Experimental Characterization of Plastic Hinge Behavior from Flexure and Axial Effects

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Abstract

The unique mechanical properties of ultra-high performance concrete (UHPC) causes changes in failure modes and ductility in reinforced components. Numerous experiments have shown these materials, and others with similar ductile characteristics in tension, can improve the damage tolerance, strength, and ductility of members subjected to large deformations from seismic loading and similar extreme conditions. The use of these materials, however, has not been systematically studied to understand their application at a system-level performance and design procedures have been complicated due to their unconventional failure mechanism. This extended abstract introduces a planned experimental program to fill this gap by testing a targeted set of components subjected to combined effects of axial loads and bending with variations in axial load ratio and longitudinal reinforcement ratio. Additional experiments are planned to compare performance across other ductile concrete materials with variations in mechanical properties. The experimental results including load-deformation, reinforcement strain, concrete surface strain will be used to understand the parameters that have the highest influence on plastic hinge length and moment-rotation response which can ultimately help to validate analytical models against experiments based on these key parameters.

Keywords: plastic hinge, moment-rotation, cyclic loading

1. Introduction

Ultra-high performance concrete (UHPC) is a relatively new class of cementitious material that exhibits high compressive strength and sustained post-cracking tensile strength. UHPC usually consists of portland cement, fine silica sand, quartz powder, silica fume, high-range water reducing admixture, discontinuous internal fibers, and has a low water-to-cement ratio (Graybeal). Replacing the coarse aggregate with very fine sand and quartz powder improves the homogeneity of the mixture which results in high durability and superior mechanical properties, while the incorporation of fibers enhances ductility of UHPC (Richard and Cheyrezy).

UHPC belongs to a class of materials known as High Performance Fiber Reinforced Cementitious Composites (HPFRCC) which show high tensile strain capabilities (0.5 to 5%), due to their multiple cracking and pseudo strain hardening behavior (Naaman and Reinhardt), and retain residual strength in compression (Kesner et al.). Experiments on UHPC (Hasgul et al.) and other HPFRCCs (Bandelt and Billington) have shown that when reinforced with longitudinal reinforcement, components can often fail with reinforcement fracture, due to their high compressive toughness, which is significantly different from the concrete crushing failure mechanism of traditional reinforced concrete elements. Another contrasting behavior shown by these materials is increased deformation capacity when increasing reinforcement ratio. Therefore, the use of traditional capacity calculation methods results in significant error and further complicates their design procedures. Researchers have proposed different modified approaches (Moreno et al.) and simulation methods to estimate the flexural strength with reasonable accuracy.

The exceptional properties of UHPC have led to its adoption in many structural applications, including accelerated bridge construction and earthquake resistant structures. Recent research efforts have been directed towards studying the use of UHPC in columns. Studies which tested UHPC columns under pure axial loading (Hosinieh et al.) found that the fibers are effective as a partial replacement for the confining reinforcement and control the premature cover spalling which results in superior damage tolerance. Other experiments which tested UPHC columns subjected to combined axial and lateral loads show ductility coefficients greater than 2 even with low shear reinforcement (Marchand et al.), improved strength and deformation capacity under cyclic loads (Chao et al.), and reverified the major failure mode to be longitudinal reinforcement fracture.

2. Planned Experimental Program

Most of the research completed on columns has been under pure axial loading and limited research has focused on combined axial and lateral loading. Little research has been done to understand the plastic hinge behavior of reinforced UHPC columns. This project aims to test UHPC columns with variations in axial load ratio and longitudinal reinforcement ratio as previous research has shown changes in reinforcement significantly affect the deformation capacity (Pokhrel and Bandelt). In total, four UHPC columns will be tested with two variations of axial load ratios and longitudinal reinforcement ratios. The column dimensions will be approximately 150 mm (6 in.) x 150 mm (6 in.) with reinforcing bars at each corner. The columns will be subjected to displacement histories based on FEMA 461 (FEMA). This experiment is a part of a larger project which aims to compare the performance across other ductile materials with variations in mechanical properties. The tentative experimental variables are shown in Table 1. The experimental measurements will include applied loads, deflections along the height of the column, reinforcement strain, concrete surface strains and digital image correlation. These measurements along with results such as moment-rotation curves will be used study the effects on deformation capacity and cyclic strength degradation. The study will also investigate the parameters that have significant impact on the plastic hinge length and moment response which will help to experimentally characterize the plastic hinge behavior. The experimental results will also be used to validate the analytical model in a systematic way based on the previously mentioned key variables.

Table 1: Experimental Variables

Experimental Variables	Range
Materials	UHPC, ECC, HyFRC, RCC
Axial Load Ratio	5% - 20%
Reinforcement ratio	1% - 2%

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