ASME STANDARDS TECHNOLOGY, LLC

STP-NU-083

BLAST TESTING OF PRESTRESSED CONCRETE UNDER IMPULSIVE LOADING

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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) to 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).

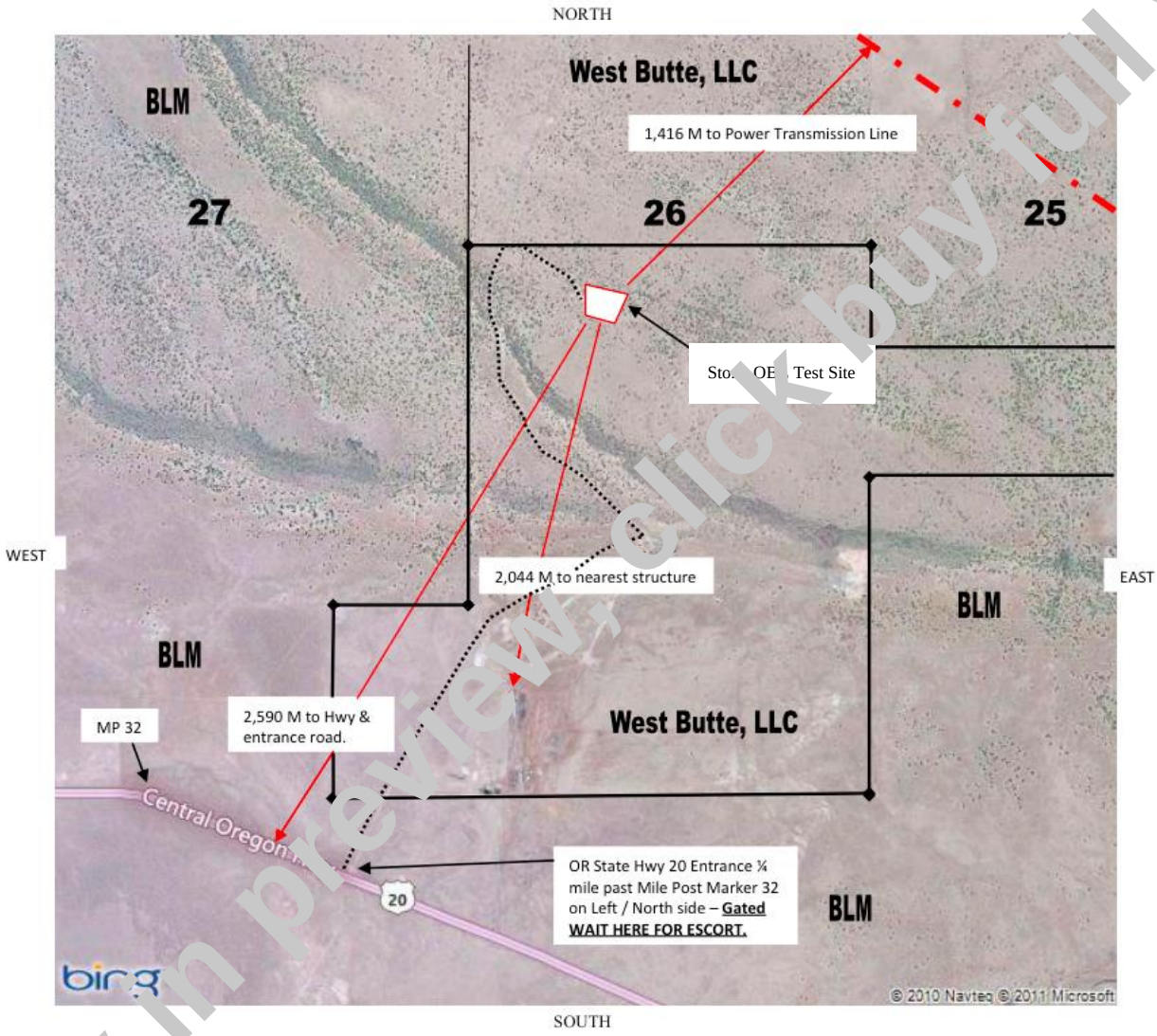
The eight slab specimens were 10-5/8 inches (270 millimeters (mm)) × 16 feet (ft) (4880 mm) × 16 feet (4880 mm) in dimensions. Two layers of conventional flexural reinforcement and local shear reinforcement around lifting points were included in each slab. Prestressing in the concrete was introduced 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.