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A Survey on Cyclic Response of Unbonded Posttensioned Precast Pier with Ductile Fiber-Reinforced Concrete

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ABSTRACT: A precast segmental concrete bridge pier system is being investigated for use in seismic regions. The proposed system uses unbonded posttensioning (UBPT) to join the precast segments and has the option of using a ductile fiber-reinforced cement-based composite (DRFCC) in the precast segments at potential plastic hinging regions. The UBPT is expected to cause minimal residual displacements and a low amount of hysteretic energy dissipation. The DRFCC material is expected to add hysteretic energy dissipation and damage tolerance to the system. Small-scale experiments on cantilever columns using the proposed system were conducted. The two main variables were the material used in the plastic hinging region segment and the depth at which that segment was embedded in the column foundation. It was found that using DRFCC allowed the system to dissipate more hysteretic energy than traditional concrete up to drift levels of 3–6%. Furthermore, DRFCC maintained its integrity better than reinforced concrete under high cyclic tensile compressive loads. The embedment depth of the bottom segment affected the extent of microcracking and hysteretic energy dissipation in the DRFCC. This research suggests that the proposed system may be promising for damage-tolerant structures in seismic regions.

KEYWORDS: Unbonded Posttensioning (BPT), Ductile Fiber-Reinforced Cement-Based Composite –(DRFCC), High-Performance Fiber-Reinforced Cementitious Composites –(HPFRCC), Slurry Infiltrated Concrete –(SIFCON), Fiber-Reinforced Polymer –(FRP), Variable Differential Transducers- (LVDT)

I. INTRODUCTION

1.1 Introduction of the Project Work

A significant number of recent earthquakes have caused serious damage to structures including precast and cast-in-place infrastructure systems. To ensure post earthquake serviceability, attention has been drawn to the development and implementation of innovative materials in new and preexisting structures to improve their performance under seismic loads. A material with strong potential for seismic applications is ductile fiber-reinforced cement-based composites (DRFCC), a class of high-performance fiber-reinforced cementitious composites (HPFRCC) that exhibits strain hardening behavior in uniaxial tension. DRFCC is composed of Portland cement, water, silica fume or fly ash, fine sand, and a low percentage by volume roughly 2% of randomly oriented polymeric fibers. DRFCC exhibits multiple, fine cracks upon loading in tension as a result of steady-state cracking.

a. Motivation

DRFCC displays higher tensile ductility, tensile strain hardening behavior, and energy dissipation than traditional concrete and many fiber-reinforced concrete materials Fig. 1. A review of the micromechanics-based design of the DRFCC studied here is given in Li (1998). Other fiber-reinforced composite materials exhibiting ductility. The system in general is an extension of a posttensioned concrete bridge pier system previously studied for no seismic areas The

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integration of a DFRCC segment into the plastic hinging regions of the segmentally precast concrete bridge piersystem is expected to result in high energy dissipation and a high damage tolerance of large cyclic displacements through evenly spaced micro cracking over the DFRCC segment. Only one hinge segment length was investigated here, whose height was roughly the width of the segment. To investigate the tolerance of theDFRCC segments to damage, the only transverse reinforcement designed for the system is that for shear forces. No additional reinforcement for concrete confinement was used in the investigation.

b. Background

Furthermore, in the proposed system there are no reinforcing bars crossing the precast segment joints. Precast segments not requiring continuous bonded reinforcement across their joints can reduce the labor and time for on-site construction of the precast system. However, without bonded reinforcement crossing the joints, there is very little hysteretic energy dissipation in the system. Therefore, while the system could possibly be used with just traditional concrete segments, the research presented here investigates the effect of using DFRCC segments in potential plastic hinging regions of the columns so as to increase the hysteretic energy dissipation of the system, through the micro cracking of the DFRCC segment.

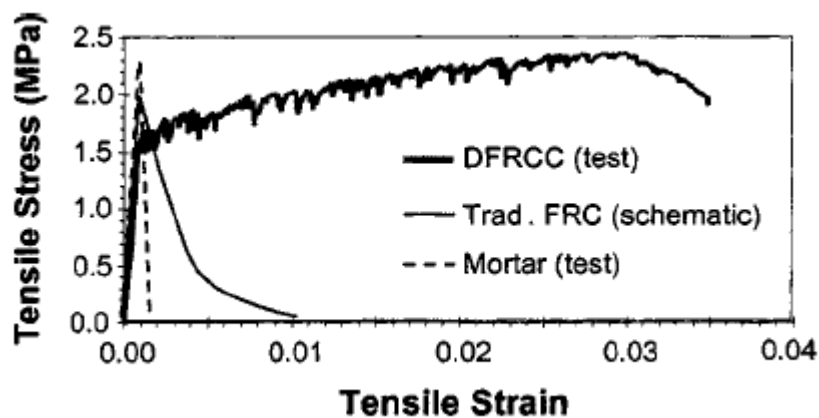


Fig. 1. Uniaxial tensile response of cement-based materials

1.2 Objectives

1. To understand the global response of unbonded posttensioned rectangular concrete columns;
2. To compare the differences in overall performance between columns with a reinforced DFRCC hinge-region segment and columns with a reinforced concrete hinge-region segment, both with shear reinforcement but no additional confinement steel.
3. To investigate the cyclic response of columns with two aspect ratios.
4. To study the effect of the hinge segment embedment into the foundation on hysteretic energy dissipation.

1.4 Scope of the Project Work

Research on related applications of DFRCC to structural design and retrofit includes cyclic testing of short span DFRCC beams and shear joint connecting panels. Investigated the use of DFRCC in exterior frame joints of reinforced concrete column-to-steel beam connections without transverse reinforcement in the joints. Finally, experiments on cantilever beams reinforced with mild reinforcing steel and with fiber-reinforced polymer (FRP) bars were presented.

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The linear elastic behavior of the FRP reinforcement allowed very small residual displacements at drift levels up to 5%. Similar behavior is expected of unbonded posttensioning while it remains in its elastic range under cyclic loading

1. Columns with DFRCC in their hinge regions exhibited more distributed, fine cracking and reached higher peak loads at each drift cycle than their corresponding all-concrete specimens.
2. Columns with DFRCC in their hinge regions dissipated more energy up to drifts between 3 and 6% than their corresponding specimens with only concrete. The drifts of 3–6% represented
3. The drifts at which deformation localized to a single base tensile crack in the specimens with DFRCC, as opposed to having continued, distributed micro cracking.
4. The taller, slender columns with DFRCC in the hinge regions exhibited more multiple cracking than their corresponding shorter, stockier columns.
5. The short and tall specimens with DFRCC segments that were more embedded ~76 mm! Below the point of fixity exhibited increased energy dissipation and experienced delayed localization of base cracks when compared to the short and tall specimens with DFRCC segments having less embedment ~38 mm!. The mild steel within the 76 mm embedded segment was able to develop close to or beyond its yield strength, whereas that within the 38 mm embedded segment was not.
6. DFRCC maintained its integrity considerably better than the normal concrete under high compressive loads without the use of transverse confinement steel beyond what was required for shear strength.
7. The DFRCC material did not spall up to the end of testing. In general, the use of unbonded posttensioning and, in particular, the combination of unbonded posttensioning with the ductile, damage-tolerant DFRCC in the plastic hinging regions was shown to be a potentially promising system for cyclically loaded bridge columns. To understand more fully the behavior of this bridge pier system using DFRCC, a larger-scale testing program is necessary.
8. While the same exact mix for the DFRCC would be used at a large scale ~eliminating size effects from mix constituents, for instance!, size effects may still be an issue due to fabrication and resulting internal flaws in the DFRCC.

II. LITERATURE REVIEW

1. BEHAVIOR OF PARTIALLY-PRESTRESSED CONCRETE INTERIOR BEAM-COLUMN JOINTS FOR HIGHLY-SEISMIC ZONES

The high intensity and frequency of earthquakes occurred in the past two decades has brought a deep trauma to the Indonesian people, particularly those who live in the highly seismic regions. According to the latest building codes including the Indonesian building standards, a multistory or high-rise building should be designed to have a ductile manner during the severe earthquake strikes. The structural components such as beam-column joints as parts of a frame system must be sound and ductile so that the building will withstand a moderate or even severe earthquake. The research conducted here is to study the ductile behavior of monolithic joints of a ductile frame system with partially prestressed concrete beams and reinforced concrete columns under cyclic loading to simulate the earthquake.

2. BEHAVIOUR OF A BEAM TO COLUMN “DRY” JOINT FOR PRECAST CONCRETE ELEMENTS

In Italy, precast concrete structures are traditionally designed as moment resisting frames with plastic hinges occurring at the column base and beams hinged to the columns. A ductile moment resisting connection between the column and the beam can provide the advantage of designing a seismic resisting frame which can develop plastic hinges at the beam-column joints, besides those at the column base. This paper aims at presenting the results of experimental tests concerning the cyclic behaviour of a particular beam-column “dry” connection for precast concrete elements. The joint is characterized by the use of high strength steel bars and of a fibre reinforced grout pad in the “Z” shaped beam-column interface, increasing the shear resistance of the connection. The experimental results show a good performance

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of the joint, in term of resistance, ductility and energy dissipation, with little damage observed in the connected members.

3. CYCLIC RESPONSE OF HIGHLY DUCTILE FIBER-REINFORCED CEMENT-BASED COMPOSITES

This paper examines the response of highly ductile fiber-reinforced cement-based composites (DFRCC) to uniaxial monotonic and cyclic loading. The DFRCC examined in this investigation is a portland cement-based mortar matrix with a low volume fraction (typically 2%) of high modulus polymeric fibers. Various cyclic testing schemes were used to examine the effect of cyclic loading on the material's compressive and tensile stress-strain envelope. The response of different tensile specimen geometries was also examined. A distinctive feature of DFRCC is its pseudo-strain hardening response in tension. Testing results identified a unique unloading and reloading response for DFRCC, which is a consequence of fibers debonding and pulling out of the matrix. Reversed cyclic loading was seen to affect the tensile response of the material if the uniaxial compressive strength during loading was exceeded and not to affect the tensile response if the compressive strength was not exceeded. The evaluation of tensile specimen geometries revealed significant variations in strain capacity between the different geometries.

4. TWO-PLASTIC-HINGE AND TWO DIMENSIONAL FINITE ELEMENT MODELS FOR POST-TENSIONED PRECAST CONCRETE SEGMENTAL BRIDGE COLUMNS

Recent studies have confirmed that unbonded post-tensioned (PT) precast concrete segmental bridge columns are capable of undergoing large lateral deformation with negligible residual drift. To provide a clear guideline for the modeling of the columns for practicing engineers as well as researchers, this paper presents two types of numerical models: (i) a two-plastic-hinge model using the sectional moment–curvature analysis procedure at two segment interfaces and (ii) a two-dimensional (2D) finite element model using truss and beam-column elements in the computer program PISA. Three unbonded PT precast concrete- filled tube segmental bridge column specimens are cyclically tested. Two specimens have mild steel bars crossing to different column heights for studying the effects of anchorage position on the hysteretic energy dissipation (ED) capacity. The test results show that (1) the mild steel bars (“ED bars”) can increase hysteretic energy dissipation, and Specimens 1–3 have equivalent viscous damping of 6.5– 8.8%, (2) a plastic hinge length in the first or second segment varies with anchorage position of ED bars and lateral displacement, and (3) an equivalent unbonded length along which the strain in the ED bar is assumed uniformly distributed on each of the two sides is 5–6 bar diameter. A 2D finite-element model is utilized to predict the cyclic behavior of the specimens. Parametric studies using finite-element models are also conducted to investigate the effects of ED bar area, initial strand force, and aspect ratio on the cyclic behavior.

5. EXPERIMENTAL STUDY ON A NEW PRECAST POST-TENSIONED CONCRETE BEAM COLUMN CONNECTION SYSTEM

The objectives of this study were to investigate the hysteresis characteristics, shear transferring capacity, damage state and possibility to disassemble the precast unbonded post-tensioned connections with and without shear bracket under the simultaneous cyclic load and large gravity load. Three half-scale specimens of precast unbonded post-tensioned exterior beam-column connection of large span frame was proposed and tested. The test results of the specimen without shear bracket showed excessive beam slip, resulted in large residual deformation, while the specimens with shear bracket that have the amount of prestressed steel 50% less than that of the specimen without shear bracket expressed very good performance with very small residual deformation, almost no slip, minor damage to the beam and column elements, and easy to disassemble even after experienced the story drift up to 6% drift.

6. BEHAVIOUR OF STEEL FIBER REINFORCED CONCRETE

Cement concrete is the most extensively used construction material in the world. The reason for its extensive use is that it provides good workability and can be moulded to any shape. Ordinary cement concrete possesses a very low tensile strength, limited ductility and little resistance to cracking. Internal micro cracks, leading to brittle failure of concrete. In this modern age, civil engineering constructions have their own structural and durability requirements, every structure

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has its own intended purpose and hence to meet this purpose, modification in traditional cement concrete has become mandatory. It has been found that different type of fibers added in specific percentage to concrete improves the mechanical properties, durability and serviceability of the structure. It is now established that one of the important properties of Steel Fiber Reinforced Concrete (SFRC) is its superior resistance to cracking and crack propagation. In this paper Flexure behaviour of concrete with the Steel fiber is studied in detail.

7. EXPERIMENTAL INVESTIGATION OF INNOVATIVE BRIDGE COLUMNS FOR A RESILIENT BRIDGE INFRASTRUCTURE

The ductile behavior of engineered cementitious composites (ECC), which is a special class of high-performance fiber-reinforced concrete (HPFRC), in tension and its superior shear resistance, energy absorption and bond characteristics compared with conventional concrete, provide a unique opportunity to improve the seismic performance of structural components. In this study, an innovative bridge column design is developed using a reinforced ECC (R/ECC) tube filled with conventional concrete. Both the innovative and conventional reinforced concrete (RC) columns are tested under simulated seismic loading. A comparison of results indicates that the proposed concept provides a higher lateral strength and reduces damage, while minimizing the use of more expensive material ECC.

8. ANALYSIS AND DESIGN OF VERTICAL POST-TENSIONED PRECAST SHEAR WALL

This study aims to provide analysis and design of Vertical-Post-tensioned Precast Shear Wall as per IS 1343:2012. Instead of using conventional cast-in-situ Shear Walls, use of precast shear wall using post-tensioned tendons for flexural reinforcement observed only small amount of damage to the concrete material. This research focuses on the use of unbonded post-tensioning tendons for wall to wall connection in precast shear wall across the horizontal joint over the portion of its length. For this purpose a commercial (G+4) storied building with shear walls modelled in ETABS2016 to analyse the structure and to found the load coming on shear walls. Design of Precast Shear walls using posttensioning tendons are done manually for each precast walls. The behaviour of vertical post-tensioned precast shear wall is captured by analysing the precast shear wall in SAP2000 software.

9. NEW DUCTILE MOMENT-RESISTING CONNECTION FOR PRECAST CONCRETE FRAMES IN SEISMIC REGIONS: AN EXPERIMENTAL INVESTIGATION

A new ductile moment-resisting beam-column connection is developed for precast reinforced concrete (RC) frames in high seismic zones. The proposed connection provides good structural integrity in the connections and can reduce construction time by eliminating the need for formworks and welding, and minimizing cast-in-place concrete volume. A series of cyclic loading tests were carried out on six full-scale interior and exterior precast connections and two monolithic connections, all designed for use in high seismic zones. Test variables included the type of stirrups (open and closed) and the stirrup spacing in the beam connection zone. Test specimens were subjected to a constant axial load and a reverse cyclic loading based on a given displacement history. Flexural strength, ductility, strength degradation and energy dissipation capacity of the precast and monolithic connections are compared.

10. A NUMERICAL STUDY ON SEISMIC RESPONSE OF SELF-CENTRING PRECAST SEGMENTAL COLUMNS AT DIFFERENT POST-TENSIONING FORCES

Precast bridge columns have shown increasing demand over the past few years due to the advantages of such columns when compared against conventional bridge columns, particularly due to the fact that precast bridge columns can be constructed off site and erected in a short period of time. The present study analytically investigates the behaviour of self-centring precast segmental bridge columns under nonlinear-static and pseudo-dynamic loading at different prestressing strand levels. Self-centring segmental columns are composed of prefabricated reinforced concrete segments which are connected by central post-tensioning (PT) strands. The present study develops a three dimensional (3D) nonlinear finite element model for hybrid post-tensioned precast segmental bridge columns. The model is subjected to constant axial loading and lateral reverse cyclic loading. The lateral force displacement results of the analysed columns show good agreement with the experimental response of the columns. Bonded post-tensioned

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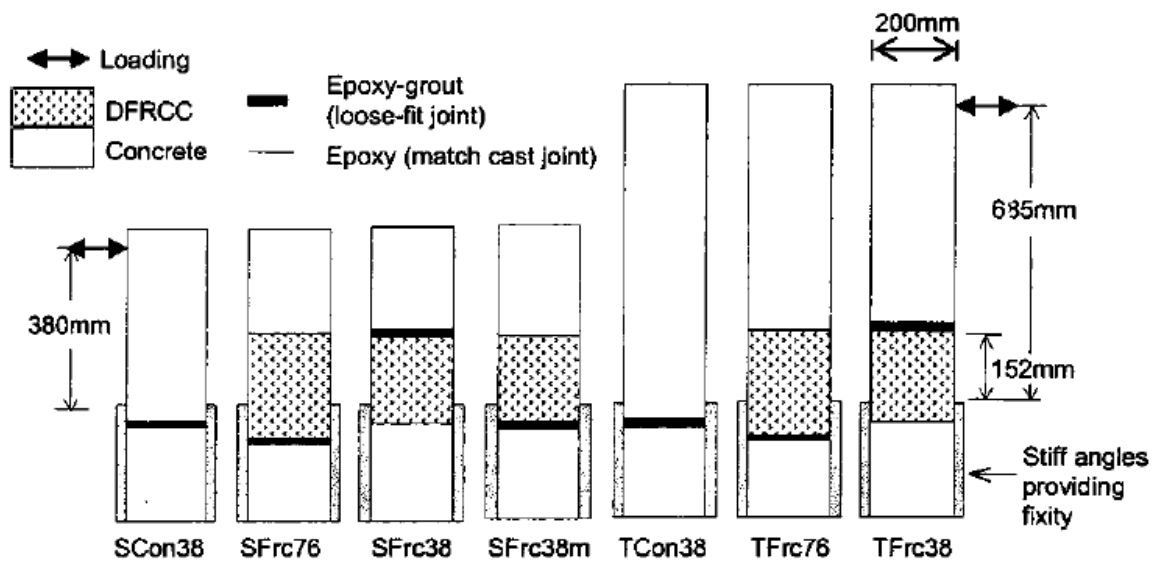
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segmental columns at 25%, 40% and 70% prestressing strand stress levels are analysed and compared with an emulative monolithic conventional column.

III. METHODOLOGY

To measure and to observe the behavior of the proposed bridge pier system under cyclic loading, a laboratory testing program was conducted. Bridge columns at a scale of roughly 1/6 of a prototype were designed. A total number of seven fixed-end cantilever column specimens were fabricated and tested: four short columns and three tall columns. One column of each height set consisted of only concrete segments, while the others included one DFRCC segment per specimen. Each specimen represented half the height of an actual bridge column that would experience reverse curvature under lateral load.



Notation: Height_Hinge Material_Embedment of Hinge

Height = S (short) or T (tall)

Hinge Material = DFRCC (Frc) or Concrete (Con)

Embedment of Hinge = 76mm (76) or 38mm (38)

Fig. 2. Schematic diagram of test specimens

IV. CONCLUSION

The use of precast DFRCC segments in designated plastic hinge regions in a bridge pier system with unbonded posttensioning was investigated experimentally under cyclic load. A small-scale test program was conducted wherein four short and three tall specimens were tested to study the use of unbonded posttensioning and the use of DFRCC's unique ductile and tensile strain-hardening characteristics to improve the cyclic performance of the proposed bridge pier system. The major findings were all of the unbonded posttensioned columns studied here reached drift levels of

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roughly 9% before posttensioning yielding occurred. Second-order effects were not taken into account in the testing. Prior to yielding of the posttensioning, all of the specimens exhibited minimal residual displacements (1%).

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