



BLAST TESTING OF PRESTRESSED CONCRETE UNDER IMPULSIVE LOADING



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BLAST TESTING OF PRESTRESSED CONCRETE UNDER IMPULSIVE LOADING

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TABLE OF CONTENTS

Foreword.....	vi
Executive Summary.....	vii
1 Introduction.....	1
2 Stone-OBL Blast Testing Site.....	2
2.1 Site Layout.....	2
2.2 Reaction Structure.....	4
3 Test Specimens.....	5
3.1 Post-Tensioned Strand Stress Level.....	5
3.2 Mild Steel Reinforcement Level and Slab Construction.....	5
3.3 Supporting Steel Frame Construction and Panel Installation.....	7
4 Open-Air Blast Testing Procedure.....	12
4.1 Instrumentation and Test Documentation.....	12
4.2 Explosives and Test Matrix.....	19
4.3 Pre-Stressed Concrete Slab Response Limits.....	20
5 Test Results.....	22
5.1 Test 1 (Panel 5A).....	23
5.2 Test 2 (Panel 1A).....	25
5.3 Test 3 (Panel 2C).....	28
5.4 Test 4a (Panel 6C).....	30
5.5 Test 4b (Panel 6C).....	32
5.6 Test 5 (Panel 7B).....	33
5.7 Test 6 (Panel 3B).....	35
5.8 Test 7 (Panel 4D).....	38
5.9 Test 8 (Panel 8D).....	39
6 Conclusions.....	42
Appendix A: Calculations and Drawing.....	43
Appendix B: VSL Stressing Protocol, Data, and Certification.....	50
Appendix C: Slab Inspection and Concrete Results.....	89
Appendix D: Instrumentation Calibration Certification.....	102
Appendix E: Test Results Documentation.....	172

LIST OF FIGURES

Figure 2-1: Site Location.....	2
Figure 2-2: Site Layout.....	3
Figure 2-3: Mud Mat Construction.....	3
Figure 2-4: Reaction Structure.....	4
Figure 3-1: Test Specimen Summary.....	5
Figure 3-2: Slab Observed during Inspection Site Visit.....	5
Figure 3-3: Concrete Crushing Test Summary.....	7
Figure 3-4: Sketches of Simple Supports Used in Test 1 and Test 2.....	7
Figure 3-5: Steel Pedestals Used in Test 1 and Test 2.....	8
Figure 3-6: Lifting of Slab with Crane for Installation onto the Test Fixture (Framing Set-Up 1).....	8

Figure 3-7: Installed Panel within Framing Set-Up 1	8
Figure 3-8: Steel Framing Set-Up 2 Layout (Isometric View)	9
Figure 3-9: Steel Framing Set-Up 2 Layout (Section View)	10
Figure 3-10: Steel Framing Set-Up 2 Pedestal (Isometric View)	10
Figure 3-11: Lifting of Slab with Crane for Installation onto the Test Fixture (Framing Set-Up 2) ...	11
Figure 3-12: Installed Panel within the Stiffer Framing Set-Up 2	11
Figure 4-1: Examples of Strain Gauge Attachment to Rebar	12
Figure 4-2: Standard Strain Gauge Locations.....	13
Figure 4-3: Standard Strain Gauge Location Schedule.....	14
Figure 4-4: Strain Gauges with Open or Short Circuits.....	14
Figure 4-5: Data Channels for Strain Gauges and Displacement Sensors	15
Figure 4-6: Pre-Test Laser Locations on Interior Slab Face.....	16
Figure 4-7: Displacement and Pressure Sensor Locations for Test 1 and Test 2.....	17
Figure 4-8: Displacement and Pressure Sensor Locations for Test 3 through Test 8.....	18
Figure 4-9: Reflected Pressure Sensor Locations for Test 3 through Test 8.....	19
Figure 4-10: Test Matrix.....	20
Figure 4-11: Flexural Response Limits for Pre-Stressed Concrete Slabs	20
Figure 4-12: Damage Levels.....	21
Figure 5-1: Test Results Summary.....	22
Figure 5-2: Pre-Test Photos of Test 1	23
Figure 5-3: Front Face Slab Scabbing in Test 1.....	23
Figure 5-4: Back Face Slab Cracking in Test 1 (at Bottom Center).....	24
Figure 5-5: Through-Thickness Slab Cracking in Test 1 (at Bottom Left).....	24
Figure 5-6: Steel Frame Damage in Test 1 (at Upper Left and Upper Right Corners).....	25
Figure 5-7: Pre-Test Photos of Frame Modifications for Test 2.....	25
Figure 5-8: Pre-Test Photos of Test 2	26
Figure 5-9: Front Face Slab Scabbing in Test 2.....	26
Figure 5-10: Back Face Slab Cracking in Test 2 (Overall and Along Left Edge)	27
Figure 5-11: Through-Thickness Slab Cracking in Test 2.....	27
Figure 5-12: Steel Frame Damage in Test 2 (Along Upper Edge)	28
Figure 5-13: Pre-Test Photos of Test 3	28
Figure 5-14: Post-Test Photos of Test 3	29
Figure 5-15: Highlighted Cracking Pattern on Back Face in Test 3	29
Figure 5-16: Through-Thickness Cracking along Top and Side Edges in Test 3	30
Figure 5-17: Disengagement of Concrete Layers in Test 3	30
Figure 5-18: Pre-Test Photos of Test 4a	31
Figure 5-19: Post-Test Photos of Test 4a.....	31
Figure 5-20: Front Face Slab Scabbing in Test 4b.....	32
Figure 5-21: Highlighted Cracking Pattern on Back Face in Test 4b	33
Figure 5-22: Through-Thickness Cracking along Side Edge in Test 4b.....	33
Figure 5-23: Pre-Test Photos of Test 5	34
Figure 5-24: Front Face Slab Scabbing in Test 5.....	34
Figure 5-25: Highlighted Cracking Pattern on Back Face in Test 5.....	35
Figure 5-26: Through-Thickness Cracking along Side Edge in Test 5.....	35
Figure 5-27: Pre-Test Photos of Test 6	36
Figure 5-28: Front Face Slab Scabbing in Test 6.....	36
Figure 5-29: Cracking Pattern on Back Face in Test 6.....	37
Figure 5-30: Through-Thickness Cracking along Side Edge in Test 6.....	37
Figure 5-31: Pre-Test Photos of Test 7	38
Figure 5-32: Post-Test Photos of Test 7.....	39
Figure 5-33: Through-Thickness Cracking along Side Edge in Test 7.....	39

Figure 5-34: Pre-Test Photos of Test 840
Figure 5-35: Front Face Slab Scabbing in Test 8.....40
Figure 5-36: Cracking Pattern on Back Face in Test 841
Figure 5-37: Through-Thickness Cracking along Side Edge in Test 8.....41

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FOREWORD

This publication was prepared by ASME ST-LLC and jointly sponsored by the CNSC, DICT, EDF/SEPTEN, the ENSI, the IRSN, the STUK, and the ASME.

The test program, including the design and fabrication of the prestressed test slabs, was conducted by Stone Security Engineering, PC (“SSE”) and at the open-air blast test site managed by Oregon Ballistic Laboratories, LLC (“OBL”) and Stone-OBL, LLC (“SOBL”) of Salem, Oregon, United States of America (U.S.A.).

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EXECUTIVE SUMMARY

This report provides the background, test set-up information, and results for the open-air blast testing of eight simply supported, two-way, precast prestressed/post-tensioned concrete slabs with varying conventional reinforcement and prestressing/post-tensioned levels.

The slabs in the main portion of the testing program sustained support rotations ranging from 0.4 degrees to 3.0 degrees. The corresponding damage level for these tests would roughly range from “Superficial Damage” to “Heavy Damage” as defined in Canadian Standards Association (“CSA”) standard S850-12, “Design and Assessment of Buildings Subjected to Blast Loads,” and the American Society of Civil Engineers (“ASCE”) standard 59-11, “Blast Protection of Buildings.” However, from the extent of concrete disengagement observed in Test 3, it would appear that a 3.0-degree rotation is approaching the post-tensioned slab’s upper limit state for non-hazardous damage (i.e., near a transition from “Heavy Damage” to “Hazardous Damage” as defined in the previously-referenced standards).

The test results seem to indicate that the actual response limits would fall between the currently published limits for prestressed concrete (lower bound) and conventionally reinforced concrete (upper bound) elements. Moreover, comparing the results for tests on slabs subjected to a similar blast threat, it appears that the increase of pre-stressing level from 725 pounds per square inch (psi) (5 megapascals (MPa)) to 1450 psi (10 MPa) may only have a marginal effect on slab flexural response to blast loading. Additional testing and/or detailed analysis that can account for concrete disengagement, as well as shear and/or concrete-crushing controlled behavior (e.g., finite element modeling), should be performed to justify any modification to the currently published response limits and further examine the effects of prestressing/post-tensioning in blast applications.

1 INTRODUCTION

Considering the properties of prestressing steel and the level of compression in concrete, prestressed concrete members should respond with lower deflections under blast loading than similarly-sized, conventionally reinforced members. However, the available acceptance criteria for prestressed concrete in typical structures, provided in CSA standard S850-12, “Design and Assessment of Buildings Subjected to Blast Loads,” ASCE standard 59-11, “Blast Protection of Buildings,” and the Precast/Prestressed Concrete Institute (“PCI”) Blast-Resistant Design Manual, First Edition are significantly more stringent than for conventionally reinforced concrete. The technical basis for the difference is unclear.

Therefore, given the number of existing prestressed concrete containment structures and new builds of similar construction anticipated in Canada, the U.S.A., and worldwide, there is a need to define design provisions for prestressed concrete elements with all specificities of nuclear structures (e.g., reinforcement ratio and detailing, prestressing level) which could potentially use more relaxed acceptance criteria than for typical structures, if warranted. This information would be beneficial for vendors, designers, regulators, and standards development organizations worldwide. This research project proposal originated from a joint task group of three different standards committees: Joint ACI-ASME Committee on Concrete Components for Nuclear Service (BPVC Section III Division 2/ACI 359), ACI 349 (Concrete Nuclear Structures), and ACI 370 (Blast and Impact Load Effects).

Toward that objective, sponsors from industry, regulatory agencies, and standards developing organizations, which have a direct interest in nuclear structures, provided the sponsorship funds for this research project to test prestressed concrete slabs under blast loading. This research project was managed by ASME ST-LLC.

ASME ST-LLC tasked SSE to perform a series of blast tests on simply supported, two-way prestressed concrete slabs to achieve a range of responses based on the research proposal from the ASME Special Working Group of Modernization reporting to the Joint ACI-ASME Committee on Concrete Components for Nuclear Service (BPV III).

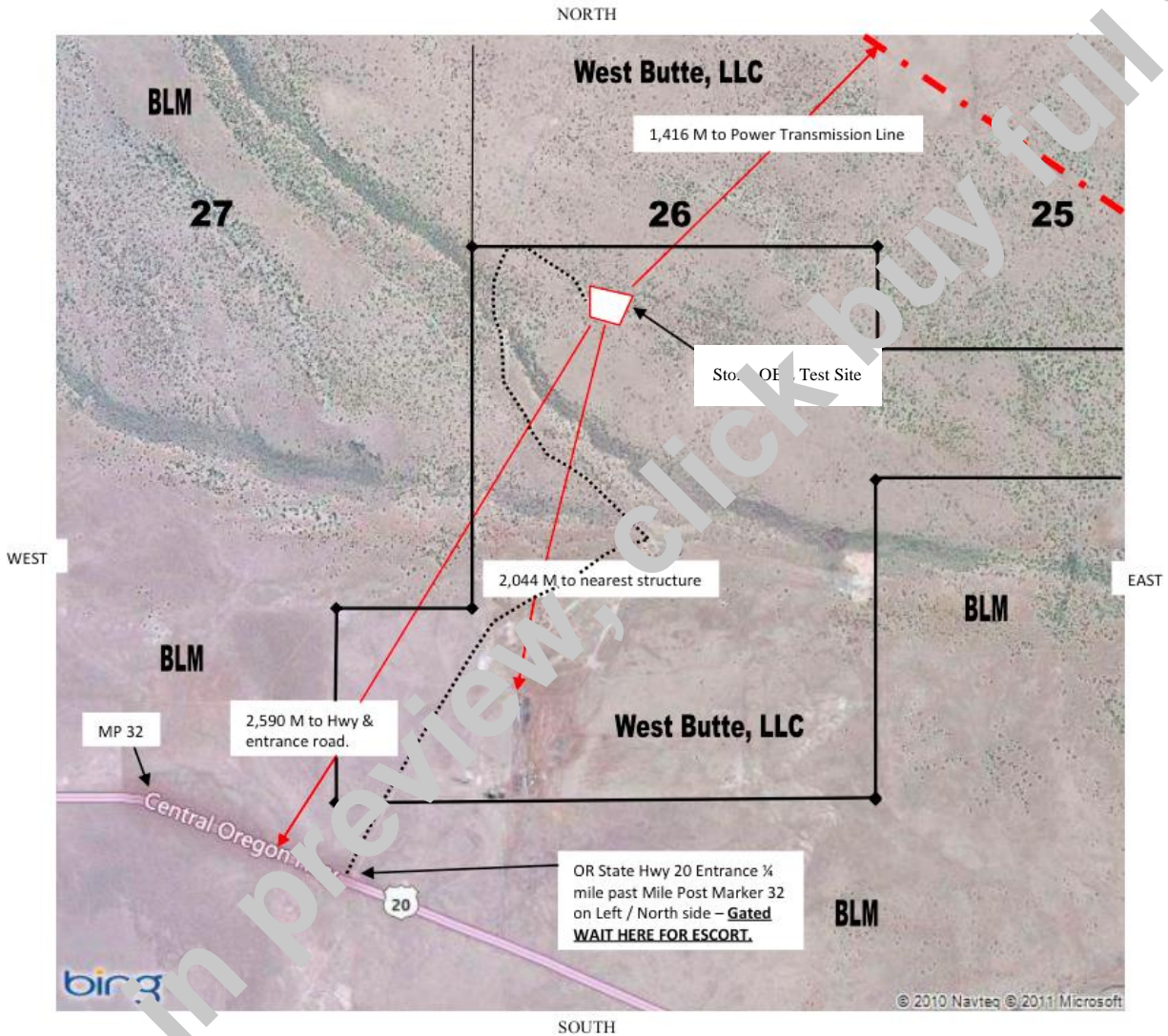
The eight slab specimens were 10-5/8 inches (270 millimeters (mm)) \times 16 feet (ft) (4880 mm) \times 16 feet (4880 mm) in dimensions. Two layers of conventional flexural reinforcement and local shear reinforcement around lifting points were included in each slab. Prestressing in the concrete was introduced using post-tensioned (PT) tendons. The parameters that varied were the pressure loading, conventional reinforcement ratio, and level of prestressing.

This publication provides the background for the open-air blast testing of the precast, prestressed slabs, and summarizes results for a total of nine blast tests performed on the eight slabs. An overview of the testing facility is provided in Section 2. A description of the test specimen and supporting steel frame construction is provided in Section 3. The open-air testing procedure, including instrumentation, explosive material and quantities used, and documentation recorded, and relevant prestressed concrete slab response limits are discussed in Section 4. Results are presented in Section 5. Some conclusions are noted in Section 6. Slab specimen calculations and drawings, relevant certifications, and pre-test and post-test documentation information are provided as appendices.

2 STONE-OBL BLAST TESTING SITE

The full testing program was carried out using the reinforced concrete test fixture at the Stone-OBL, LLC testing site. The blast testing site is located in Deschutes County, Oregon, approximately 30 miles East of Bend, Oregon. The property area is approximately four acres. The site, shown in Figure 2-1, is located approximately 4600 feet (1400 meters (m)) from the nearest utility, 6700 feet (2000 m) from the nearest structure, and approximately 8500 feet (2600 m) from the nearest public roadway.

Figure 2-1: Site Location



2.1 Site Layout

The blast testing site is located in the northwest corner of the property and is accessed via a private access road off the highway, as shown in Figure 2-1: Site Location. A construction area was established along this road where eight mud mats were constructed and poured in place, as shown in Figure 2-2. Each test slab specimen was assembled on a mud mat and cured on-site. In-process test slab specimen construction is shown in Figure 2-3.