Protecting the Coastal Infrastructure against the Coupled effects of Corrosion and Catastrophic Fire

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ABSTRACT

One of the major causes of structural repairs worldwide is the corrosion of reinforced concrete structures, such as residential buildings and piers, which are exposed to harsh marine environments. In the last two decades, high strength concrete has grown in popularity as an effective alternative to normal weight concrete for the construction of new structures. This investigation aims to provide experimental evidence of the fire resistance of corroded high strength reinforced concrete. For this, two sets of high strength reinforced concrete beams were cast as well as three concrete cylinders to test for compression strength (ASTM C 39/C 39M-04a). After proper moist curing, both sets were corroded with impressed current, and one set exposed to fire using a gas kiln (ASTM E-119-12). Both sets were then tested for flexural strength using the four-point loading method (ASTM C78-02). After the fire exposure, the flexural strength loss of the corroded beams exposed to fire as compared to the flexural strength of the corroded beams not exposed to fire was determined and the results and trends analyzed.

Keywords: Concrete, High-Strength, Corrosion, Fire-Resistance, Flexure.

1. INTRODUCTION

In the United States, there are approximately 12,380 miles of ocean coastline. Lying along the coasts are many reinforced concrete structures, such as high rise residential buildings, bridges, and piers, which are exposed to a harsh marine and coastal environment. This exposure increases their susceptibility to the corrosion of the reinforcing steel. In the marine environment, chloride ions from deicing salts, salt splashes, salt sprays, or sea water will access the steel through the concrete's pores, and accumulate beyond a certain concentration level, at which the protective film breaks and the steel begins to corrode in the presence of oxygen and moisture in the concrete-steel interface.

The exposure to fire, either natural or man-induced, can aggravate the structural damage, compared to uncorroded structures. This research addresses the compounding of the effects of corrosion and fire on the structural integrity, which is an important concern for structural and materials engineers, when designing buildings that will be exposed to the effects of corrosion.

BACKGROUND

The following earlier investigations at Florida Atlantic University by 2006 and 2008 Master's degree candidates are the catalysts for the current investigation:

“Effect of Elevated Temperature and Fire on Structural Elements Retrofitted by Carbon Fiber Reinforced Polymer Composites” (2006), by Jody Young, provides the background on the effect of fire and elevated temperature on the structural integrity of reinforced concrete structural elements.

Publication:

D. V. Reddy, K. Sobhan, and J.D. Young, “ Effect of Fire On Structural Elements Retrofitted by Carbon Fiber Reinforced Polymer Composites”, 31st Conference on Our World in Concrete and Structures, Singapore, August 16-17/06, **Received the STUP Consultants Ltd. Award for an Outstanding and Original Paper.**

“Experimental Evaluation of the Structural Integrity of the Repairs for Corrosion-Damaged Marine Piles” (2008), by Juan Carlos Bolivar, provides the background on the effects of corrosion on reinforced concrete structures subjected to harsh marine environments.

Publication:

Reddy, D. V., Bolivar, J, C., and Sobhan, K. (2013). “Durability-based Ranking of Typical Structural Repairs for Corrosion-Damaged Marine Piles,” ASCE Practice Periodical on Structural Design and Construction, Volume 18, Issue 4, pp. 225-237.

METHODOLOGY

SPECIMEN PREPARATION

Two sets of beam specimens (3 for each set) and one set of cylinder specimens (3 specimens) were used for this investigation. The specimens were made using high strength concrete.

Cylinder’s 6 in Φ x 12 in were used to test the 28 day compressive strength of the concrete according to the ASTM C 39/C 39M-04a, “Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens”. The compressive strength obtained was over 6,000psi (average 10,000 psi) indicating high strength concrete

The dimensions for all the beam specimens were 6 in x 6 in x 21in. Also, two #4 steel rebars were used for reinforcement as shown in Figures 1 and 2.

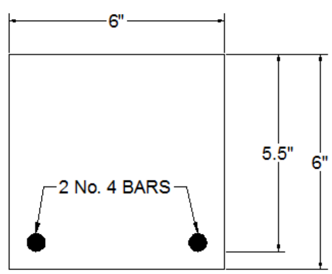

Figure 1 Reinforced Concrete Beam Cross Sectional View

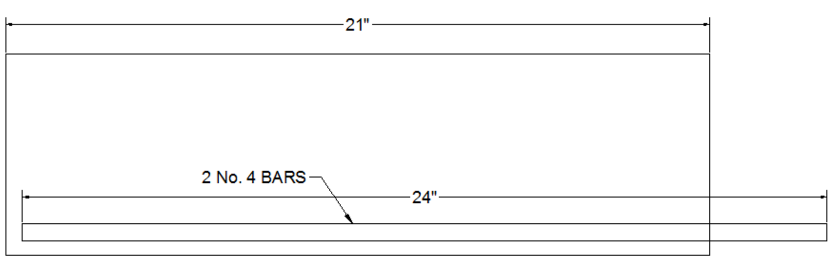

Figure 2 Reinforced Concrete Beam Longitudinal View

ACCELERATED CORROSION

The two sets of specimens were subjected to accelerated corrosion following the Florida Method for Corrosion Testing of Reinforced Concrete Using Impressed Current, designated as FM 5-522. The equipment needed to perform the accelerated corrosion test included:

1. A Voltage Controlled Direct Current power supply with sufficient current output to feed the 6 specimens.
2. Multimeter and other Data Acquisition System instrumentation. The instrument was able to measure the current transmitted to the beams without interfering with the direct current supply.
3. A Fiberglass Reinforced Tank with dimensions 1.2m x 2.4 m x 38 cm.
4. Connectors or alligator clips for attachment to the rebars in the specimen, 14 or 16 gage stranded insulated copper wire, terminal blocks or electrical bus strips, and miscellaneous hardware.

Once the specimens were prepared and cured for 28 days, they were conditioned in the test tank for an additional 5 days in a 3% NaCL solution. After the specimens were conditioned, the impressed current test was conducted to accelerate the corrosion procedure. The test steps were as follow:

1. Insulated wires were connected to the exposed rebars in each specimen in the tank.
2. A titanium anode mesh material was placed around the beams in the tank, and connected to the negative output terminal of the Direct Current power supplier.
3. After the proper connections were made, the DC power supply was turned on and the output adjusted to 30V.
4. The current to each specimen was measured on a daily basis.
5. The NaCl solution level was maintained 18 in above the bottom of the specimens. Also, the salinity was kept at 3% during the duration of the test.
6. The test measurements continued until cracks in the concrete specimens were detected by visual means or by large current increases.

Figure 3 shows a schematic of the accelerated corrosion test set up.

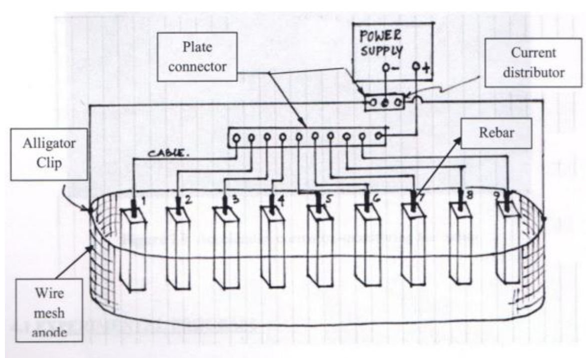

Figure 3 Schematic of the accelerated corrosion test set up

FIRE EXPOSURE

An Olympic Torchbearer gas kiln was utilized for the fire testing of all the specimens. The 2827G Torchbearer gas kiln is a top loading, stackable kiln with an ignition system and thermocouple safety shut-off system, as shown in Figure 4. Its inner dimensions are 28 ¼ in wide by 27 in deep. This model is equipped with a 5 burner system that is able to reach a maximum temperature of 2350°F (or 1288 °C) at 280,000 BTUs.

Figure 4 2827G Torchbearer Gas Kiln

The gas kiln was fueled by propane gas, emitted from a 115 lb (52Kg) tank with a R632-BF LP-Gas Regulator providing an 11 in. water column outlet pressure and 250 psi inlet pressure.

After the two sets of specimens were subjected to accelerated corrosion, one set was be exposed to fire by subjecting the beams to elevated temperatures in the gas kiln, and following the guidelines presented by ASTM E-119-12 "Standard Test Methods for Fire Tests of Building Construction and Materials". Young (2006) pointed out that the two-hour exposure time taken at elevated temperatures, for the heat to reach the center of a full scale beam (14in x 14in cross-section), can be reduced by a factor of ¼ for the small scale beams (6in x 6in cross-section) that will be used in this investigation, that represents a fire exposure time of 30 minutes.

The time-temperature curve presented in ASTM E-119-12 "Standard Test Methods for Fire Tests of Building Construction and Materials" was followed throughout the fire test by monitoring the temperature in the kiln and regulating each of the five burners. The time-temperature curve is shown in Figure 5.

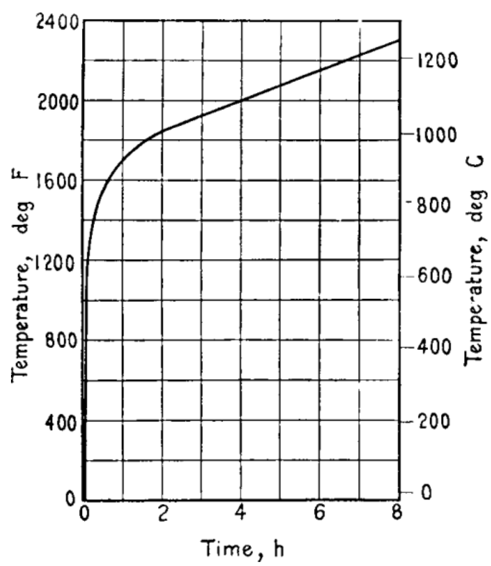

Figure 5 ASTM Time-Temperature Curve for fire testing of construction materials

FLEXURAL STRENGTH TESTING

After the corroded beams were exposed to fire, the maximum bending stress that the corroded and fire-exposed specimens were able to sustain was determined, using the four-point loading method, according to ASTM C 78-02 "Standard Test Method for Flexural Strength of Concrete". Also, the flexural strengths of the set of beams, not exposed to fire, was determined using the same test method. After the fire exposure, the flexural strength loss of the corroded beams exposed to fire, compared to the flexural strength of the corroded beams not exposed to fire, was determined and the results and trends analyzed.

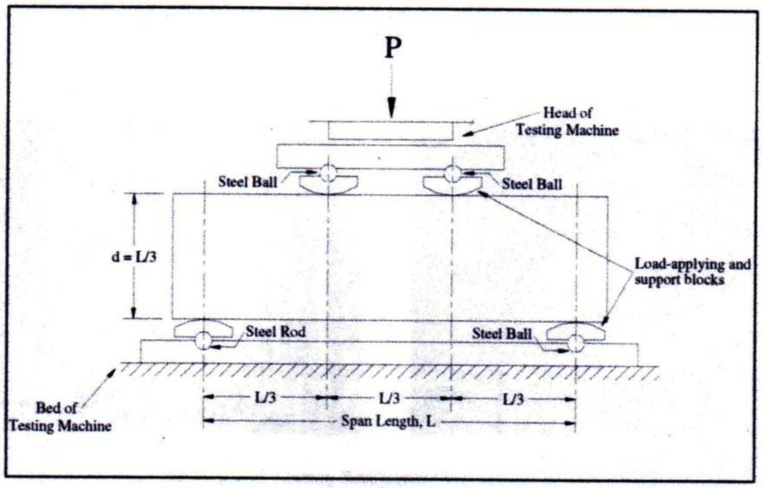

Figure 6 Flexural Test of Concrete by Four-Point Loading Method

CONCLUSION

Concrete, in its many forms, is a versatile building material that can provide many sustainable benefits by virtue of its economic, thermal mass, durability, fire resistance, acoustic performance, adaptability, and recyclability. This investigation will benefit the concrete industry by providing experimental evidence of the sustainability features of corroded high strength concrete, when fire resistance is considered. This research is relevant given high strength concrete's growing popularity as an effective alternative to normal weight concrete, and the significant impact that corrosion has on the structural integrity of buildings exposed to marine environments.

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