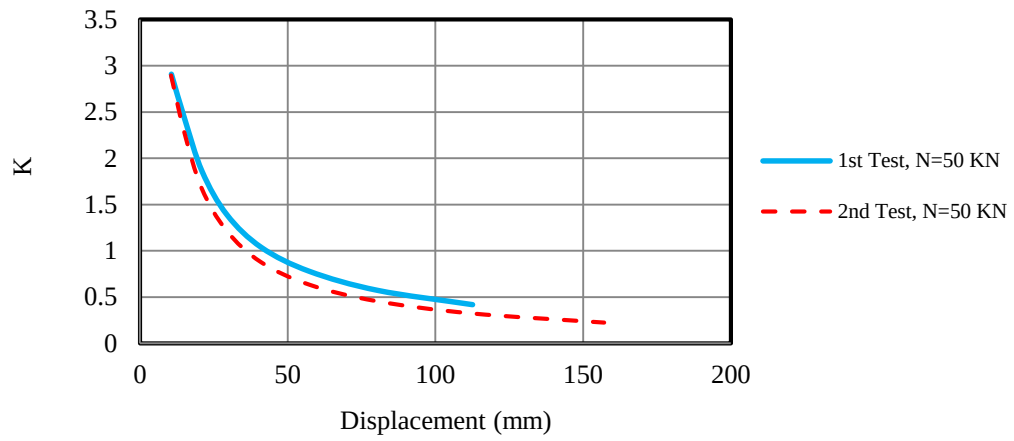


Figure 4.8 : Stiffness-displacement Relation for 8 mm thick specimen.

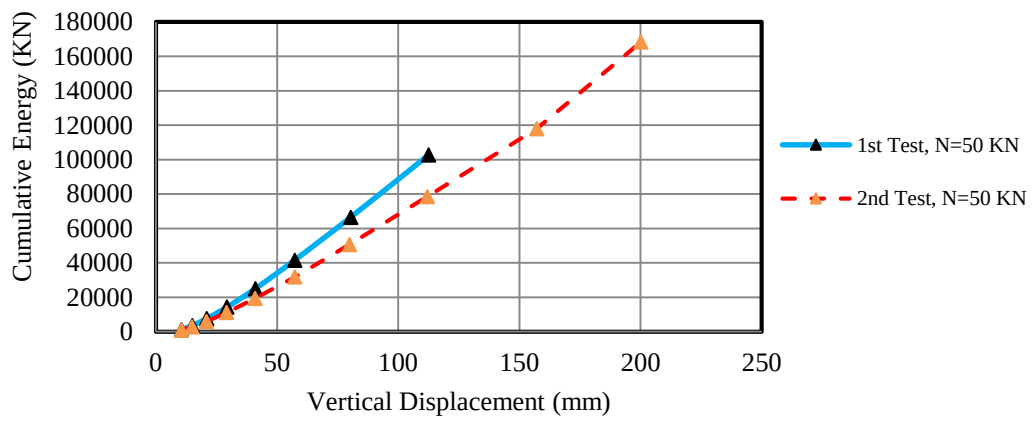


Figure 4.9 : Cumulative energy-displacement relation of 8 mm thick specimen.

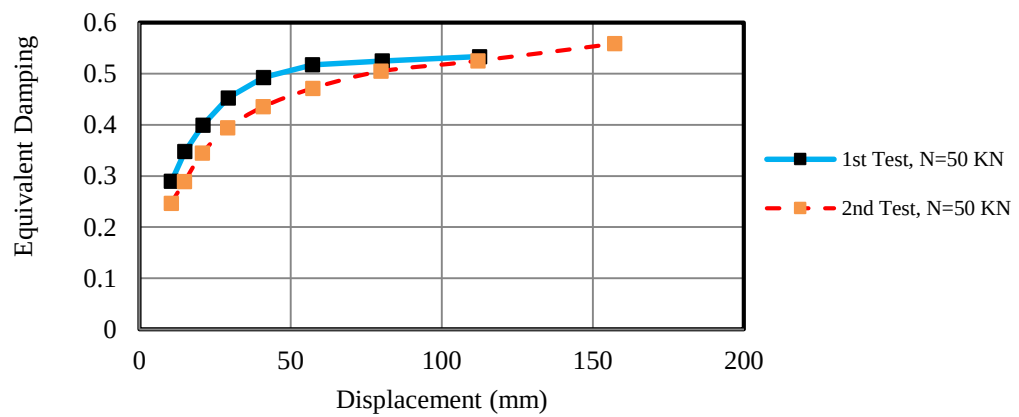


Figure 4.10 : Equivalent damping-displacement relation of 8 mm thick specimen.

4.1.1.3. 75 kN axial load

Two similar N+V(+) tests were carried out on 8 mm thick specimen for 75 kN compression axial load. Cycles obtained from the tests are presented in Figure 4.11.

8 mm thick steel specimen has a nominal strength of 39 kN from first test and 51 kN from second test, as well as a maximum displacement capacity of 200 mm. The ultimate compression strength of 8 mm thick specimen is 47 kN. Based on the obtained strain gauges measurements from two tests, the average yielding displacement is calculated as 10.53 mm. The specimen has a symmetric behavior.

Some cracks are observed at the final steps of the test. The first specimen ruptured at the end of the test.

The partially deformed shape of the specimen and the ultimate deformed shape are presented in Figure 4.12.

The stiffness of the specimen at the beginning of the test is about 3.13 kN/mm while it is calculated as 0.26 kN/mm at the end of the test, Figure 4.13.

The cumulative energy which is calculated as the enclosed area of force-displacement curve is equal to 200000 kN.mm, Figure 4.14.

The ultimate equivalent damping calculated from the tests is about 54 percent, Figure 4.15.

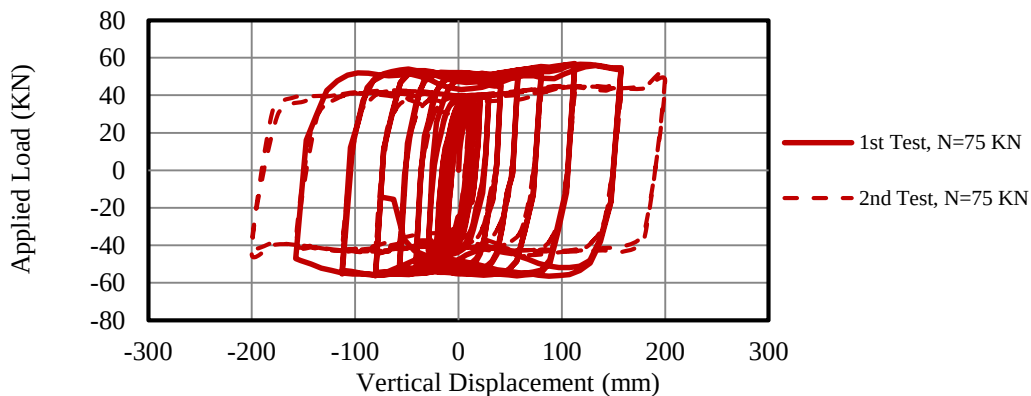
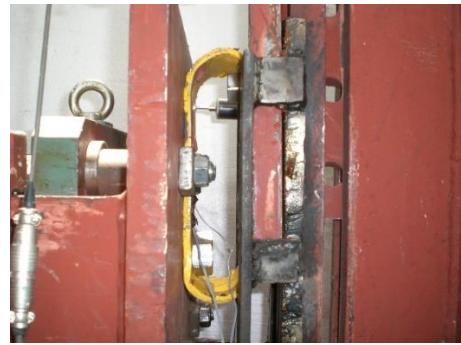


Figure 4.11 : Force-displacement relation from N+V (+) test of 8 mm thick specimen.



Partially deformed shape of the specimen



Ultimate deformed shape of the specimen

Figure 4.12 : Deformed shapes of the specimen during the test.

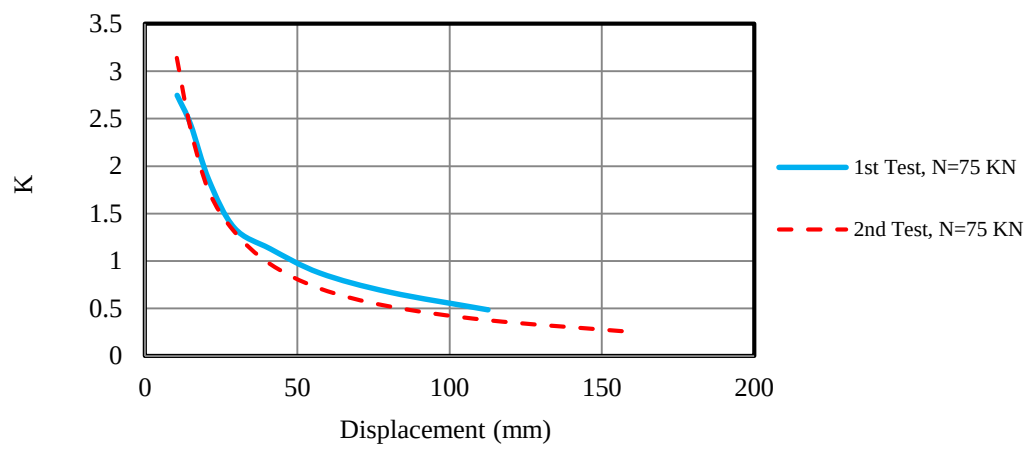


Figure 4.13 : Stiffness-displacement relation for 8 mm thick specimen.

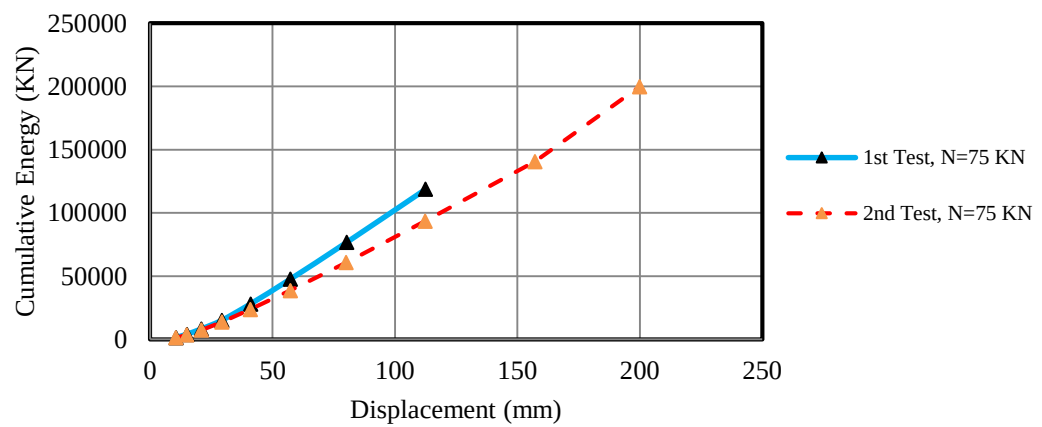


Figure 4.14 : Cumulative energy-displacement relation of 8 mm thick specimen.

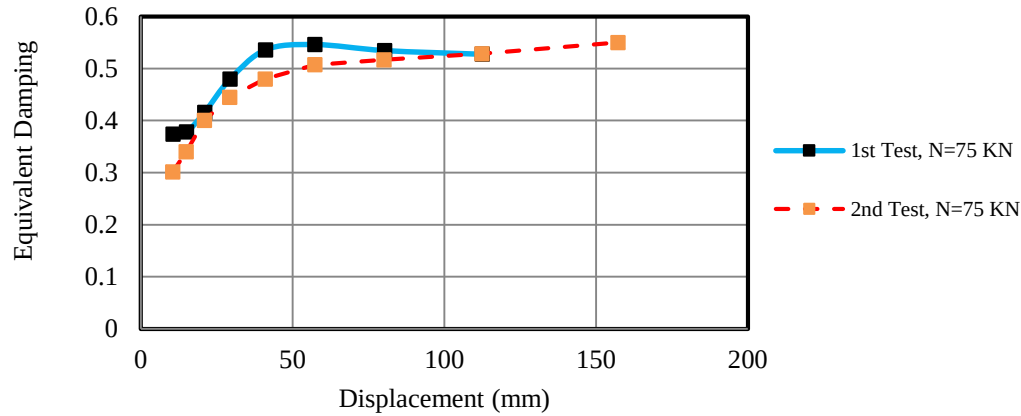


Figure 4.15 : Equivalent damping-displacement relation of 8 mm thick specimen.

4.1.2. 5 mm thick specimen

4.1.2.1. 7.5 kN axial load

Two similar N+V(+) tests were carried out on 5 mm thick specimen for 7.5 kN compression axial load. Cycles obtained from the tests are presented in Figure 4.16.

5 mm thick steel specimen has a nominal strength of 10 kN from first test and 8 kN from second test, as well as a maximum displacement capacity of 200 mm. The ultimate compression strength of 5 mm thick specimen is 17 kN. Based on the obtained strain gauges measurements from two tests, the average yielding displacement is calculated as 12.75 mm. The specimen has a symmetric behavior.

Some cracks are observed at the final steps of the test. The first specimen ruptured at the end of the test.

The partially deformed shape of the specimen and the ultimate deformed shape are presented in Figure 4.17.

The stiffness of the specimen at the beginning of the test is about 0.84 kN/mm while it is calculated as 0.062 kN/mm at the end of the test, Figure 4.18.

The cumulative energy which is calculated as the enclosed area of force-displacement curve is equal to 42500 kN.mm, Figure 4.19.

The ultimate equivalent damping calculated from the tests is about 54 percent, Figure 4.20.

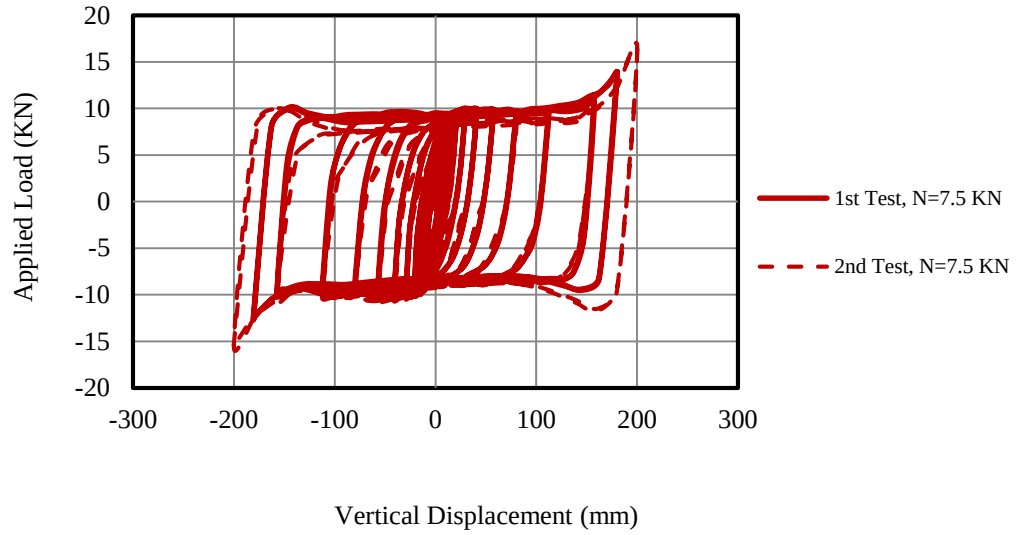
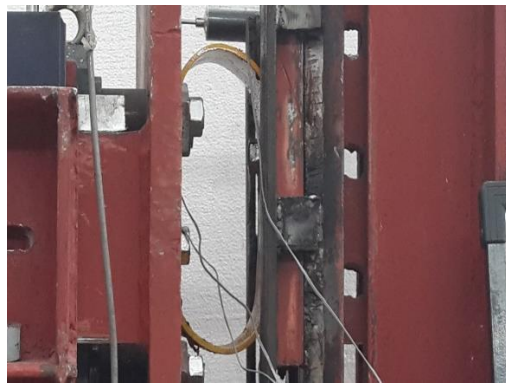
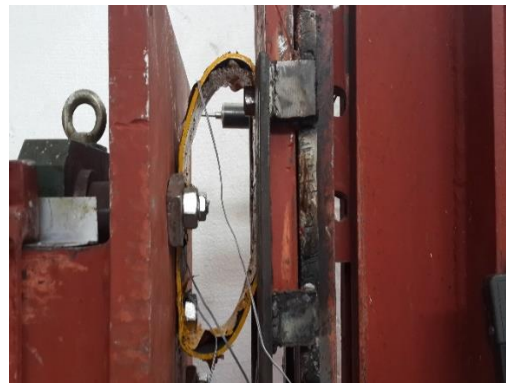


Figure 4.16 : Force-displacement relation from N+V (+) test of 5 mm thick specimen.



Partially deformed shape of the specimen



Ultimate deformed shape of the specimen

Figure 4.17 : Deformed shapes of the specimen during the test.

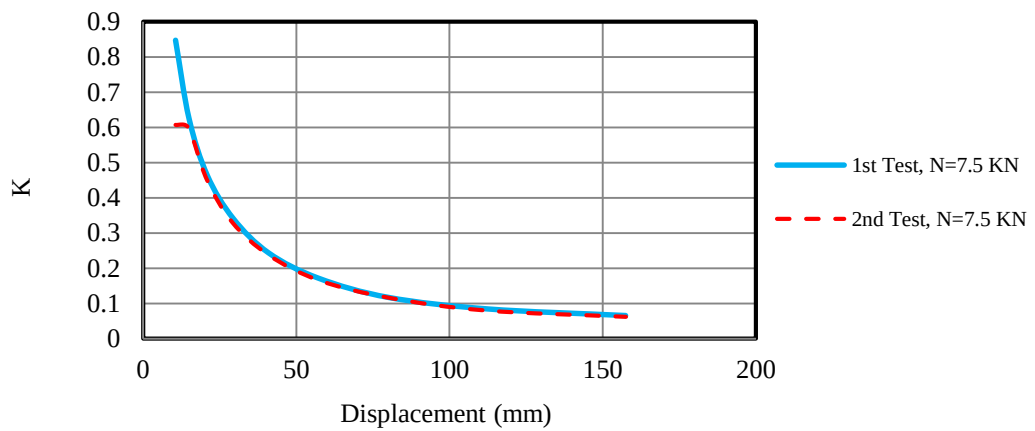


Figure 4.18 : Stiffness-displacement relation for 5 mm thick specimen.

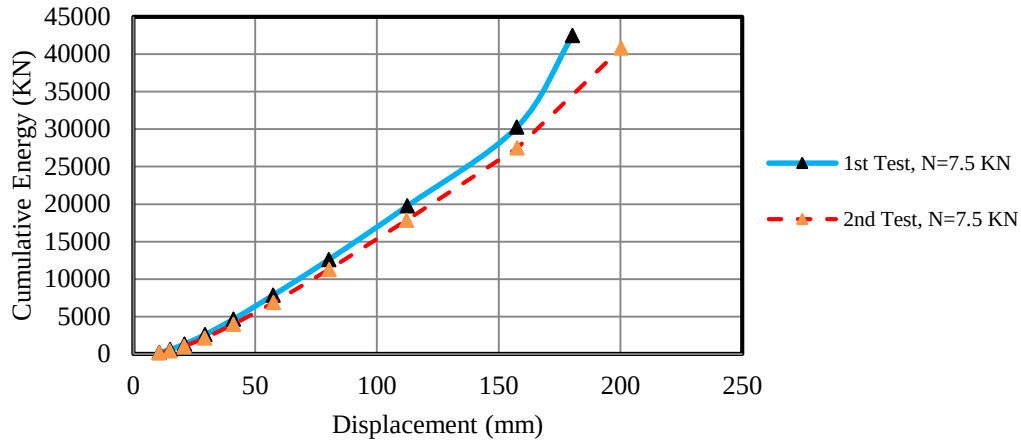


Figure 4.19 : Cumulative energy-displacement relation of 5 mm thick specimen.

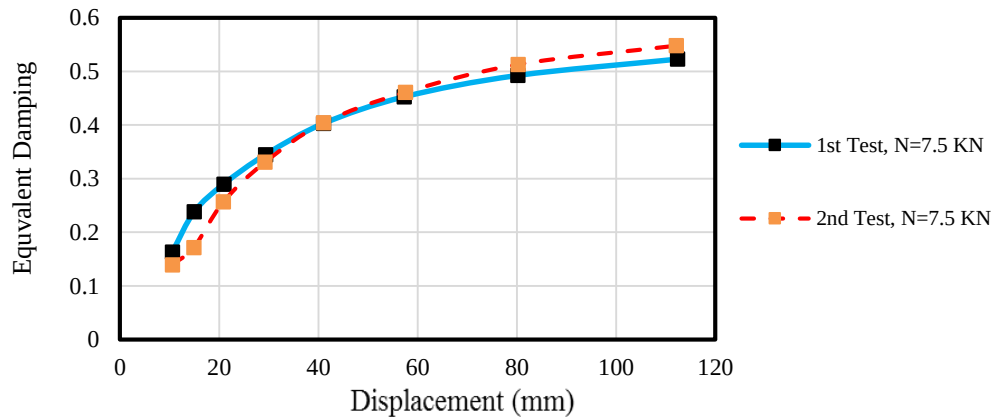


Figure 4.20 : Equivalent damping-displacement relation of 5 mm thick specimen.

4.1.2.2. 15 kN axial load

Two similar N+V(+) tests were carried out on 5 mm thick specimen for 15 kN compression axial load. Cycles obtained from the tests are presented in Figure 4.21.

5 mm thick steel specimen has a nominal strength of 10 kN from first test and 9 kN from second test, as well as a maximum displacement capacity of 200 mm. The ultimate compression strength of 5 mm thick specimen is 16.3 kN. Based on the obtained strain gauges measurements from two tests, the average yielding displacement is calculated as 10.57 mm. The specimen has a symmetric behavior.

Some cracks are observed at the final steps of the test. The first specimen ruptured at the end of the test.

The partially deformed shape of the specimen and the ultimate deformed shape are presented in Figure 4.22.

The stiffness of the specimen at the beginning of the test is about 0.88 kN/mm while it is calculated as 0.068 kN/mm at the end of the test, Figure 4.23.

The cumulative energy which is calculated as the enclosed area of force-displacement curve is equal to 49000 kN.mm, Figure 4.24.

The ultimate equivalent damping calculated from the tests is about 58 percent, Figure 4.25.

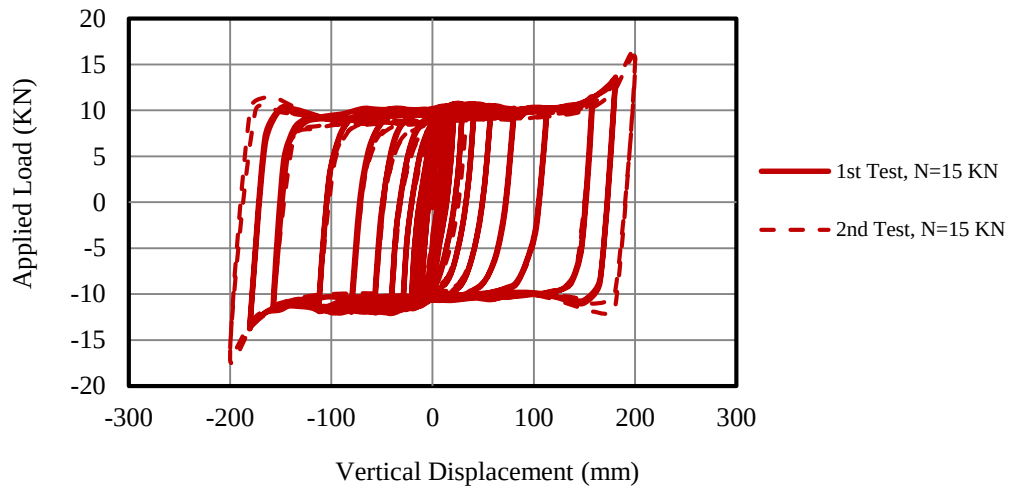
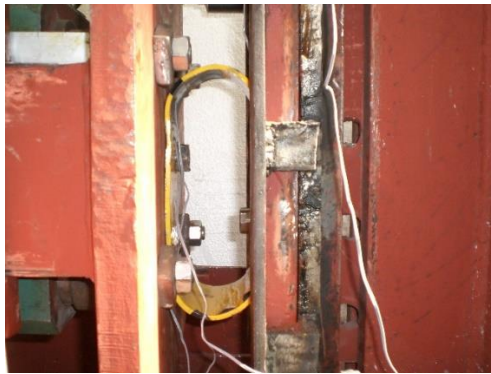
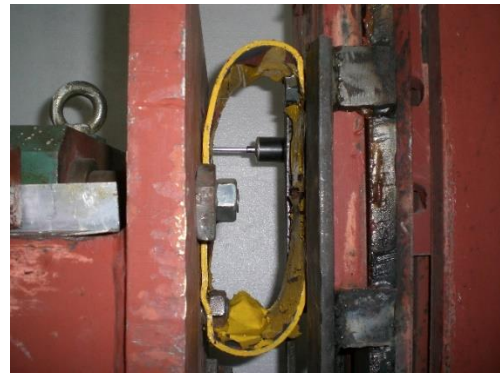


Figure 4.21 : Force-displacement relation from N+V (+) test of 5 mm thick specimen.



Partially deformed shape of the specimen



Ultimate deformed shape of the specimen

Figure 4.22 : Deformed shapes of the specimen during the test.

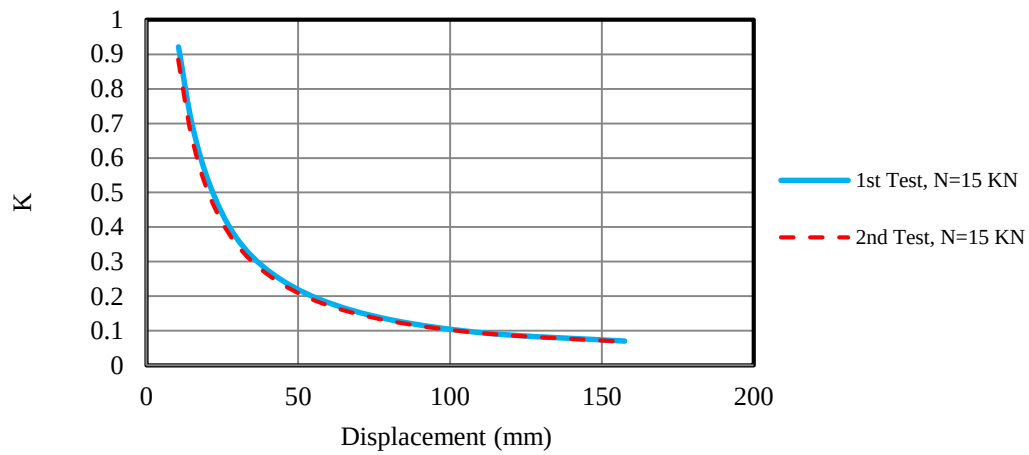


Figure 4.23 : Stiffness-displacement relation for 5 mm thick specimen.

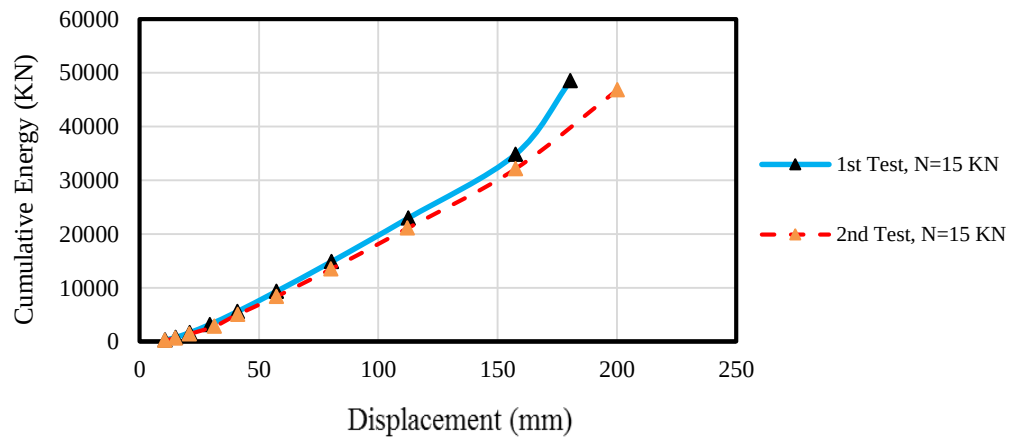


Figure 4.24 : Cumulative energy-displacement relation of 5 mm thick specimen.

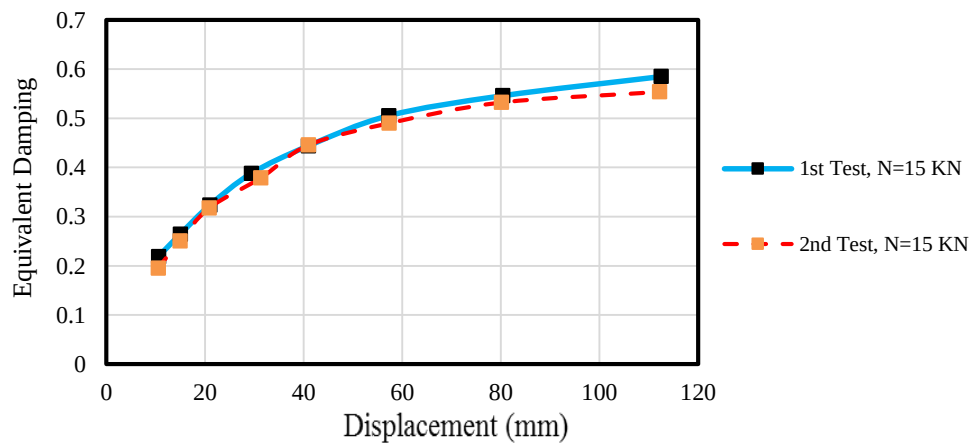


Figure 4.25 : Equivalent damping-displacement relation of 5 mm thick specimen.

4.1.2.3. 25 kN axial load

Two similar N+V(+) tests were carried out on 5 mm thick specimen for 25 kN compression axial load. Cycles obtained from the tests are presented in Figure 4.26.

5 mm thick steel specimen has a nominal strength of 11.5 kN from first test and 10.5 kN from second test, as well as a maximum displacement capacity of 200 mm. The ultimate compression strength of 5 mm thick specimen is 16 kN. Based on the obtained strain gauges measurements from two tests, the average yielding displacement is calculated as 10.54 mm. The specimen has a symmetric behavior.

Some cracks are observed at the final steps of the test. The first specimen ruptured at the end of the test.

The partially deformed shape of the specimen and the ultimate deformed shape are presented in Figure 4.27.

The stiffness of the specimen at the beginning of the test is about 0.91 kN/mm while it is calculated as 0.077 kN/mm at the end of the test, Figure 4.28.

The cumulative energy which is calculated as the enclosed area of force-displacement curve is equal to 52000 kN.mm, Figure 4.29.

The ultimate equivalent damping calculated from the tests is about 59 percent, Figure 4.30.

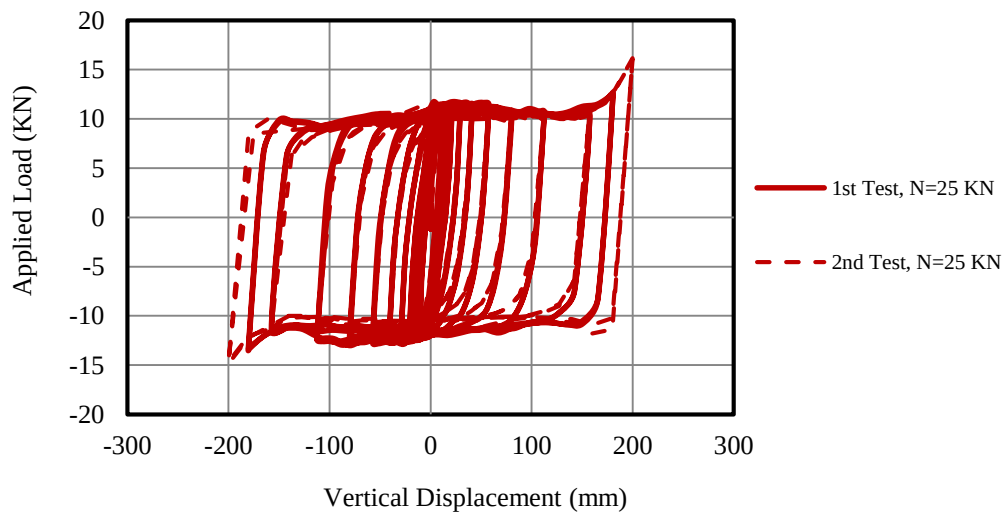
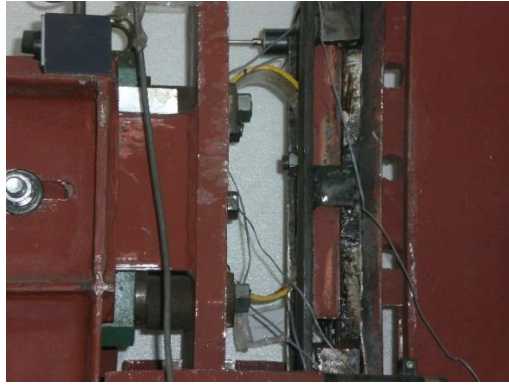
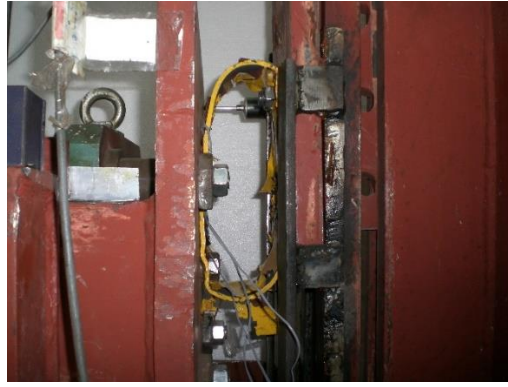


Figure 4.26 : Force-displacement relation from N+V (+) test of 5 mm thick specimen.



Partially deformed shape of the specimen



Ultimate deformed shape of the specimen

Figure 4.27 : Deformed shapes of the specimen during the test.

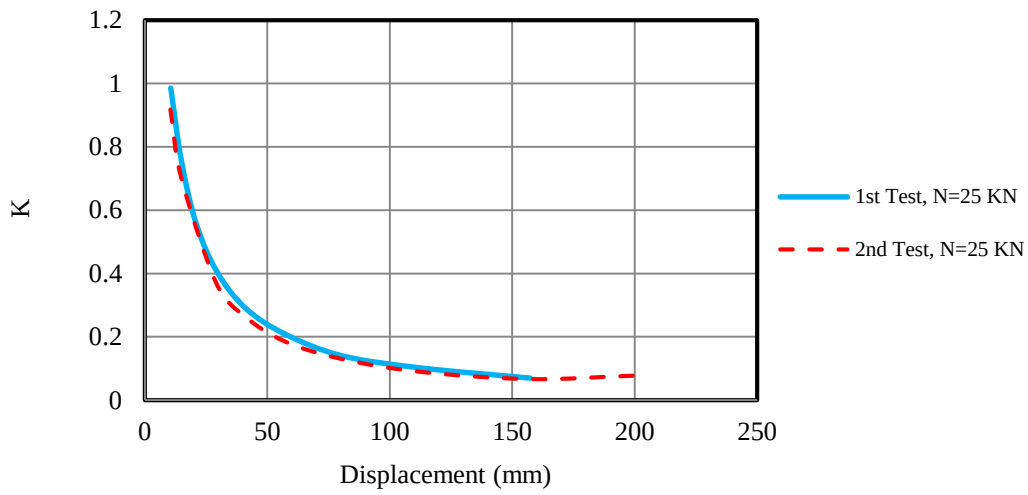


Figure 4.28 : Stiffness-displacement relation for 5 mm thick specimen.

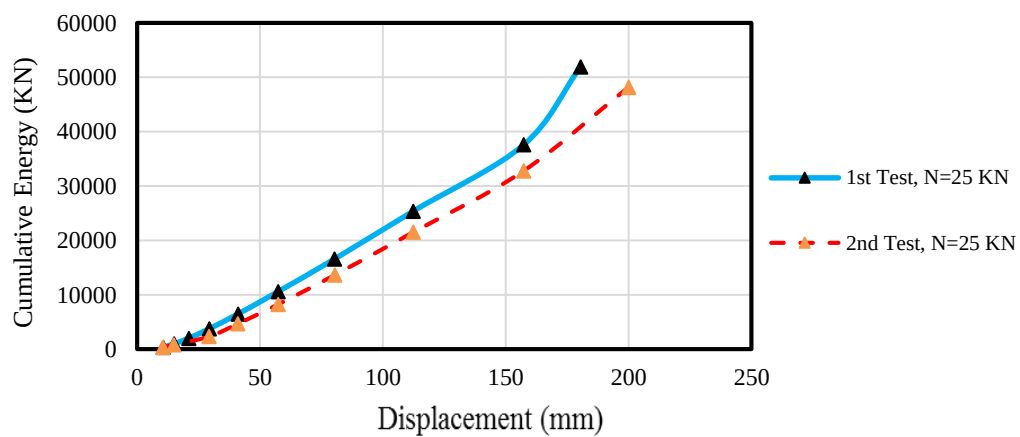


Figure 4.29 : Cumulative energy-displacement relation of 5 mm thick specimen.

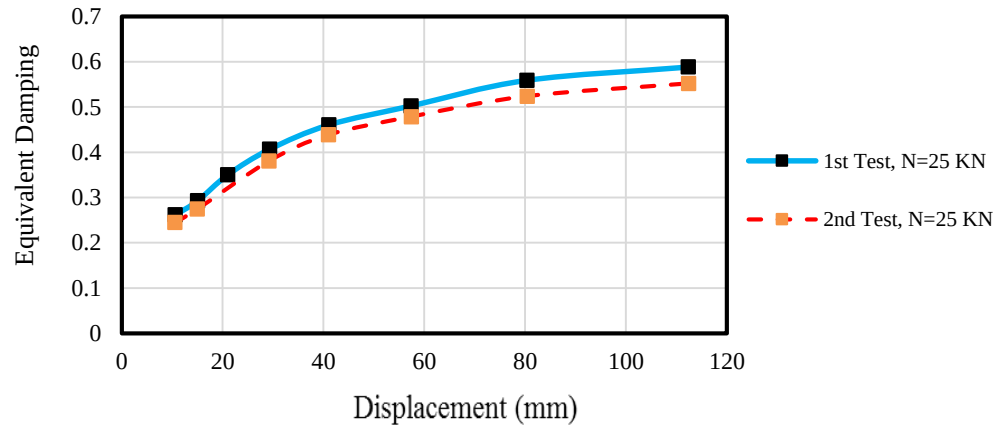


Figure 4.30 : Equivalent damping-displacement relation of 5 mm thick specimen.

4.1.3. 3 mm thick specimen

4.1.3.1. 2.5 kN axial load

Two similar N+V(+) tests were carried out on 3 mm thick specimen for 2.5 kN compression axial load. Cycles obtained from the tests are presented in Figure 4.31.

3 mm thick steel specimen has a nominal strength of 2 kN from first test and 1.5 kN from second test, as well as a maximum displacement capacity of 200 mm. The ultimate compression strength of 3 mm thick specimen is 3.7 kN. Based on the obtained strain gauges measurements from two tests, the average yielding displacement is calculated as 10.59 mm. The specimen has a symmetric behavior.

Some cracks are observed at the final steps of the test. The first specimen ruptured at the end of the test.

The partially deformed shape of the specimen and the ultimate deformed shape are presented in Figure 4.32.

The stiffness of the specimen at the beginning of the test is about 0.21 kN/mm while it is calculated as 0.019 kN/mm at the end of the test, Figure 4.33.

The cumulative energy which is calculated as the enclosed area of force-displacement curve is equal to 12000 kN.mm, Figure 4.34.

The ultimate equivalent damping calculated from the tests is about 53 percent, Figure 4.35.

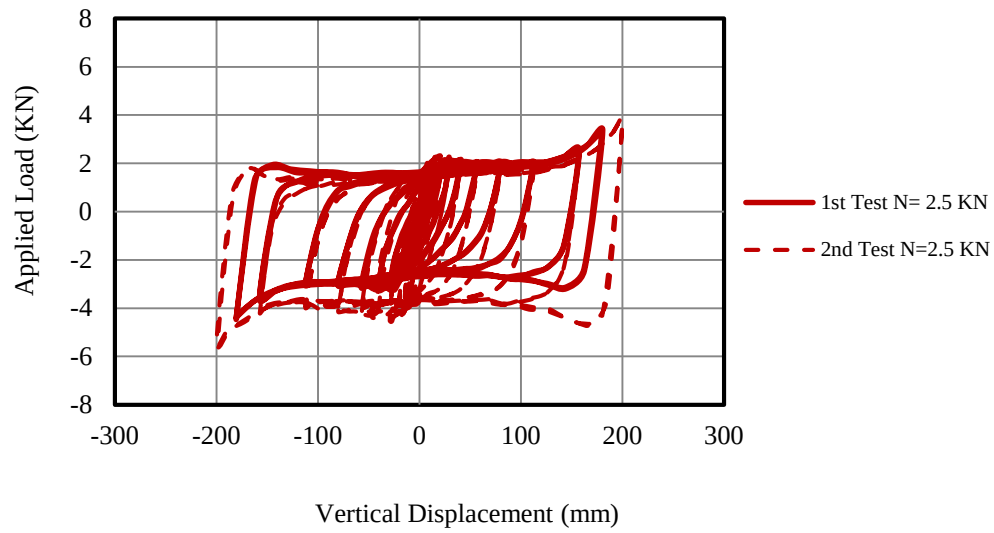
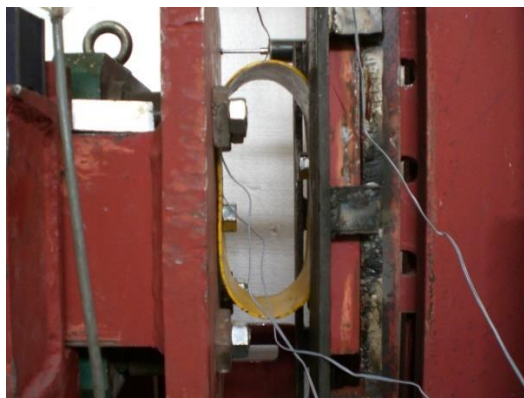
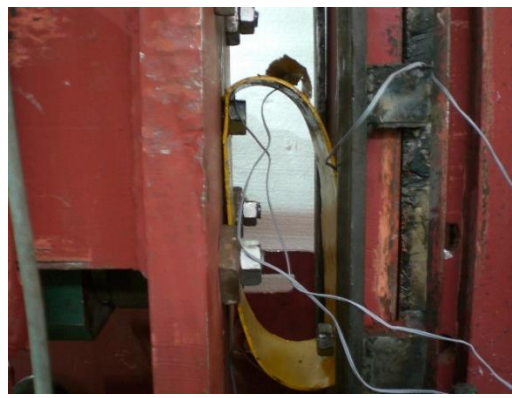


Figure 4.31 : Force-displacement relation from N+V (+) test of 3 mm thick specimen.



Partially deformed shape of the specimen



Ultimate deformed shape of the specimen

Figure 4.32 : Deformed shapes of the specimen during the test.

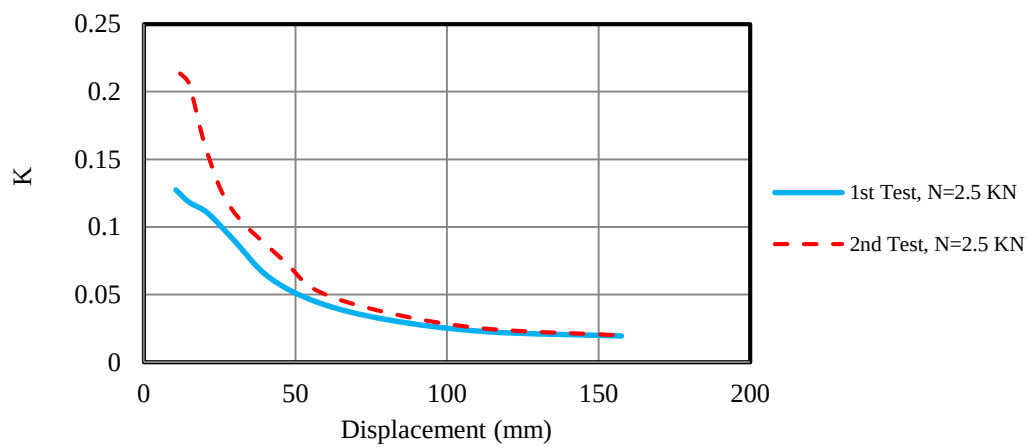


Figure 4.33 : Stiffness-displacement relation for 3 mm thick specimen.

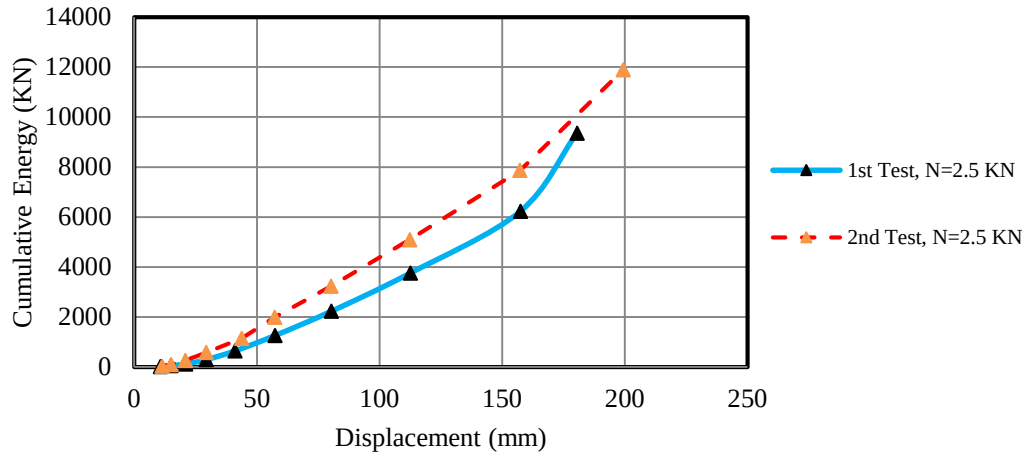


Figure 4.34 : Cumulative energy-displacement relation of 3 mm thick specimen.

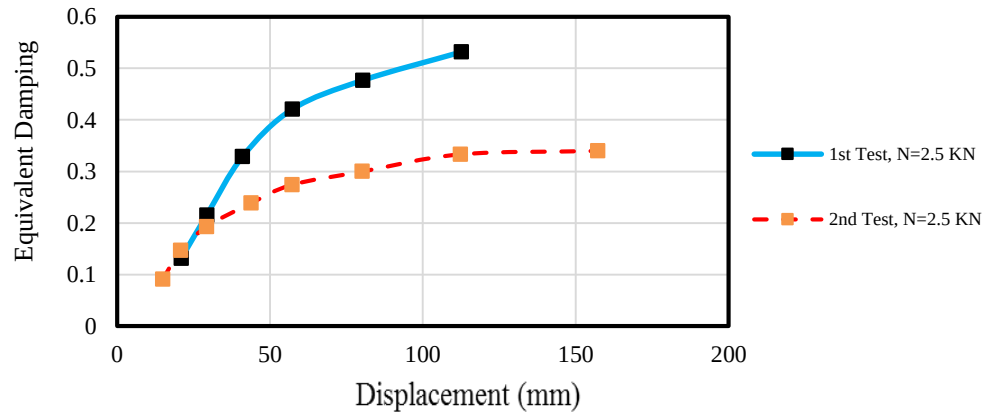


Figure 4.35 : Equivalent damping-displacement relation of 3 mm thick specimen.

4.1.3.2. 7.5 kN axial load

Two similar N+V(+) tests were carried out on 3 mm thick specimen for 7.5 kN compression axial load. Cycles obtained from the tests are presented in Figure 4.36.

3 mm thick steel specimen has a nominal strength of 2.5 kN from first test and 2.6 kN from second test, as well as a maximum displacement capacity of 200 mm. The ultimate compression strength of 3 mm thick specimen is 4.4 kN. Based on the obtained strain gauges measurements from two tests, the average yielding displacement is calculated as 12.72 mm. The specimen has a symmetric behavior.

Some cracks are observed at the final steps of the test. None of the specimens ruptured at the end of the test.

The partially deformed shape of the specimen and the ultimate deformed shape are presented in Figure 4.37.

The stiffness of the specimen at the beginning of the test is about 0.33 kN/mm while it is calculated as 0.021 kN/mm at the end of the test, Figure 4.38.

The cumulative energy which is calculated as the enclosed area of force-displacement curve is equal to 12500 kN.mm, Figure 4.39.

The ultimate equivalent damping calculated from the tests is about 57 percent, Figure 4.40.

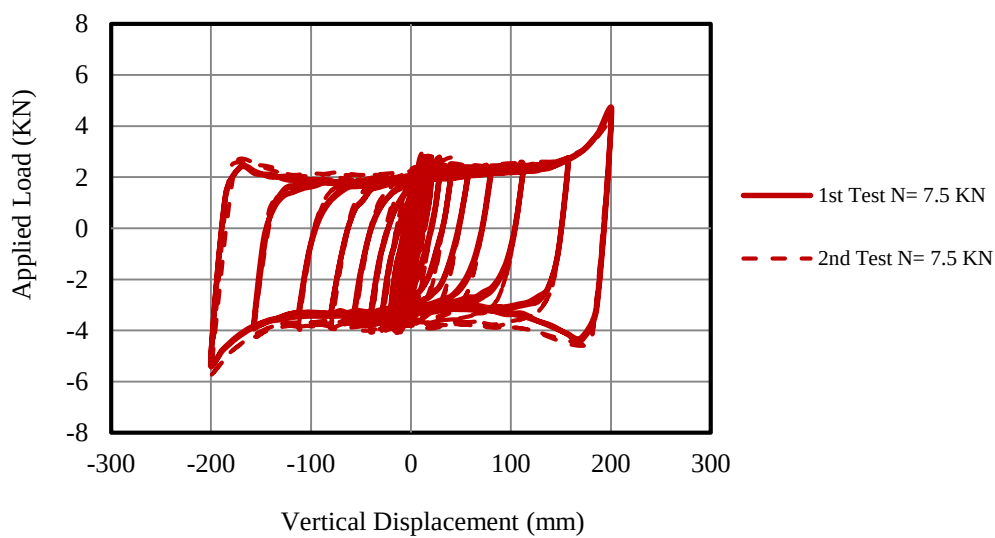
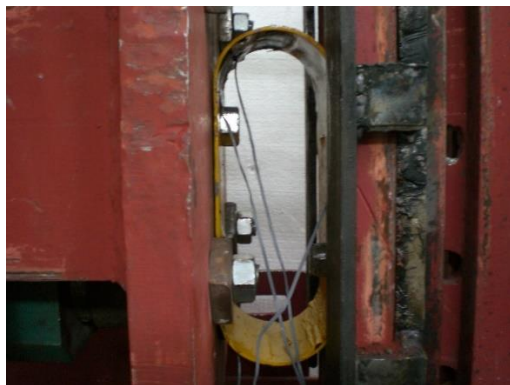


Figure 4.36 : Force-displacement relation from N+V (+) test of 3 mm thick specimen.



Partially deformed shape of the specimen



Ultimate deformed shape of the specimen

Figure 4.37 : Deformed shapes of the specimen during the test.

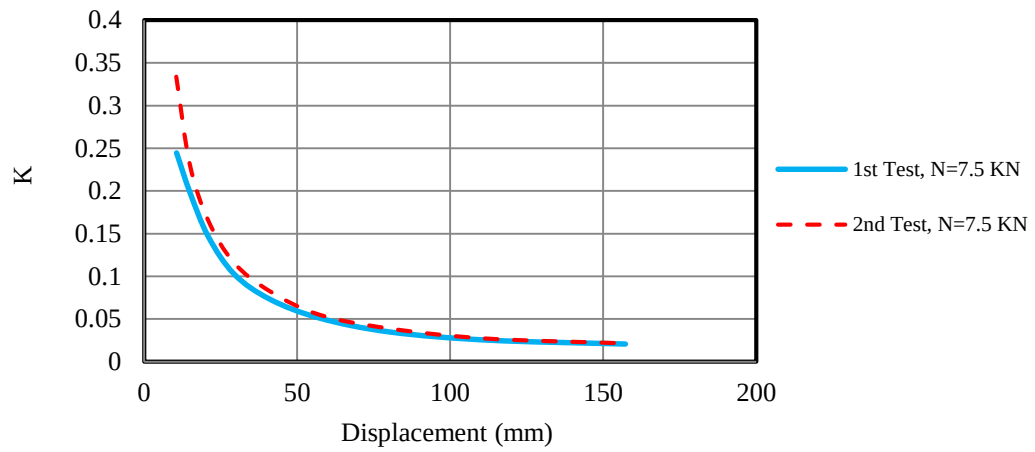


Figure 4.38 : Stiffness-displacement relation for 3 mm thick specimen.

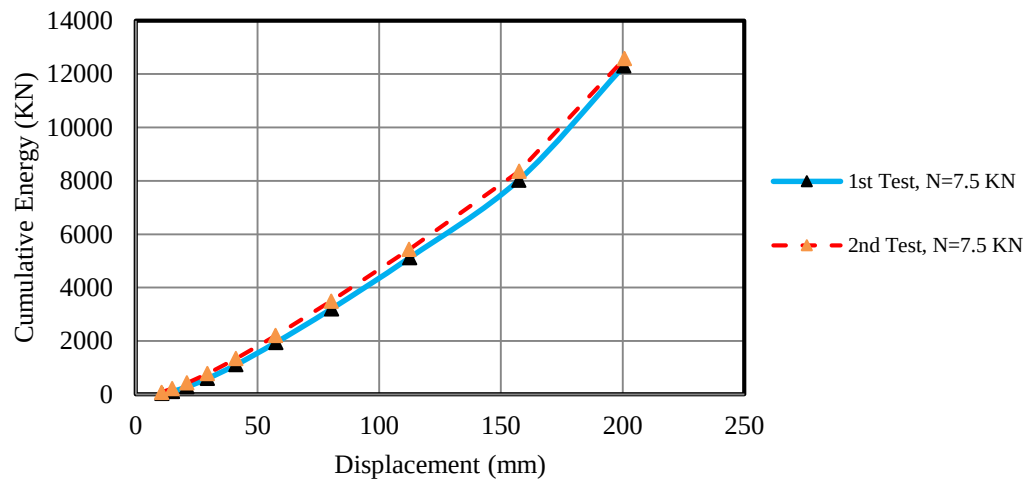


Figure 4.39 : Cumulative energy-displacement relation of 3 mm thick specimen.

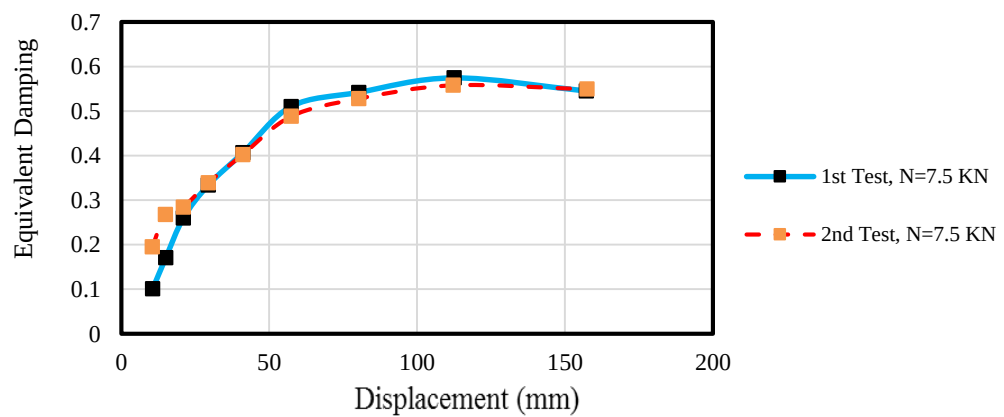


Figure 4.40 : Equivalent damping-displacement relation of 3 mm thick specimen.

4.1.3.3. 10 kN axial load

Two similar N+V(+) tests were carried out on 3 mm thick specimen for 10 kN compression axial load. Cycles obtained from the tests are presented in Figure 4.41.

3 mm thick steel specimen has a nominal strength of 2.4 kN from first test and 1.8 kN from second test, as well as a maximum displacement capacity of 200 mm. The ultimate compression strength of 3 mm thick specimen is 5 kN. Based on the obtained strain gauges measurements from two tests, the average yielding displacement is calculated as 12.73 mm. The specimen has a symmetric behavior.

Some cracks are observed at the final steps of the test. None of the specimens ruptured at the end of the test.

The partially deformed shape of the specimen and the ultimate deformed shape are presented in Figure 4.42.

The stiffness of the specimen at the beginning of the test is about 0.23 kN/mm while it is calculated as 0.02 kN/mm at the end of the test, Figure 4.43.

The cumulative energy which is calculated as the enclosed area of force-displacement curve is equal to 12000 kN.mm, Figure 4.44.

The ultimate equivalent damping calculated from the tests is about 85 percent, Figure 4.45.

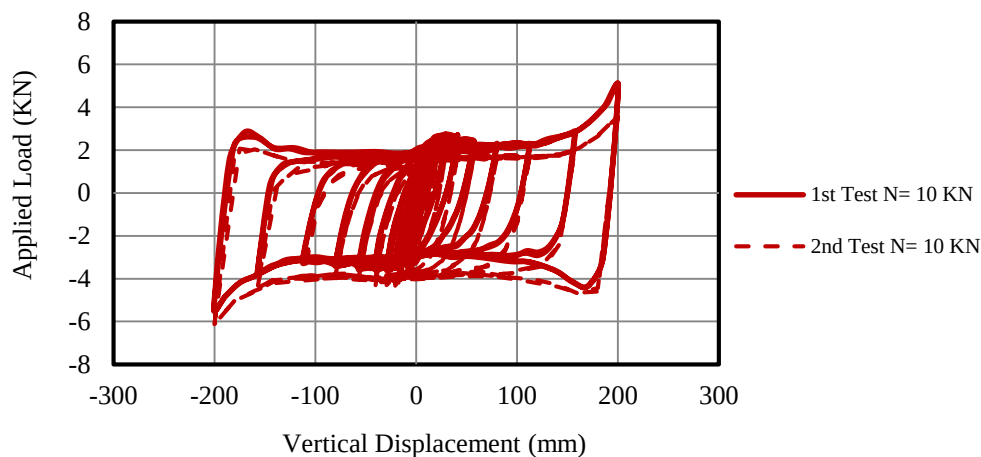


Figure 4.41 : Force-displacement relation from N+V (+) test of 3 mm thick specimen.



Partially deformed shape of the specimen



Ultimate deformed shape of the specimen

Figure 4.42 : Deformed shapes of the specimen during the test.

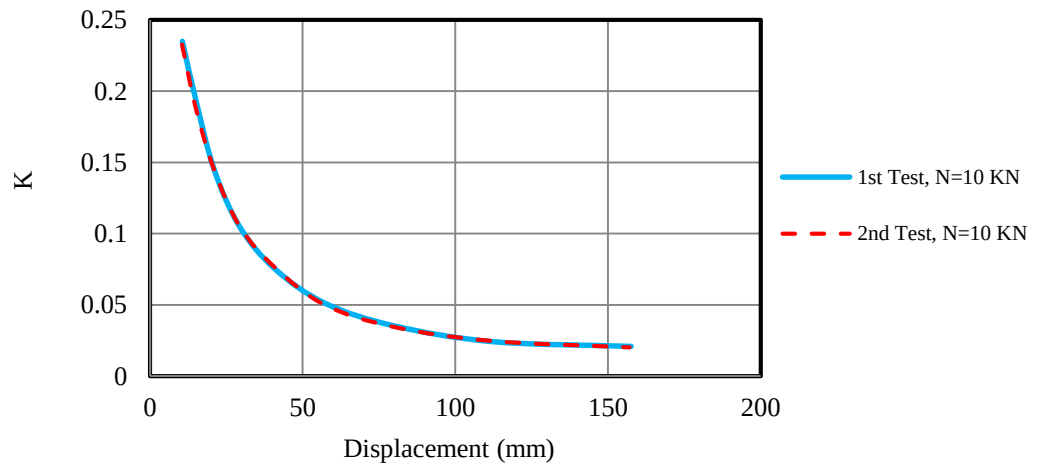


Figure 4.43 : Stiffness-displacement relation for 3 mm thick specimen.

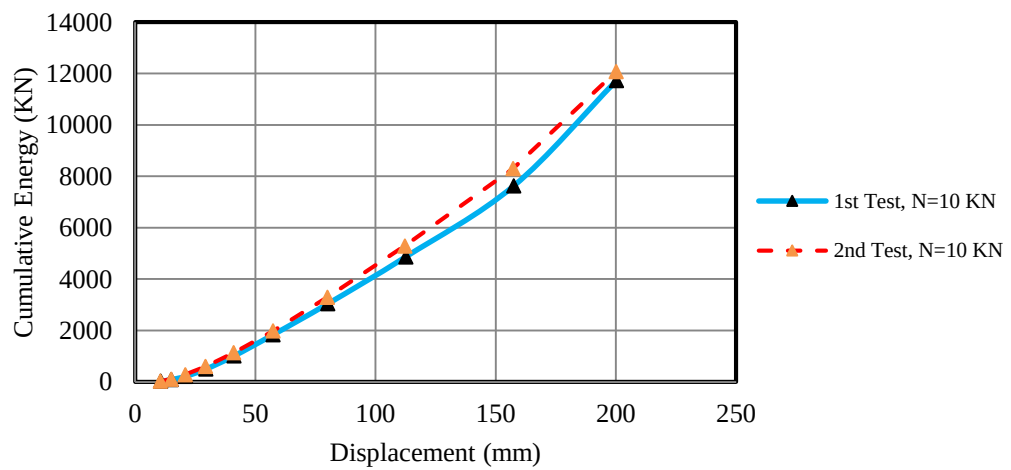


Figure 4.44 : Cumulative energy-displacement relation of 3 mm thick specimen.

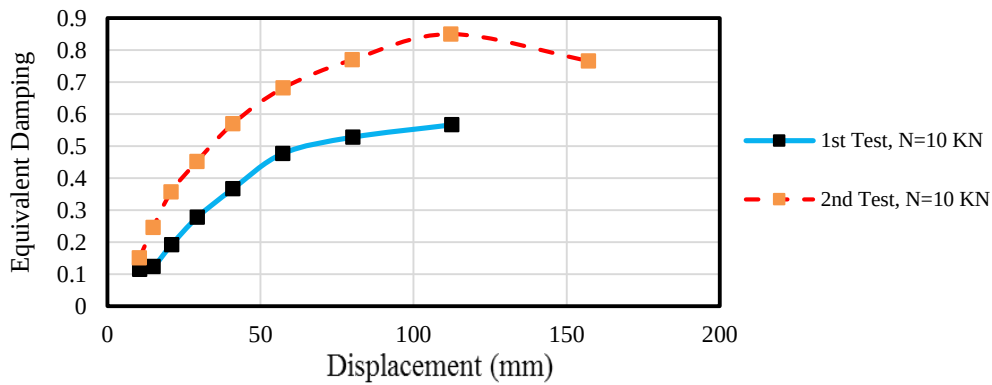


Figure 4.45 : Equivalent damping-displacement relation of 3 mm thick specimen.

4.2. Tension Tests For Bare Specimens

4.2.1. 8 mm thick specimen

4.2.1.1. 25 kN axial load

Two similar N+V(-) tests were carried out on 8 mm thick specimen for 25 kN tension axial load. Cycles obtained from the tests are presented in Figure 4.46.

8 mm thick steel specimen has a nominal strength of 18.5 kN from first test and 16.5 kN from second test, as well as a maximum displacement capacity of 180 mm. The ultimate compression strength of 8 mm thick specimen is 45 kN. Based on the obtained strain gauges measurements from two tests, the average yielding displacement is calculated as 10.54 mm. The specimen has a symmetric behavior.

Some cracks are observed at the final steps of the test. Both of the specimens ruptured at the end of the test.

The partially deformed shape of the specimen and the ultimate deformed shape are presented in Figure 4.47.

The stiffness of the specimen at the beginning of the test is about 2.1 kN/mm while it is calculated as 0.2 kN/mm at the end of the test, Figure 4.48.

The cumulative energy which is calculated as the enclosed area of force-displacement curve is equal to 100000 kN.mm, Figure 4.49.

The ultimate equivalent damping calculated from the tests is about 45 percent, Figure 4.50.

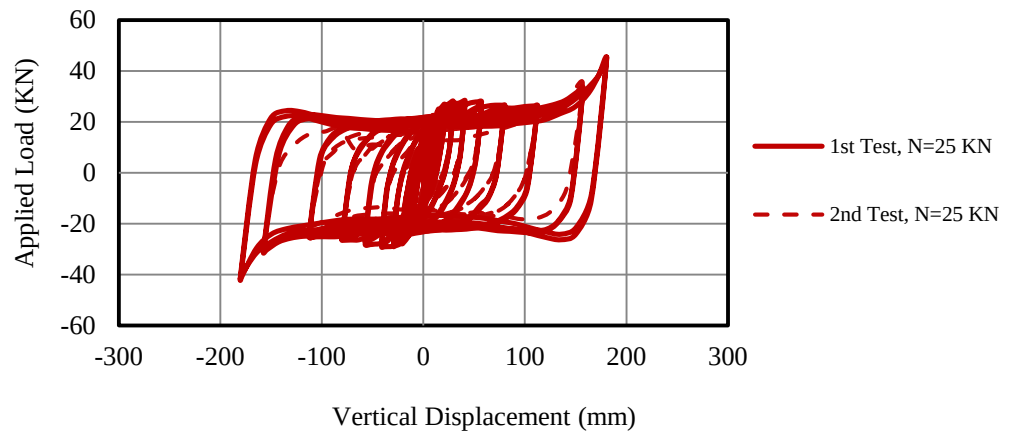


Figure 4.46 : Force-displacement relation from N+V (-) test of 8 mm thick specimen.

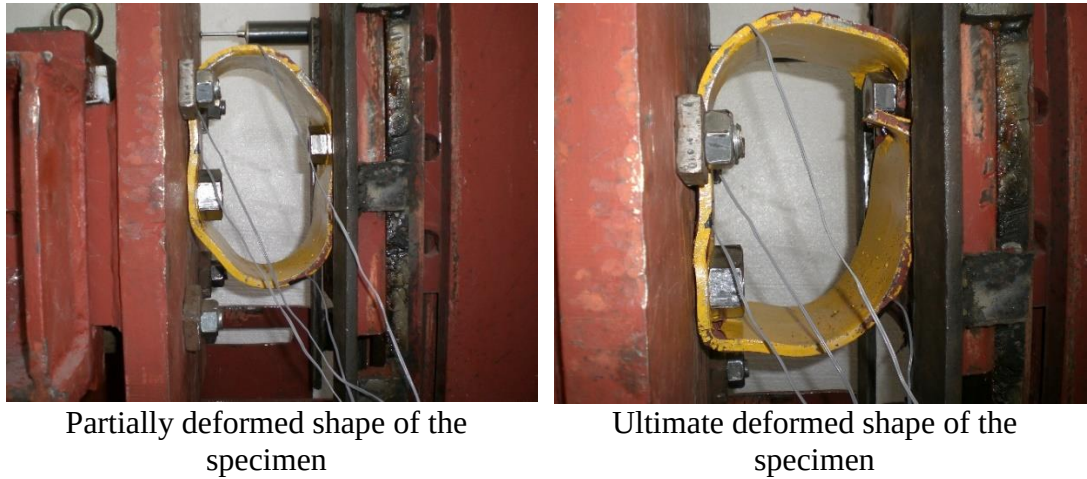


Figure 4.47 : Deformed shapes of the specimen during the test.

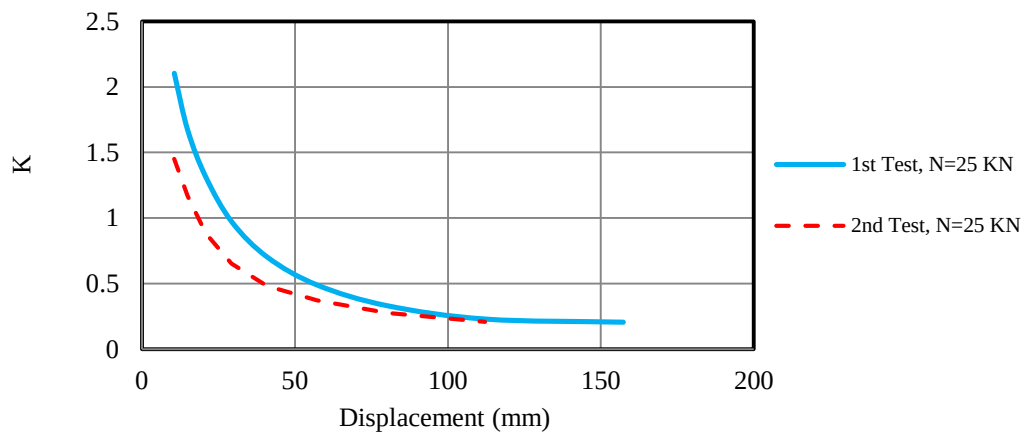


Figure 4.48 : Stiffness-displacement relation for 8 mm thick specimen.

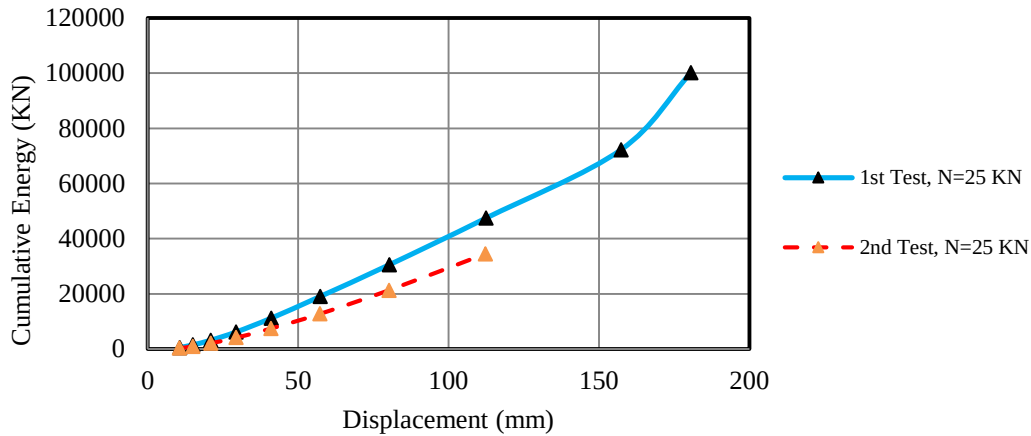


Figure 4.49 : Cumulative energy-displacement relation of 8 mm thick specimen.

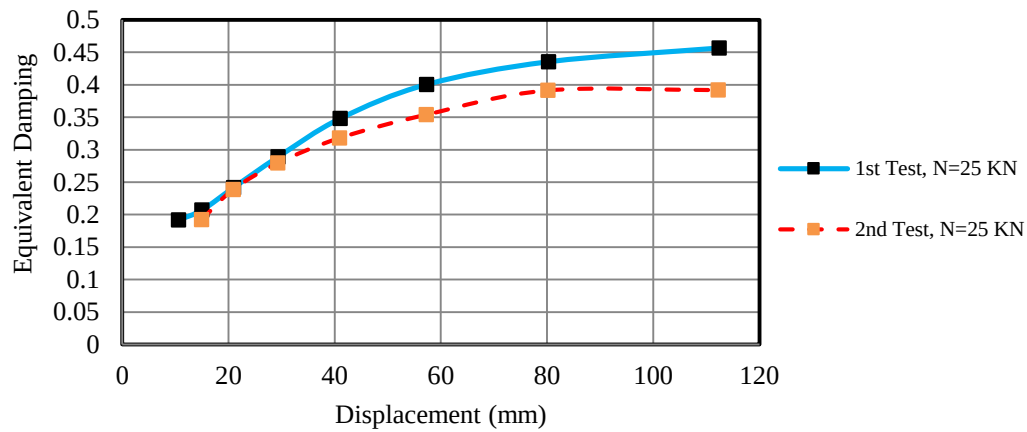


Figure 4.50 : Equivalent damping-displacement relation of 8 mm thick specimen.

4.2.1.2. 50 kN axial load

Two similar N+V(-) tests were carried out on 8 mm thick specimen for 50 kN tension axial load. Cycles obtained from the tests are presented in Figure 4.51.

8 mm thick steel specimen has a nominal strength of 16.8 kN from first test and 16.5 kN from second test, as well as a maximum displacement capacity of 200 mm. The ultimate compression strength of 8 mm thick specimen is 85 kN. Based on the obtained strain gauges measurements from two tests, the average yielding displacement is calculated as 10.54 mm. The specimen has a symmetric behavior.

Some cracks are observed at the final steps of the test. Both of the specimens ruptured at the end of the test.

The partially deformed shape of the specimen and the ultimate deformed shape are presented in Figure 4.52.

The stiffness of the specimen at the beginning of the test is about 1.41 kN/mm while it is calculated as 0.21 kN/mm at the end of the test, Figure 4.53.

The cumulative energy which is calculated as the enclosed area of force-displacement curve is equal to 55000 kN.mm, Figure 4.54.

The ultimate equivalent damping calculated from the tests is about 39 percent, Figure 4.55.

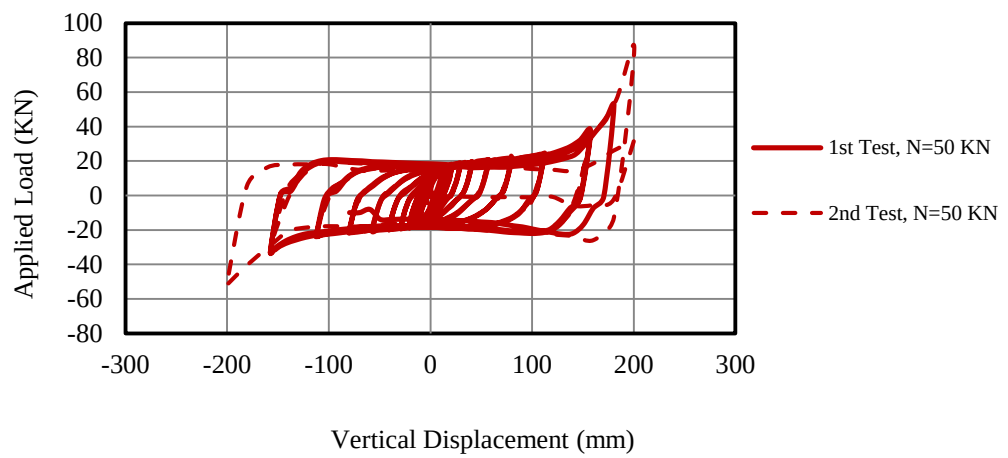


Figure 4.51 : Force-displacement relation from N+V (-) test of 8 mm thick specimen.



Partially deformed shape of the specimen



Ultimate deformed shape of the specimen

Figure 4.52 : Deformed shapes of the specimen during the test.

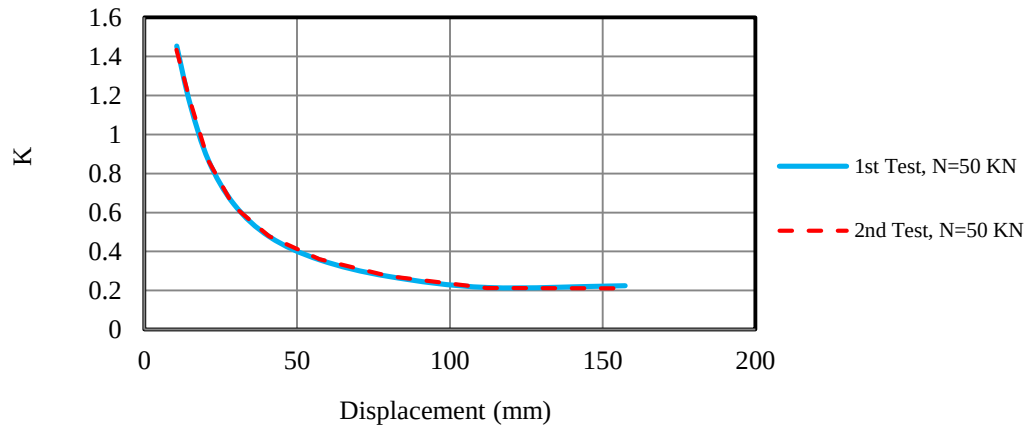


Figure 4.53 : Stiffness-displacement relation for 8 mm thick specimen.

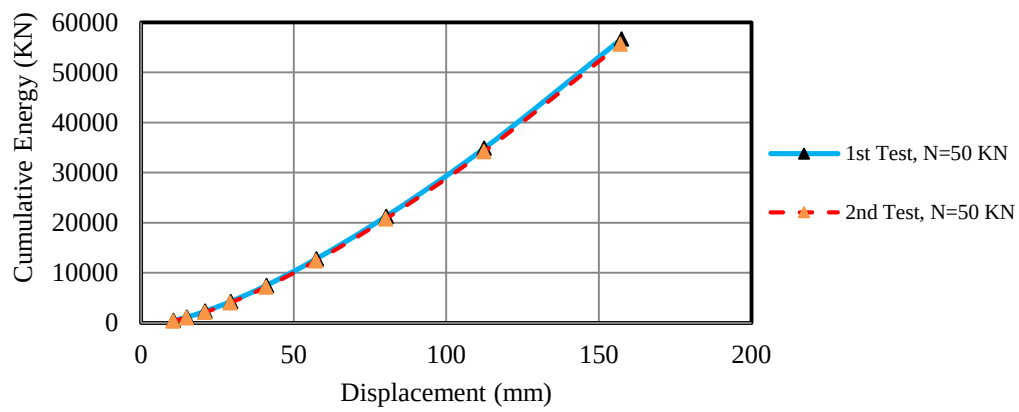


Figure 4.54 : Cumulative energy-displacement relation of 8 mm thick specimen.

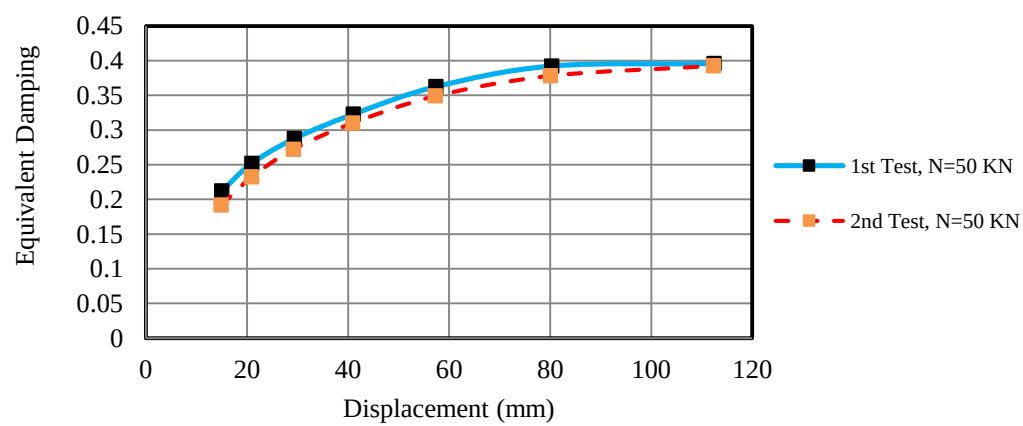


Figure 4.55 : Equivalent damping-displacement relation of 8 mm thick specimen.

4.2.1.3. 75 kN axial load

Two similar N+V(-) tests were carried out on 8 mm thick specimen for 75 kN tension axial load. Cycles obtained from the tests are presented in Figure 4.56.

8 mm thick steel specimen has a nominal strength of 16 kN from first test and 16.5 kN from second test, as well as a maximum displacement capacity of 180 mm. The ultimate compression strength of 8 mm thick specimen is 45 kN. Based on the obtained strain gauges measurements from two tests, the average yielding displacement is calculated as 10.53 mm. The specimen has a symmetric behavior.

Some cracks are observed at the final steps of the test. The first specimen ruptured at the end of the test.

The partially deformed shape of the specimen and the ultimate deformed shape are presented in Figure 4.57.

The stiffness of the specimen at the beginning of the test is about 1.41 kN/mm while it is calculated as 0.21 kN/mm at the end of the test, Figure 4.58.

The cumulative energy which is calculated as the enclosed area of force-displacement curve is equal to 54000 kN.mm, Figure 4.59.

The ultimate equivalent damping calculated from the tests is about 40 percent, Figure 4.60.

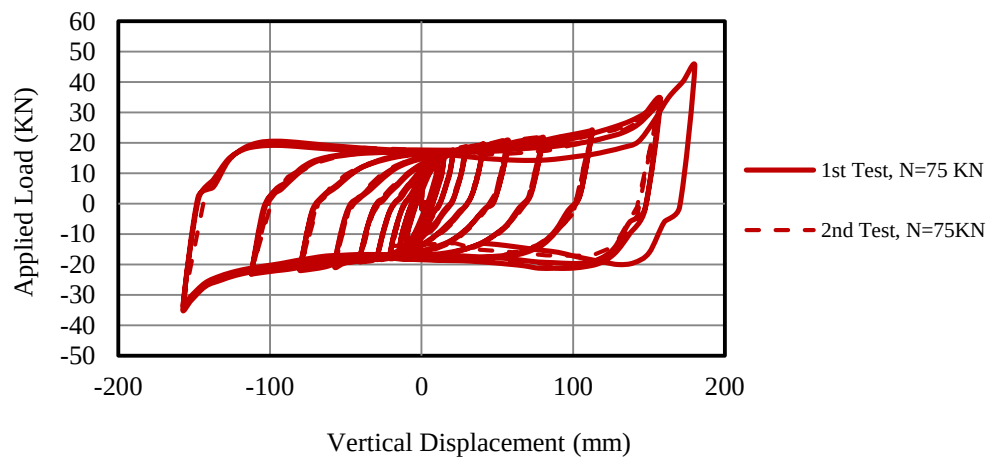


Figure 4.56 : Force-displacement relation from N+V (-) test of 8 mm thick specimen.



Partially deformed shape of the specimen



Ultimate deformed shape of the specimen

Figure 4.57 : Deformed shapes of the specimen during the test.

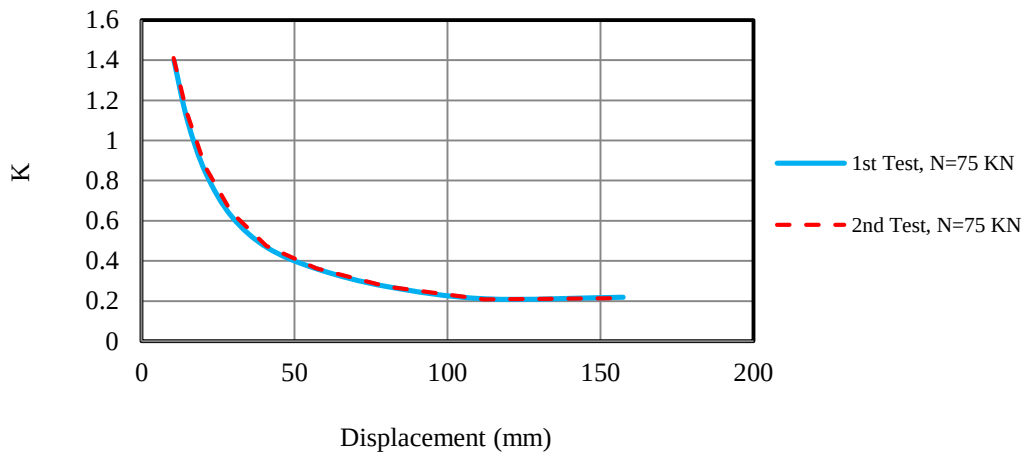


Figure 4.58 : Stiffness-displacement relation for 8 mm thick specimen.

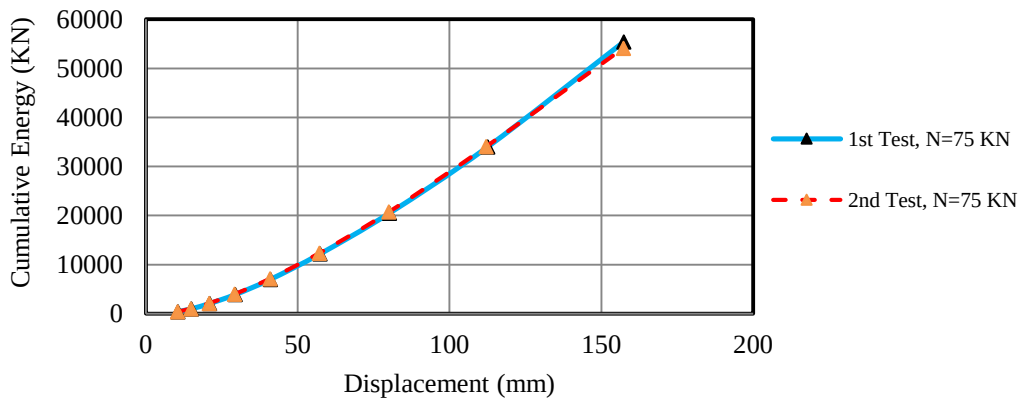


Figure 4.59 : Cumulative energy-displacement relation of 8 mm thick specimen.

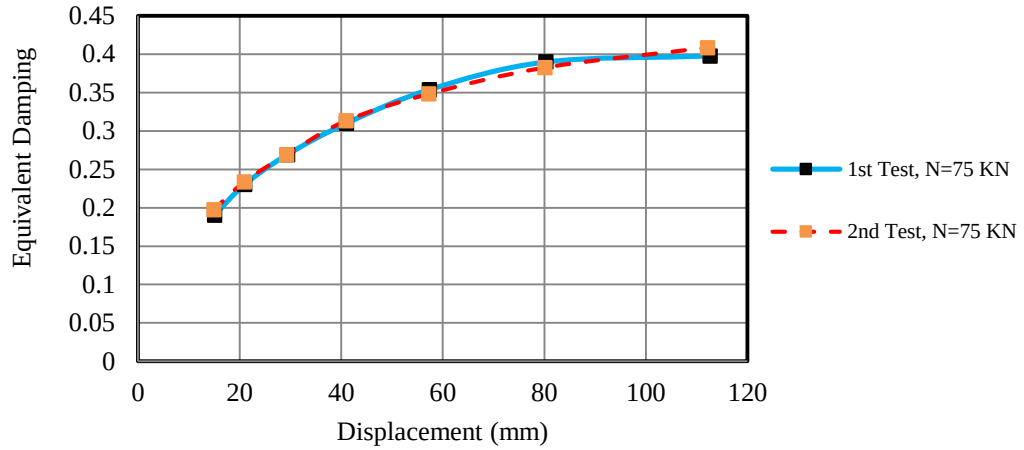


Figure 4.60 : Equivalent damping-displacement relation of 8 mm thick specimen.

4.2.2. 5 mm thick specimen

4.2.2.1. 7.5 kN axial load

Two similar N+V(-) tests were carried out on 5 mm thick specimen for 7.5 kN tension axial load. Cycles obtained from the tests are presented in Figure 4.61.

5 mm thick steel specimen has a nominal strength of 8 kN from first test and 8 kN from second test, as well as a maximum displacement capacity of 200 mm. The ultimate compression strength of 5 mm thick specimen is 16 kN. Based on the obtained strain gauges measurements from two tests, the average yielding displacement is calculated as 12.72 mm. The specimen has a symmetric behavior.

Some cracks are observed at the final steps of the test. Both specimens ruptured at the end of the test.

The partially deformed shape of the specimen and the ultimate deformed shape are presented in Figure 4.62.

The stiffness of the specimen at the beginning of the test is about 0.64 kN/mm while it is calculated as 0.061 kN/mm at the end of the test, Figure 4.63.

The cumulative energy which is calculated as the enclosed area of force-displacement curve is equal to 39000 kN.mm, Figure 4.64.

The ultimate equivalent damping calculated from the tests is about 54 percent, Figure 4.65.

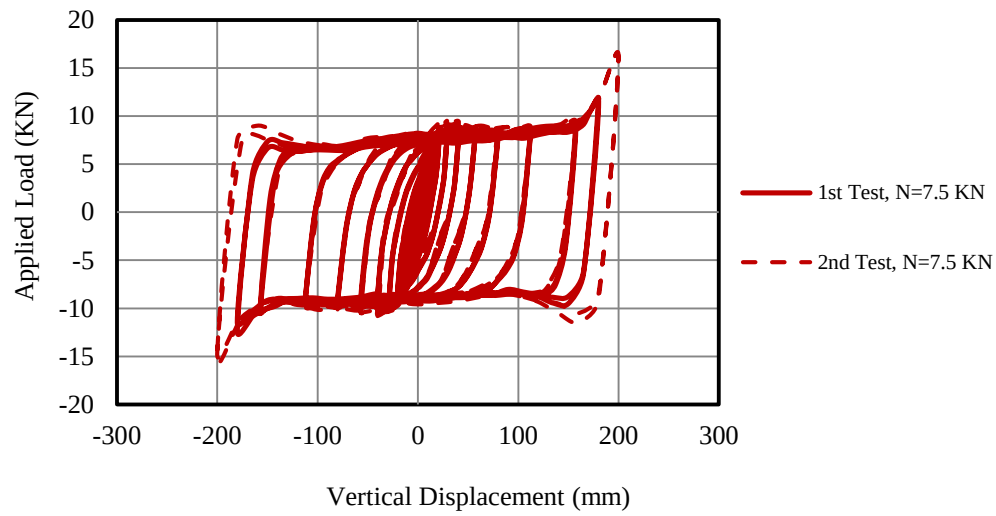
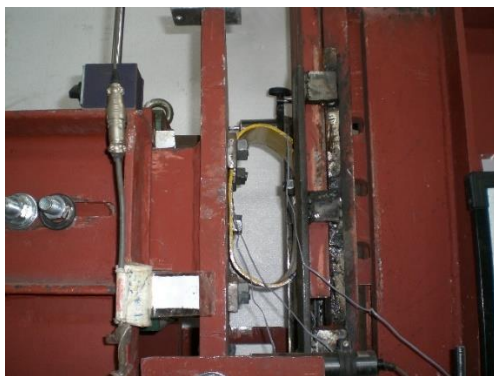
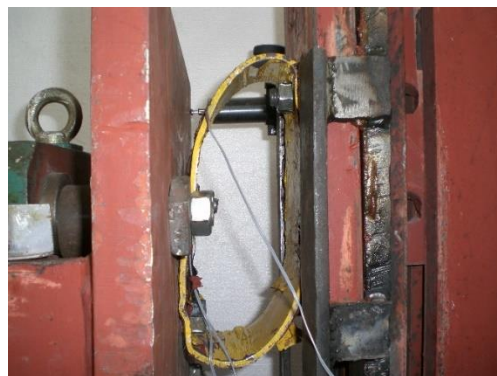


Figure 4.61 : Force-displacement relation from N+V (-) test of 5 mm thick specimen.



Partially deformed shape of the specimen



Ultimate deformed shape of the specimen

Figure 4.62 : Deformed shapes of the specimen during the test.

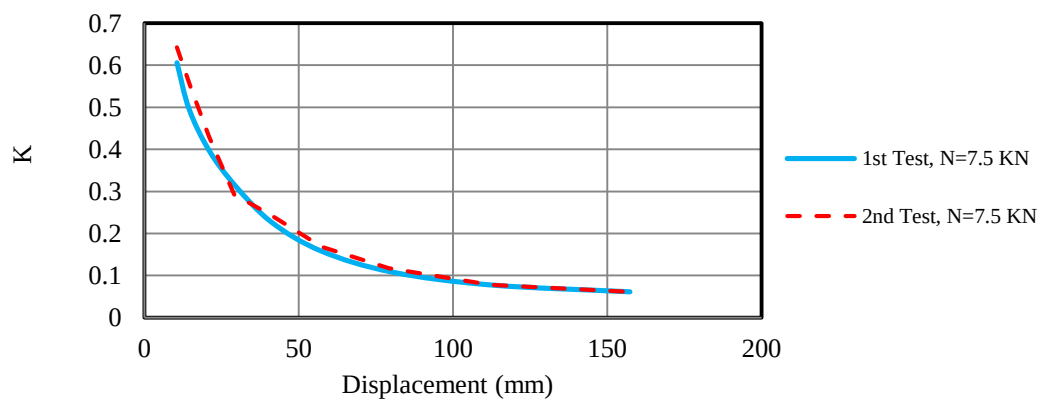


Figure 4.63 : Stiffness-displacement relation for 5 mm thick specimen.

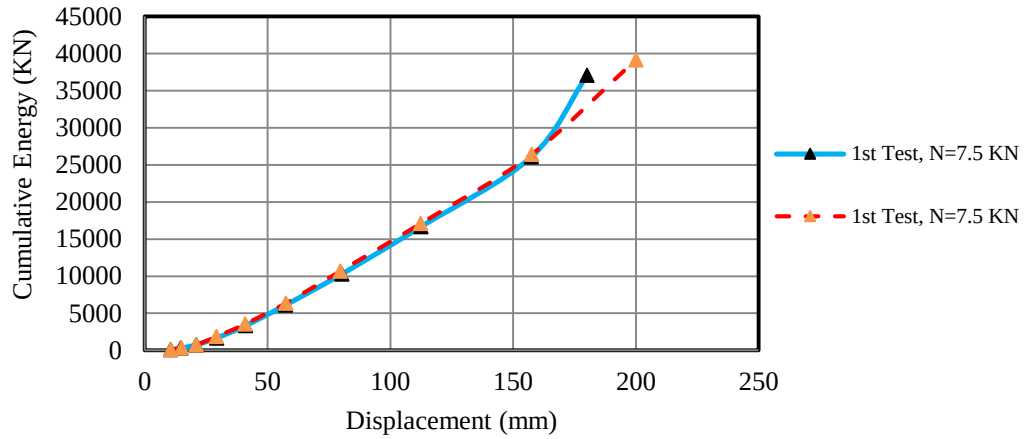


Figure 4.64 : Cumulative energy-displacement relation of 5 mm thick specimen.

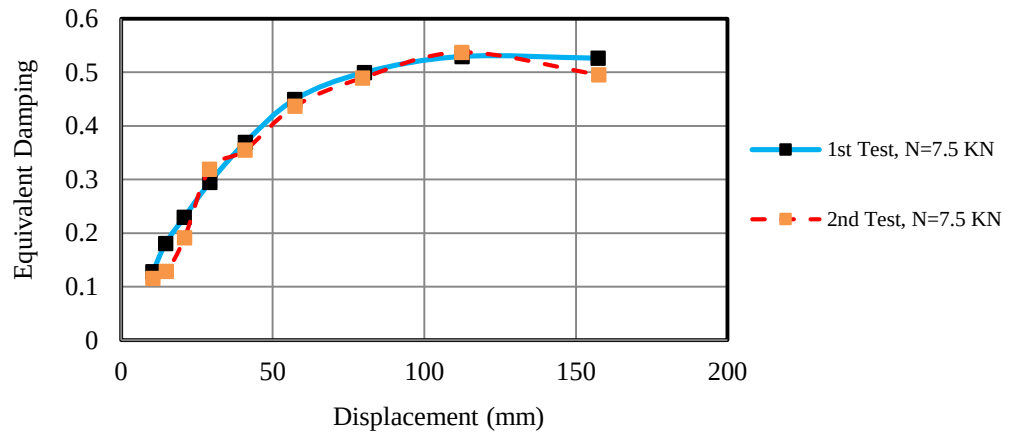


Figure 4.65 : Equivalent damping-displacement relation of 5 mm thick specimen.

4.2.2.2. 15 kN axial load

Two similar N+V(-) tests were carried out on 5 mm thick specimen for 15 kN tension axial load. Cycles obtained from the tests are presented in Figure 4.66.

5 mm thick steel specimen has a nominal strength of 4 kN from first test and 3.5 kN from second test, as well as a maximum displacement capacity of 180 mm. The ultimate compression strength of 5 mm thick specimen is 11 kN. Based on the obtained strain gauges measurements from two tests, the average yielding displacement is calculated as 19.9 mm. The specimen has a symmetric behavior.

Some cracks are observed at the final steps of the test. First specimen ruptured at the end of the test.

The partially deformed shape of the specimen and the ultimate deformed shape are presented in Figure 4.67.

The stiffness of the specimen at the beginning of the test is about 0.45 kN/mm while it is calculated as 0.062 kN/mm at the end of the test, Figure 4.68.

The cumulative energy which is calculated as the enclosed area of force-displacement curve is equal to 15000 kN.mm, Figure 4.69.

The ultimate equivalent damping calculated from the tests is about 44 percent, Figure 4.70.

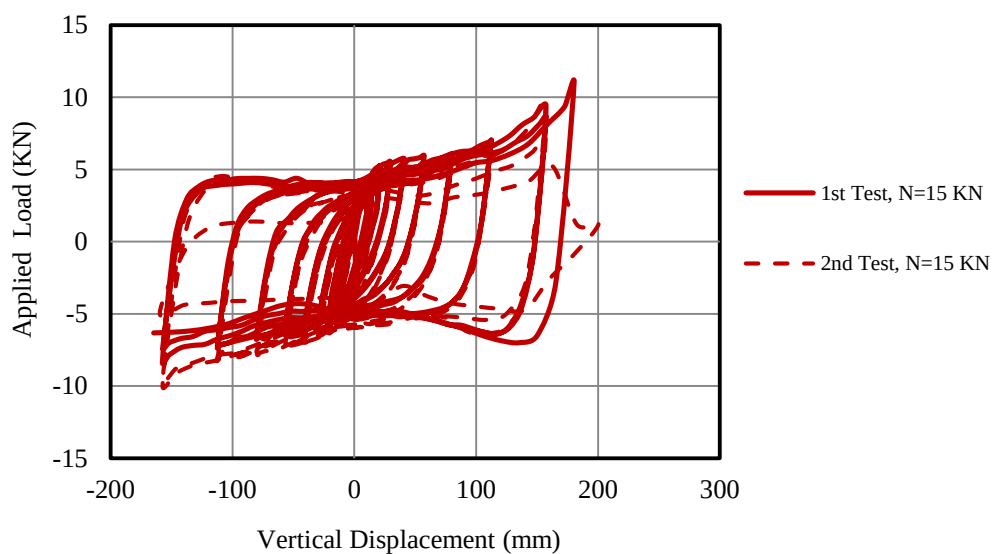
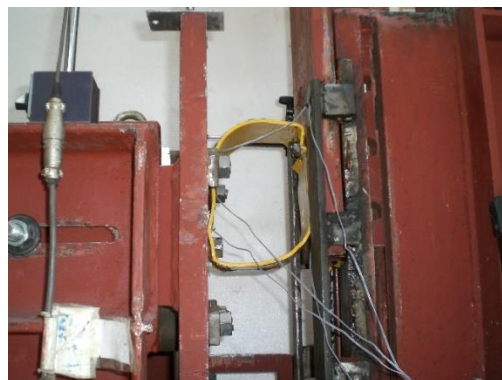


Figure 4.66 : Force-displacement relation from N+V (-) test of 5 mm thick specimen.



Partially deformed shape of the specimen



Ultimate deformed shape of the specimen

Figure 4.67 : Deformed shapes of the specimen during the test.

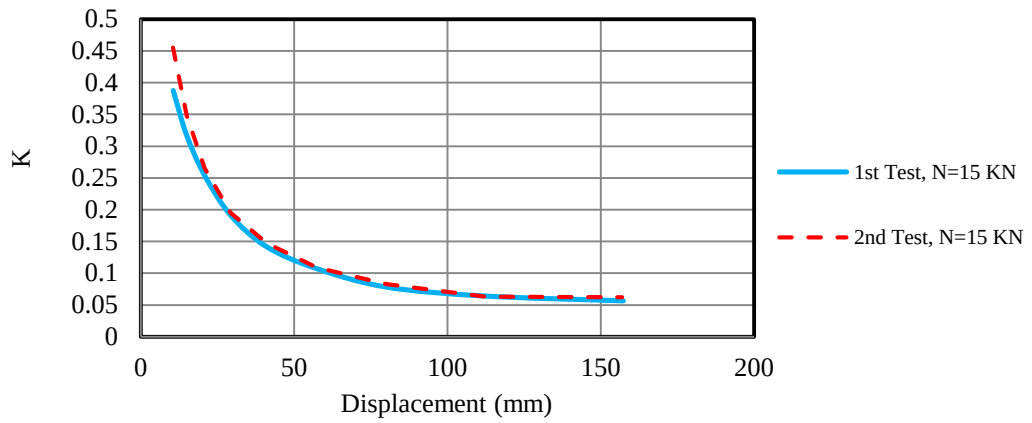


Figure 4.68 : Stiffness-displacement relation for 5 mm specimen.

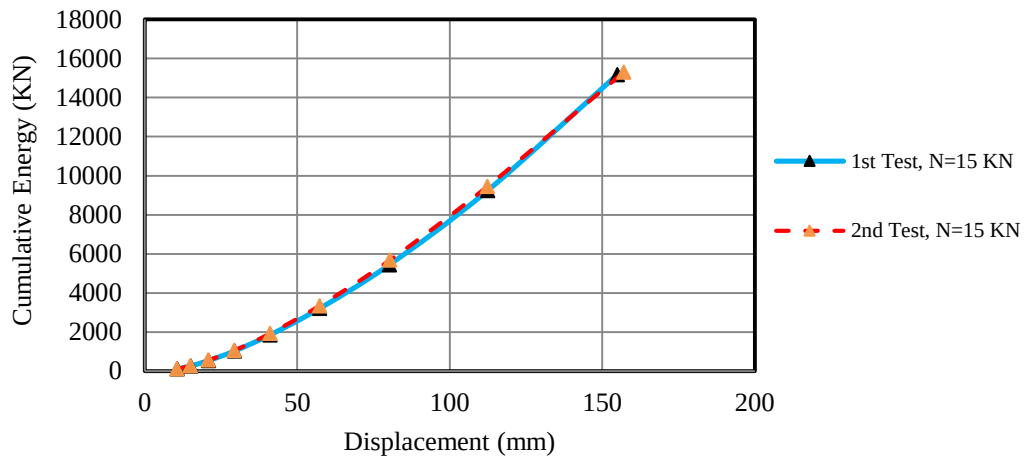


Figure 4.69 : Cumulative energy-displacement relation of 5 mm thick specimen.

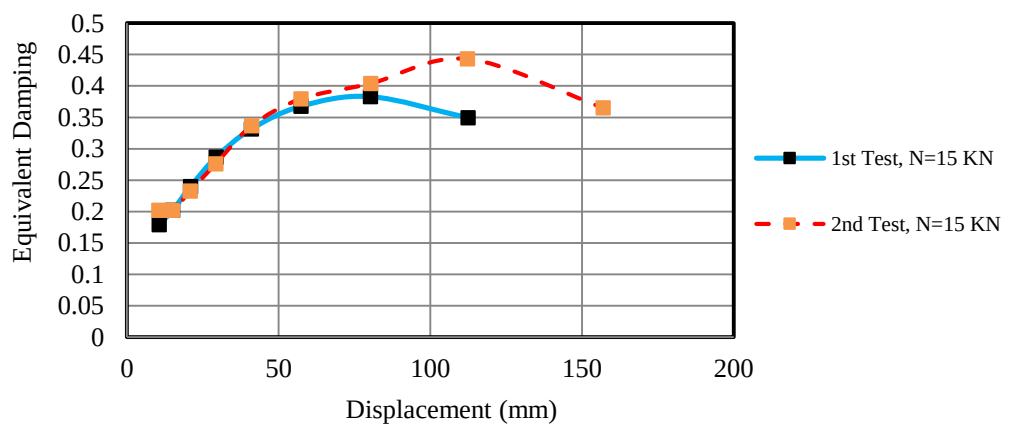


Figure 4.70 : Equivalent damping-displacement relation of 5 mm thick specimen.

4.2.2.3. 25 kN axial load

Two similar N+V(-) tests were carried out on 5 mm thick specimen for 25 kN tension axial load. Cycles obtained from the tests are presented in Figure 4.71.

5 mm thick steel specimen has a nominal strength of 3.5 kN from first test and 4.5 kN from second test, as well as a maximum displacement capacity of 200 mm. The ultimate compression strength of 5 mm thick specimen is 20 kN. Based on the obtained strain gauges measurements from two tests, the average yielding displacement is calculated as 10.54 mm. The specimen has a symmetric behavior.

Some cracks are observed at the final steps of the test. First specimen ruptured at the end of the test.

The partially deformed shape of the specimen and the ultimate deformed shape are presented in Figure 4.72.

The stiffness of the specimen at the beginning of the test is about 0.44 kN/mm while it is calculated as 0.063 kN/mm at the end of the test, Figure 4.73.

The cumulative energy which is calculated as the enclosed area of force-displacement curve is equal to 25700 kN.mm, Figure 4.74.

The ultimate equivalent damping calculated from the tests is about 39 percent, Figure 4.75.

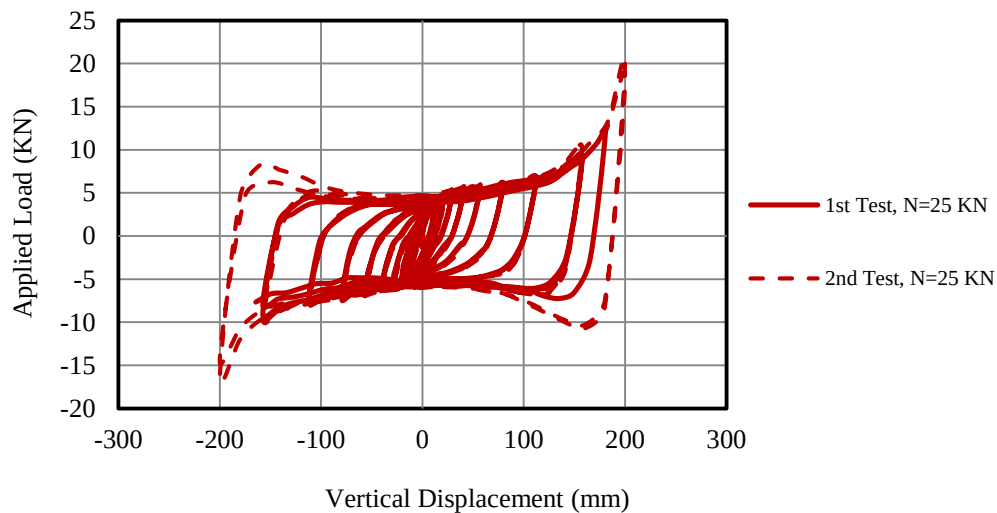


Figure 4.71 : Force-displacement relation from N+V (-) test of 5 mm thick specimen.



Partially deformed shape of the specimen



Ultimate deformed shape of the specimen

Figure 4.72 : Deformed shapes of the specimen during the test.

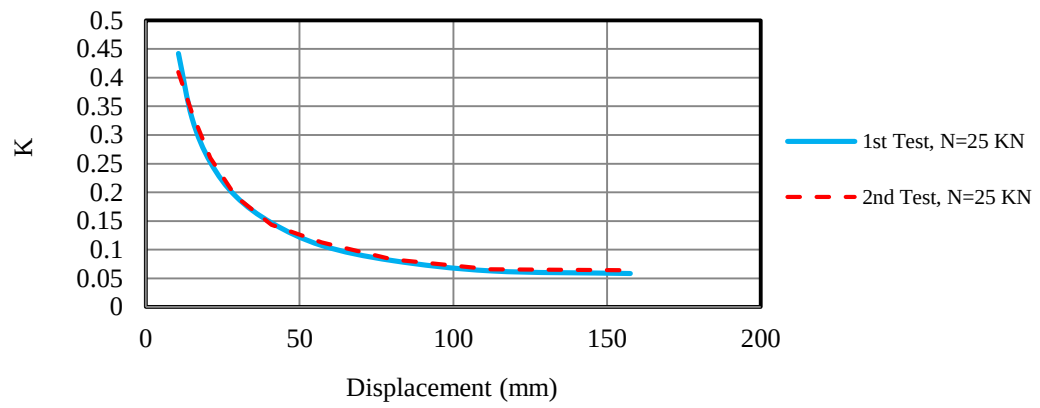


Figure 4.73 : Stiffness-displacement relation for 5 mm thick specimen.

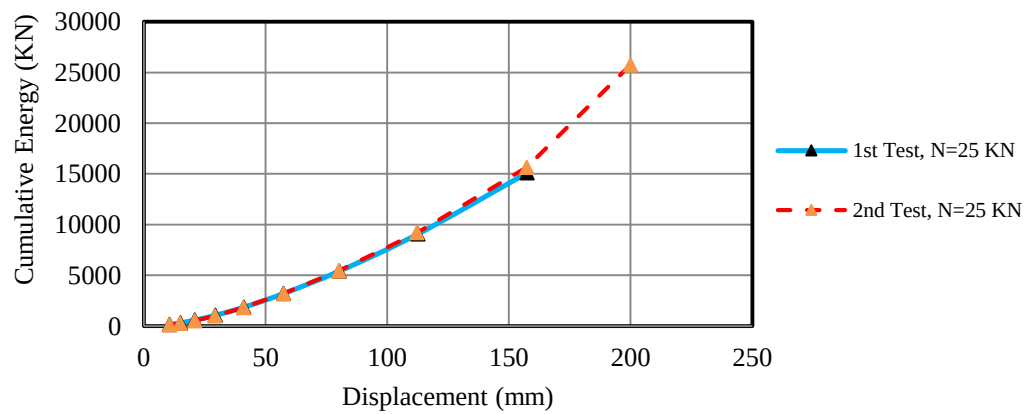


Figure 4.74 : Cumulative energy-displacement relation of 5 mm thick specimen.

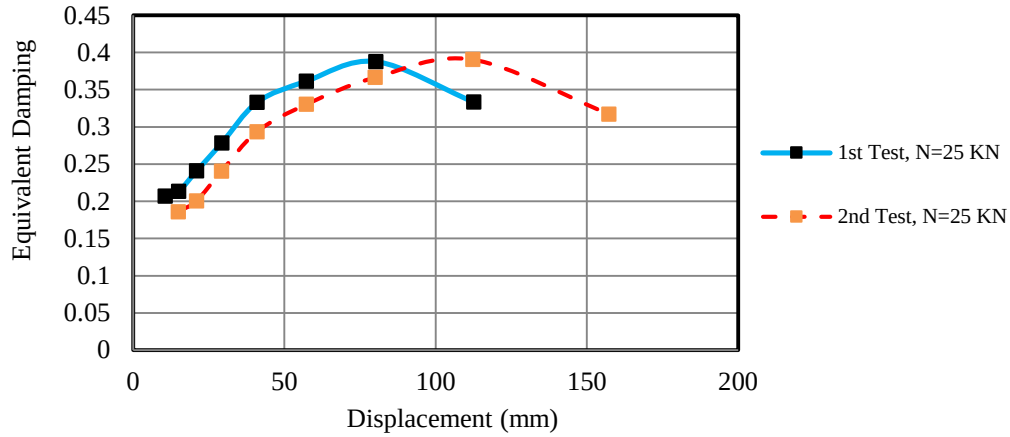


Figure 4.75 : Equivalent damping-displacement relation of 5 mm thick specimen.

4.2.3. 3 mm thick specimen

4.2.3.1. 2.5 kN axial load

Two similar N+V(-) tests were carried out on 3 mm thick specimen for 2.5 kN tension axial load. Cycles obtained from the tests are presented in Figure 4.76.

3 mm thick steel specimen has a nominal strength of 2 kN from first test and 1.5 kN from second test, as well as a maximum displacement capacity of 200 mm. The ultimate compression strength of 3 mm thick specimen is 5 kN. Based on the obtained strain gauges measurements from two tests, the average yielding displacement is calculated as 12.79 mm. The specimen has a symmetric behavior.

Some cracks are observed at the final steps of the test. The first specimen ruptured at the end of the test.

The partially deformed shape of the specimen and the ultimate deformed shape are presented in Figure 4.77.

The stiffness of the specimen at the beginning of the test is about 0.29 kN/mm while it is calculated as 0.021 kN/mm at the end of the test, Figure 4.78.

The cumulative energy which is calculated as the enclosed area of force-displacement curve is equal to 12000 kN.mm, Figure 4.79.

The ultimate equivalent damping calculated from the tests is about 65 percent, Figure 4.80.

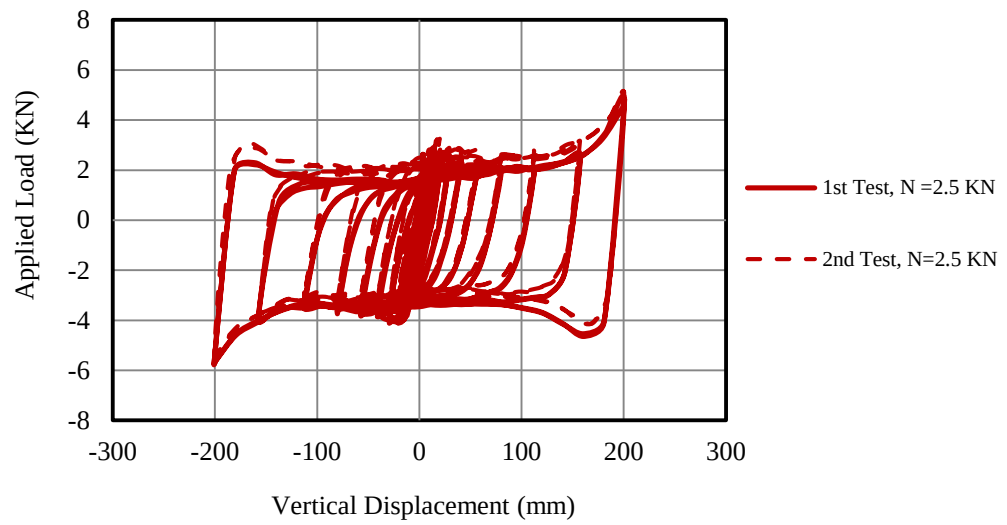
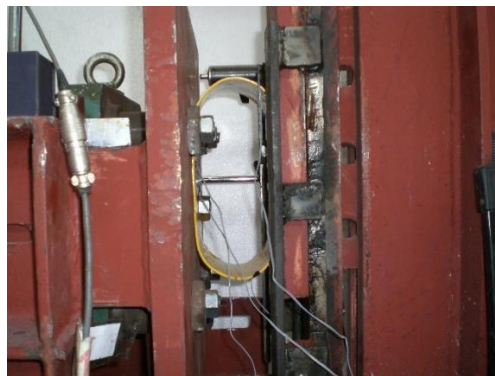
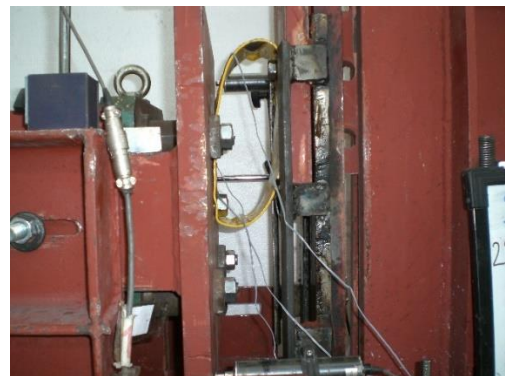


Figure 4.76 : Force-displacement relation from N+V (-) test of 3 mm thick specimen.



Partially deformed shape of the specimen



Ultimate deformed shape of the specimen

Figure 4.77 : Deformed shapes of the specimen during the test.

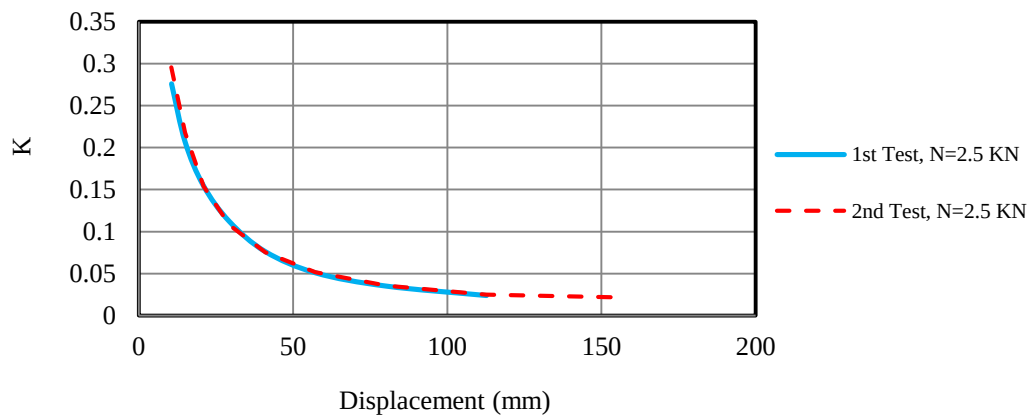


Figure 4.78 : Stiffness-displacement relation for 3 mm thick specimen.

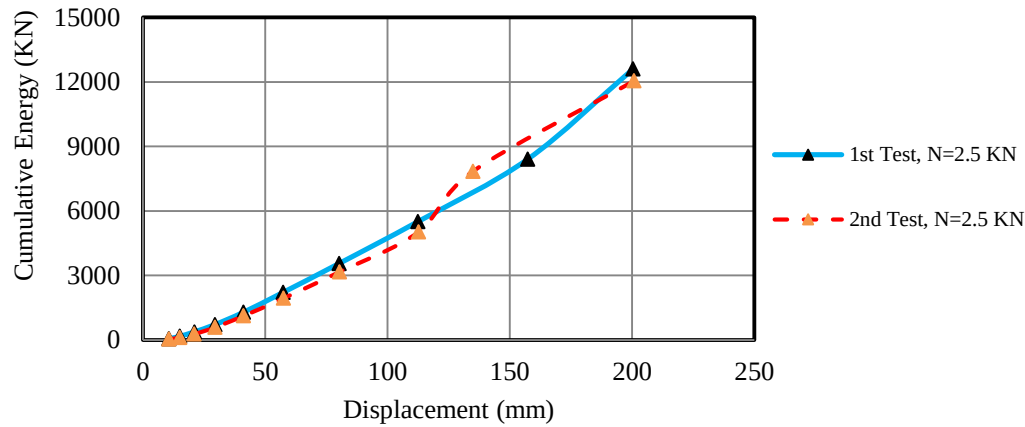


Figure 4.79 : Cumulative energy-displacement relation of 3 mm thick specimen.

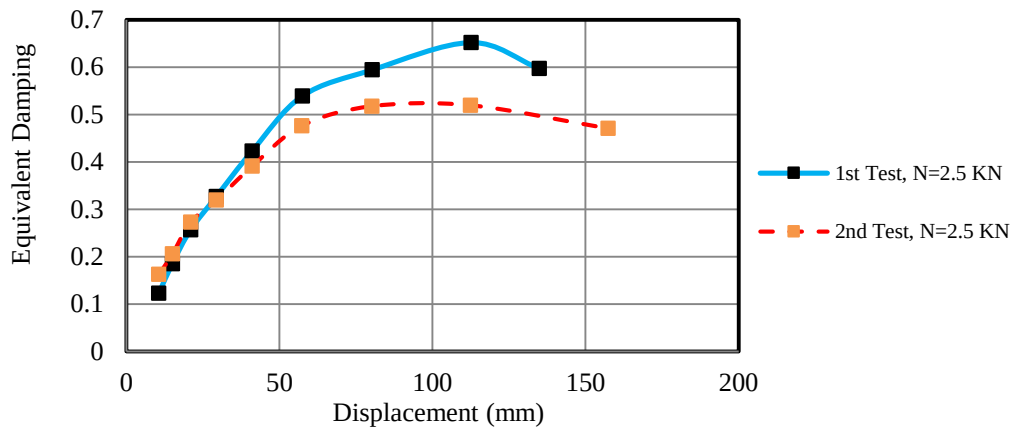


Figure 4.80 : Equivalent damping-displacement relation of 3 mm thick specimen.

4.2.3.2. 5 kN axial load

Two similar N+V(-) tests were carried out on 3 mm thick specimen for 5 kN tension axial load. Cycles obtained from the tests are presented in Figure 4.81.

3 mm thick steel specimen has a nominal strength of 2 kN from first test and 0.5 kN from second test, as well as a maximum displacement capacity of 200 mm. The ultimate compression strength of 3 mm thick specimen is 6 kN. Based on the obtained strain gauges measurements from two tests, the average yielding displacement is calculated as 15.75 mm. The specimen has a symmetric behavior.

Some cracks are observed at the final steps of the test. The first specimen ruptured at the end of the test.

The partially deformed shape of the specimen and the ultimate deformed shape are presented in Figure 4.82.

The stiffness of the specimen at the beginning of the test is about 0.21 kN/mm while it is calculated as 0.018 kN/mm at the end of the test, Figure 4.83.

The cumulative energy which is calculated as the enclosed area of force-displacement curve is equal to 10800 kN.mm, Figure 4.84.

The ultimate equivalent damping calculated from the tests is about 44 percent, Figure 4.85.

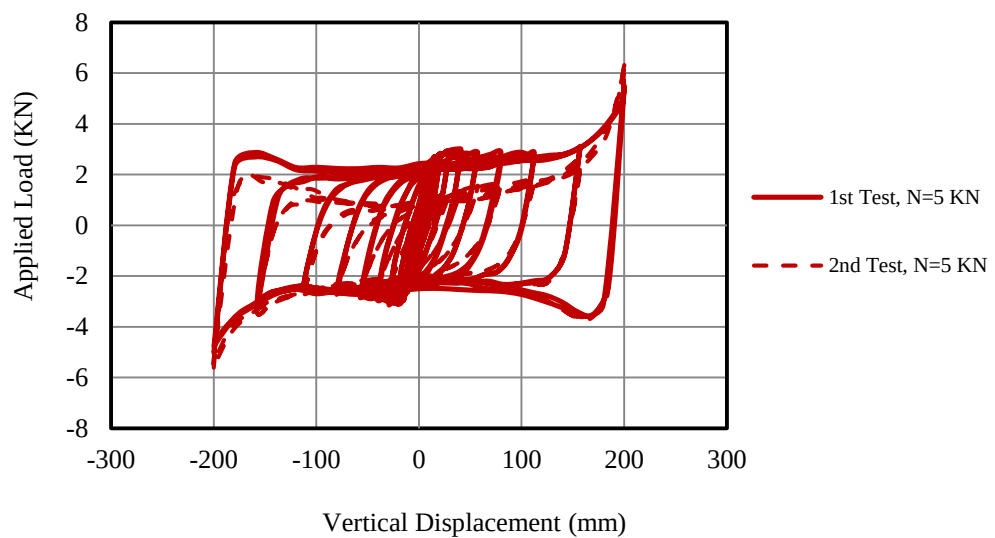


Figure 4.81 : Force-displacement relation from N+V (-) test of 3 mm thick specimen.



Partially deformed shape of the specimen



Ultimate deformed shape of the specimen

Figure 4.82 : Deformed shapes of the specimen during the test.

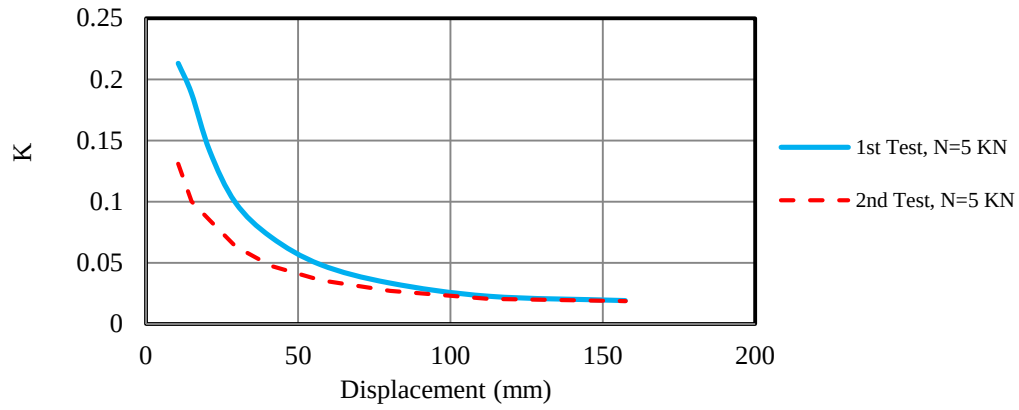


Figure 4.83 : Stiffness-displacement relation for 3 mm thick specimen.

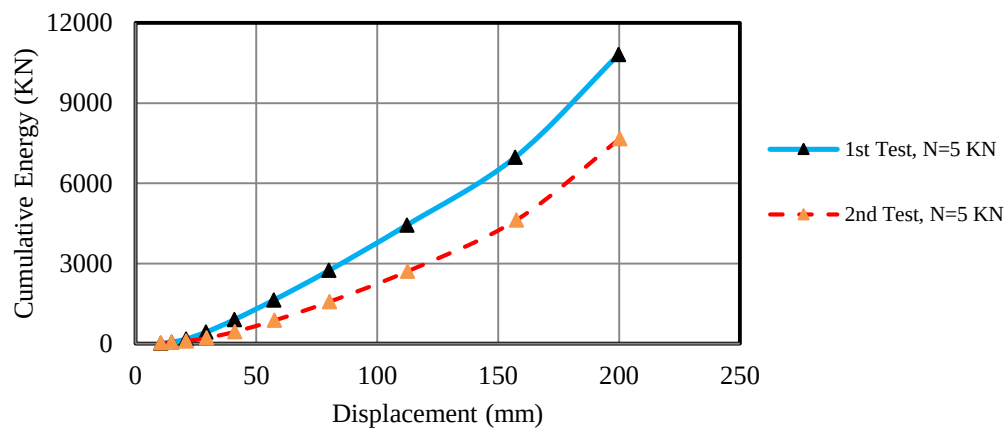


Figure 4.84 : Cumulative energy-displacement relation of 3 mm thick specimen.

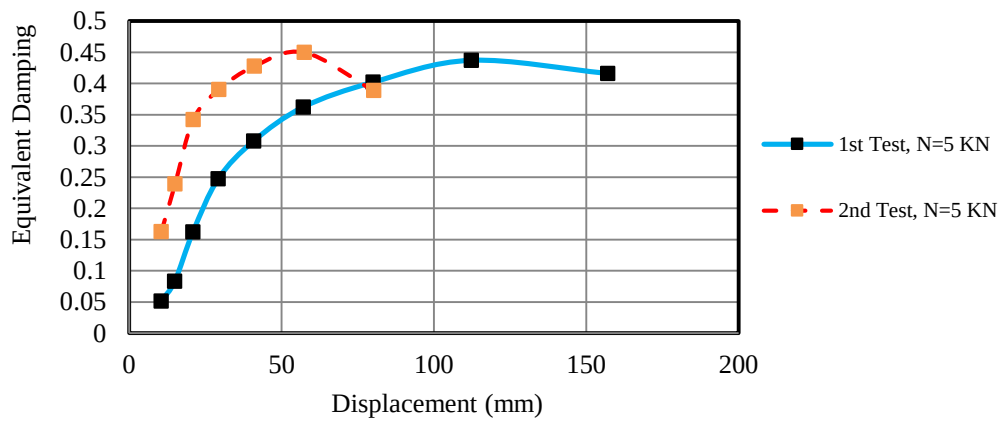


Figure 4.85 : Equivalent damping-displacement relation of 3 mm thick specimen.

4.2.3.3. 7.5 kN axial load

Two similar N+V(-) tests were carried out on 3 mm thick specimen for 7.5 kN tension axial load. Cycles obtained from the tests are presented in Figure 4.86.

3 mm thick steel specimen has a nominal strength of 1.5 kN from first test and 2 kN from second test, as well as a maximum displacement capacity of 200 mm. The ultimate compression strength of 3 mm thick specimen is 5.4 kN. Based on the obtained strain gauges measurements from two tests, the average yielding displacement is calculated as 12.78 mm. The specimen has a symmetric behavior.

Some cracks are observed at the final steps of the test. The first specimen ruptured at the end of the test.

The partially deformed shape of the specimen and the ultimate deformed shape are presented in Figure 4.87.

The stiffness of the specimen at the beginning of the test is about 0.22 kN/mm while it is calculated as 0.02 kN/mm at the end of the test, Figure 4.88.

The cumulative energy which is calculated as the enclosed area of force-displacement curve is equal to 11400 kN.mm, Figure 4.89.

The ultimate equivalent damping calculated from the tests is about 52 percent, Figure 4.90.

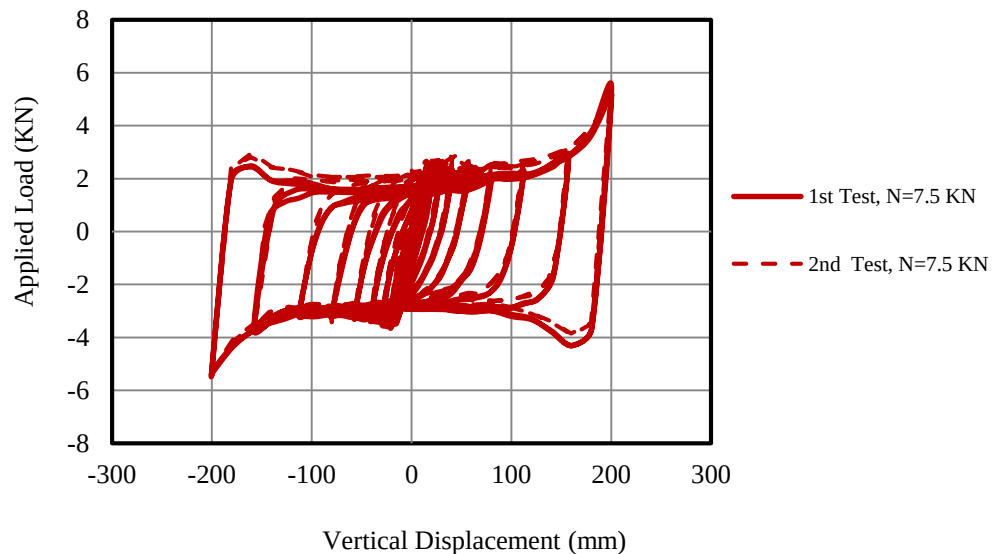
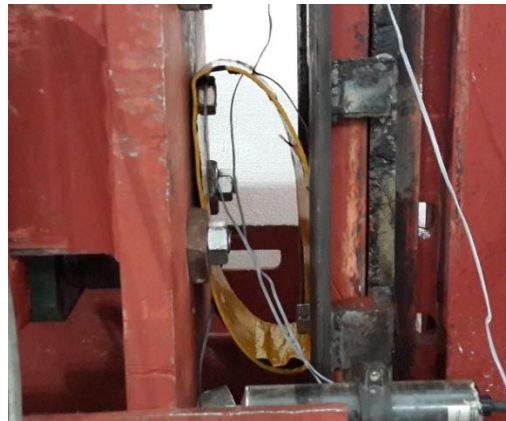


Figure 4.86 : Force-displacement relation from N+V (-) test of 3 mm thick specimen.



Partially deformed shape of the specimen



Ultimate deformed shape of the specimen

Figure 4.87 : Deformed shapes of the specimen during the test.

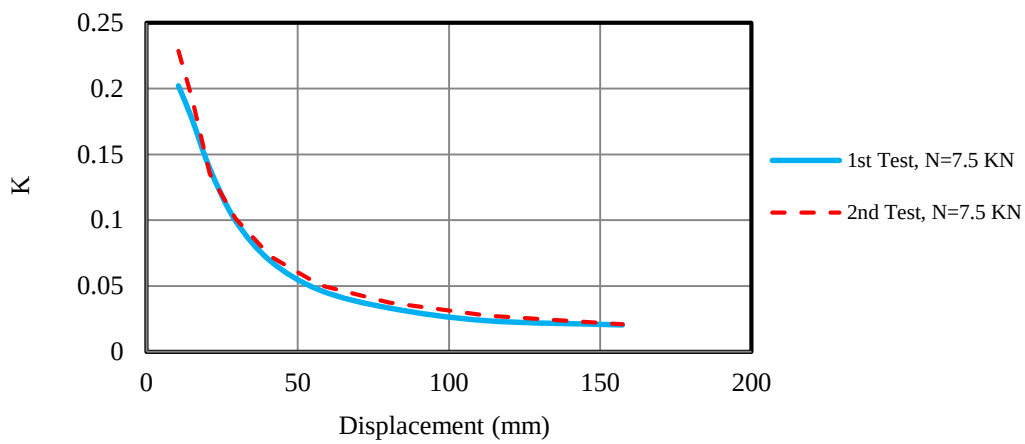


Figure 4.88 : Stiffness-displacement relation for 3 mm thick specimen.

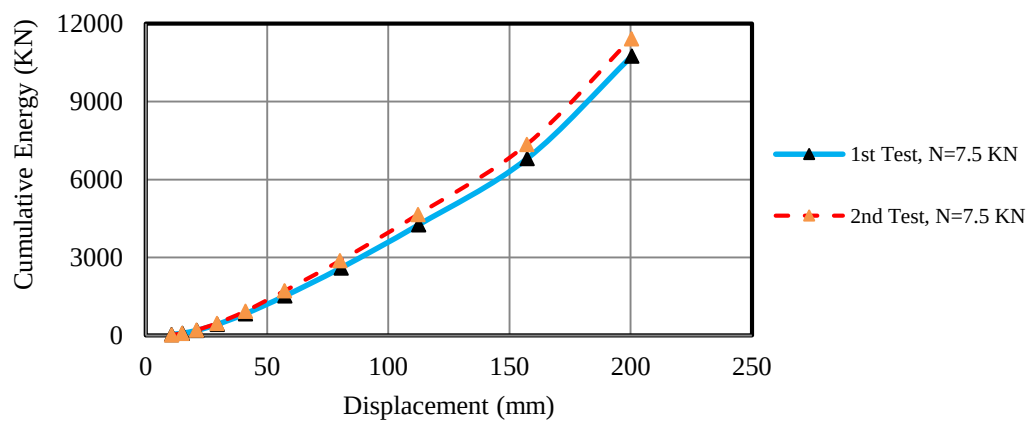


Figure 4.89 : Cumulative energy-displacement relation of 3 mm thick specimen.

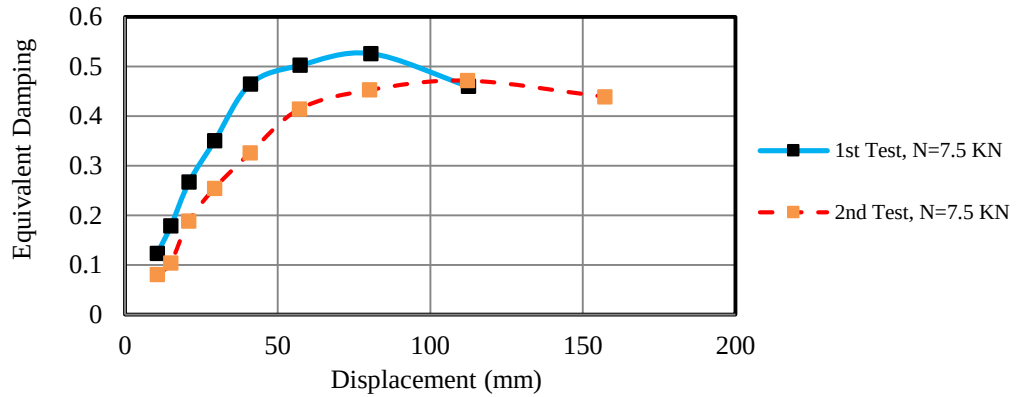


Figure 4.90 : Equivalent damping-displacement relation of 3 mm thick specimen.

8 mm thick steel cushions are infilled by the following materials:

- 1) Cord layered neoprene.
- 2) FRP layered neoprene.
- 3) Pure neoprene.
- 4) Steel layered neoprene.

Two types of multi-axial tests were carried out on these specimens. The first test is cyclic shear load plus compression axial load stands for $N+V(+)$ and the second one is uni-axial monotonic compression test.

4.3. Compression Tests For Infilled Specimens

4.3.1. Cord layered neoprene infilled specimen

4.3.1.1. 50 kN axial load

One $N+V(+)$ test was carried out on cord layered neoprene infilled specimen for 50 kN compression axial load. Cycles obtained from the tests are presented in Figure 4.91.

The specimen has a nominal strength of 38 kN, as well as a maximum displacement capacity of 200 mm. The ultimate compression strength of the specimen is 67.5 kN and the specimen has a symmetric behavior.

First damages to the infilled material started by applying 112.5 mm displacement to the specimen that caused some ruptures inside the infilled material at the first steps and then at final steps the infilled material separated from the outer steel formwork.

The partially deformed shape of the specimen and the ultimate deformed shape are presented in Figure 4.92.

The stiffness of the specimen at the beginning of the test is about 3.43 kN/mm while it is calculated as 0.3 kN/mm at the end of the test and the stiffness degradation amount is 91 percent, Figure 4.93.

The cumulative energy which is calculated as the enclosed area of force-displacement curve is equal to 183000 kN.mm, Figure 4.94.

The ultimate equivalent damping calculated from the tests is about 45 percent, Figure 4.95.

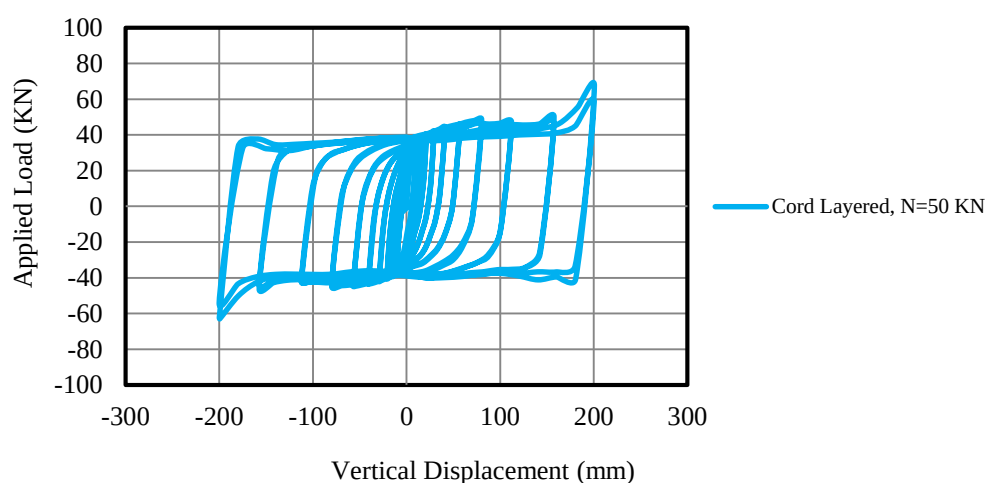
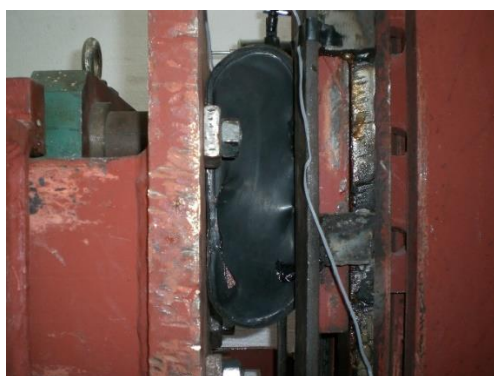
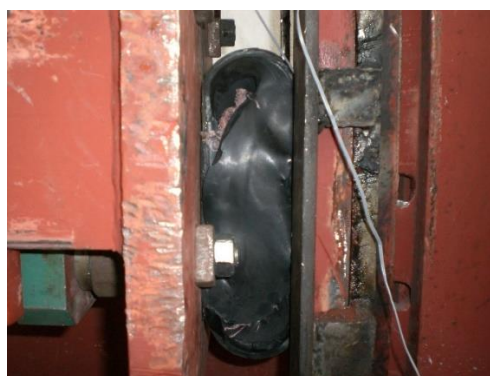


Figure 4.91 : Force-displacement relation from N+V (+) test of cord neoprene layered specimen.



Partially deformed shape of the specimen



Ultimate deformed shape of the specimen

Figure 4.92 : Deformed shapes of the specimen during the test.

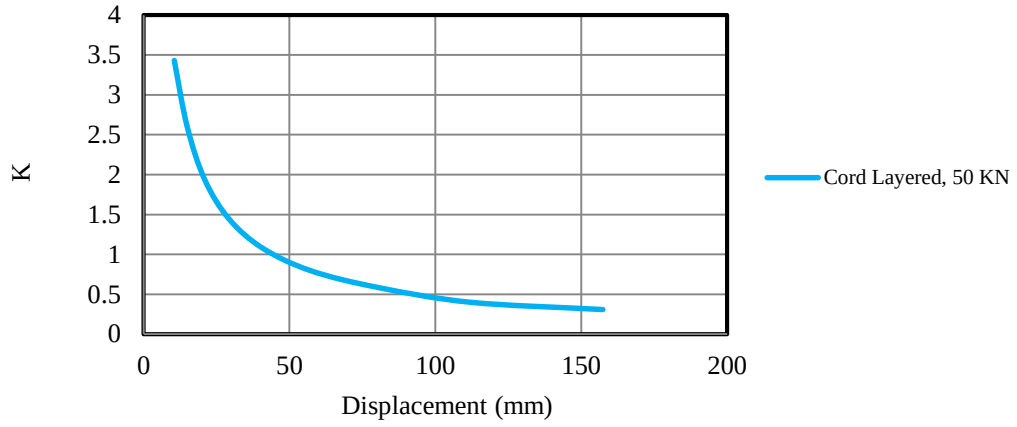


Figure 4.93 : Stiffness-displacement relation for cord neoprene layered specimen.

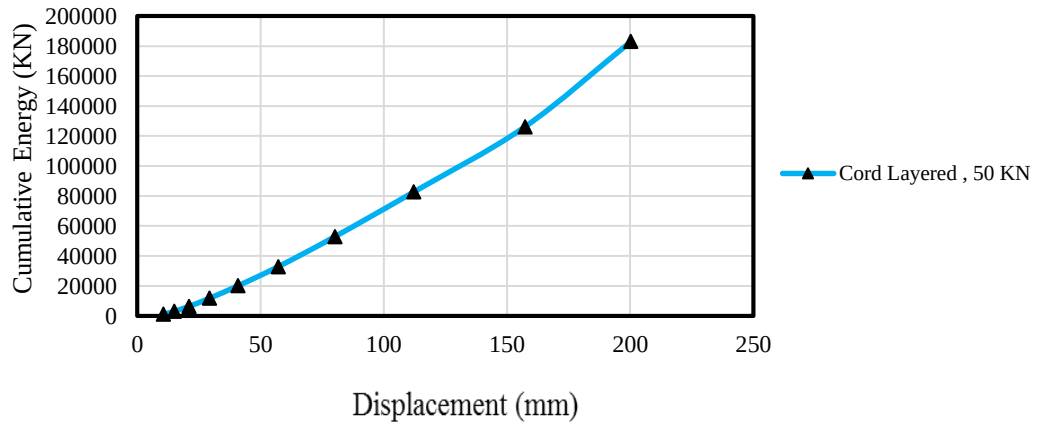


Figure 4.94 : Cumulative energy-displacement relation of cord neoprene layered specimen.

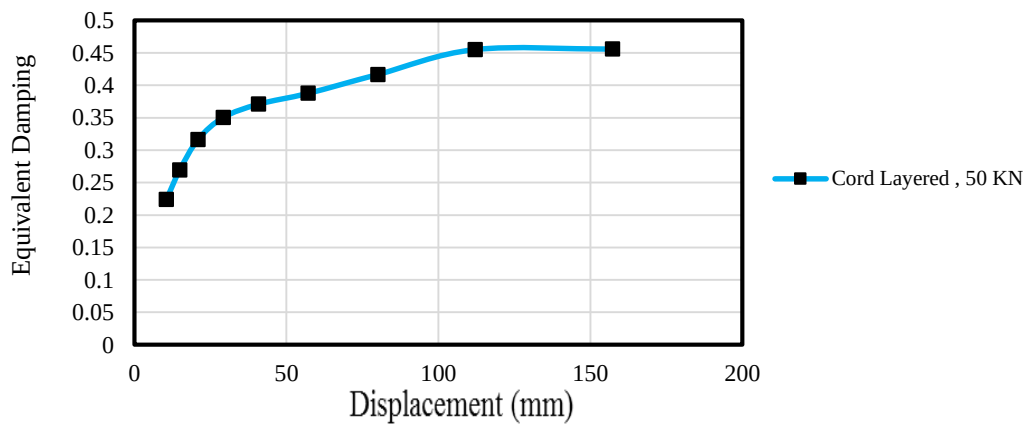


Figure 4.95 : Equivalent damping-displacement relation of cord neoprene layered specimen.

4.3.1.2. 100 kN axial load

One N+V(+) test was carried out on cord layered neoprene infilled specimen for 100 kN compression axial load. Cycles obtained from the tests are presented in Figure 4.96.

The specimen has a nominal strength of 50 kN, as well as a maximum displacement capacity of 157 mm. The ultimate compression strength of the specimen is 81 kN and the specimen has a symmetric behavior.

First damages to the infilled material started by applying 112.5 mm displacement to the specimen that caused some ruptures inside the infilled material at the first steps and then at final steps the infilled material separated from the outer steel formwork.

The partially deformed shape of the specimen and the ultimate deformed shape are presented in Figure 4.97.

The stiffness of the specimen at the beginning of the test is about 4.05 kN/mm while it is calculated as 0.44 kN/mm at the end of the test and the stiffness degradation amount is 89 percent, Figure 4.98.

The cumulative energy which is calculated as the enclosed area of force-displacement curve is equal to 188000 kN.mm, Figure 4.99.

The ultimate equivalent damping calculated from the tests is about 42 percent, Figure 4.100.

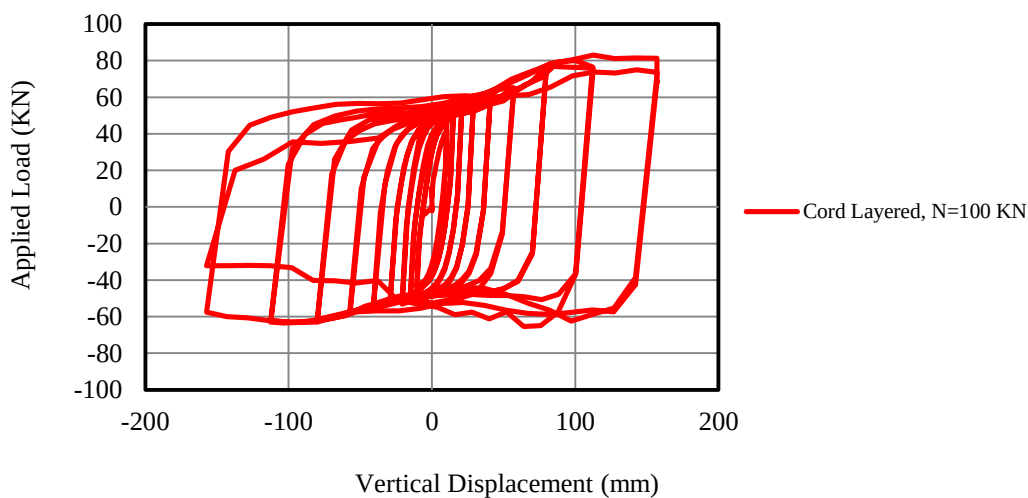


Figure 4.96 : Force-displacement relation from N+V (+) test of cord neoprene layered specimen.



Partially deformed shape of the specimen



Ultimate deformed shape of the specimen

Figure 4.97 : Deformed shapes of the specimen during the test.

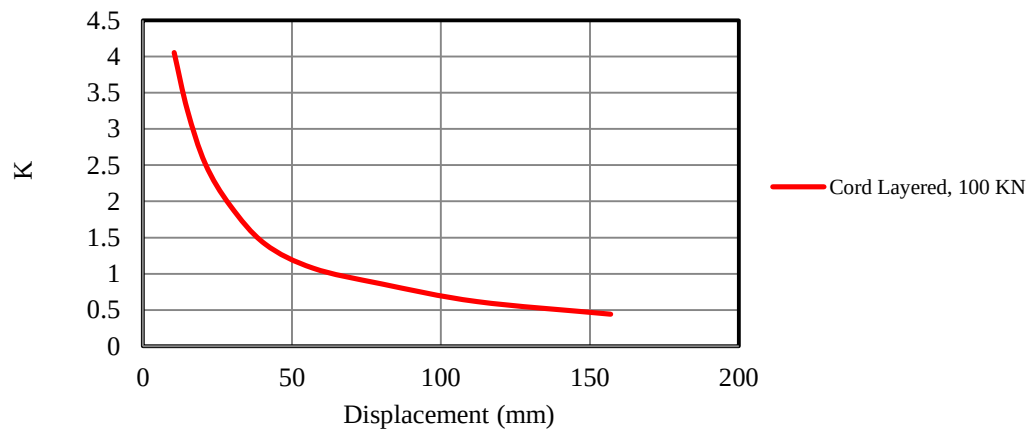


Figure 4.98 : Stiffness-displacement relation for cord neoprene layered specimen.

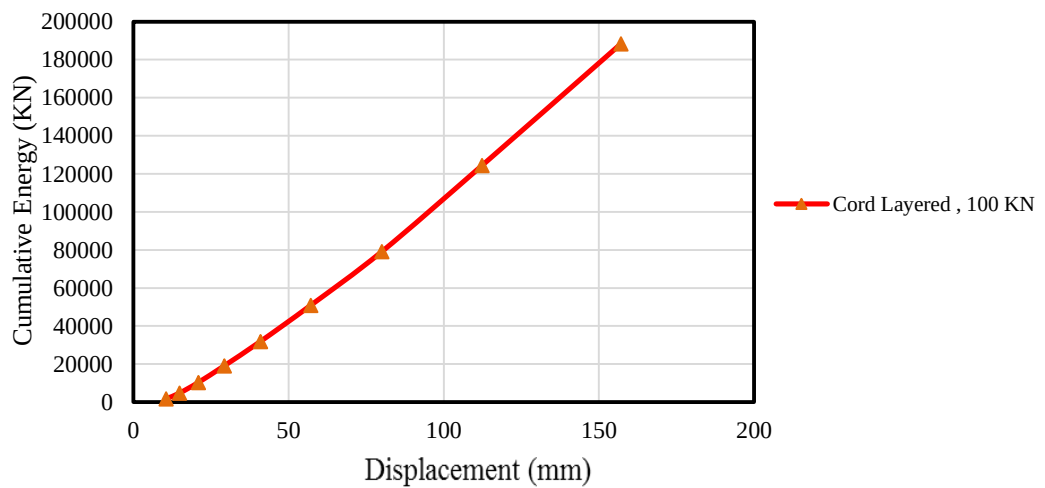


Figure 4.99 : Cumulative energy-displacement relation of cord neoprene layered specimen.

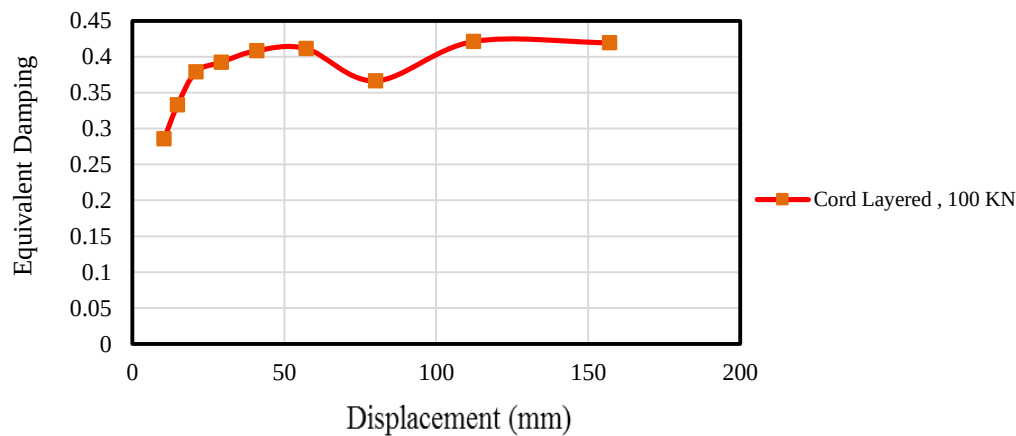


Figure 4.100 : Equivalent damping-displacement relation of cord neoprene layered specimen.

4.3.2. FRP layered neoprene infilled specimen

4.3.2.1. 50 kN axial load

One N+V(+) test was carried out on FRP layered neoprene infilled specimen for 50 kN compression axial load. Cycles obtained from the tests are presented in Figure 4.101.

The specimen has a nominal strength of 35 kN, as well as a maximum displacement capacity of 200 mm. The ultimate compression strength of the specimen is 70 kN and the specimen has a symmetric behavior.

First damages to the infilled material started by applying 157.08 mm displacement to the specimen that caused some ruptures inside the infilled material at the first steps and then the ruptures started to extend.

The partially deformed shape of the specimen and the ultimate deformed shape are presented in Figure 4.102.

The stiffness of the specimen at the beginning of the test is about 3.47 kN/mm while it is calculated as 0.3 kN/mm at the end of the test and the stiffness degradation amount is 91 percent, Figure 4.103.

The cumulative energy which is calculated as the enclosed area of force-displacement curve is equal to 174000 kN.mm, Figure 4.104.

The ultimate equivalent damping calculated from the tests is about 45 percent, Figure 4.105.

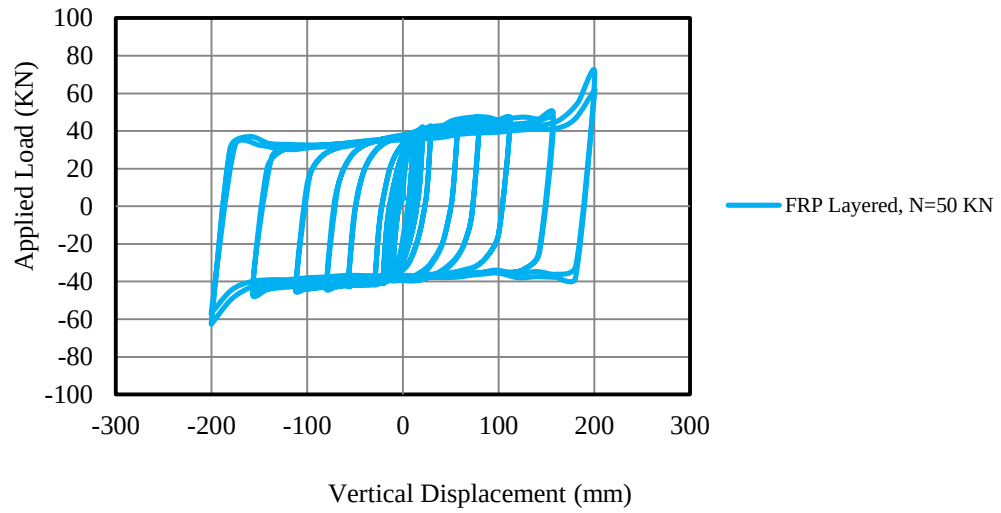


Figure 4.101 : Force-displacement relation from N+V (+) test of FRP neoprene layered specimen.

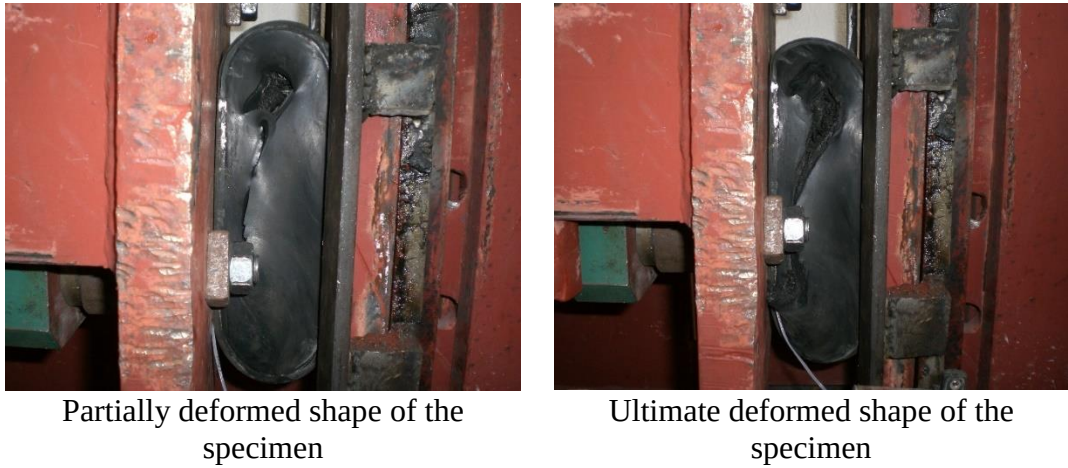


Figure 4.102 : Deformed shapes of the specimen during the test.

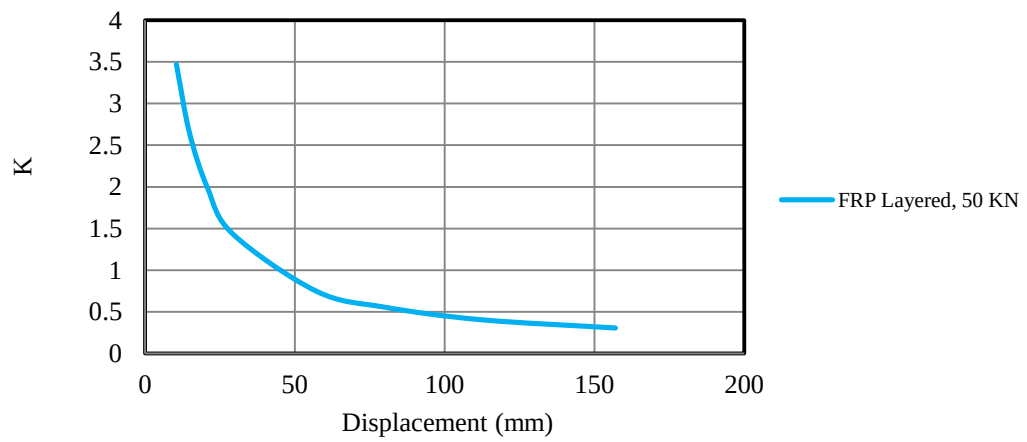


Figure 4.103 : Stiffness-displacement relation of FRP neoprene layered specimen.

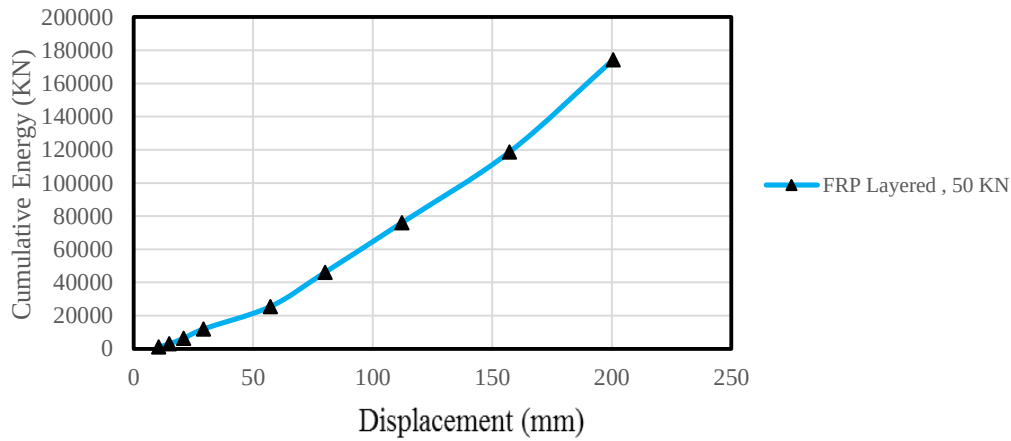


Figure 4.104 : Cumulative energy-displacement relation of FRP neoprene layered specimen.

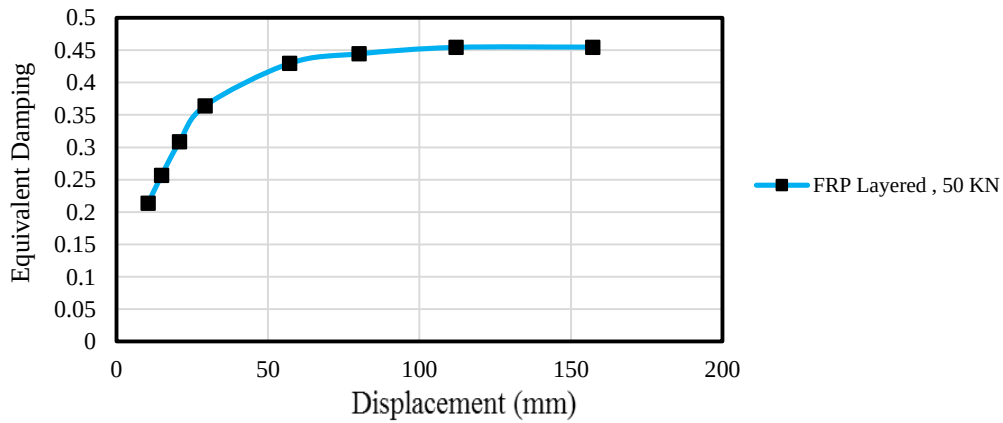


Figure 4.105 : Equivalent damping-displacement relation of FRP neoprene layered specimen.

4.3.2.2. 100 kN axial load

One N+V(+) test was carried out on FRP layered neoprene infilled specimen for 100 kN compression axial load. Cycles obtained from the tests are presented in Figure 4.106.

The specimen has a nominal strength of 58 kN, as well as a maximum displacement capacity of 157 mm. The ultimate compression strength of the specimen is 80 kN and the specimen has a symmetric behavior.

First damages to the infilled material started by applying 157.08 mm displacement to the specimen that caused some ruptures inside the infilled material at the first steps and then at final steps the infilled material separated from the outer steel formwork.

The partially deformed shape of the specimen and the ultimate deformed shape are presented in Figure 4.107.

The stiffness of the specimen at the beginning of the test is about 4.11 kN/mm while it is calculated as 0.63 kN/mm at the end of the test and the stiffness degradation amount is 84 percent, Figure 4.108.

The cumulative energy which is calculated as the enclosed area of force-displacement curve is equal to 133000 kN.mm, Figure 4.109.

The ultimate equivalent damping calculated from the tests is about 45 percent, Figure 4.110.

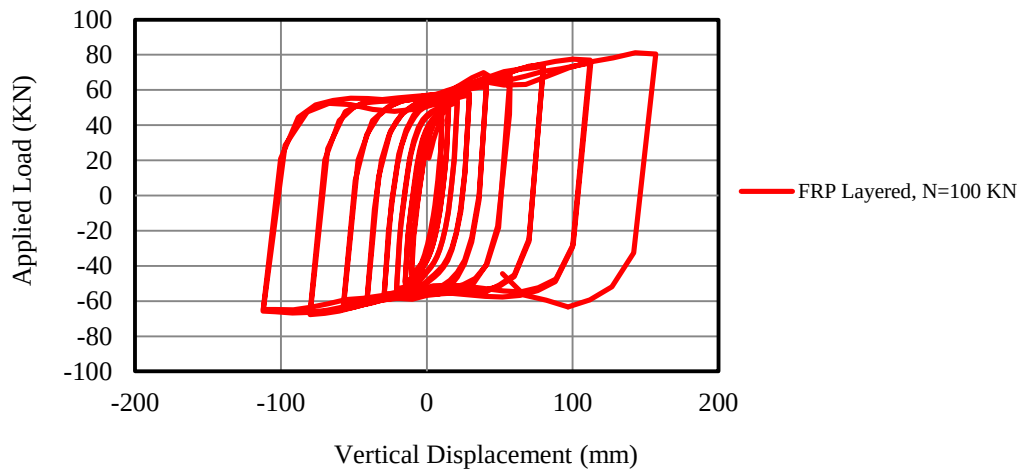


Figure 4.106 : Force-displacement relation from N+V (+) test of FRP neoprene layered specimen.



Partially deformed shape of the specimen



Ultimate deformed shape of the specimen

Figure 4.107 : Deformed shapes of the specimen during the test.

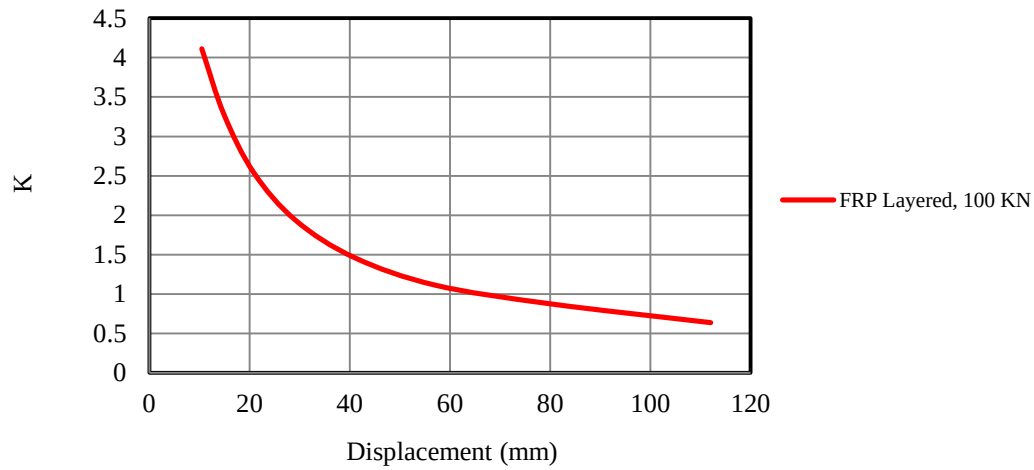


Figure 4.108 : Stiffness-displacement relation for FRP neoprene layered specimen.

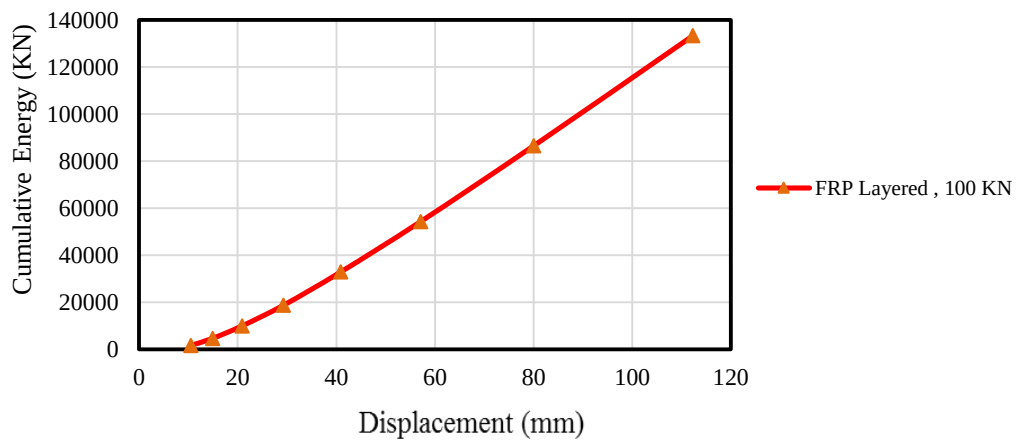


Figure 4.109 : Cumulative energy-displacement Relation of FRP neoprene layered specimen.

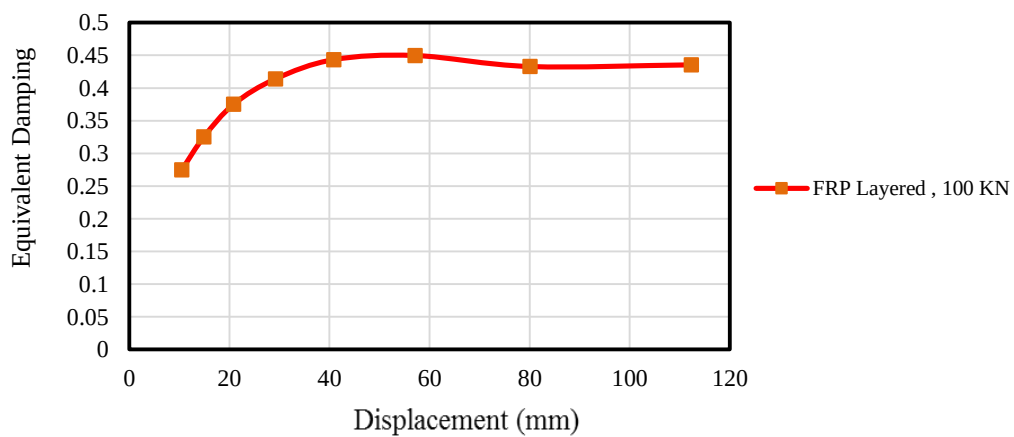


Figure 4.110 : Equivalent damping-displacement Relation of FRP neoprene layered specimen.

4.3.3. Neoprene infilled specimen

4.3.3.1. 0 kN axial load

One N+V(+) test was carried out on pure neoprene infilled specimen for 0 kN compression axial load. Cycles obtained from the tests are presented in Figure 4.111.

The specimen has a nominal strength of 40 kN, as well as a maximum displacement capacity of 220 mm. The ultimate compression strength of the specimen is 93 kN and the specimen has a symmetric behavior.

First damages to the infilled material started by applying 157.08 mm displacement to the specimen that caused some ruptures inside the infilled material at the first steps and then at final steps the infilled material separated from the outer steel formwork.

The partially deformed shape of the specimen and the ultimate deformed shape are presented in Figure 4.112.

The stiffness of the specimen at the beginning of the test is about 3.44 kN/mm while it is calculated as 0.34 kN/mm at the end of the test and the stiffness degradation amount is 90 percent, Figure 4.113.

The cumulative energy which is calculated as the enclosed area of force-displacement curve is equal to 177000 kN.mm, Figure 4.114.

The ultimate equivalent damping calculated from the tests is about 35 percent, Figure 4.115.

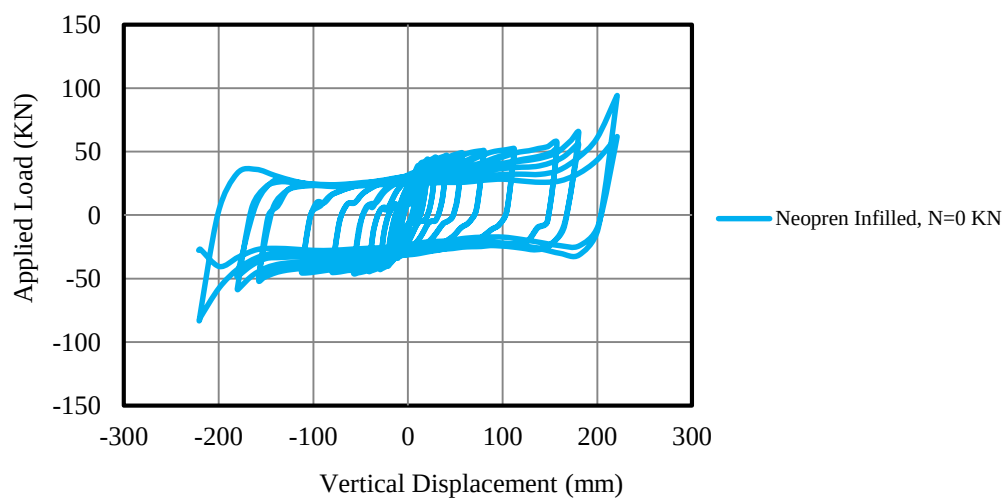


Figure 4.111 : Force-displacement relation from N+V (+) test of neoprene infilled specimen.



Partially deformed shape of the specimen



Ultimate deformed shape of the specimen

Figure 4.112 : Deformed shapes of the specimen during the test.

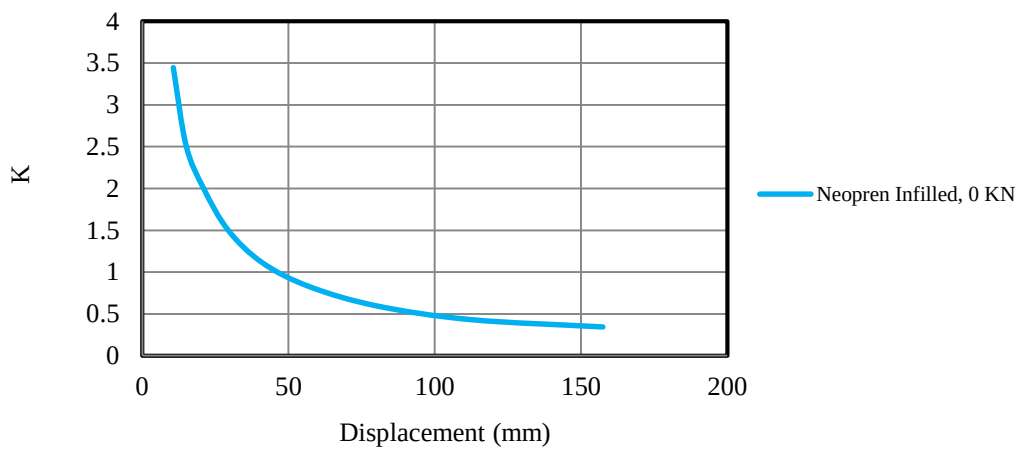


Figure 4.113 : Stiffness-displacement relation for neoprene infilled specimen.

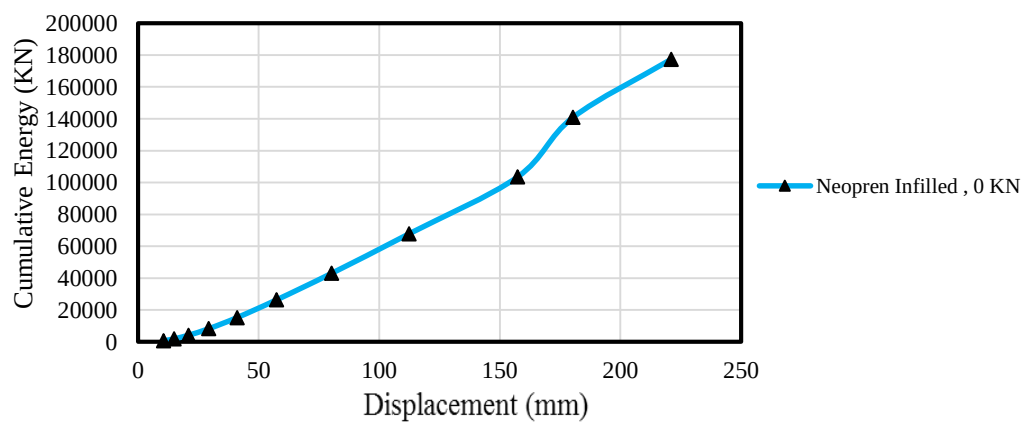


Figure 4.114 : Cumulative energy-displacement relation of neoprene infilled specimen.

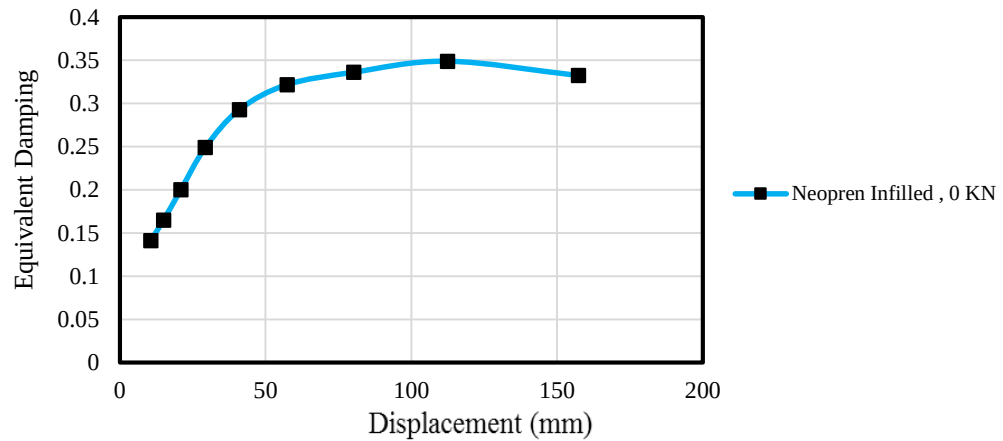


Figure 4.115 : Equivalent damping-displacement relation of neoprene infilled specimen.

4.3.3.2. 50 kN axial load

One N+V(+) test was carried out on pure neoprene infilled specimen for 50 kN compression axial load. Cycles obtained from the tests are presented in Figure 4.116.

The specimen has a nominal strength of 50 kN, as well as a maximum displacement capacity of 220 mm. The ultimate compression strength of the specimen is 106 kN and the specimen has a symmetric behavior.

First damages to the infilled material started by applying 157.08 mm displacement to the specimen that caused some ruptures inside the infilled material at the first steps and then at final steps the infilled material separated from the outer steel formwork.

The partially deformed shape of the specimen and the ultimate deformed shape are presented in Figure 4.117.

The stiffness of the specimen at the beginning of the test is about 3.3 kN/mm while it is calculated as 0.4 kN/mm at the end of the test and the stiffness degradation amount is 87 percent, Figure 4.118.

The cumulative energy which is calculated as the enclosed area of force-displacement curve is equal to 196000 kN.mm, Figure 4.119.

The ultimate equivalent damping calculated from the tests is about 32 percent, Figure 4.120.

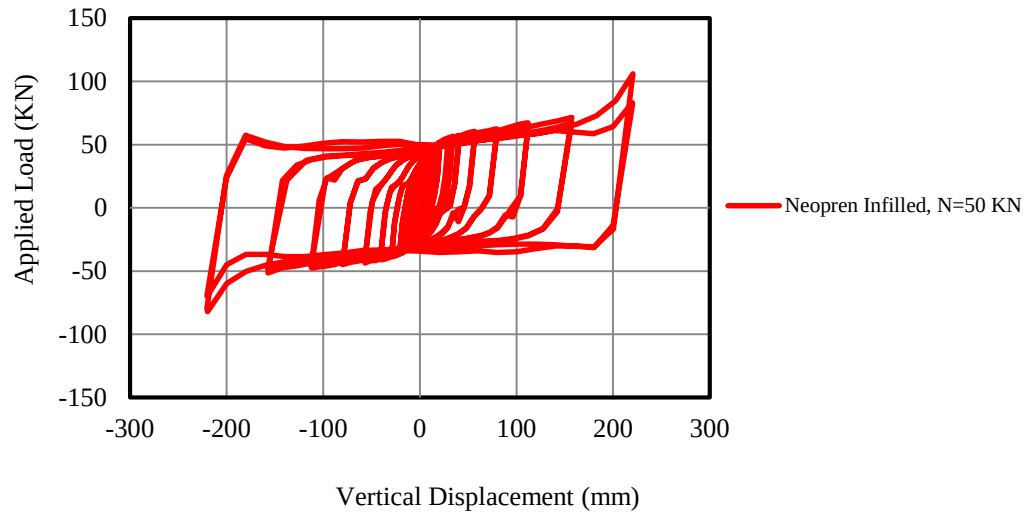


Figure 4.116 : Force-displacement relation from N+V (+) test of neoprene infilled specimen.



Partially deformed shape of the specimen



Ultimate deformed shape of the specimen

Figure 4.117 : Deformed shapes of the specimen during the test.

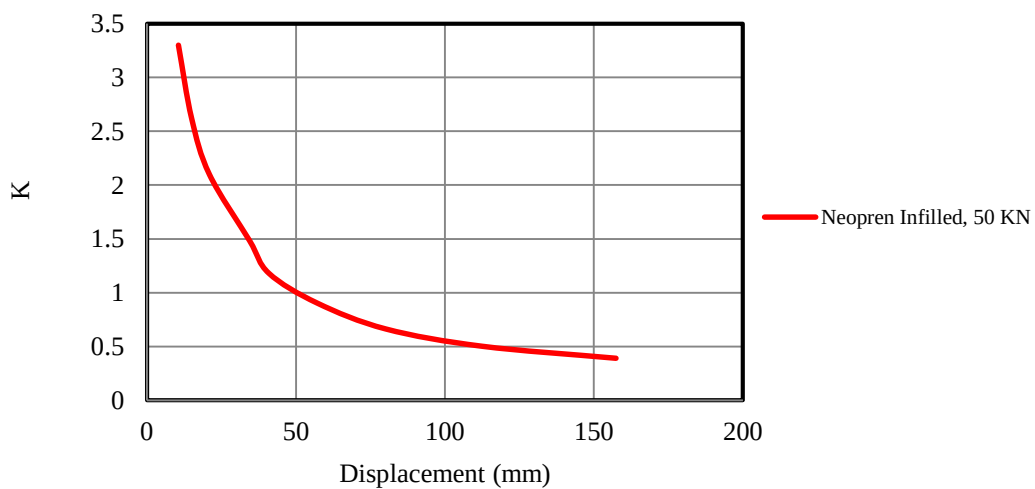


Figure 4.118 : Stiffness-displacement relation for neoprene infilled specimen.

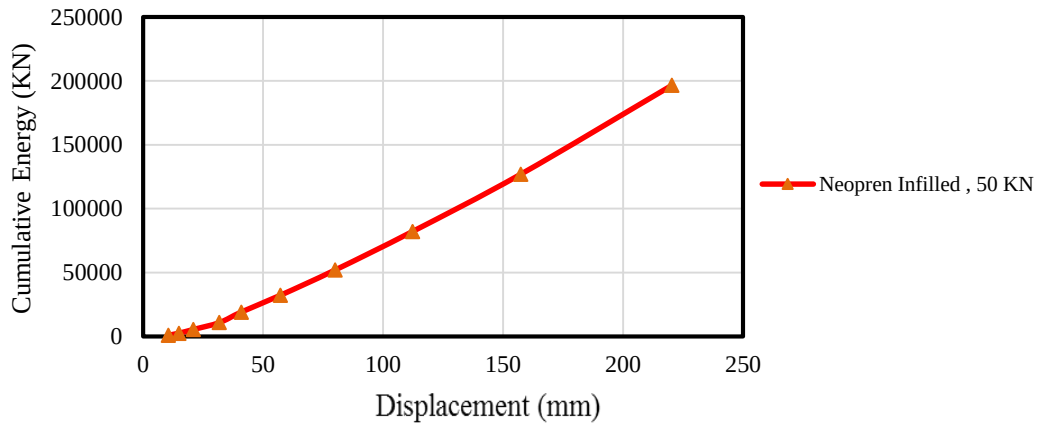


Figure 4.119 : Cumulative energy-displacement relation of neoprene infilled specimen.

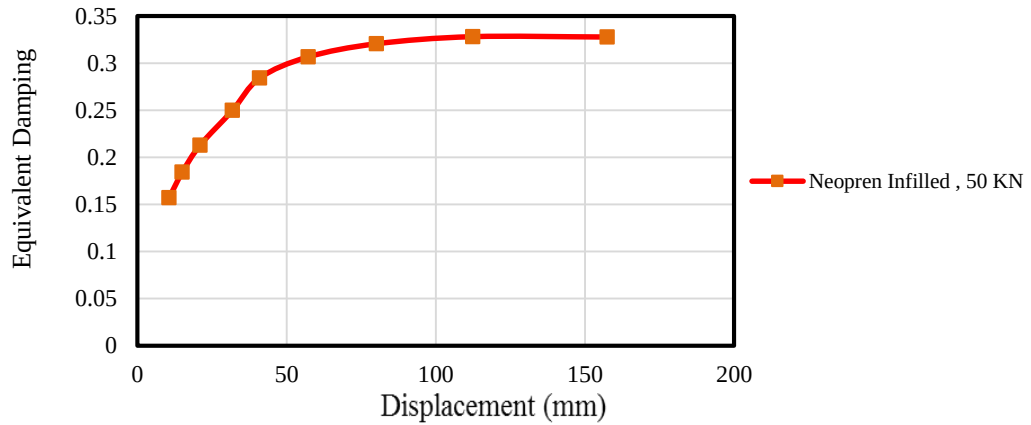


Figure 4.120 : Equivalent damping-displacement relation of neoprene infilled specimen.

4.3.4. Steel layered neoprene infilled specimen

4.3.4.1. 50 kN axial load

One N+V(+) test was carried out on steel layered infilled specimen for 50 kN compression axial load. Cycles obtained from the tests are presented in Figure 4.121.

The specimen has a nominal strength of 35 kN, as well as a maximum displacement capacity of 200 mm. The ultimate compression strength of the specimen is 95 kN and the specimen has a symmetric behavior.

First damages to the infilled material started by applying 157.08 mm displacement to the specimen that caused some ruptures inside the infilled material at the first steps and then at final steps the infilled material separated from the outer steel formwork.

The partially deformed shape of the specimen and the ultimate deformed shape are presented in Figure 4.122.

The stiffness of the specimen at the beginning of the test is about 3.32 kN/mm while it is calculated as 0.44 kN/mm at the end of the test and the stiffness degradation amount is 86 percent, Figure 4.123.

The cumulative energy which is calculated as the enclosed area of force-displacement curve is equal to 184000 kN.mm, Figure 4.124.

The ultimate equivalent damping calculated from the tests is about 37 percent, Figure 4.125.

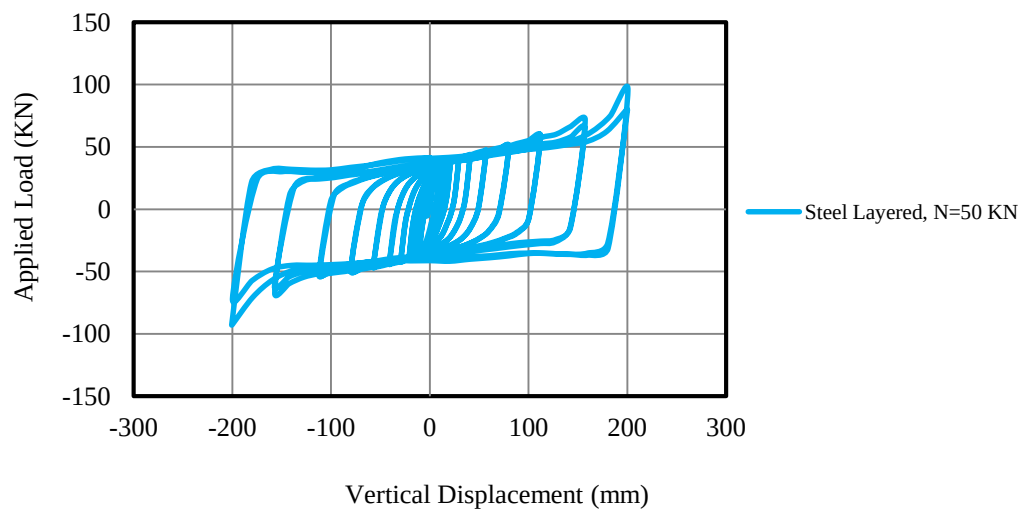
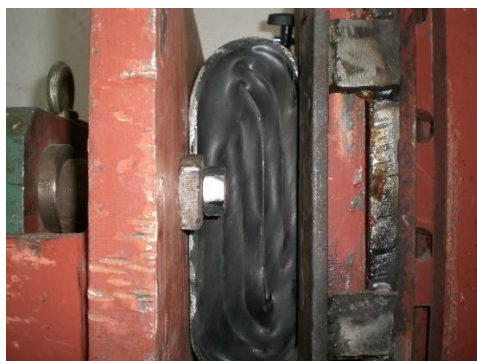
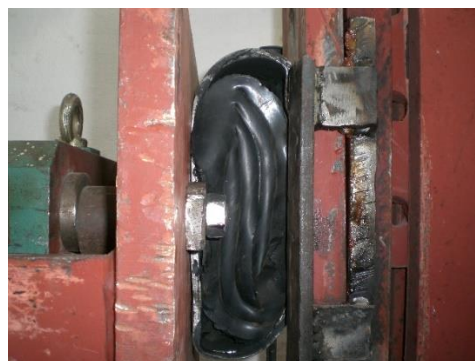


Figure 4.121 : Force-displacement relation from N+V (+) test of steel neoprene layered specimen.



Partially deformed shape of the specimen



Ultimate deformed shape of the specimen

Figure 4.122 : Deformed shapes of the specimen during the test.

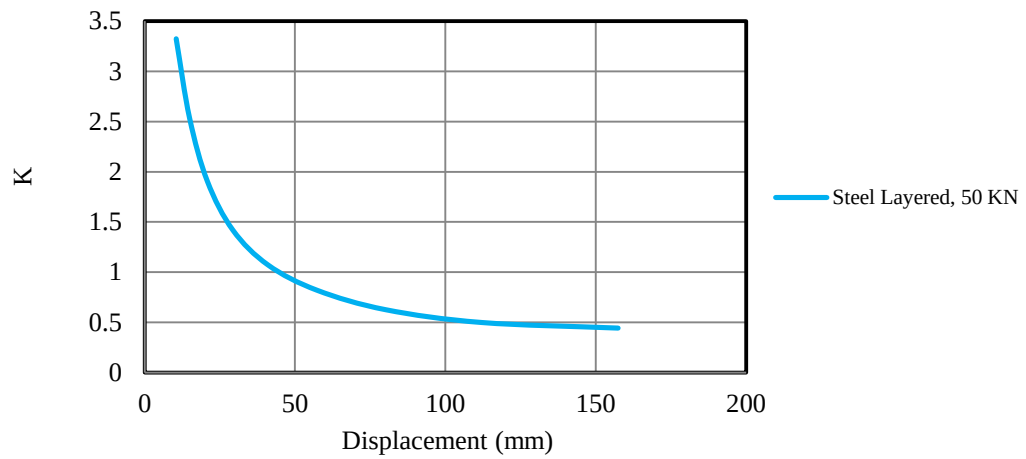


Figure 4.123 : Stiffness-displacement relation for steel neoprene layered specimen.

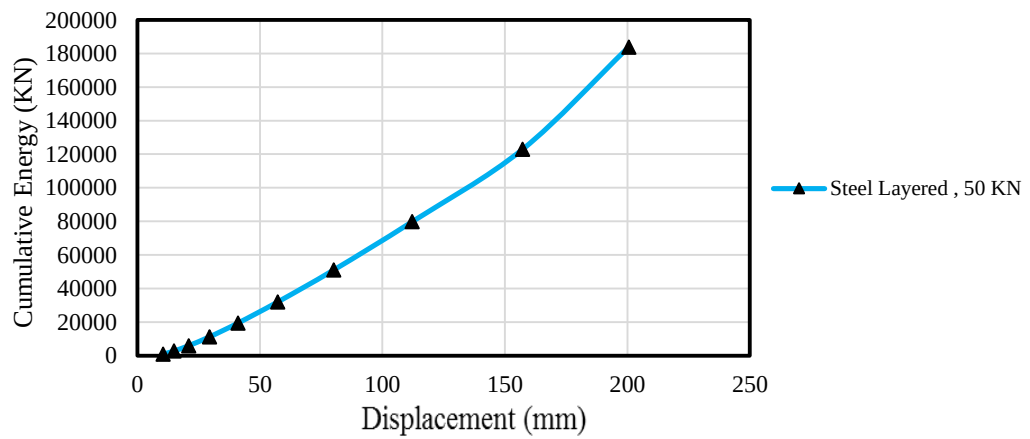


Figure 4.124 : Cumulative energy-displacement relation of steel neoprene layered specimen.

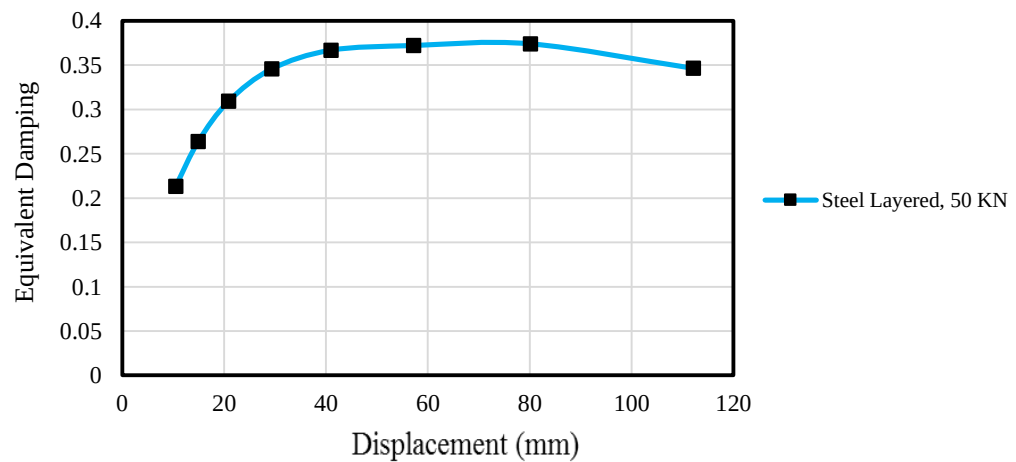


Figure 4.125 : Equivalent damping-displacement relation of steel neoprene layered specimen.

4.3.4.2. 100 kN axial load

One N+V(+) test was carried out on steel layered infilled specimen for 100 kN compression axial load. Cycles obtained from the tests are presented in Figure 4.126.

The specimen has a nominal strength of 52 kN, as well as a maximum displacement capacity of 200 mm. The ultimate compression strength of the specimen is 106 kN and the specimen has a symmetric behavior.

First damages to the infilled material started by applying 157.08 mm displacement to the specimen that caused some ruptures inside the infilled material at the first steps and then at final steps the infilled material separated from the outer steel formwork.

The partially deformed shape of the specimen and the ultimate deformed shape are presented in Figure 4.127.

The stiffness of the specimen at the beginning of the test is about 4 kN/mm while it is calculated as 0.47 kN/mm at the end of the test and the stiffness degradation amount is 88 percent, Figure 4.128.

The cumulative energy which is calculated as the enclosed area of force-displacement curve is equal to 220000 kN.mm, Figure 4.129.

The ultimate equivalent damping calculated from the tests is about 41 percent, Figure 4.130.

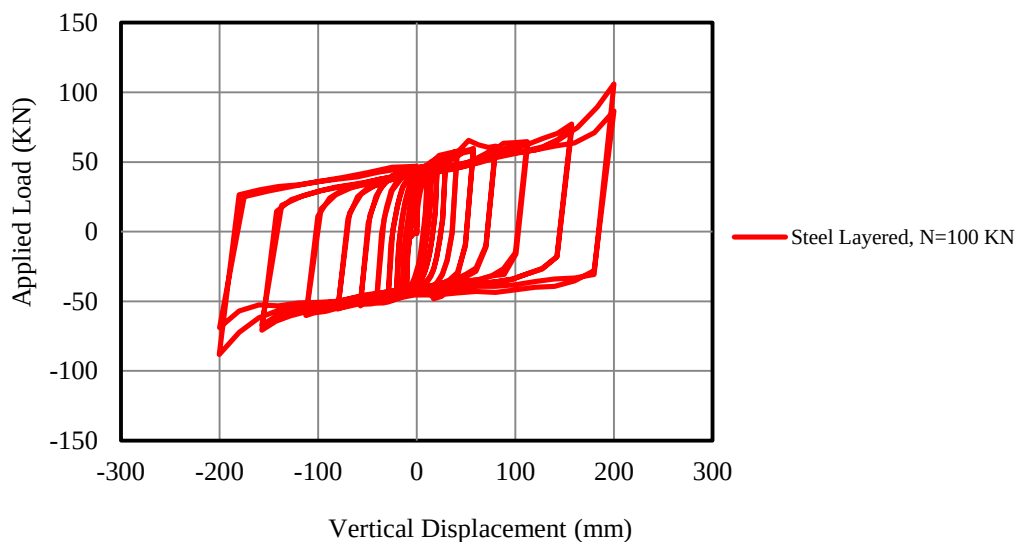


Figure 4.126 : Force-displacement relation from N+V (+) test of steel neoprene layered specimen.



Partially deformed shape of the specimen



Ultimate deformed shape of the specimen

Figure 4.127 : Deformed shapes of the specimen during the test.

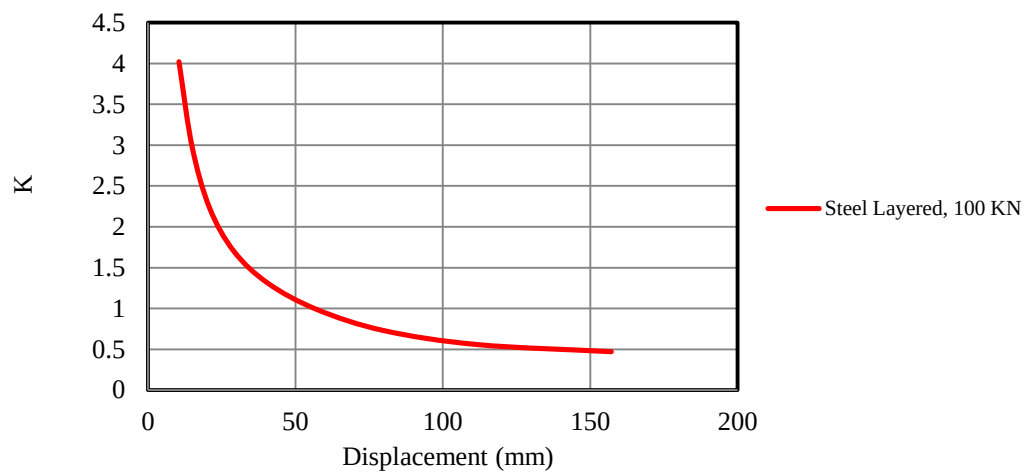


Figure 4.128 : Stiffness-displacement relation for steel neoprene layered specimen.

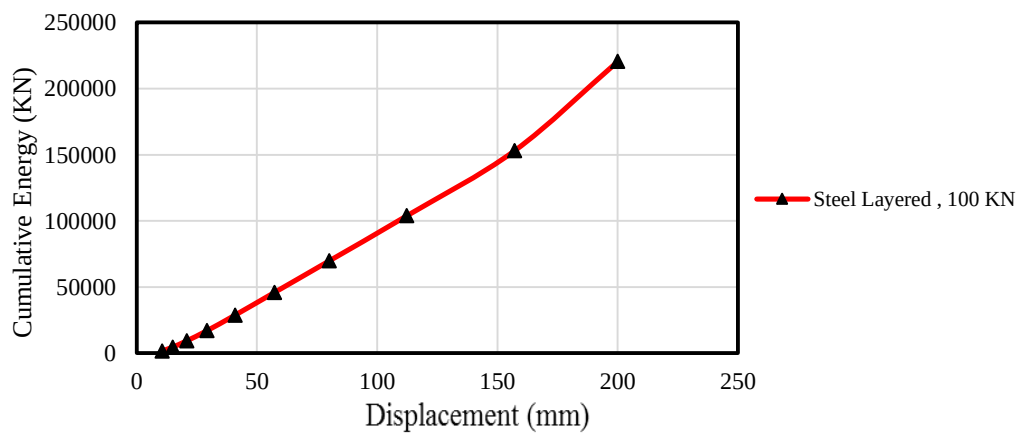


Figure 4.129 : Cumulative energy-displacement relation of steel neoprene layered specimen.

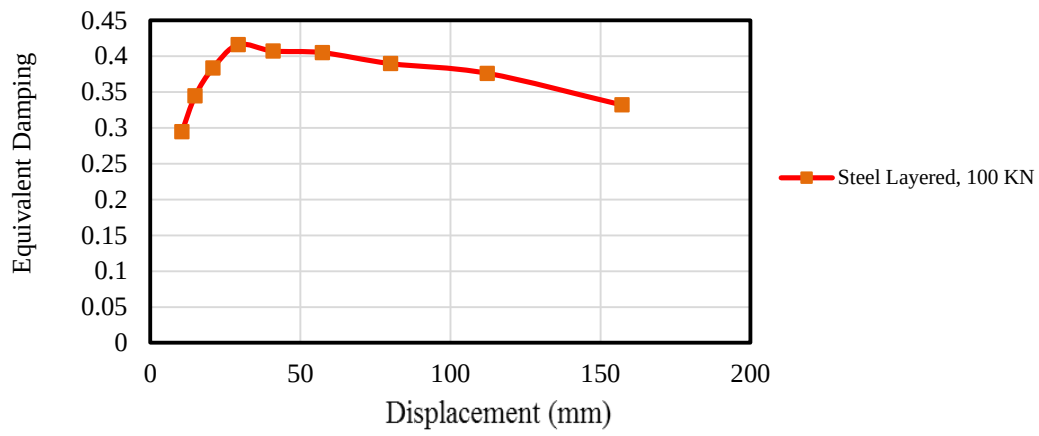


Figure 4.130 : Equivalent damping-displacement relation of steel neoprene layered specimen.

5. EXPERIMENTAL RESULTS FROM MONOTONIC AXIAL COMPRESSION TESTS

5.1. Bare Steel Specimens

5.1.1. 3 mm thick specimen

The force displacement relation obtained from the test is presented in Figure 5.1.

The specimen has a nominal strength of 7.5 kN and a displacement capacity of 64 mm and the ultimate compression strength of the specimen is 12 kN.

The partially deformed shape of the specimen during the test and the ultimate deformed shape are presented in Figure 5.2.

The stiffness degradation of the specimen is shown in Figure 5.3.

The maximum amount of cumulative energy which is the enclosed area of force-displacement curve is equal to 3450 kN.mm Figure 5.4.

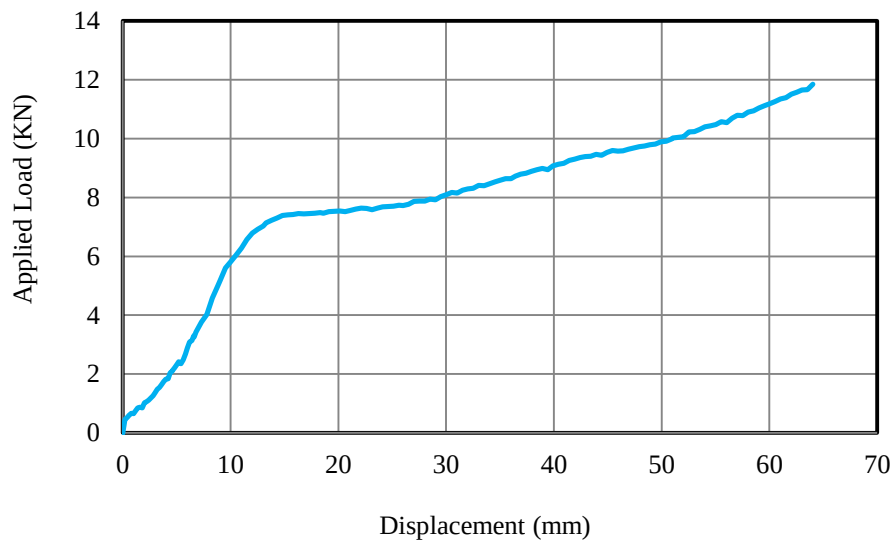


Figure 5.1 : Force-displacement relation from monotonic axial test of 3 mm thick specimen.



Partially deformed shape of the specimen



Ultimate deformed shape of the specimen

Figure 5.2 : Deformed shapes of the specimen during the test.

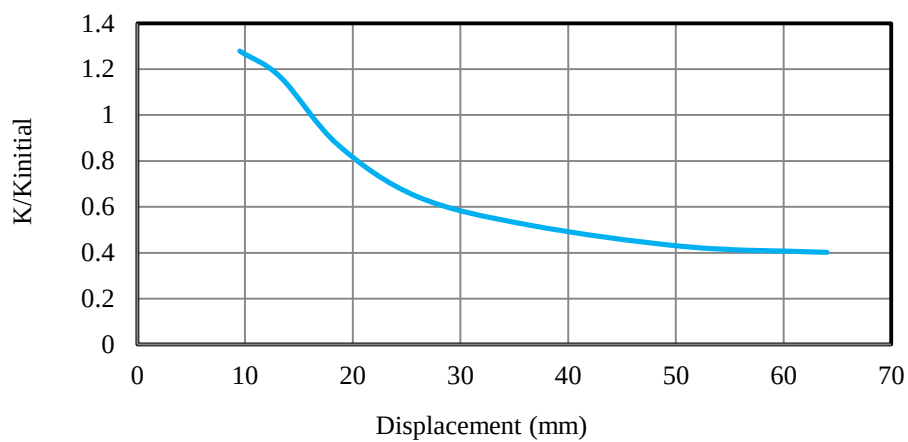


Figure 5.3 : Ratio of stiffness-displacement relation for 3 mm thick specimen.

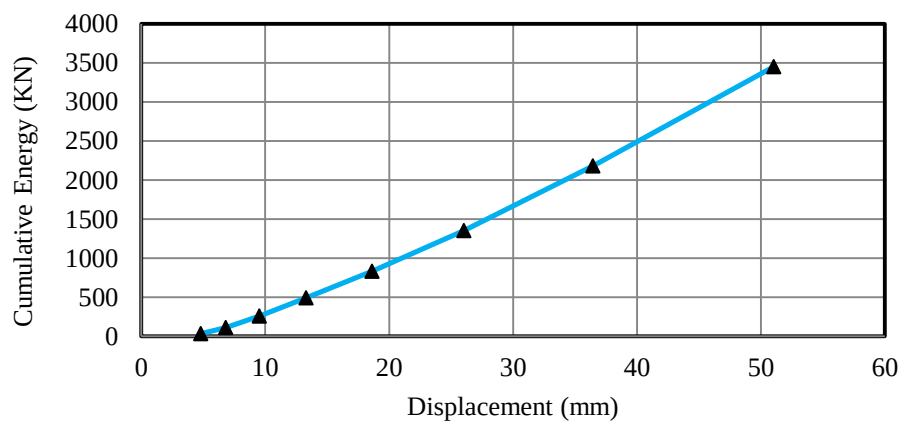


Figure 5.4 : Cumulative energy-displacement relation of 3 mm thick specimen.

5.1.2. 5 mm thick specimen

The force displacement relation obtained from the test is presented in Figure 5.5.

The specimen has a nominal strength of 18 kN and a displacement capacity of 64 mm and the ultimate compression strength of the specimen is 25 kN.

The partially deformed shape of the specimen during the test and the ultimate deformed shape are presented in Figure 5.6.

The stiffness degradation of the specimen is shown in Figure 5.7.

The maximum amount of cumulative energy which is the enclosed area of force-displacement curve is equal to 8150 kN.mm Figure 5.8.

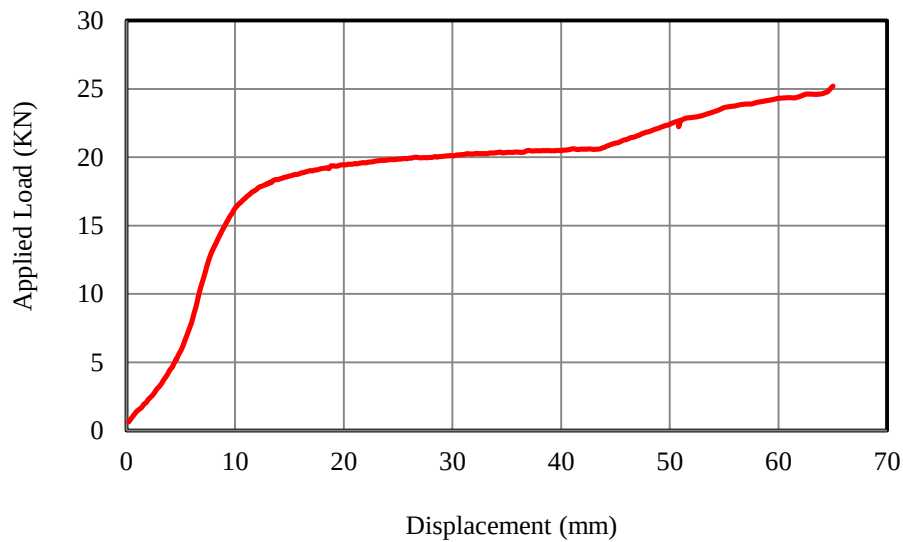


Figure 5.5 : Force-displacement relation from monotonic axial test of 5 mm thick specimen.



Partially deformed shape of the specimen



Ultimate deformed shape of the specimen

Figure 5.6 : Deformed shapes of the specimen during the test.

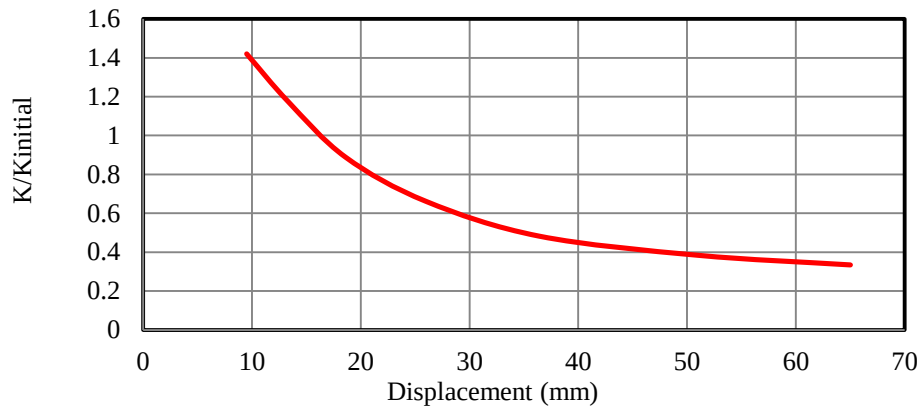


Figure 5.7 : Ratio of stiffness-displacement relation for 5 mm thick specimen.

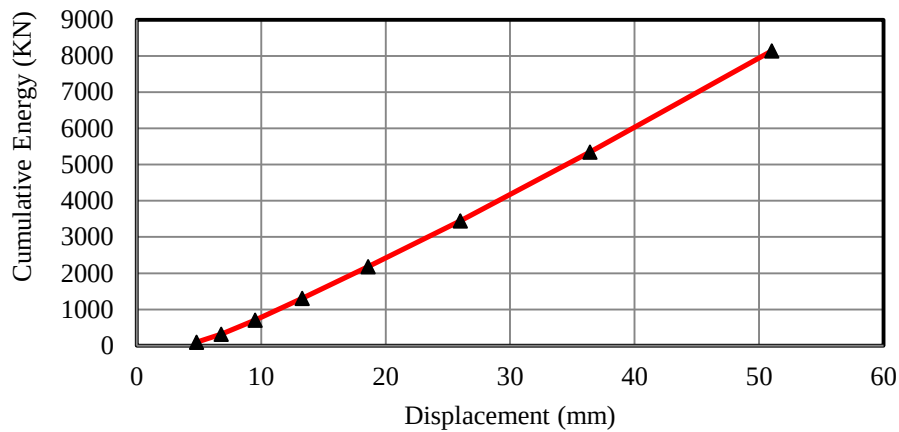


Figure 5.8 : Cumulative energy-displacement relation of 5 mm thick specimen.

5.1.3. 8 mm thick specimen

The force displacement relation obtained from the test is presented in Figure 5.1.

The specimen has a nominal strength of 55 kN and a displacement capacity of 66 mm and the ultimate compression strength of the specimen is 157 kN.

The partially deformed shape of the specimen during the test and the ultimate deformed shape are presented in Figure 5.2.

The stiffness degradation of the specimen is shown in Figure 5.3.

The maximum amount of cumulative energy which is the enclosed area of force-displacement curve is equal to 36600 kN.mm Figure 5.4.

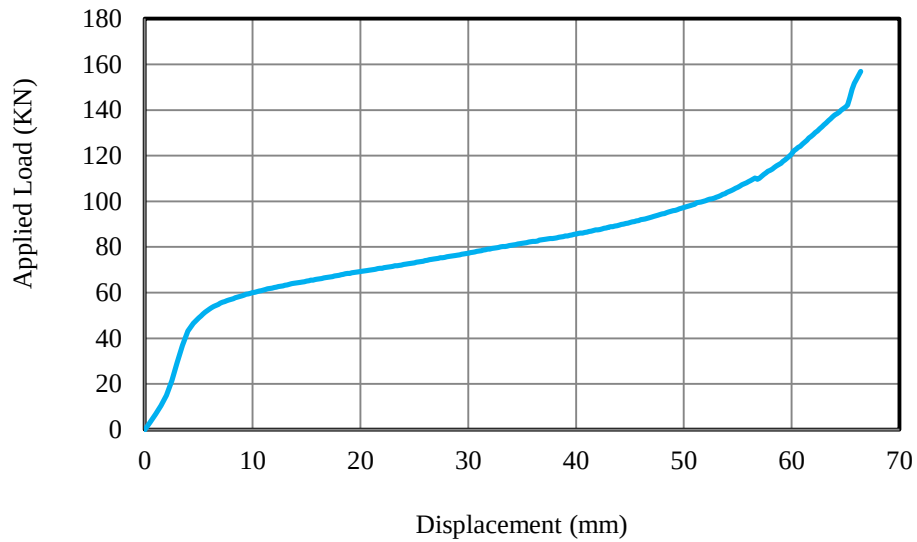


Figure 5.9 : Force-displacement relation from monotonic axial test of 8 mm thick specimen.



Partially deformed shape of the specimen



Ultimate deformed shape of the specimen

Figure 5.10 : Deformed shapes of the specimen during the test.

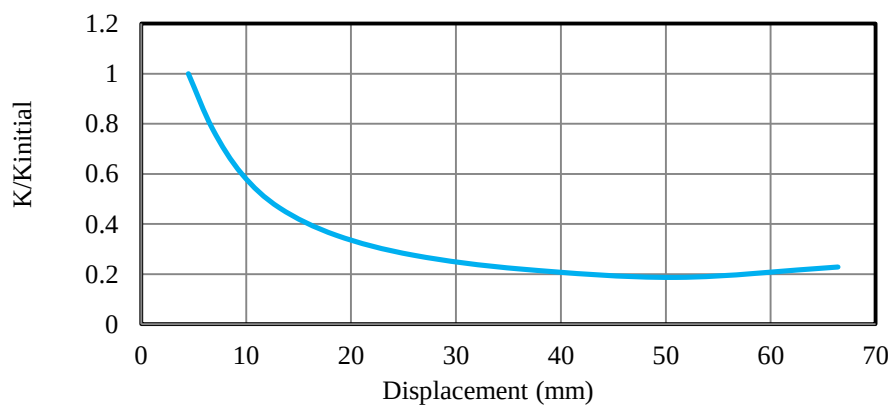


Figure 5.11 : Ratio of stiffness-displacement relation for 8 mm thick specimen.

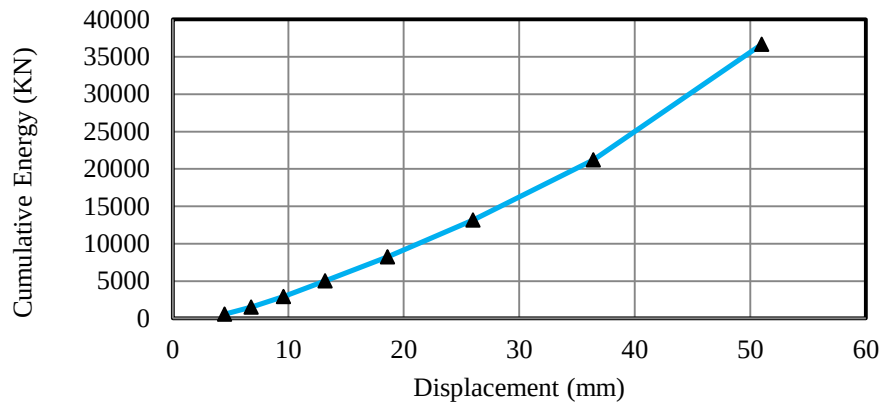


Figure 5.12 : Cumulative energy-displacement relation of 8 mm thick specimen.

5.2. Infilled Steel Specimens

5.2.1. Cord layered neoprene infilling

The force displacement relation obtained from the test is presented in Figure 5.13.

This test continued up to 26 mm displacement due to the characteristics of the testing setup and infilling materials in the cushions. The ultimate compression strength of this specimen up to this displacement is about 148 kN.

The partially deformed shape of the specimen during the test and the ultimate deformed shape are presented in Figure 5.14.

The stiffness degradation of the specimen is shown in Figure 5.15.

The maximum amount of cumulative energy which is the enclosed area of force-displacement curve is equal to 15800 kN.mm Figure 5.16.

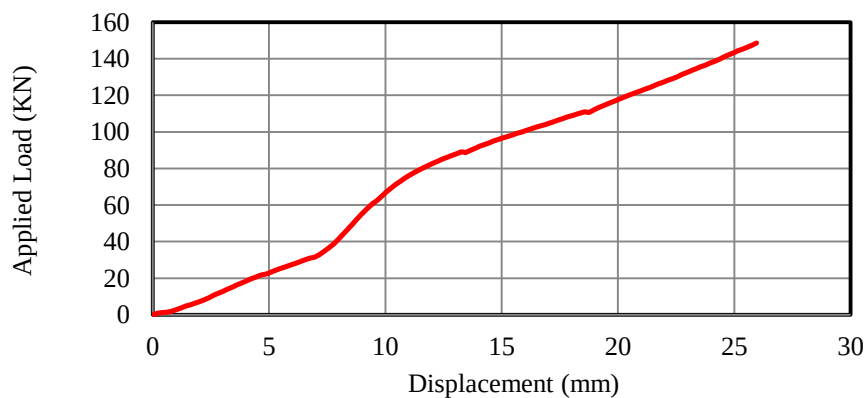


Figure 5.13 : Force-displacement relation from monotonic axial test of cord neoprene layered specimen.



Partially deformed shape of the specimen



Ultimate deformed shape of the specimen

Figure 5.14 : Deformed shapes of the specimen during the test.

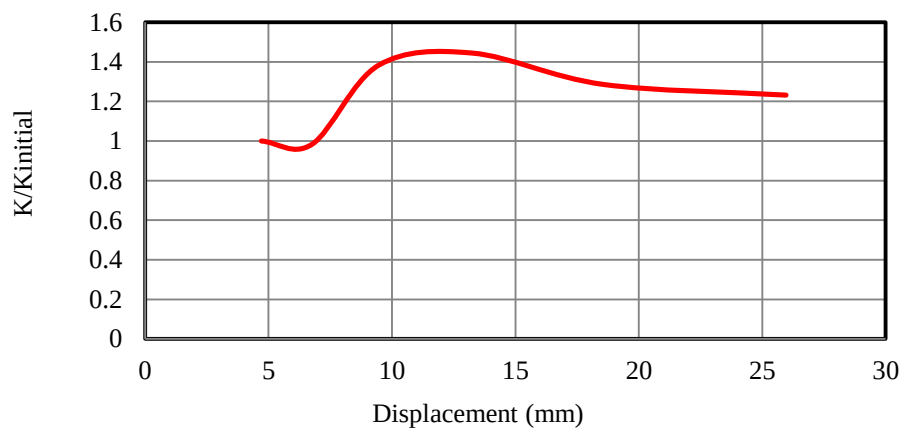


Figure 5.15 : Ratio of stiffness-displacement relation for cord neoprene layered specimen.

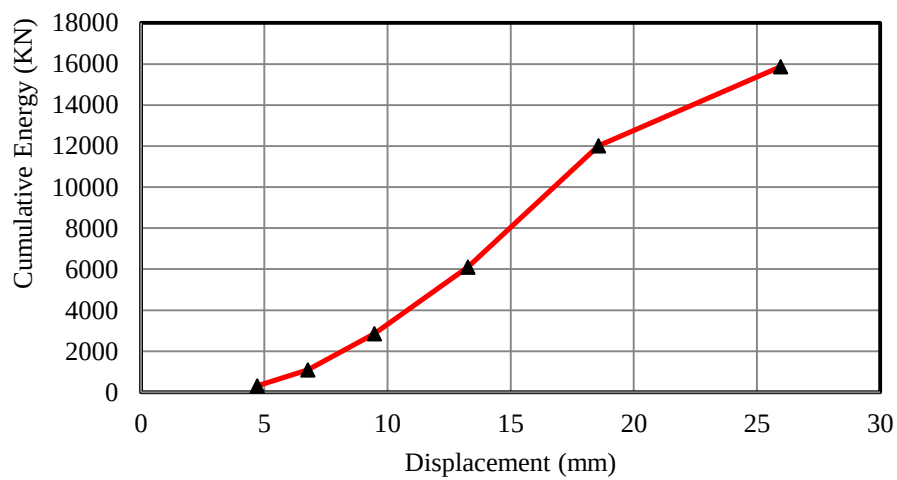


Figure 5.16 : Cumulative energy-displacement relation of cord neoprene layered specimen.

5.2.2. Frp layered neoprene infilling

The force displacement relation obtained from the test is presented in Figure 5.17.

This test continued up to 26 mm displacement due to the characteristics of the testing setup and infilling materials in the cushions. The ultimate compression strength of this specimen up to this displacement is about 115 kN.

The partially deformed shape of the specimen during the test and the ultimate deformed shape are presented in Figure 5.18.

The stiffness degradation of the specimen is shown in Figure 5.19.

The maximum amount of cumulative energy which is the enclosed area of force-displacement curve is equal to 12700 kN.mm Figure 5.20.

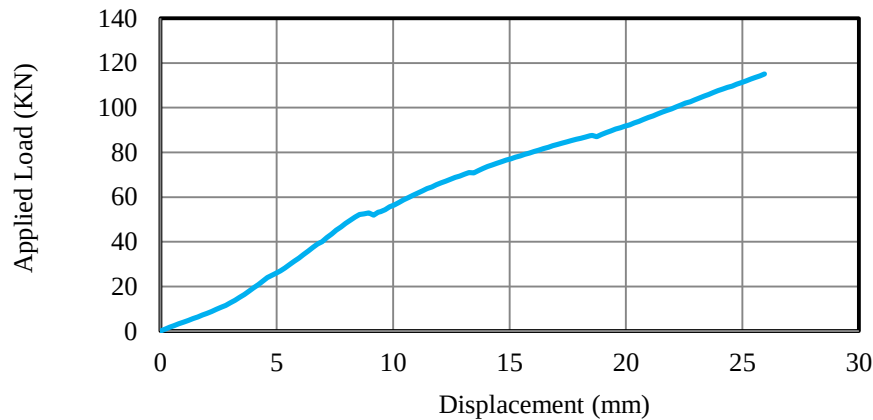


Figure 5.17 : Force-displacement relation from monotonic axial test of FRP neoprene layered specimen.



Partially deformed shape of the specimen



Ultimate deformed shape of the specimen

Figure 5.18 : Deformed shapes of the specimen during the test.

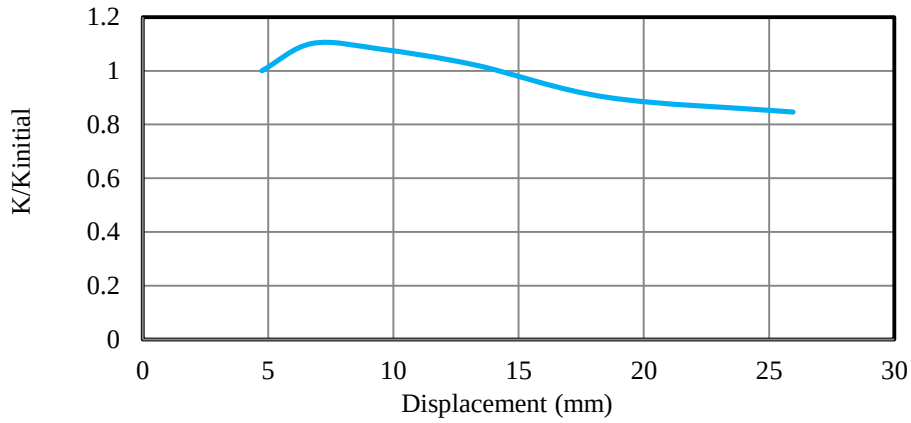


Figure 5.19 : Ratio of stiffness-displacement relation for FRP neoprene layered specimen.

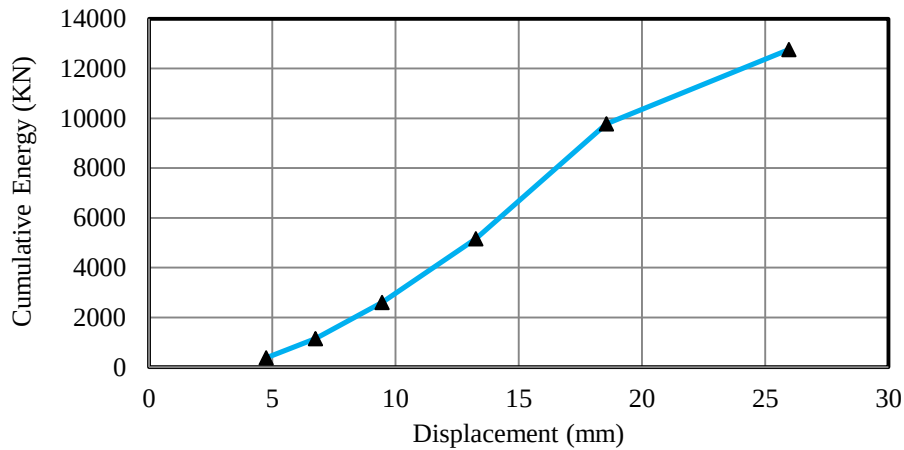


Figure 5.20 : Cumulative energy-displacement relation of FRP neoprene layered specimen.

5.2.3. Steel layered neoprene infilling

The force displacement relation obtained from the test is presented in Figure 5.21.

This test continued up to 22 mm displacement due to the characteristics of the testing setup and infilling materials in the cushions. The ultimate compression strength of this specimen up to this displacement is about 193 kN.

The partially deformed shape of the specimen during the test and the ultimate deformed shape are presented in Figure 5.22

The stiffness degradation of the specimen is shown in Figure 5.23.

The maximum amount of cumulative energy which is the enclosed area of force-displacement curve is equal to 21300 kN.mm Figure 5.24.

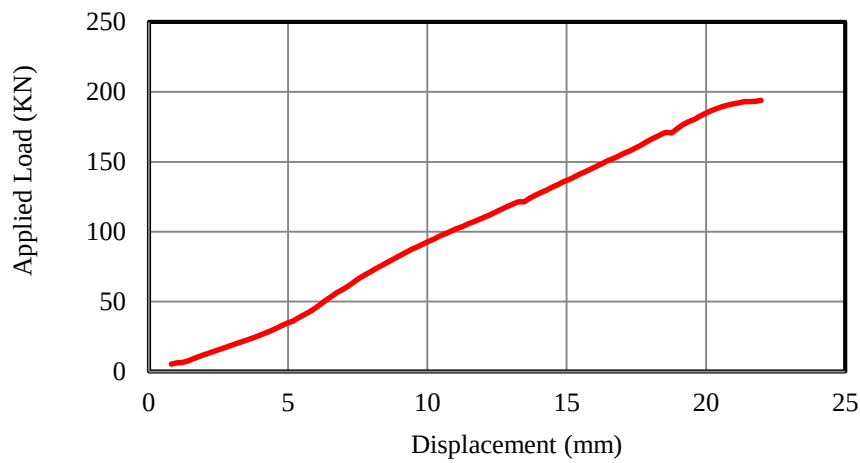


Figure 5.21 : Force-displacement relation from monotonic axial test of steel neoprene layered specimen.



Partially deformed shape of the specimen



Ultimate deformed shape of the specimen

Figure 5.22 : Deformed shapes of the specimen during the test.

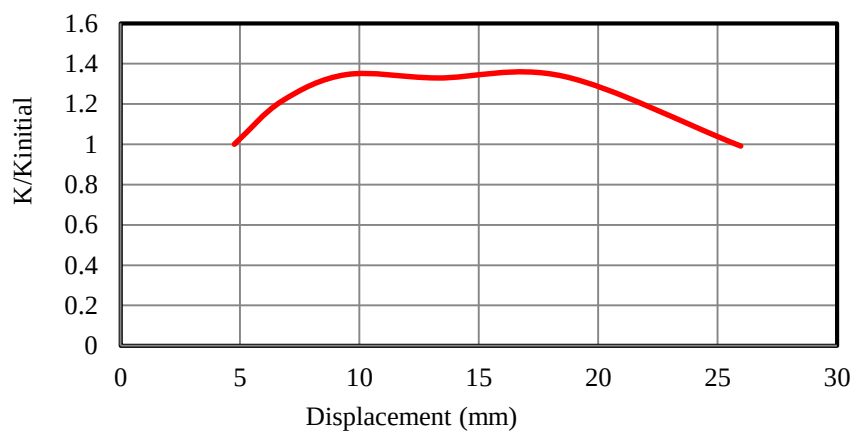


Figure 5.23 : Ratio of stiffness-displacement relation for steel neoprene layered specimen.

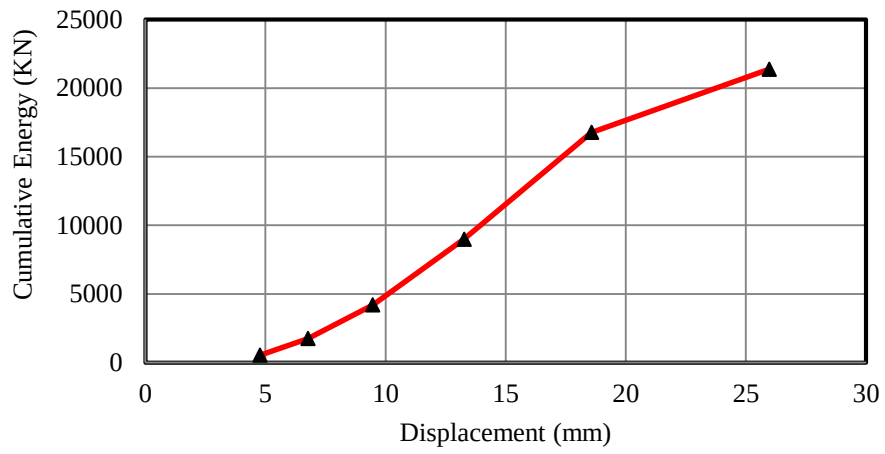


Figure 5.24 : Cumulative energy-displacement relation of steel neoprene layered specimen.

6. COMPARISONS OF TEST RESULTS

6.1. Force-Displacement Diagrams

6.1.1. Infilled specimens

6.1.1.1 Cord layered neoprene specimen

From the force-displacement diagrams of cord layered neoprene infilled specimen, it is observed that by increasing the amount of the constant compression load from 50 kN to 100 kN the ultimate strength and also the capacity of the specimen increases, Figure 6.1.

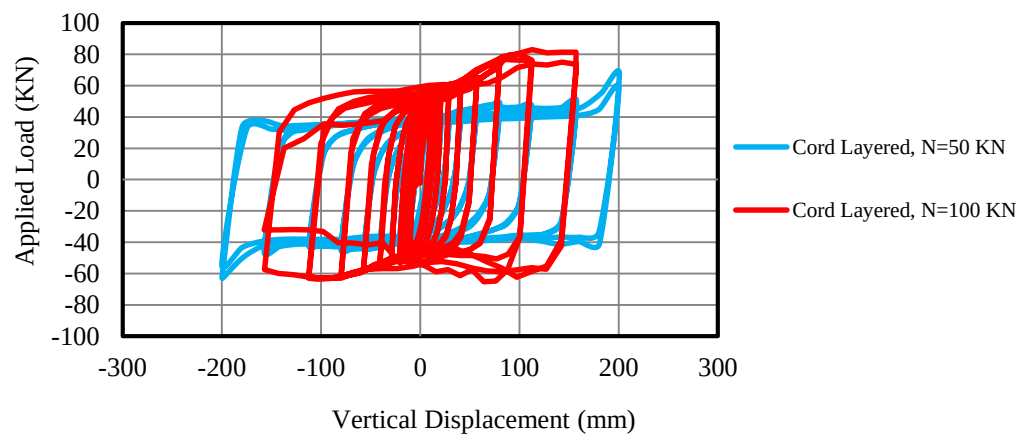


Figure 6.1 : Force-displacement relation from N+V (+) test of cord neoprene layered specimen.

6.1.1.2. Frp layered neoprene specimen

From the force-displacement diagram of the FRP layered neoprene infilled specimen, it is observed that by increasing the amount of the constant compression load from 50 kN to 100 kN the ultimate strength and also the capacity of the specimen increases, Figure 6.2.

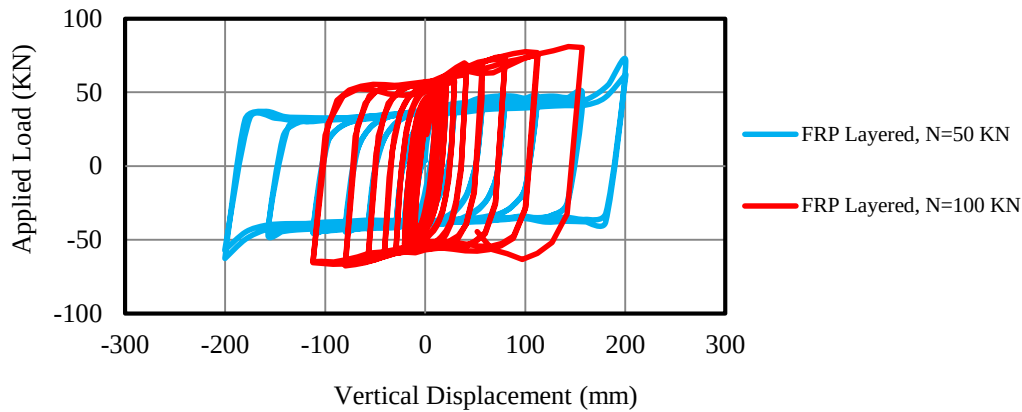


Figure 6.2 : Force-displacement relation from N+V (+) test of FRP neoprene layered specimen.

6.1.1.3. Infilled pure neoprene layered specimen

From the force-displacement diagram of the pure neoprene infilled specimen, it is observed that by increasing the amount of the constant compression load from 0 kN to 50 kN the ultimate strength of the specimen does not change a lot but the capacity of the specimen increases a bit, Figure 6.3.

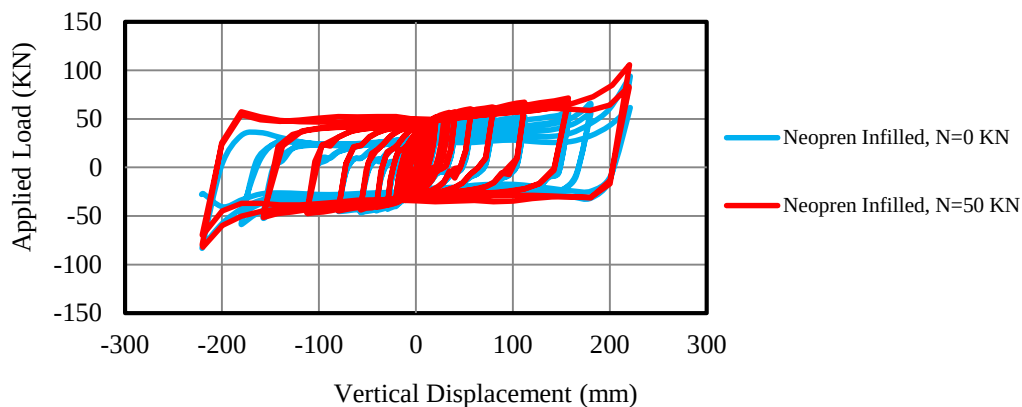


Figure 6.3 : Force-displacement relation from N+V (+) test of neoprene infilled specimen.

6.1.1.4. Steel layered neoprene specimen

From the force-displacement diagram of steel layered neoprene infilled specimen, it is observed that by increasing the amount of the constant compression load from 50 kN to 100 kN the ultimate strength and also the capacity of the specimen does not change a lot, Figure 6.4.

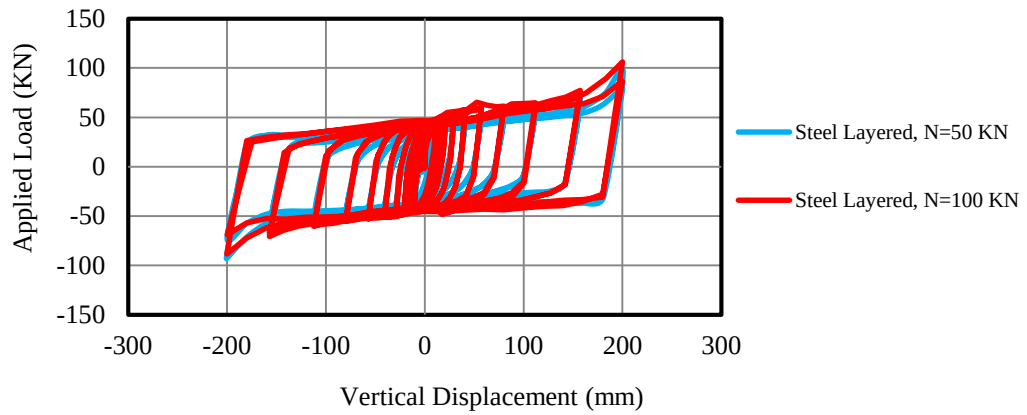


Figure 6.4 : Force-displacement relation from N+V (+) test of steel neoprene layered specimen.

6.1.1.5. Infilled specimens under 50 kN constant compression load

By comparing the force-displacement diagrams of four infilled specimens for 50 kN constant compression load, it is observed that pure neoprene infilled and steel layered neoprene infilled specimens have the greatest amounts of ultimate strengths respectively and also the capacity of the cord layered, FRP layered and steel layered neoprene specimens are almost the same but the capacity of neoprene infilled specimen is a bit more than the remaining three specimens, Figure 6.5.

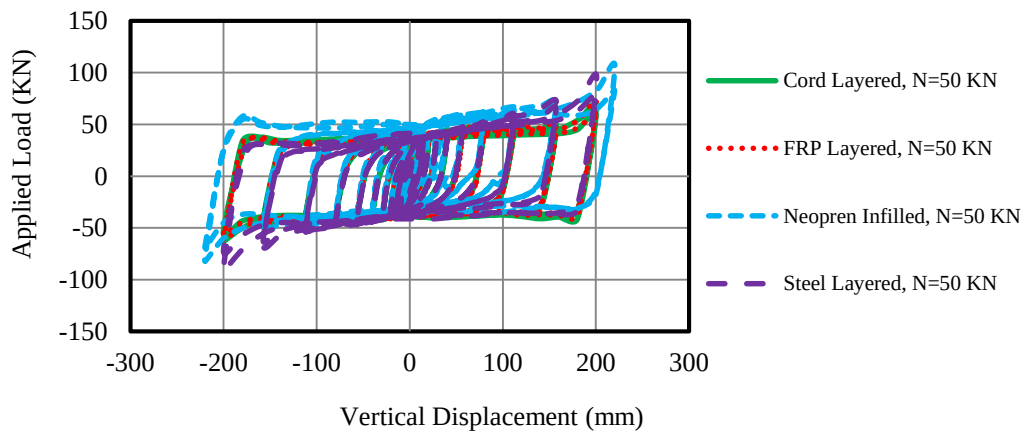


Figure 6.5 : Force-displacement relation from N+V (+) test of infilled specimens.

6.1.1.6. Infilled specimens under 100 kN constant compression load

By comparing the force-displacement diagrams of three infilled specimens for 100 kN constant compression load, it is observed that steel layered neoprene infilled specimen has the greatest amount of ultimate strength and also the capacity of the cord layered

and FRP layered neoprene infilled specimens are almost the same and are the largest in this group, Figure 6.6.

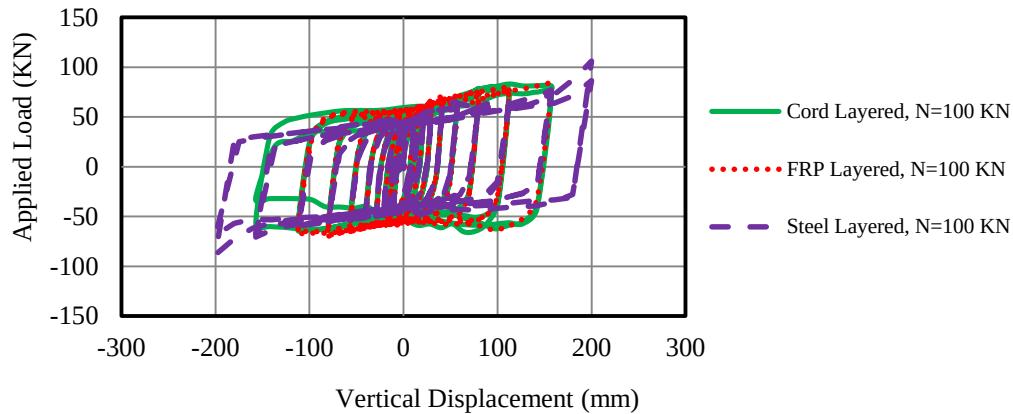


Figure 6.6 : Force-displacement relation from N+V (+) test of infilled specimens.

6.1.2. Bare and infilled specimens

6.1.2.1. Bare 8 mm specimen vs. cord layered neoprene infilled specimen

By comparing the force-displacement diagrams of a cord layered neoprene infilled specimen for 100 kN constant compression load by 8 mm thick bare specimen for 75 kN constant compression load, it is observed that the ultimate strength and also the capacity of the specimen increases by using infilling material inside the specimen, Figure 6.7.

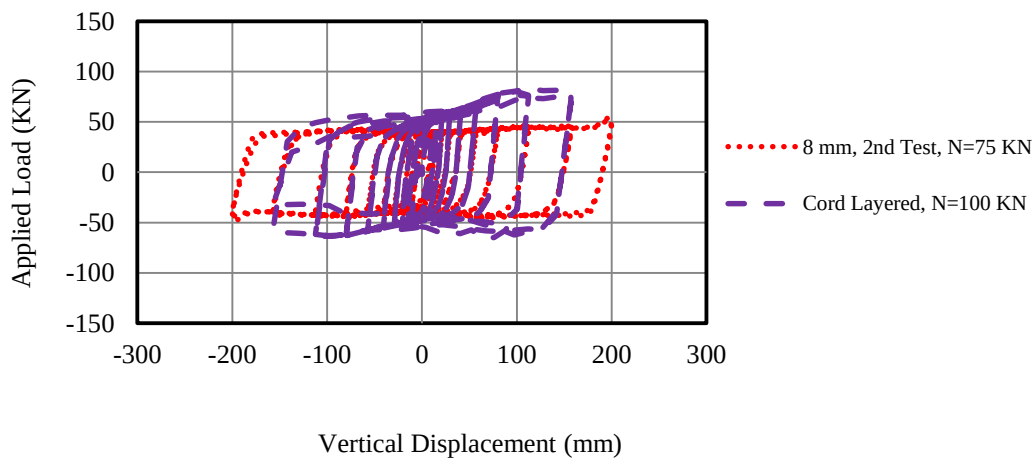


Figure 6.7 : Force-displacement relation from N+V (+) test of infilled and bare specimens.

6.1.2.2. Bare 8 mm specimen vs. frp layered neoprene infilled specimen

By comparing the force-displacement diagrams of a FRP layered neoprene infilled specimen for 100 kN constant compression load by 8 mm thick bare specimen for 75 kN constant compression load, it is observed that the ultimate strength and also the capacity of the specimen increases by using infilling material inside the specimen, Figure 6.8.

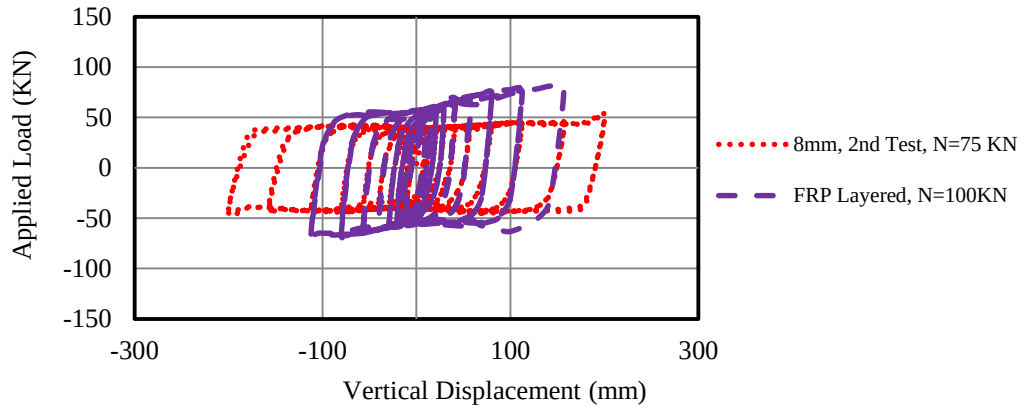


Figure 6.8 : Force-displacement relation from N+V (+) test of infilled and bare specimens.

6.1.2.3. Bare 8 mm specimen vs. steel layered neoprene infilled specimen

By comparing the force-displacement diagrams of a steel layered neoprene infilled specimen for 100 kN constant compression load by 8 mm thick bare specimen for 75 kN constant compression load, it is observed that the ultimate strength of the specimen increases but the capacity of the specimen does not change a lot by using infilling material inside the specimen, Figure 6.9.

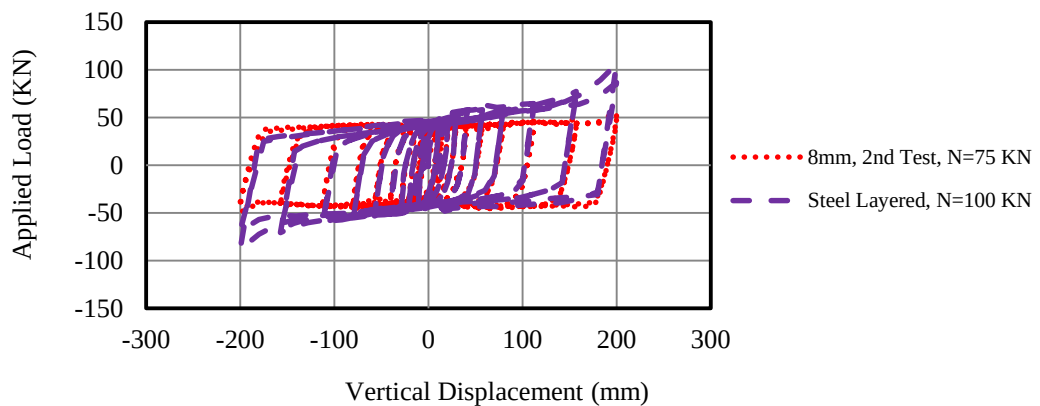


Figure 6.9 : Force-displacement relation from N+V (+) test of infilled and bare specimens.

6.1.2.4. Bare 8 mm specimen vs. cord layered neoprene infilled specimen

By comparing the force-displacement diagrams of a cord layered neoprene infilled specimen by 8 mm thick bare specimen for 50 kN constant compression load, it is observed that the capacity of the specimen does not change a lot by using infilling material inside the specimen, Figure 6.10.

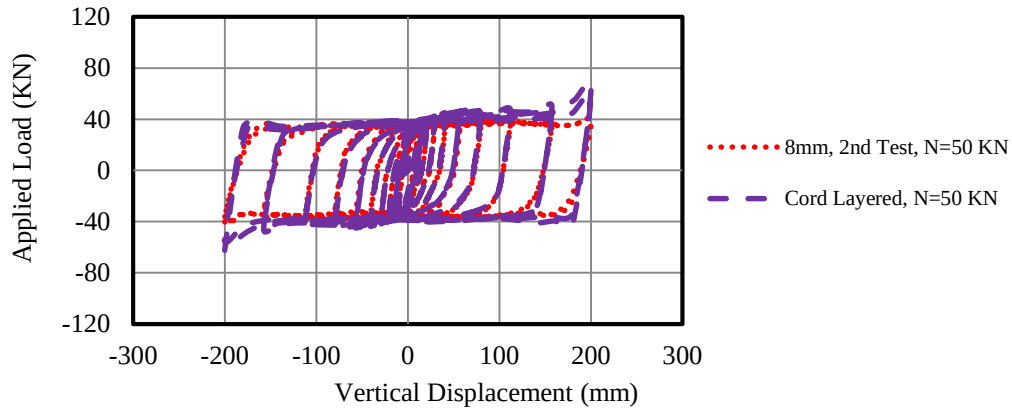


Figure 6.10 : Force-displacement relation from N+V (+) test of infilled and bare specimens.

6.1.2.5. Bare 8 mm specimen vs. frp layered neoprene infilled specimen

By comparing the force-displacement diagrams of a FRP layered neoprene infilled specimen by 8 mm thick bare specimen for 50 kN constant compression load, it is observed that the capacity of the specimen does not change a lot by using infilling material inside the specimen, Figure 6.11.

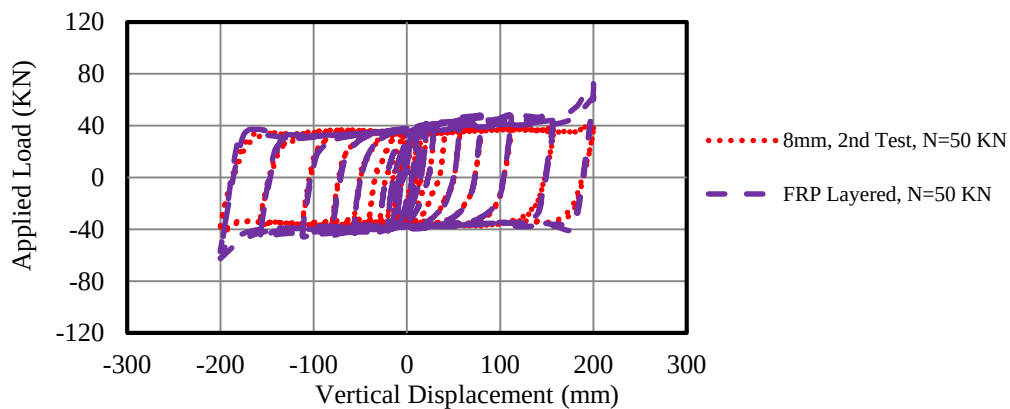


Figure 6.11 : Force-displacement relation from N+V (+) test of infilled and bare specimens.

6.1.2.6. Bare 8 mm specimen vs. pure neoprene infilled specimen

By comparing the force-displacement diagrams of a pure neoprene infilled specimen by 8 mm thick bare specimen for 50 kN constant compression load, it is observed that the ultimate strength and also the capacity of the specimen increases by using infilling material inside the specimen, Figure 6.12.

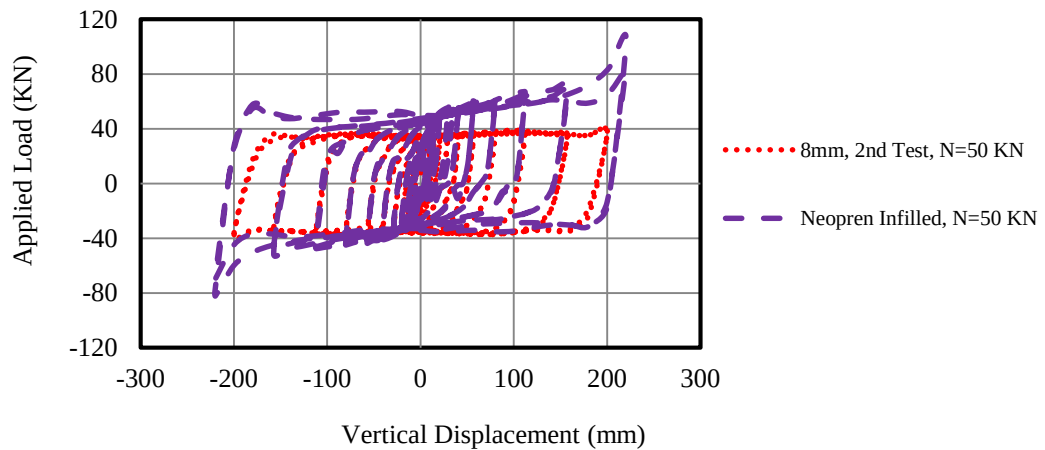


Figure 6.12 : Force-displacement relation from N+V (+) test of infilled and bare specimens.

6.1.2.7. Bare 8 mm specimen vs. steel layered neoprene infilled specimen

By comparing the force-displacement diagrams of a steel layered neoprene infilled specimen by 8 mm thick bare specimen for 50 kN constant compression load, it is observed that the capacity of the specimen does not change a lot by using infilling material inside the specimen, Figure 6.13.

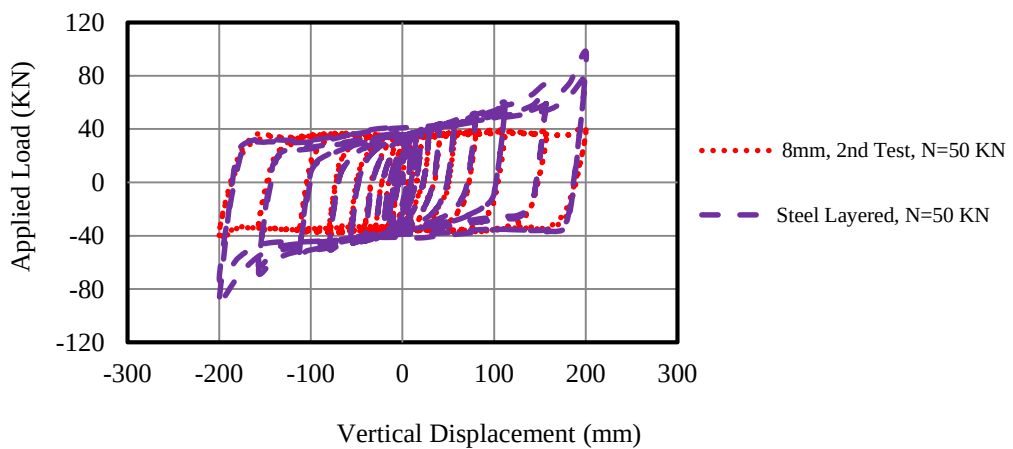


Figure 6.13 : Force-displacement relation from N+V (+) test of infilled and bare specimens.

6.1.2.8. Bare 8 mm specimens vs. frp layered neoprene infilled specimen

By comparing the force-displacement diagrams of a FRP layered neoprene infilled specimen for 0 kN by two 8 mm thick bare specimens for 25 kN constant compression load, it is observed that the ultimate strength of the specimen increases but the capacity of the specimen does not change a lot by using infilling material inside the specimen, Figure 6.14.

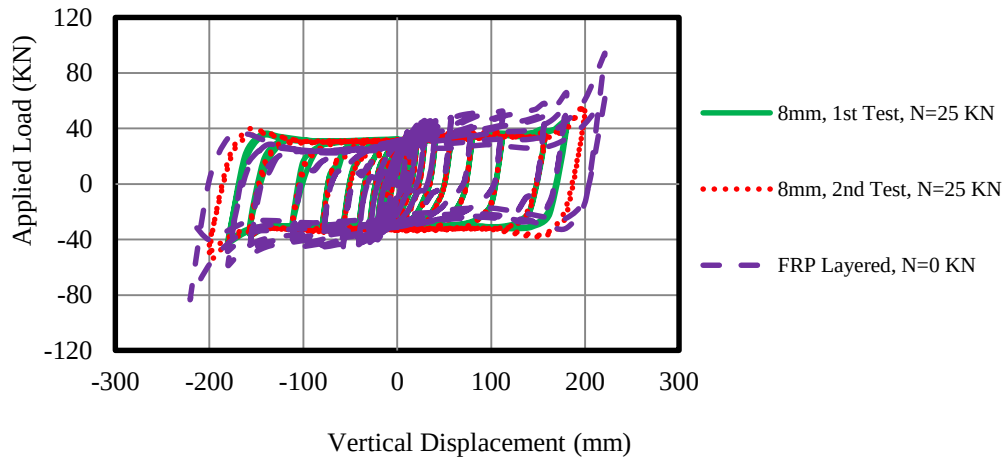


Figure 6.14 : Force-displacement relation from N+V (+) test of infilled and bare specimens.

6.2. Cumulative Energy-Displacement Diagrams

6.2.1. Bare 8 mm specimen vs. infilled specimens

By comparing cumulative energy diagrams of four infilled specimens with 8 mm thick bare specimen for 50 kN constant compression axial load, it is observed that pure neoprene infilled specimen has the best performance and dissipates energy better than all other specimens and also energy dissipation capacity of the specimens increases by using infilling material inside the specimen because as it could be seen from the graphs the 8 mm thick bare specimen has the least amount of cumulative energy, Figure 6.15.

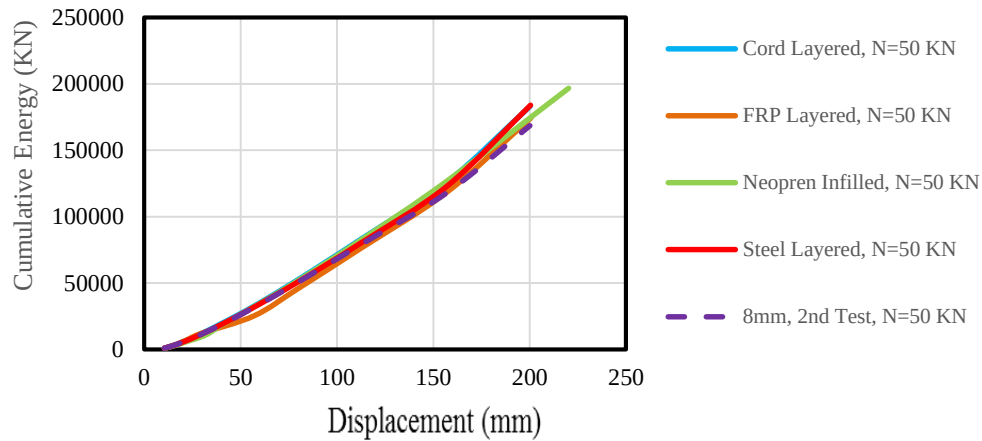


Figure 6.15 : Cumulative energy-displacement relation from N+V (+) test of infilled and bare specimens.

6.2.2. Bare 8 mm specimen vs. infilled specimens

By comparing cumulative energy diagrams of three infilled specimens for 100 kN constant axial compression load with 8 mm thick bare specimen for 75 kN constant compression axial load it is observed that steel layered neoprene infilled specimen has the best performance and dissipates energy better than all other specimens and also energy dissipation capacity of the specimens increases by using infilling material inside the specimen because as it could be seen from the graphs the 8 mm thick bare specimen has the least amount of cumulative energy, Figure 6.16.

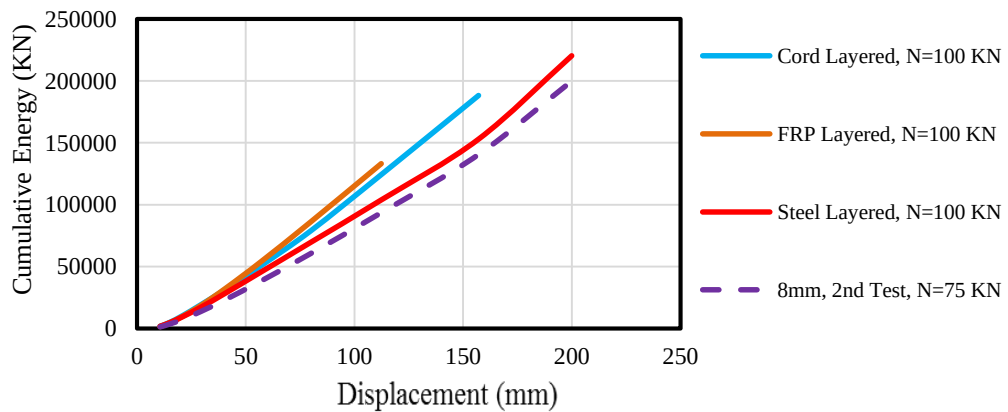


Figure 6.16 : Cumulative energy-displacement relation from N+V (+) test of infilled and bare specimens.

6.2.3. Infilled specimens under 50 kN and 100 kN constant compression loads

By comparing cumulative energy diagrams of different infilled specimens for 50 kN and 100 kN constant axial compression loads, it is observed that by increasing the amount of compression load the performance of infilled specimens increases and as it could be seen the steel layered neoprene infilled specimen has the best energy dissipation capability among all of the infilled specimens for 50 and 100 kN constant axial compression loads, Figure 6.17.

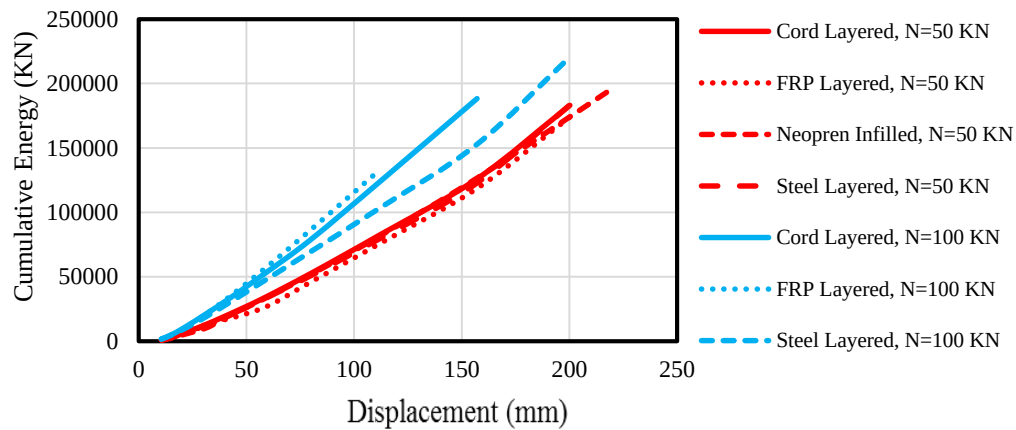


Figure 6.17 : Cumulative energy-displacement relation from N+V (+) test of infilled specimens.

6.3. Equivalent Damping-Displacement Diagrams

6.3.1. Bare 8 mm specimens vs. infilled specimens

By comparing equivalent damping diagrams of four infilled specimens with 8 mm thick bare specimens for 50 kN constant compression axial load, it is observed that by using infilling material inside the specimen the amount of equivalent damping decreases because as it could be seen in the diagram the 8 mm thick bare specimen has the greatest amount of equivalent damping and also between the infilled specimens FRP layered and cord layered neoprene infilled specimens both have the greatest amount, Figure 6.18.

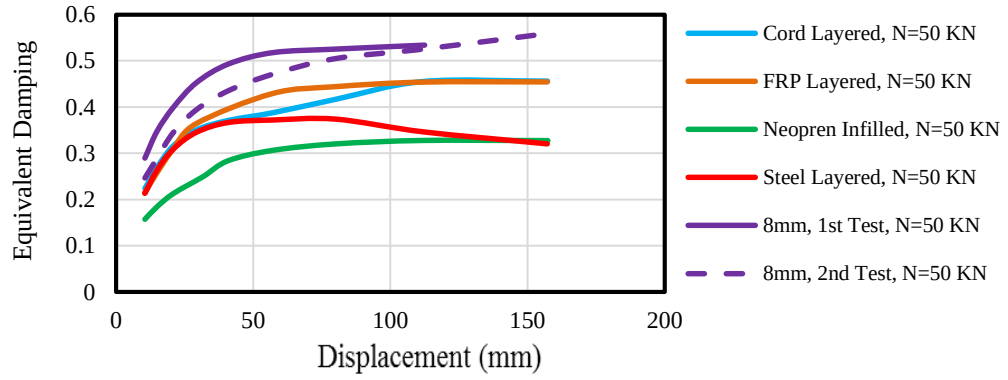


Figure 6.18 : Equivalent damping-displacement relation from N+V (+) test of infilled and bare specimens.

6.3.2. Bare 8 mm specimens vs. infilled specimens

By comparing equivalent damping diagrams of three infilled specimens for 100 kN constant compression load with 8 mm thick bare specimens for 75 kN constant compression axial load, it is observed that by using infilling material inside the specimen the amount of equivalent damping decreases because as it could be seen in the diagram the 8 mm thick bare specimen has the greatest amount of equivalent damping and also between the infilled specimens FRP layered neoprene infilled specimen has the greatest amount, Figure 6.19.

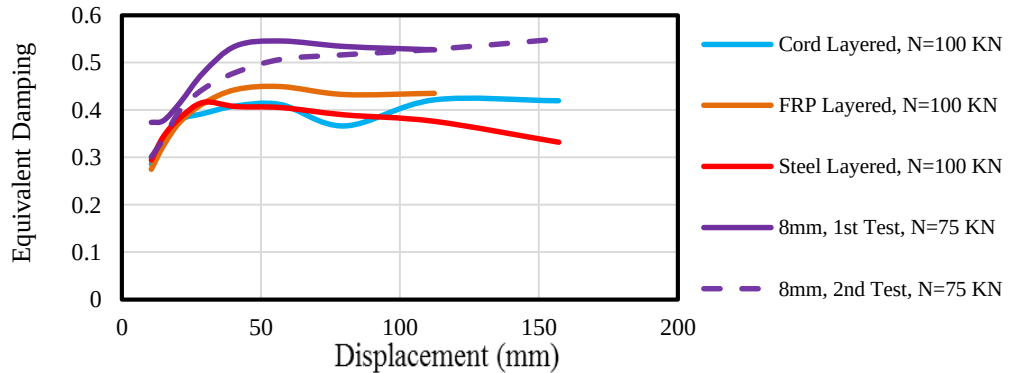


Figure 6.19 : Equivalent damping-displacement relation from N+V (+) test of infilled and bare specimens.

6.3.3. Infilled specimens under 50 kN and 100 kN constant compression loads

By comparing equivalent damping diagrams of infilled specimens for 50 kN and 100 kN constant compression loads there is no exact relation, Figure 6.20.

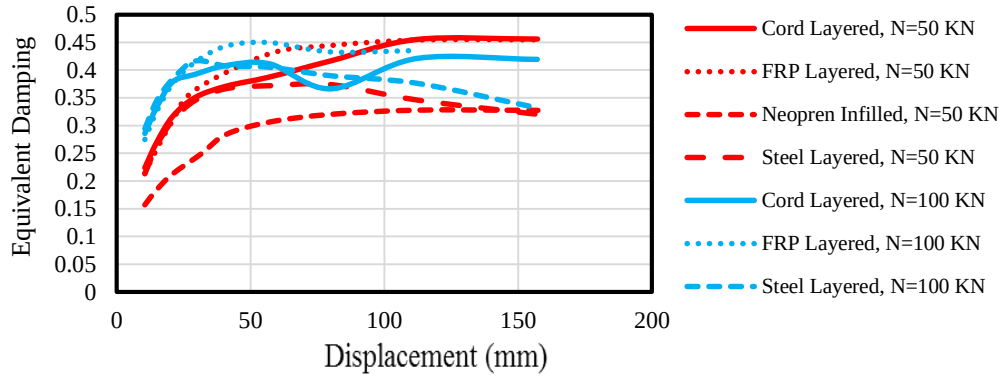


Figure 6.20 : Equivalent damping-displacement relation from N+V (+) test of infilled specimens.

6.4. Stiffness-Displacement Diagrams

6.4.1. Bare 8 mm specimen vs. infilled specimens

By comparing stiffness ratio diagrams of infilled specimens together and with 8 mm thick bare specimen for 50 kN constant axial compression load, it is observed that there is no big changes in the trend of stiffness degradation by adding infilling material inside the specimen, Figure 6.21.

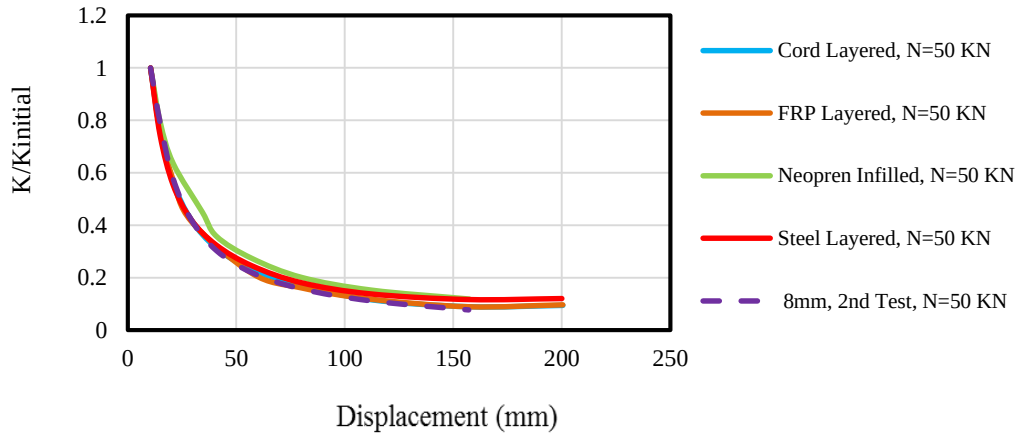


Figure 6.21 : Ratio of stiffness-displacement relation from N+V (+) test for infilled and bare specimens.

6.4.2. Bare 8 mm specimen vs. infilled specimens

By comparing stiffness ratio diagrams of infilled specimens together for 100 kN constant axial compression load with 8 mm thick bare specimen for 75 kN constant axial compression load, it is observed that there is no big changes in the trend of stiffness degradation by adding infilling material inside the specimen, Figure 6.22.

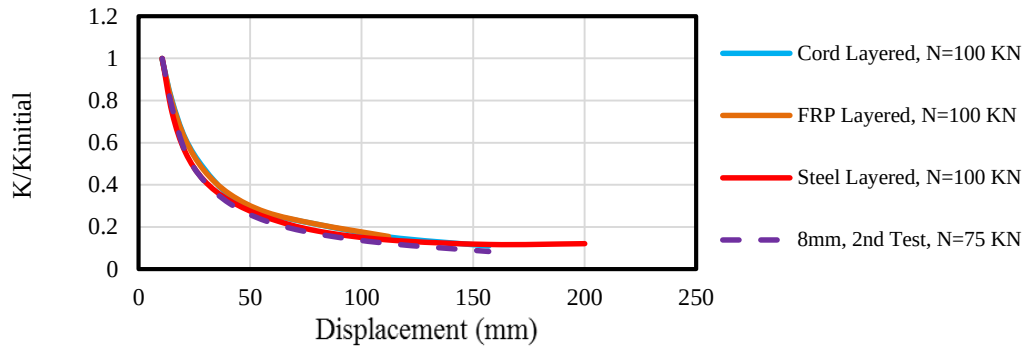


Figure 6.22 : Ratio of stiffness-displacement relation from N+V (+) test for infilled and empty specimens.

6.4.3. Infilled specimens under 50 kN and 100 kN constant compression loads

By comparing stiffness ratio diagrams of infilled specimens together for 100 kN and 50 kN constant axial compression loads, it is observed that there is no big changes in the trend of stiffness degradation, Figure 6.23.

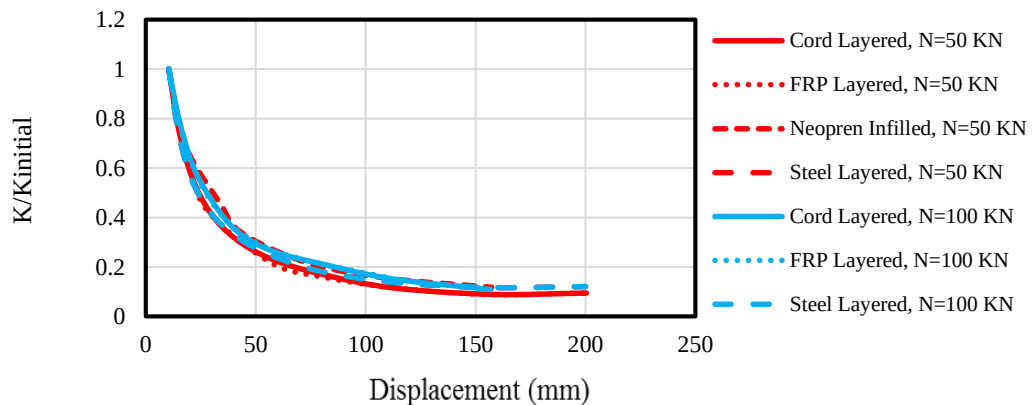


Figure 6.23 : Ratio of stiffness-displacement relation from N+V (+) test for infilled specimens.

6.5. Envelope Diagrams

6.5.1. Bare 8 mm specimen vs. infilled specimens

By comparing the envelope of force-displacement curves of infilled specimens with 8 mm thick bare specimens for 50 kN constant axial compression load, it is observed that maximum peak strength of the specimen increases by using infilling material inside the cushion and also the steel layered neoprene infilled specimen has the greatest amount of strength and it's maximum strength is about 1.8 times higher than the yield

strength, while the maximum strength of 8 mm thick bare specimen is about 1.2 times higher than the yield strength amount, Figure 6.24.

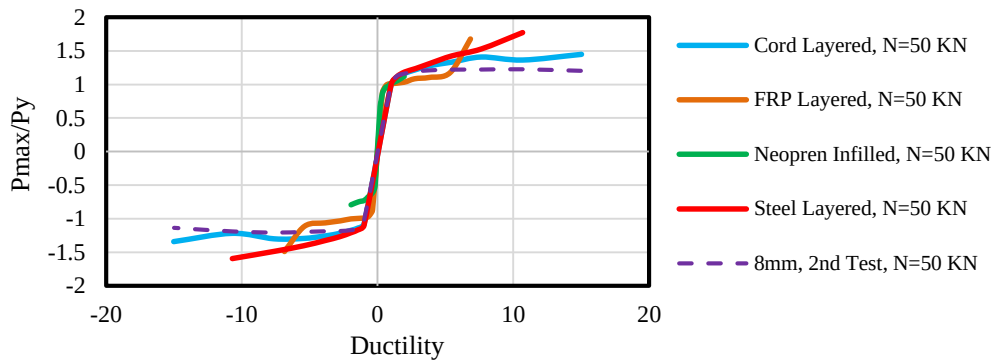


Figure 6.24 : Ratio of peak strength to yield strength for infilled and bare specimens from N+V (+) test.

6.5.2. Bare 8 mm specimen vs. infilled specimens

By comparing the envelope of force-displacement curves of three infilled specimens for 100 kN with 8 mm thick bare specimens for 75 kN constant axial compression load, it is observed that maximum peak strength of the specimen increases by using infilling material inside the cushion and also the cord layered neoprene infilled specimen has the greatest amount of strength and it's maximum strength is about 1.9 times higher than the yield strength, while the maximum strength of 8 mm thick bare specimen is about 1.4 times higher than the yield strength amount, Figure 6.25.

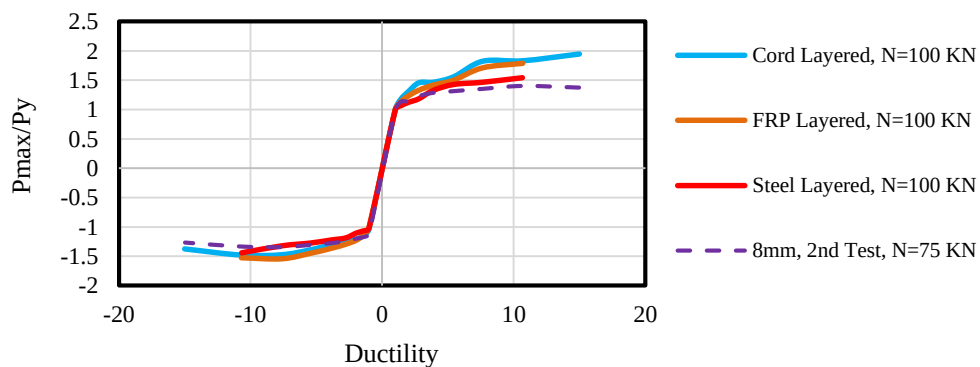


Figure 6.25 : Ratio of peak strength to yield strength for infilled and bare specimens from N+V (+) test.

6.6. Damping-Stiffness Diagrams

6.6.1. Bare 8 mm specimen vs. infilled specimens

From the following diagrams it is observed that for 50 kN constant axial compression load in all of infilled and bare specimens, by decreasing the amount of stiffness the amount of damping increases and in every step at the same amounts of stiffness 8 mm thick bare specimen has the greatest amount of damping in comparison with the infilled specimens and also at the same amounts of stiffness the pure neoprene infilled specimen has the least amount of damping and all of the diagrams are almost parallel to each other, Figure 6.26.

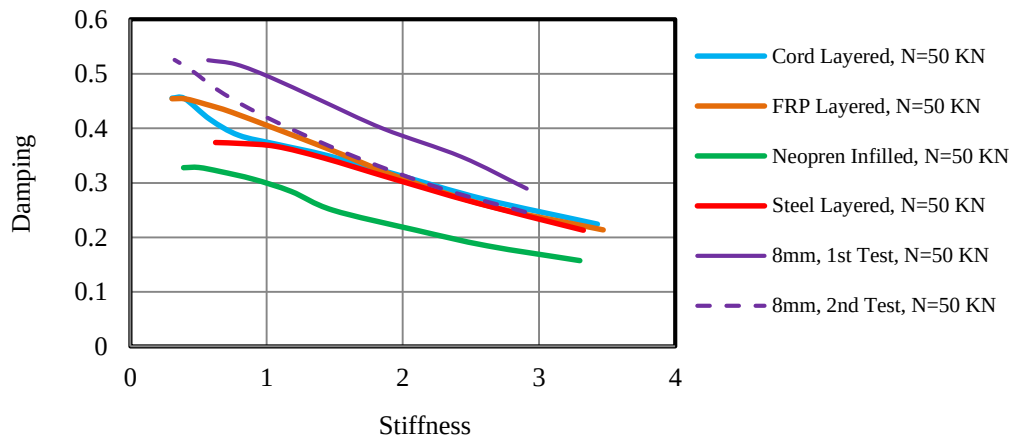


Figure 6.26 : Stiffness-damping relation from N+V (+) test for infilled and bare specimens.

6.6.2. Bare 8 mm specimen vs. infilled specimens

From the following diagrams it is observed that for 100 kN and 75 kN constant axial compression load in all of the infilled and bare specimens by decreasing the amount of stiffness the amount of damping increases and also at the same amounts of stiffness the infilled specimens have almost the same damping amounts and also in comparison with other specimens at the small amounts of stiffness 8 mm thick bare specimen has the greatest amount of damping, Figure 6.27.

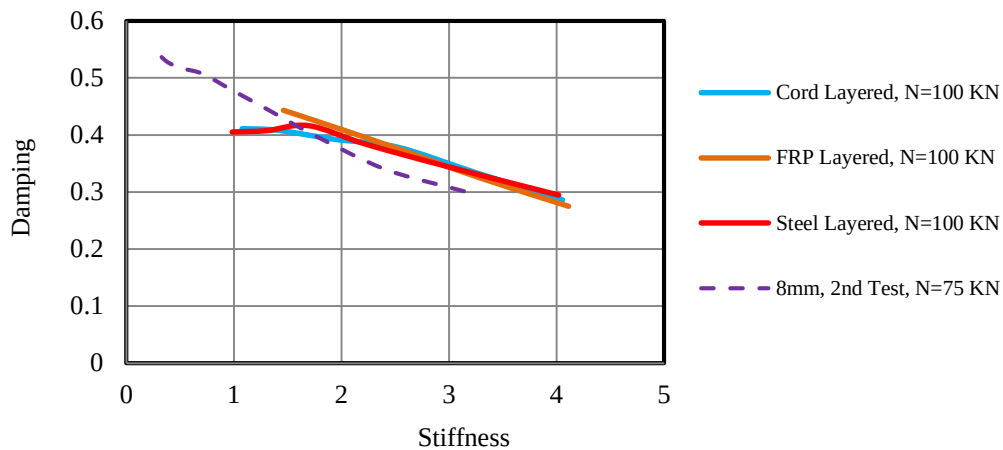


Figure 6.27 : Stiffness-damping relation from N+V (+) test for infilled and bare specimens.

6.7. Ductility Diagrams

6.7.1. Bare 8 mm vs. infilled specimens

By comparing the ductility capacity of four infilled specimens with bare specimens for 50 kN constant axial compression load, it is observed that cord layered neoprene infilled, steel layered neoprene infilled and bare specimens have almost the same amounts of ductility but pure neoprene infilled specimen has the least amount of ductility, Figure 6.28.

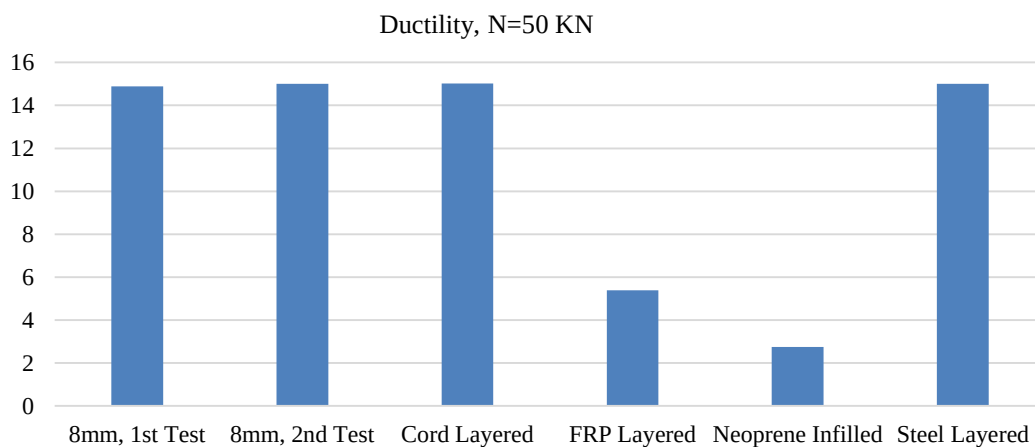


Figure 6.28 : Ductility amounts from N+V (+) test for infilled and bare specimens.

6.7.2. Bare 8 mm specimens vs. infilled specimens

By comparing the ductility capacity of three infilled specimens for 100 kN with bare specimens for 75 kN constant axial compression load, it is observed that cord layered

neoprene infilled, steel layered neoprene infilled and bare specimens have almost the same amounts of ductility but FRP layered neoprene infilled specimen has the least amount of ductility, Figure 6.29.

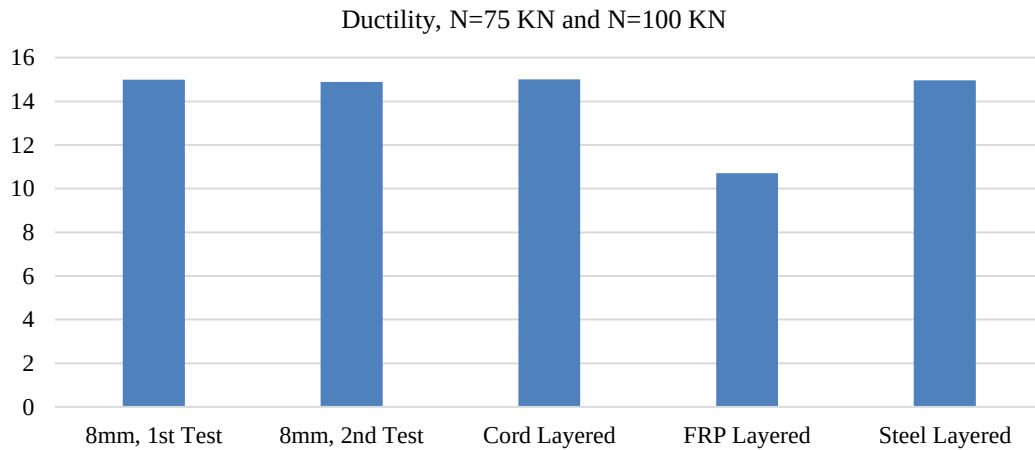


Figure 6.29 : Ductility amounts from N+V (+) test for infilled and bare specimens.

6.8. Yield Displacement Diagrams

6.8.1. Bare 8 mm vs. infilled specimens

By comparing the yield displacements of four infilled specimens with bare specimen for 50 kN constant axial compression load, it is observed that cord layered neoprene infilled, steel layered neoprene infilled and bare specimen have almost the same amounts of yield displacements but pure neoprene infilled specimen yields at the greatest amount of displacement, Figure 6.30.

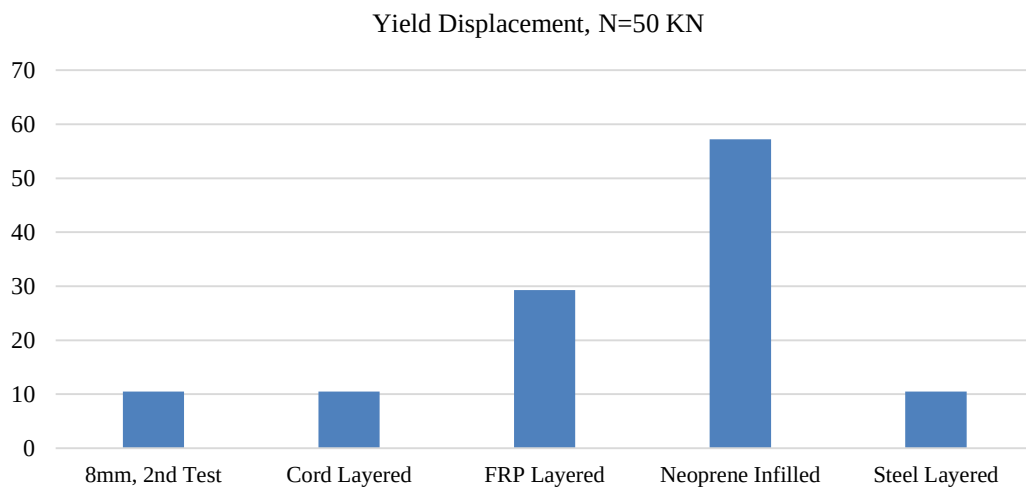


Figure 6.30 : Yield displacement amount from N+V (+) test for infilled and bare specimens.

6.8.2. Bare 8 mm specimen vs. infilled specimens

By comparing the yield displacements of three infilled specimens for 100 kN bare specimen for 75 kN constant axial compression load, it is observed that almost all of the specimens have the same amounts of yield displacements but the steel layered neoprene infilled specimen yields at a bit more displacement amount, Figure 6.31.

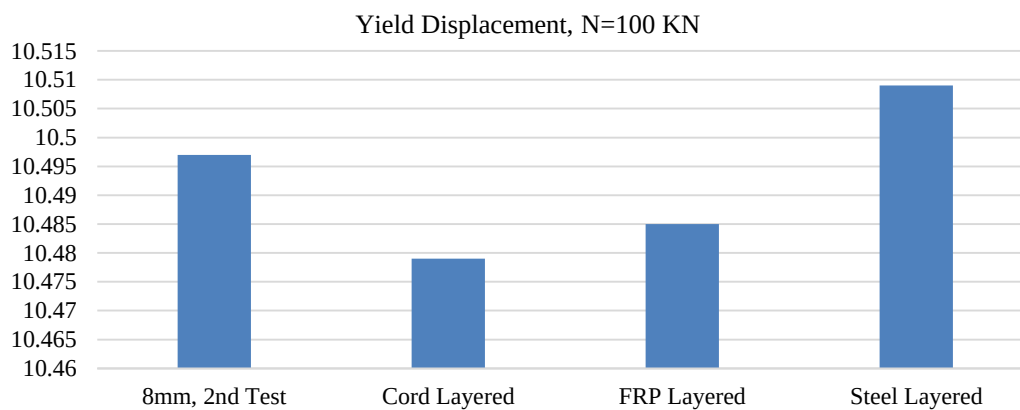


Figure 6.31 : Yield displacement amount from N+V (+) test for infilled and bare specimens.

6.9. Yield Force Diagrams

6.9.1. Bare 8 mm vs. infilled specimens

By comparing the yield forces of four infilled specimens with bare specimen for 50 kN constant axial compression load, it is observed that pure neoprene infilled specimen has the greatest amount of force and the bare specimen has the least amount of force at the yield point, Figure 6.32.

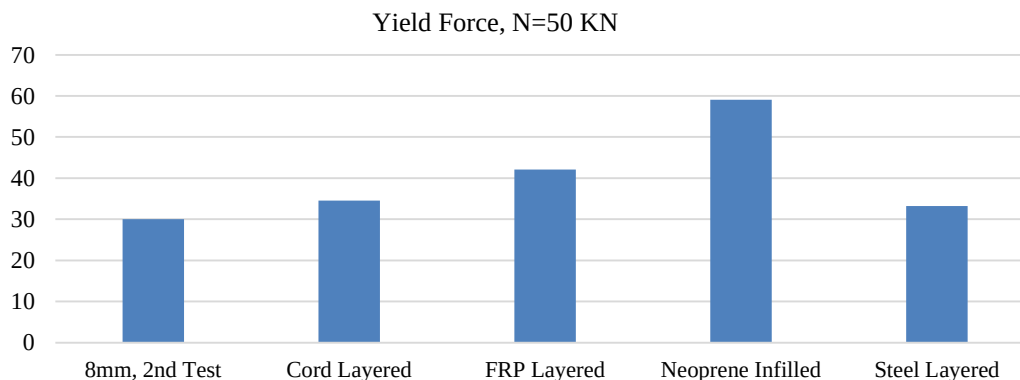


Figure 6.32 : Yield force amount from N+V (+) test for infilled and bare specimens.

6.9.2. Bare 8 mm specimen vs. infilled specimens

By comparing the yield forces of three infilled specimens for 100 kN with bare specimen for 75 kN constant axial compression load, it is observed that FRP layered neoprene infilled specimen has the greatest amount of force and the bare specimen has the least amount of force at the yield point, Figure 6.33.

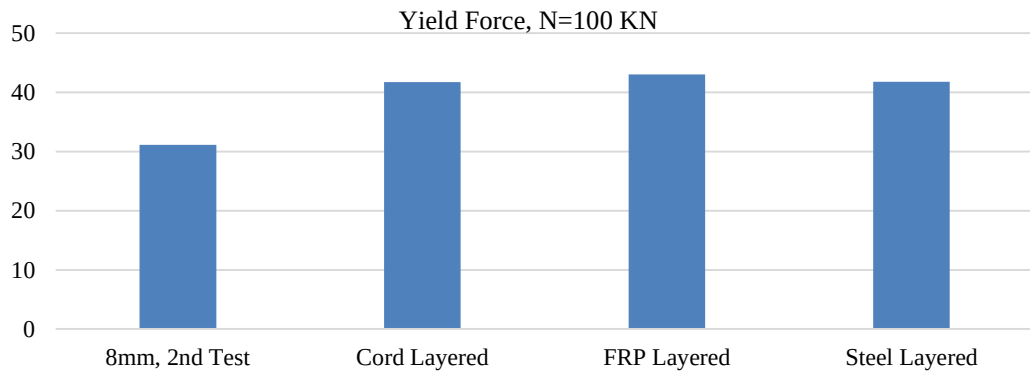


Figure 6.33 : Yield force amount from N+V (+) test for infilled and bare specimens.

6.10. Maximum Force Diagrams

6.10.1. Bare 8 mm vs. infilled specimens

By comparing the maximum shear force amounts of four infilled specimens with bare specimen for 50 kN constant axial compression load, it is observed that pure neoprene infilled and steel layered neoprene infilled specimens have almost the greatest amounts of shear force and the bare specimen has the least amount of shear force and it could be said that by using infilling material such as pure neoprene or steel material inside the specimen the shear force increases about 84 percent, Figure 6.34.

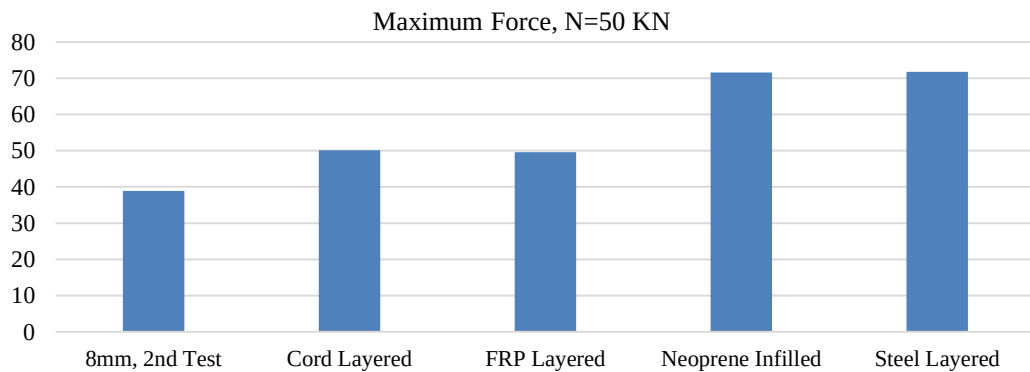


Figure 6.34 : Maximum force amount from N+V (+) test for infilled and bare specimens.

6.10.2. Bare 8 mm specimen vs. infilled specimens

By comparing the maximum shear force amounts of three infilled specimens for 100 kN with bare specimen for 75 kN constant axial compression load, it is observed that cord layered neoprene infilled and FRP layered neoprene infilled specimens have almost the greatest amounts of shear force and the bare specimen has the least amount of shear force and it could be said that by using infilling material such as cord material inside the specimen the shear force increases about 84 percent, Figure 6.35.

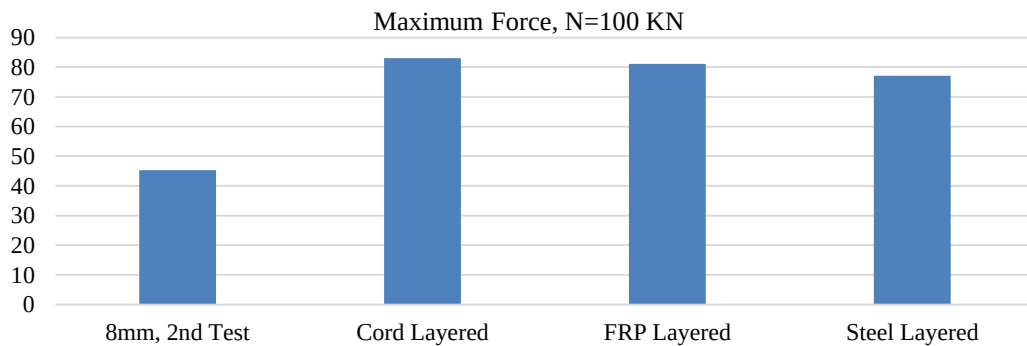


Figure 6.35 : Maximum force amount from N+V (+) test for infilled and bare specimens.

6.11. Stiffness Diagrams

6.11.1. Bare 8 mm vs. infilled specimens

By comparing the stiffness amounts of four infilled specimens with bare specimens for 50 kN constant axial compression load, it is observed that FRP layered neoprene infilled specimen has the greatest amount of stiffness and the bare specimen has the least amount of stiffness and it could be said that by using infilling material such as FRP material inside the specimen the stiffness amount increases about 20 percent, Figure 6.36.

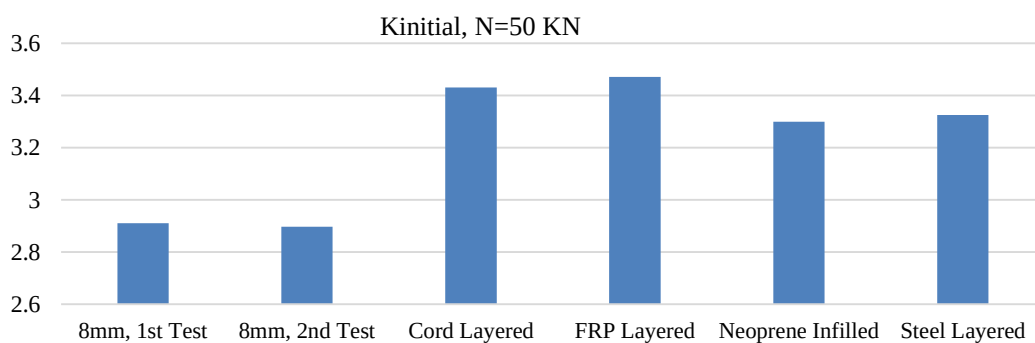


Figure 6.36 : Stiffness amount from N+V (+) test for infilled and bare specimens.

6.11.2. Bare 8 mm vs. infilled specimens

By comparing the stiffness amounts of three infilled specimens for 100 kN with bare specimens for 75 kN constant axial compression load, it is observed that cord, FRP and steel layered neoprene infilled specimens have the greatest amounts of stiffness and the bare specimen has the least amount of stiffness and it could be said that by using infilling material such as FRP material inside the specimen the stiffness amount increases about 30 percent, Figure 6.37.

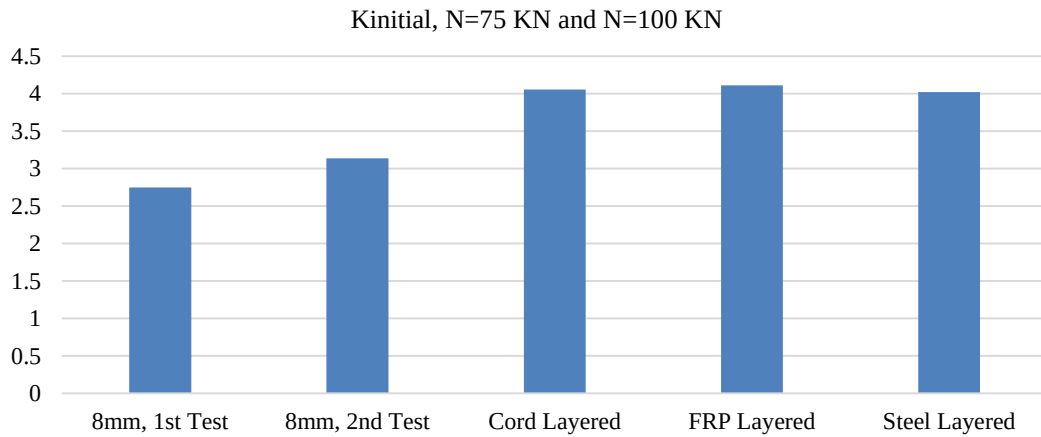


Figure 6.37 : Stiffness amount from N+V (+) test for infilled and bare specimens.

6.12. Monotonic Compression Axial Test

6.12.1. Force-Displacement diagrams

6.12.1.1. Bare specimens

By comparing the force-displacement diagrams of three different bare specimens with the thicknesses of 3, 5 and 8 mm for monotonic axial compression load, it is observed that the ultimate strength of the 8 mm specimen is more than 5 mm and it is more than 3 mm specimen, Figure 6.38.

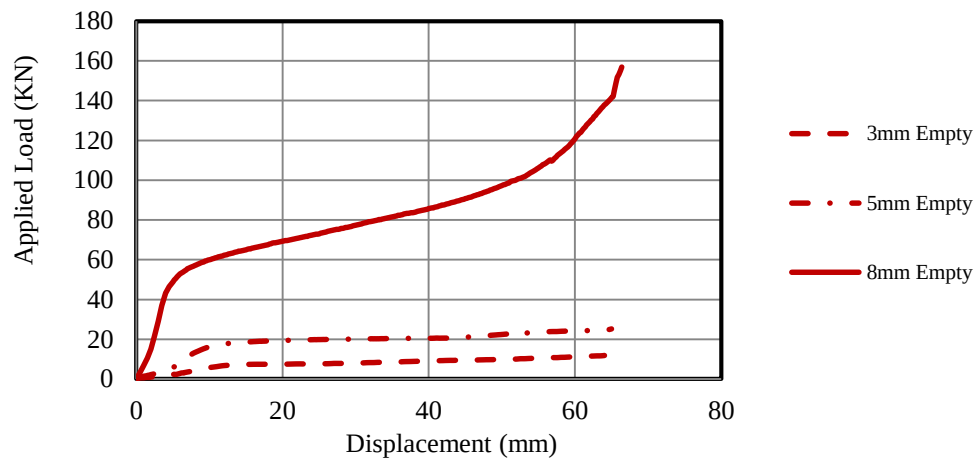


Figure 6.38 : Force-displacement relation from monotonic axial test of bare specimens.

6.12.1.2. Bare and infilled specimens

By comparing the force-displacement diagrams of three infilled specimens with 8 mm thick bare specimen for axial compression load at about 20 mm displacement it is observed that the ultimate strength of the steel layered neoprene infilled specimen is more than cord layered neoprene infilled, FRP layered neoprene infilled and also the 8 mm bare specimen, Figure 6.39.

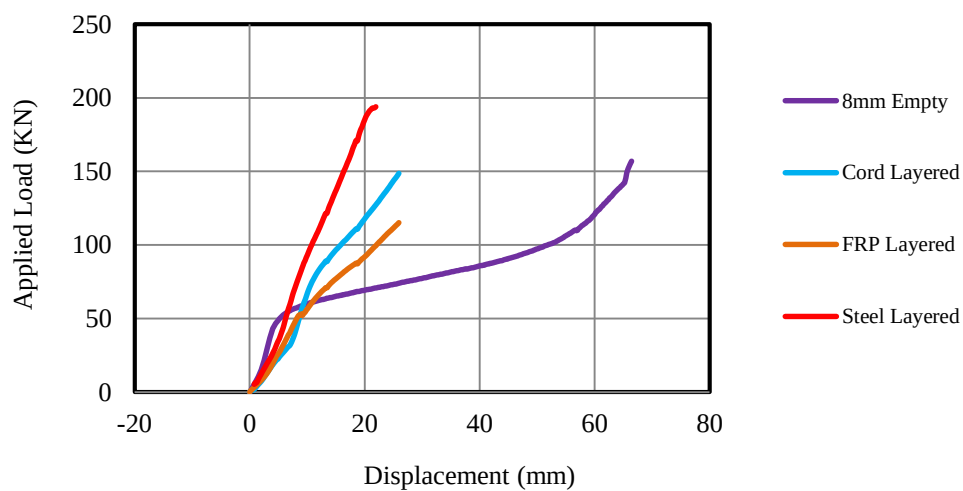


Figure 6.39 : Force-displacement relation from monotonic axial test of infilled and bare specimens.

6.12.2. Cumulative energy-displacement diagrams

6.12.2.1. Bare specimens

By comparing the cumulative energy diagrams of three bare specimens with the thicknesses 3, 5 and 8 mm together for axial compression load it is observed that the 8 mm bare specimen dissipates more energy than 5 mm and 3 mm specimens, Figure 6.40.

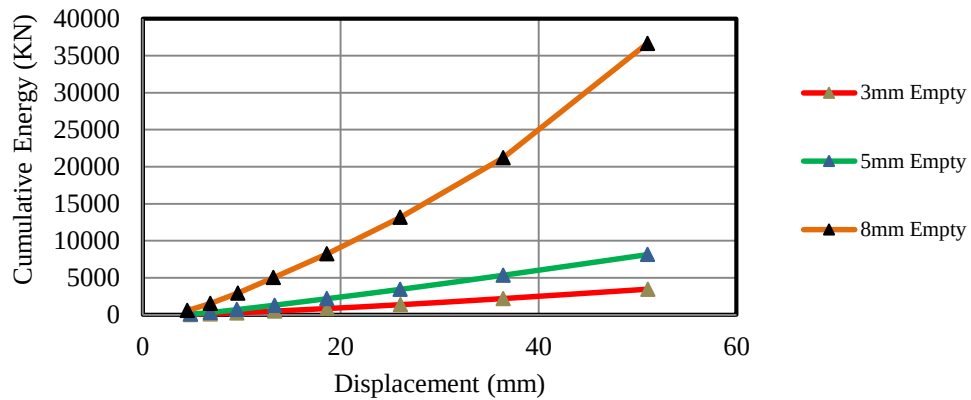


Figure 6.40 : Cumulative energy-displacement relation from monotonic axial test of bare specimens.

6.12.2.2. Bare and infilled specimens

By comparing the cumulative energy diagrams of three infilled specimens with 8 mm bare specimen for axial compression load at about 26 mm displacement, it is observed that the steel layered neoprene infilled specimen dissipates more energy than other three specimens, Figure 6.41.

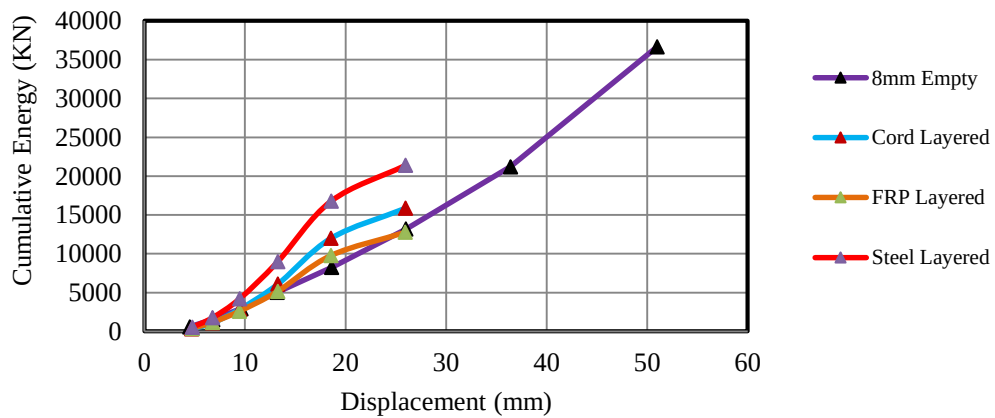


Figure 6.41 : Cumulative energy-displacement relation from monotonic axial test of infilled and bare specimens.

6.12.3. Stiffness diagrams

6.12.3.1. Bare specimens

By comparing the stiffness ratio diagrams of three bare specimens with the thicknesses 3, 5 and 8 mm together for axial compression load, no clear relation is observed, Figure 6.42.

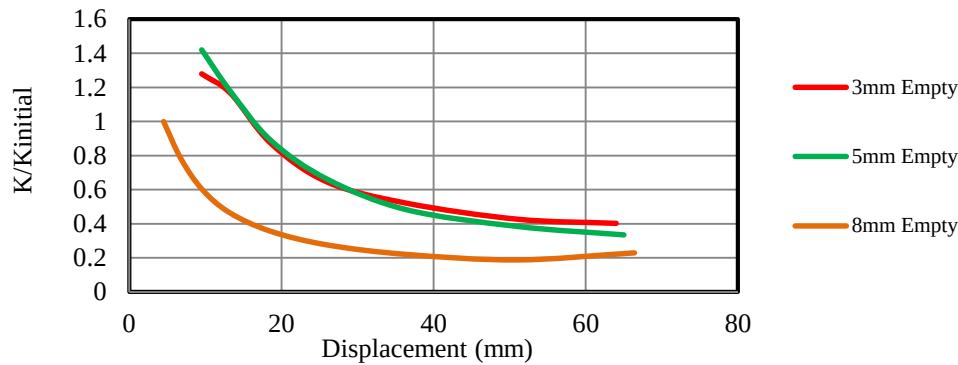


Figure 6.42 : Ratio of stiffness-displacement relation from monotonic axial test of bare specimens.

6.12.3.2. Bare and infilled specimens

By comparing the stiffness ratio diagrams of three infilled specimens together and with the 8 mm bare specimen for axial compression load it is observed that 8 mm bare specimen has the least amount of stiffness and among the infilled specimens at first steps the stiffness of all three specimens increases and then they start to decrease and this performance is related to the type of the infilling material inside the specimen, and there is no clear relation between the stiffness ratios amounts of three infilled specimens, Figure 6.43.

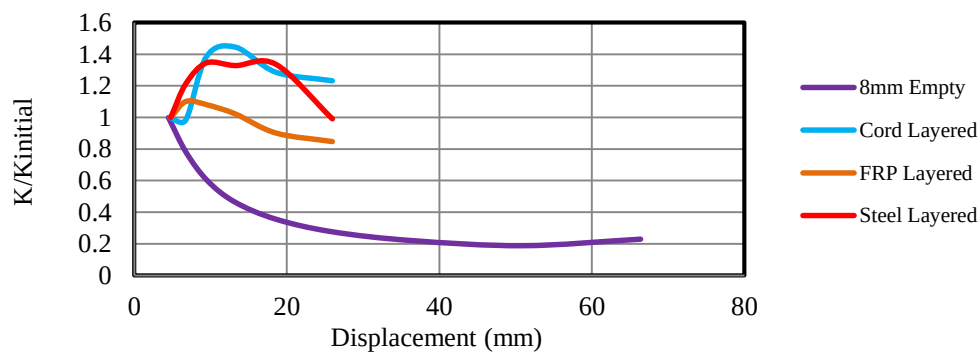


Figure 6.43 : Ratio of stiffness-displacement relation from monotonic axial test of infilled and bare specimens.

6.12.4. General comparison between bare and infilled specimens

By comparing bare and infilled specimens for monotonic axial test the following results are observed:

The value of nominal strength increases by using infilling material inside the specimen and the steel layered neoprene infilled specimen has the greatest amount of nominal strength.

The amount of cumulative energy increases by using infilling material inside the specimen and the steel layered neoprene infilled specimen has the greatest amount of cumulative energy.

The amount of stiffness increases by using infilling material inside the specimen and in infilled specimens the amount of stiffness increases at the first steps but it starts to decrease by increasing the amount of axial load.

6.13. General Comparison Between Bare And Infilled Specimens Under Cyclic Shear Load Plus Compression Load For 50 KN Compression Load

From all of the experiments performed on bare and infilled steel specimens under cyclic shear load plus compression axial load stands for N+V(+) under 50 kN constant compression load for both types of the specimens, the observed values are shown in the following table, Table 6.1.

Table 6.1 : Specimens under 50 KN load in N+V(+) test.

Specimen	Nominal Strength	Reduction In Stiffness (%)	Max Cumulative Energy	Max Equivalent Damping (%)	Ductility	Yield Force	Maximum Force
Infilled Cord Layered	38	91	183000	45	15	34.55	50
Infilled FRP Layered	35	91	174000	45	5.38	42.05	50
Infilled Neoprene Layered	40	87	196000	32	2.75	59	72
Infilled Steel Layered	35	86	184000	37	15	33.22	72
Empty 8 mm	35	92	168000	55	15	32.5	39

6.14. General Comparison Between Bare And Infilled Specimens Under Cyclic Shear Load Plus Compression Load For 75 kN and 100 kN Compression Loads

From all of the experiments performed on bare and infilled steel specimens under cyclic shear load plus compression axial load stands for N+V(+) under 75 kN constant compression load for bare specimens and under 100 kN constant compression load for infilled specimens, the observed values are shown in the following table, Table 6.2.

Table 6.2 : Specimens under 75 kN and 100 kN loads in N+V(+) test.

Specimen	Nominal Strength	Reduction In Stiffness (%)	Max Cumulative Energy	Max Equivalent Damping (%)	Ductility	Yield Force	Maximum Force
Infilled Cord Layered	50	89	188000	42	15	41.7	83
Infilled FRP Layered	58	84	133000	45	10.7	43.03	81
Infilled Steel Layered	52	88	220000	41	15	41.8	77
Empty 8 mm	38	91	200000	55	15	28	45

7. CONCLUSIONS AND RECOMMENDATIONS

7.1. Conclusions

The following conclusions could be stated based on the conducted experimental analysis.

By comparing the performance of bare and infilled specimens under 50 kN constant compression axial load it could be concluded that:

- In comparison with bare specimen the amount of nominal strength increases by using pure neoprene and cord neoprene infilling material inside the cushion.
- The amount of reduction in stiffness decreases by using infilling material inside the cushion.
- The amount of cumulative energy increases by using infilling material inside the cushion and pure neoprene infilled specimen has the greatest amount of cumulative energy.
- The amount of equivalent damping decreases by using infilling material inside the cushion and pure neoprene infilled specimen has the least amount of equivalent damping.
- The FRP layered neoprene infilled and pure neoprene infilled specimens have the least amounts of ductility and the ductility amount of bare specimen is equal to some of infilled specimens.
- The ultimate shear force capacity increases by using infilling material inside the cushion and pure neoprene infilled and steel layered neoprene infilled specimens have the greatest amounts of shear capacity.

By comparing the performance of bare specimens under 75 kN with infilled specimens under 100 kN constant compression axial loads it could be concluded that:

- In comparison with bare specimen the amount of nominal strength increases by using infilling material inside the cushion.
- The amount of reduction in stiffness decreases by using infilling material inside the cushion.
- The amount of cumulative energy increases by using infilling material inside the cushion and steel layered neoprene infilled specimen has the greatest amount of cumulative energy, but it should be mentioned that there is a rupture in FRP layered infilled specimen at about 112 mm displacement.
- The amount of equivalent damping decreases by using infilling material inside the cushion and steel layered neoprene infilled specimen has the least amount of equivalent damping.
- The FRP layered neoprene infilled specimen has the least amount of ductility and the ductility amount of bare specimen is equal to other infilled specimens.
- The ultimate shear force capacity increases by using infilling material inside the cushion and the cord layered neoprene infilled specimen has the greatest amount of shear capacity.

By comparing the performance of infilled specimens together under 50 kN and 100 kN constant compression axial loads the following results could be concluded:

- By increasing the amount of constant axial compression load the value of nominal strength increases in all of infilled specimens.
- By increasing the amount of constant axial compression load the value of cumulative energy increases in all of infilled specimens except FRP layered neoprene infilled specimen because of rupture that happened in this specimen by applying 100 kN compression load and it decreased the value of cumulative energy in this specimen.
- By increasing the amount of constant axial compression load the value of ductility does not change a lot in cord and steel layered neoprene infilled specimens but this

value increases in FRP layered neoprene infilled specimen due to the rupture happened in this specimen by applying 100 kN compression load.

- By increasing the amount of constant axial compression load the value of ultimate shear force capacity increases in all of infilled specimens.

7.2. Recommendations

Due to the obtained experimental results it is clear that nominal strength, cumulative energy and also ultimate shear capacity increase by adding filling material inside the steel cushions. Then it is appropriate to use the infilled cushions at the base or better to say at the cladding panel to foundation connection in the precast construction.

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