

# TABLE OF CONTENTS

<b>Acknowledgements .....</b>	<b>i</b>
<b>Executive Summary .....</b>	<b>ii</b>
<b>Table of Contents.....</b>	<b>iii</b>
<b>List of Figures.....</b>	<b>vii</b>
<b>List of Tables .....</b>	<b>viii</b>
<b>List of Photos .....</b>	<b>ix</b>
<b>Section 1 - Introduction.....</b>	<b>1-1</b>
1.1    Problem Statement .....	1-1
1.2    Study Objectives .....	1-2
1.3    Approach.....	1-2
1.4    Literature Review.....	1-2
1.5    Site Description.....	1-4
1.5.1    General.....	1-4
1.5.2    Physiography/Topography .....	1-4
1.5.3    Geologic History .....	1-5
1.5.4    Bedrock Geology .....	1-5
1.5.4.1    Gypsum Mining.....	1-6
1.5.5    Surficial Geology .....	1-6
1.5.6    Soils .....	1-7
1.5.6.1    Regional Soils .....	1-8
1.5.6.2    Amherst Soils .....	1-9
1.5.6.3    Soil Boring Data.....	1-9
1.5.6.4    Geotechnical/Geologic Cross Section .....	1-10
1.5.6.5    Expansive Soils .....	1-10
1.5.6.5.1    Soil Moisture Variation.....	1-11
1.5.6.5.2    Quantitative Mineralogy .....	1-12
1.5.7    Hydrology .....	1-12
1.5.7.1    Climate/Precipitation.....	1-13
1.5.8    Hydrogeology.....	1-14
1.5.8.1    Upper Soil Zone .....	1-14

1.5.8.2	Middle Soil Zone.....	1-16
1.5.8.3	Deep Soil Zone .....	1-17
1.5.8.4	Bedrock Aquifers .....	1-18
1.5.8.5	Summary .....	1-18
1.6	Historical Perspective.....	1-19
1.6.1	Amherst Growth and Land-Use .....	1-19
1.6.2	Special Flood Hazard Areas .....	1-19
1.6.3	Building Codes for NYS and Amherst.....	1-20
1.7	Figures, Table, Photos.....	1-22
<b>Section 2 – Scope and Extent .....</b>		<b>2-1</b>
2.1	Overview.....	2-1
2.1.1	Phone Survey.....	2-1
2.1.2	Home Inspections.....	2-1
2.1.3	Field Inspections.....	2-2
2.2	Town Data .....	2-2
2.2.1	Spatial Patterns.....	2-3
2.2.2	Rate of Occurrence .....	2-4
2.2.3	Age of Damaged Homes.....	2-5
2.2.4	Repair Costs.....	2-5
2.3	Remote Sensing .....	2-5
2.4	Related Findings .....	2-6
2.4.1	Interviews .....	2-6
2.4.2	Associative Damages .....	2-7
2.4.3	Foundation Repairs.....	2-8
2.4.4	Multi-Family Structures.....	2-9
2.5	Summary .....	2-9
2.6	Figures, Tables, Photos.....	2-10
<b>Section 3 – Causative Factors .....</b>		<b>3-1</b>
3.1	Overview.....	3-1
3.2	Lateral Wall Pressure.....	3-1
3.2.1	Symptoms .....	3-1
3.2.2	Soil Weight .....	3-2
3.2.3	Soil Swell .....	3-2

3.2.4	Hydrostatic Pressure .....	3-3
3.2.5	Frost.....	3-4
3.2.6	Summary .....	3-4
3.3	Settlement .....	3-4
3.3.1	Symptoms .....	3-5
3.3.2	Allowable Settlement.....	3-5
3.3.3	Differential Settlement.....	3-6
3.3.3.1	Stiff Stratum.....	3-6
3.3.3.1.1	General Characterization .....	3-7
3.3.3.1.2	Vertical Strain and Moisture Content.....	3-7
3.3.3.1.3	Foundation Soil Moisture Content .....	3-8
3.3.3.1.4	Estimated Differential Settlement .....	3-9
3.3.3.1.5	Moisture Content Changes .....	3-10
3.3.3.1.5.1	Concentration and Mineralogy of Clay .....	3-10
3.3.3.1.5.2	Water Availability .....	3-10
3.3.3.1.5.3	Confining Pressure .....	3-11
3.3.3.1.5.4	Initial Moisture Content.....	3-12
3.3.3.1.5.5	Laterally Variable Moisture Content Changes.....	3-12
3.3.3.1.6	Summary .....	3-13
3.3.3.2	Soft Stratum.....	3-13
3.3.3.2.1	Load Case I.....	3-15
3.3.3.2.2	Load Case II .....	3-16
3.3.3.2.3	Load Case III.....	3-16
3.3.3.2.4	Load Case IV .....	3-17
3.3.3.2.5	Summary .....	3-17
3.4	Design and Construction.....	3-17
3.4.1	Design .....	3-17
3.4.2	Footing.....	3-18
3.4.3	Concrete Strength .....	3-18
3.4.4	Wall Thickness.....	3-18
3.4.5	Backfill .....	3-19
3.4.6	Anchor Rods.....	3-19
3.4.7	Geometry .....	3-19
3.4.8	Concentrated Loadings.....	3-19
3.4.9	Exterior Foundation Drains.....	3-19
3.4.10	Construction.....	3-19
3.4.11	Wall Strength Modeling .....	3-20
3.4.11.1	Modeling Results.....	3-20
3.5	Associative Factors .....	3-21
3.6	Figures, Tables, Photos.....	3-22
<b>Section 4 – Summary and Conclusion.....</b>		<b>4-1</b>
4.1	Summary .....	4-1

4.1.1	Extent and Scope.....	4-1
4.1.2	Causative Factors.....	4-1
4.2	Conclusion.....	4-2
<b>Section 5 – Recommendations .....</b>		<b>5-1</b>
5.1	Primary .....	5-1
5.2	Secondary.....	5-2
<b>Section 6 – Appendices .....</b>		<b>6-1</b>
6.1	Geologic Cross Section.....	6-1
6.2	Mineralogical and Remote Sensing Reports.....	6-4
6.3	Typical Ohio Water Budget.....	6-35
6.4	Tonawanda Landfill Data.....	6-37
6.5	Basement Wall Structural Modeling Parameters .....	6-58
6.6	Geotechnical Calculations.....	6-61
6.7	Guidelines for Design/Construction.....	6-83
6.8	Guidelines for Evaluation/Repair .....	6-88
6.9	Homeowner Inspection.....	6-90
<b>Section 7 – Literature Cited.....</b>		<b>7-1</b>
<b>Section 8 – Glossary of Terms .....</b>		<b>8-1</b>
<b>Section 9 – Abbreviations .....</b>		<b>9-1</b>

## LIST OF FIGURES

1. Study location map of Amherst, NY.....	1-23
2. Digital elevation model (DEM) of Amherst, NY .....	1-24
3. Lake Dana-Lundy and evolution of Lake Tonawanda.....	1-25
4. Bedrock and surficial geology in Amherst, NY.....	1-26
5. Distribution of five lacustrine soils types in Amherst, NY.....	1-27
6. Borehole locations with soft, semi-soft and not soft stratum in Amherst, NY..	1-28
7. Geotechnical/geologic cross section across central Amherst .....	1-29
8. Stratigraphic/soil profile of in central and northern Amherst, NY .....	1-30
9. Soil moisture content profile .....	1-31
10. Map of expansive soils in the Great Lakes and Northeastern United States .....	1-32
11. Hydrography of Amherst, NY .....	1-33
12. Annual and summer precipitation and Palmer Drought Index .....	1-34
13. Ransomville well hydrograph.....	1-35
14. Qualitative change in annual groundwater storage for Ransomville well .....	1-36
15. Hydrograph from shallow wells at Spaulding site near Tonawanda Landfill ...	1-37
16. Hydrograph of Tonawanda Landfill wells BM-13 .....	1-38
17. Hydrograph of Tonawanda Landfill wells BM-14 .....	1-38
18. Hydrograph of till wells near sewage treatment plant .....	1-39
19. Hydrograph of till wells along Youngs Road .....	1-40
20. Hydrographs of till wells at Tonawanda Landfill .....	1-41
21. Special Flood Hazard Areas .....	1-42
22. Number of foundation repair permits and complaints in Amherst, NY .....	2-11
23. Location of foundation-related repair permits and inquiries in Amherst, NY. .	2-12
24. Relationship of foundation-related repair permits and inquiries to five lacustrine soils.....	2-13
25. Relationship of foundation-related repair permits and inquiries to surficial geology units.....	2-14
26. Relationship of foundation-related repair permits and inquiries to 100- and 500-year flood plain.....	2-15
27. Number of repair permits issued by age class .....	2-16
28. Soil sampling locations for lateral backfill soil samples .....	3-23
29. Soil sampling locations for foundation and undisturbed sites .....	3-24
30. Regression analysis of EI and liquid limit for lacustrine samples .....	3-25
31. Regression analyses for EI and plasticity for lacustrine samples .....	3-25
32. Foundation soil moisture content variation at Site 7 in Amherst .....	3-26
33. Foundation soil moisture content variation at Site 4 in Amherst .....	3-27
34. Hypothetical loading scenario .....	3-28
35. Typical structural components of basement.....	3-29
36. Modeling results of lateral loads on 20 ft basement wall .....	3-30
37. Modeling results of lateral loads on 40 ft basement wall .....	3-31

## LIST OF TABLES

1. Historical plasticity index data for Amherst, NY, and surrounding area.....	1-43
2. Natural and man-made factors affecting soil moisture variation.....	1-44
3. Climate data for Buffalo area.....	1-45
4. Population growth in Amherst, NY .....	1-46
5. Land-use changes 1972-2000 in Amherst, NY.....	1-46
6. Chronology of building code changes in Amherst, NY .....	1-47
7. Rate of foundation repair permits and complaints on lacustrine soils .....	2-17
8. Laboratory test results for basement wall backfill soils in Amherst, NY .....	3-32
9. Laboratory test results for stiff foundation soil samples in Amherst, NY .....	3-32
10. Laboratory test results for undisturbed samples of stiff foundation soils in Amherst, NY .....	3-33
11. Laboratory test results for upper portion of soft stratum in Amherst, NY .....	3-33
12. Laboratory test results for consolidation test samples obtained from soft stratum in Amherst, NY.....	3-33
13. Calculated post-construction settlement/rebound due to strain response of soft stratum at Site 29 in Amherst, NY .....	3-34
14. Calculated post-construction angular distortion due to strain response of soft stratum at Site 29 in Amherst, NY .....	3-34

## LIST OF PHOTOS

1. Varved clay of Lake Dana-Lundy.....	1-48
2. Desiccation cracks in foundation soils .....	1-48
3. Downspout system.....	2-18
4. Lateral pressure damage to multi-family structure .....	2-19
5. Lateral pressure affecting basement wall in central Amherst, NY. ....	3-35
6. Lateral pressure causing vertical fracture in mid-span of basement wall in north-central Amherst, NY .....	3-35
7. Drive sampler for undisturbed sampling of stiff stratum in north Amherst, ....	3-36
8. Heterogeneity in shallow soil conditions in north Amherst, NY. ....	3-36
9. Root hairs penetrating into sump pit in central Amherst, NY. ....	3-37
10. Construction of footing on stiff stratum in north-central Amherst, NY .....	3-37
11. Perimeters loading of home with 3 to 4 feet fill north Amherst, NY. ....	3-38
12. Winter foundation site in East Amherst, NY .....	3-38
13. Deflection of basement wall (and pilasters) in central Amherst NY. ....	3-39
14. Erosion of strip footing during construction .....	3-39