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Review paper on self-centering pier and ultra-high performance concrete in bridge construction

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ABSTRACT: Due to excessive lateral drifts during an earthquake, traditional reinforced concrete bridges become non-functional and even need to be demolished, leading to long term closures of important highways. Segmental unbounded post-tensioned self-centering pier is widely used in bridges mainly because of its capacity to resist large lateral drifts. The prefabrication of these segmental piers makes the construction process faster as well. For inspecting the performance of self-centering piers, many analytical and experimental researches have been carried out; analytical results being validated by experiments performed or available experimental data. Different researchers used different materials for constructing bridge piers. Some preferred using Energy Dissipation bars or shear keys, and some did not. They also varied the construction material and level of prestressing force in different experimental and analytical studies. Observations by various previous researchers on segmental unbounded post-tensioned self-centering columns using ultra-high performance concrete have been reviewed and summarized in this paper.

1 INTRODUCTION

Bridges are an integral part of a qualified transportation network. New bridges are being constructed all over the world for transporting passengers and freight. Furthermore, since so many bridges have reached the end of their service lives, some bridges are in dire need of being repaired, retrofitted, or even replaced (Dawood 2010, Zhang & Alam 2016). This can lead to long term closure of important highways of a country. In this era of modern civilization, when time is the most precious and invaluable thing a person can spend, accelerated construction work of bridges is essential. Segmental unbounded posttensioned piers or self-centering piers can play a significant role in accelerating the bridge construction since they are prefabricated in factories (Hao et al. 2018, Nikbakht et al. 2014). Segmental bridges have been widely used around the globe in the last few decades (Dawood 2010, Lin & Yoda 2017). Being manufactured beforehand also ensures better quality control considering the construction difficulties during the rainy season. Its construction process is better for workers in terms of safety and is a greener solution creating fewer pollutants (Glass 1999). However, the most significant property of a segmental self-centering pier is its capacity to resist large lateral drifts (Zhang & Alam 2016). In contrast, the more common monolithic reinforced concrete (RC) pier bridges are prone to inelastic response resulting in structural damage (Dawood 2010). The reason behind this drift resisting capacity lies in its nomenclature: the system of unbounded posttensioning makes the column tend to return to its center even after a cyclic loading like the earthquake comes upon it. Because the prestressed tendon is unbounded through the segments of the pier, incremental stress and strain do not get concentrated at cracks. If the applied post-tensioning is there during and after an earthquake, the pier gets a self-centering capability, and it returns to its original position with the help of this restoring force (Dawood 2010).

Ultra-high performance concrete (UHPC) is a popularly used material in segmental bridge construction. Although high-performance concrete (HPC), which obtained significant advancement over the last decade, is comparable to high strength concrete (HSC), HPC has improved microstructure resulting in better durability properties along with high compressive strength (Shin 2017). UHPC is the next generation of HPC and can achieve exceptionally high compressive strength (even exceeding 200 MPa), high tensile strength (about 12 MPa) (Chang et al. 2002), durability, stability, structural efficiency, economic making it worthwhile in bridge construction (Shin 2017). UHPC is used at the plastic hinge sections of the columns for achieving seismic resistivity because even an adequately designed RC column deteriorates under lateral seismic load due to significant damage to the plastic hinges of a bridge (Ichikawa et al. 2015). Many private and government bodies have started using UHPC as construction material, believing it to be a solution to sustainable construction (Voo et al. 2015).

Precast concrete segmental bridge concept has been gaining much popularity among Civil Engineers around the world over the past years (Lin & Yoda 2017, Dawood 2010). These constructions of segmental bridges are the direct results of experiments performed by many researchers (Hewes & Priestley 2002, Marriott et al. 2009, Ichikawa et al. 2015, Wang et al. 2018, Li et al. 2018, Zhang et al. 2019) and also many more researches are being carried out to further improve the system of these bridges. This paper, however, focuses mainly on the experiments on self-centering segmental unbounded posttensioned piers carried out by the previous researchers, and their findings were compiled.

2 PHILOSOPHY AND DEVELOPMENT OF SELF-CENTERING PIER

A major earthquake happened near the city Kobe in Japan in 1995, and as aftermath, more than hundred RC bridges needed to be demolished, which failed due to residual drifts of only about 2% (Jeong et al. 2008, Lee & Billington 2010). After this earthquake incident, Japanese seismic design specifications lowered the allowable residual drift limit to 1%. (Japan Road Association 2002). Since post-tensioning induces self-centering ability in piers, this can be very useful in controlling excessive residual drifts in concrete bridges. Also if the pier is divided into segments (Figure 2), the number of interfaces for rocking is increased instead of the single one between the foundation and the superstructure that causes major damage to the structure (Chang et al. 2002, Chou & Chen 2006, Marriott et al. 2009, ElGawady et al. 2010, Ichikawa et al. 2016).

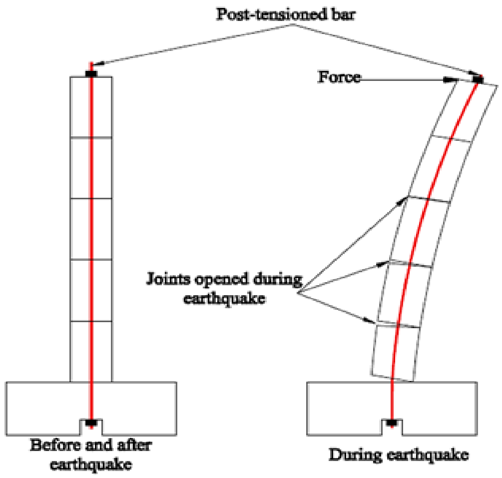


Figure 1. Behavior of segmental post-tensioned column under earthquake load (adapted from Dawood 2010)

This increased number of interfaces increases the available surface for rocking. From this philosophy, the idea of a segmental unbounded post-tensioned pier system is derived. Large peak drifts and low residual drifts could be achieved using this system (Mander & Cheng 1997, Hewes & Priestley 2002, Billington & Yoon 2004, Chou & Chen 2006, Palermo et al. 2007, Shim et al. 2008, Wong et al. 2008, Marriott et al. 2009, Solberg et al., 2009; Ou et al., 2009; ElGawady et al., 2010; ElGawady & Sha'lan, 2010; Kim et al., 2010; Ou et al. 2010, Trono et al. 2014, Ichikawa et al. 2016). Studies (Hewes & Priestley 2002, Chou & Chen 2006, Wang et al. 2008) have also confirmed the re-centering ability of unbounded post-tensioned precast segmental bridge columns and their capacity to resist large lateral deformation. Since the tendon is unbounded over the height of the pier, it must be prestressed because it is not possible to continue the non-prestressed reinforcement past the joints of each segment (Khan 2015). The post-tensioning force binds the whole system of segments together. When a lateral load comes upon the pier, a normal force is induced by prestressing, and a moment comes from this lateral load. These two loads combine to provide the stress under each prefabricated concrete segment stacked over each other (Dawood 2010). When the stress becomes nullified at any point under a particular concrete segment of a pier, further increase in the lateral load creates an opening between the two consecutive segments (Figure 1). Then this opening keeps propagating with the increase in lateral load till it reaches the prestressed tendons at the centroid of this segment. At this point, the post-tensioned reinforcement gets stretched, and the stress in the rebars increases. This mechanism is illustrated in Figure 1 (adapted from Dawood 2010).

3 TYPES OF SELF-CENTERING PIER

Segmental bridge construction is becoming quite popular nowadays (Dawood 2010, Lin & Yoda 2017). Prestressed segmental piers are basically of two types- bounded and unbounded. In bounded piers, bonding between the tendons and surrounding concrete is generated by grouting the steel ducts with cementing materials after applying the prestressing force. This bonding increases the lateral strength of the piers. On the other hand, in the unbounded posttensioning system, the tendons are kept unbounded with the concrete. This reduces the possibility of yielding of tendons during a seismic event (Ou et al. 2007). Segmental bridges can be of various types. Some of the common forms are:

- Simply supported or continuous superstructure having dry joint or epoxy joint
- Spliced girder construction using epoxy joint or concrete stitch
- Balanced cantilever structure having precast or cast-in-place segments

Segmental bridges can be used for various span lengths. Typical spans of segmental bridges are summarized in Table 1 (adapted from Martin 2016).

Table 1. Typical span length of segmental bridges (adapted from Martin 2016).

Bridge type	Span length (m)
Precast posttensioned box girder of constant depth erected with balanced cantilever	30–90
Cast-in-situ posttensioned box girder of constant depth	30–90
Precast balanced cantilever of variable depth	60–180
Cast-in-situ cantilever	60–300

4 MATERIALS

4.1 *Ultra-High Performance Concrete (UHPC)*

Ultra-high performance concrete (UHPC) is a modern cement-based composite material that is becoming popular as a sustainable solution on bridge construction. The main components of UHPC include ordinary portland cement, densified silica fume, fine sand having particle size ranging from 100 to 1000 mm and superplasticizer. UHPC was first used in Sherbrooke Bridge, a 60 m single-span pedestrian bridge located in Quebec, Canada (Lachemi et al. 1998). A study was carried out in 2014, and it was found that more than 100 bridges used UHPC as one or more of their components (Voo et al. 2015).

Fine aggregates and fibers at varying proportions enhance cement paste and can improve the mechanical properties of UHPC to a desired compressive strength, tensile strength, or elastic modulus (Carey et al. 2020). Low permeability of these high performance concretes ensure good durability against corrosion of the embedded reinforcements (Lau & Lasa 2016).

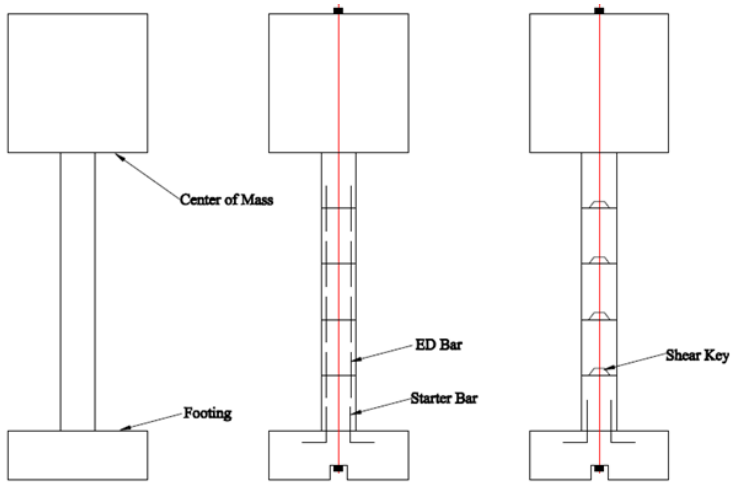
The flexural capacity of even a well-designed reinforced concrete (RC) pier deteriorates due to damage in the plastic hinge regions under an extreme seismic event. These damages may include concrete cover spalling, crushing of concrete core and buckling or rupture of longitudinal reinforcements. Therefore to develop seismic resistant piers, it is important to prevent damage at the plastic hinge regions (Ichikawa et al. 2015). Ultra-high performance fiber reinforced concrete (UHPFRC) can be used to prevent this damage. UHPFRC containing a high amount of cement and silica fume, and no coarse aggregate can achieve a very low water-cement ratio (w/c). Polycarboxylate based water-reducing admixtures are used to achieve acceptable workability. These concretes are usually steel fiber reinforced in case of use in structural application (Graybeal 2007).

Seismic resistance of columns can be achieved by using ultra-high performance steel fiber reinforced concrete (UFC) segments at the plastic hinge region. UFC consists of dense matrix and micro steel fiber. (Ichikawa et al. 2015) UFC is able to achieve compressive strength of 200 MPa and tensile strength of 12 MPa (Chang et al. 2002). Although the high construction cost of UFC makes it expensive for the construction of a full bridge pier, it can be used in the construction of plastic hinge regions to improve the strength and deformability of the piers under a seismic event (Ichikawa et al. 2015).

4.2 *Energy Dissipation (ED) Bars*

Energy Dissipation (ED) bars are longitudinal steel reinforcements provided in the joints of the segmental columns to improve the hysteretic energy dissipation property of the columns (Ou et al. 2007). In seismic design philosophy, it is expected that the ends of a column should have plastic hinging to dissipate seismic energy. One shortcoming of the precast segmental column is that the joint openings of these columns prevent the plastic hinging where the longitudinal reinforcements are kept discontinuous at the segment joints. As a result, the hysteretic energy dissipation capability of these columns is inadequate as compared to the conventional monolithic columns (Chang et al. 2002, Hewes & Priestley 2002). This shortcoming can be overcome by providing ED bars at the column segment joints as ED bars are able to dissipate the seismic energy by yielding during a strong seismic event. Ou et al. (2007) observed that both the lateral strength of a pier and hysteretic energy dissipation increase with an increase in the ED bar ratio. Moreover, a flag-shaped hysteretic behavior having increased hysteretic energy dissipation, a highly desirable property during an earthquake, can be achieved if the ED bar ratio is kept below a certain threshold. Ou et al. (2007) concluded that for a desirable flag-shaped hysteretic behavior, the optimum ED bar ratio is around 0.5%.

Although ED bars are able to increase energy dissipation, they can also cause more damage to the piers. Therefore, Moon et al. (2005) suggested the introduction of shape memory alloy (SMA) in the segmental columns to improve seismic behavior. Sideris et al. (2014) proposed hybrid sliding rocking systems in order to increase energy dissipation and to reduce damage.



(a) (b) (c)

Figure 2. Schematic drawing, (a) typical monolithic column, (b) 5 segment column with ED bar, (c) 5 segment column with shear key (adapted from Li et al., 2018).

4.3 *Shear Key*

During the service life of a pier, extreme loading conditions like vehicle or barge collision may impart significant shear forces in the pier causing permanent damage. So, the piers should be designed considering adequate shear resistance between the segments. This can be achieved by providing shear keys in the segmental column. Shear keys are able to reduce the relative deformation between column segments during an event of extreme impact force. (Zhang et al. 2016).

However, Mashal et al. (2013) suggested that the friction between the column segments is sufficient to resist the shear forces induced by a seismic event. Some studies, therefore, proposed concrete segments without the use of shear keys (Chou & Chen 2006, ElGawady et al. 2010, Yamashita & Sanders 2009). Although shear key increases shear resistance, it may also cause stress concentration, which eventually results in more damage to the concrete segments (Li et al. 2018, Zhang et al. 2016). So further study is required to understand the influence of shear key on the behavior of segmental column during a seismic event. Figure 2 illustrates the concept of segmental column and its components. Figure 2(a) shows a traditional monolithic column connected to a footing. Figure 2(b) illustrates a five-segment precast segmental column having bonded ED bars crossing the segment joints. The column shown in figure 2(c) is also a precast segmental column having five segments, but it includes trapezoidal concrete shear key instead of the ED bars. The segmental columns also include two starter bars to connect the footing with the base segment.

5 RESEARCH METHODOLOGY

Some of the previous researches carried out have been compiled here. Both analytical and experimental works were conducted regarding self-centering piers. Some researchers carried out Finite Element (FE) models and validated them through experimental data. Moreover, some others used a previous model validated through experiments to implement different factors to investigate their effect, and some used experimental results of previous literature for validating their own FE models.

5.1 *Finite Element Models*

The following table (Table 2) summarizes the numerical analyses carried out by various researchers on self-centering piers of segmental concrete bridges.

Table 2. Summary of analytical investigations.

Ahmadi & Kashani (2019)	numerically investigated the nonlinear static and dynamic behavior of segmental precast piers using a FE framework in Open Sees (2012). Three degrees-of-freedom were used for each node that included horizontal translations, vertical translations and rotational rocking. Comparison was made between tapered and non-tapered segmental piers and also for conventional cast-in-situ RC piers.
Hao et al. (2018)	investigated the behavior of segmental precast bridge piers having unbounded prestressed tendons under truck impact load in ANSYS-APDL/LS-DYNA and compared to a conventional monolithic column (CMC). Shear force and bending moment induced by truck impact along with the failure modes were investigated for both segmental columns and monolithic columns. The numerical model was also validated using experimental results.
Moustafa et al. (2018)	developed a three-dimensional FE model of hollow-core segmental bridge piers having post-tensioned unbounded tendons under seismic force using LS-DYNA. Contact elements were used to predict the rocking behavior of the piers. Results were validated with past experimental results.
Hung et al. (2017)	proposed a hybrid semi-rigid connection using two different FE models for precast segmental columns in order to prevent excessive axial prestressing forces. One was a simple analytical model using beam-column element in SAP2000, and the other advanced model was simulated using solid elements in ANSYS. To ensure sufficient shear resistance, bonded PT bars were provided, which were spliced by shear keys and bar couplers.
Zhang & Alam (2016)	used Abaqus for generating FE models of unbounded post-tensioned concrete columns and carried out a parametric study. They validated those models with experimental data from previous studies (Hewes and Pristley, 2002) and used the validated models for projecting the seismic behavior of the piers under reverse cyclic loading. The analysis was carried out in two stages. At first, a full factorial analysis was carried out where the three factors were: post-tensioning (PT) level, PT ratio and concrete compressive strength. Afterwards a comprehensive fractional factorial study was performed with seven factors, each at two levels.
Nikbakht et al. (2014)	performed analysis on 3D nonlinear FE model for observing the behavior of segmental post-tensioned self-centering piers using ANSYS (2012). The loading condition was nonlinear-static and pseudo-dynamic loading at different prestressed strand levels. The axial loading and lateral reverse cyclic loading were kept constant on the models.
Ou et al. (2007)	developed a 3D FE model for predicting the behavior of segmental post-tensioned piers under lateral loading. Parametric studies were also carried out using simplified analytical models. Their proposed analytical model could predict the lateral force-displacement response (pushover curve) for analyzing the seismic behavior of the columns with hollow cross-sections.

5.2 *Experiments*

Hewes & Priestley (2002) applied cyclic loading on four segmental unbounded post-tensioned columns, which scaled 40% of the original ones and had different aspect ratios. Each of these four piers was tested two times: once under low and then under high initial posttensioning stress. The researchers used two types of thickness for steel jacketing that were used in the lower segments only, whereas all the upper ones were made of reinforced concrete. All of the test samples performed well when the initial prestressing force was low. The piers did not experience any drastic strength loss even when the drifts coming upon them were up to 4%. However, when the initial prestressing force was high, the piers with thicker confinement at the lower segments performed better than the ones with thinner confinement. The columns using thicker jackets could achieve a drift of 6% with minimum strength loss. In addition, the residual drift after these tests were minimum because the system was an unbounded post-tensioned segmental column. Column damage was also very low and only occurred at the column base by minor crushing of concrete.

Marriott et al. (2009) experimented on three piers, two were segmental, and the other one was a monolithic RC column. The specimens scaled 33% of the original piers. The first two posttensioned segmental columns resulted in minimal damage, and they showed stable energy dissipation and self-centering ability.

Ichikawa et al. (2015) tested two columns of same strength and different plastic hinge details using orbital bilateral cyclic load used for imposing flexural deformation and twisting tendency of the columns. One of them had ultra-high performance steel fiber concrete (UFC) confining the RC core, and the other one used UFC hollow core plastic hinge and post-tensioning. The first one with solid RC core could resist a drift of 6% while the post-tensioned pier could resist a lateral drift of 3.5%. Wang et al. (2018) tested three segmental self-centering post-tensioned bridge columns made with UFC using river sand and coarse aggregate upon the application of cyclic loading, and their research parameters were the number of Energy Dissipation (ED) bars and level of PT forces. The columns were scaled 33% of the original size. ED bars were used, which were continuous throughout all the segments and unbounded at the lowest joint. No noticeable cracks or spalling of concrete were observed. Both of these research parameters had significant effects on stiffness, lateral strength, and ductility of the columns. When the total axial loading ratio was no more than 0.08, ductility improved with increased PT force. However, the contribution of λ_{ED} of ED bars to lateral strength must be less than 25% for ensuring self-centering capacity.

Five segmental columns and one control monolithic RC column were tested by Li et al. (2018) upon the application of cyclic loading, and their damage mode, hysteretic behavior, residual drift and energy dissipation capability were observed. Shear keys were used, and their effect on the columns was inspected. After the experiments, it was found out that the segmental columns were more ductile and showed smaller residual drift than the monolithic column. However, they exhibited less loading capacity and less energy absorption than the latter. Zhang et al. (2019) designed a control monolithic bridge column (MBC), a hybrid bridge column (HBC) and a precast segments bridge column (PSBC) scaling 25%. The lowest segment of the HBC and foundation were cast monolithically. The geometry of the PSBC and HBC was similar except that all segments were precast and no monolithic connection was maintained for the latter one. All through the precast segments, three post-tensioned tendons were used. It was observed that HBC performed better in hysteretic characteristics, energy dissipation, and stiffness degradation than PSBC. The HBC and PSBC both exhibited significantly higher self-centering capacity than the MBC. Along with the experimental programs of various previous studies described above, some of the other attributes are summarized in Table 3.

Table 3. Summary of experimental attributes.

Author	No. of segments used	Segment size (mm)	Use of ED bar
Moustafa et al. (2018)	4	300	No
Li et al. (2018)	5, 7	Variable	Used in some piers, exempted in others
Hung et al. (2017)	3	900	No
Hewes and Priestley (2002)	2, 4	914	No
Ichikawa et al. (2015)	12	50	No
Zhang et al. (2019)	4	400	No

6 RESULTS & DISCUSSION

6.1 *Influence of Geometric Property of Pier*

Some parameters for example the aspect ratio of the pier, size and shape, position of the post-tensioned bar, segment size and number of segments etc. have a significant effect on the characteristics of self-centering pier. The effect of some of these parameters such as column height and diameter, duct size, and thickness and ultimate tensile strain of fiber-reinforced polymer wraps on the behavior of unbounded post-tensioned segmental columns was investigated by Hassanli et al. (2017). The research showed that the ductility of the column is affected by the column's aspect ratio and axial stress ratio.

The varying number of segments of the columns was also taken into consideration in previous researches. For instance, Ichikawa et al. (2016) used 12 segments with a small height of 50 mm. On the contrary, researchers (Bu et al. 2015, Chou & Chen 2006, Ou et al. 2010, Marriott et al. 2009) used fewer numbers of segments with larger segment height. The conclusion cannot be made on the comparison among the different size and number of segments of the column because of the limited number of studies found regarding the influence of segment number and size on pier behavior (ElGawady et al. 2010, ElGawady & Sha'lan 2010).

Elgawady & Sha'Lan (2010) did some studies on the performance of precast posttensioned concrete-filled fiber tubes (PPT-CFFT), which had single segment and three segments, respectively. The findings from both researches show that both multi-segment and single-segment bents act in a similar way in terms of strength, lateral drift capacity, stiffness, and residual drifts. Li et al. (2018), considering five and seven segments of the segmental column for investigating the strength of the column, came to a conclusion that both the columns exhibited similar performance. To achieve a precise decision about the effect of the number of segments on column strength, further studies and experiments are much needed.

6.2 *Influence of Prestressing Force*

The prestressing force level is one of the most essential elements for the segmental column, as the prestressing force helps the segmental column to be integrated, specifically when the column is without ED bars across the joints. There are few investigations on the effects of prestress level on the segmental column strength. A numerical assessment was done by Dawood et al. (2014) on the effect for prestressing force on seismic behavior of the columns and made a statement that 40-60% of the yield stress of the tendon for the initial prestressing force would be suitable for the design of segmental column in practical life and this amount of initial prestressing forces would allow 4.5% lateral drift angle without yielding. Besides, the research mentioned that the maximum strength of the column could be increased by increasing the prestressing force level, but concrete compression failure at the toe of the segment joint lessened the lateral drift. This specific behavior indicates the decreasing of the ductility of the segmental column (Dawood et al. 2014).

Nikbakht et al. (2014) took three different initial stress levels (70%, 40%, 25%) to study the earthquake effect on self-centering precast segmental columns. The highest initial stress level (70%) caused the highest stiffness reduction, with a 4.0% drift. The initial stiffness and strength of the self-centering segmental column were also improved by increasing the prestressing force levels. Posttensioning force levels had a slight influence on residual displacement and the joint opening of the precast segmental samples, even though the higher level of initial stresses in the segmental column caused the larger amount of equivalent viscous damping. Axial stress level, axial stress ratio, stress ratio of the PT bars were considered for the investigation on the unbounded post-tensioned segmental columns (Hassanli et al. 2017). In their research, the moment capacity of these columns showed sensitivity to the level of axial stress ratio, whereas it was not sensitive to the concrete compressive strength. The level of axial stress ratio and aspect ratio are the two aspects that influenced the ductility of unbounded post-tensioned columns. Compressive strength of concrete, f_c' and the level of axial stress, f_c did not alter the ductility when the axial stress ratio, f_c'/f_c, was constant.

Wang et al. (2017) studied the impact of axial compression ratio limit for the post-earthquake residual axial loading capacity on the self-centering precast segmental hollow piers. The findings of the research indicated that the proposed axial compression ratio limit should be 0.25 when the ratio of ED bars is less than 1.5%.

6.3 *Damage State*

Moustafa et al. (2018) analyzed segmental hollow-core bridge columns having post-tensioned unbounded strands and found that the columns had excellent self-centering capability under ground motion excitations. On the other hand, rebar yielding and concrete spalling cause irreparable damages under a seismic event in case of the traditional reinforced concrete column.

Zhang et al. (2019) compared a monolithic bridge column (MBC) and a precast segmental bridge column (PSBC) under lateral loading to assess the seismic capacity and found that PSBC had significantly higher self-centering capability compared to the MBC. The greatest damage in the MBC occurred mainly around the regions of plastic hinges in the form of concrete spalling and crushing. For the PSBC, damage was primarily concentrated at the joint between the base segment and the footing in the form of partial concrete crushing.

Dawood (2010) studied the seismic behavior of segmental precast concrete piers and found that the piers can withstand large lateral drift angles (approximately 4%) with minimum damage in the form of spalling. The piers also resulted in minimum residual displacements.

Two columns having different plastic hinge detailing and made of ultra-high performance steel fiber concrete (UFC) were investigated by Ichikawa et al. (2015) using lateral loading. One column consisted of post-tensioned UFC hollow-core plastic hinge, namely PC-UFC, and the other column had RC core encased in UFC jacket, namely RC-UFC. For the PC-UFC, very few concrete spalling was observed. But for the RC-UFC, extensive concrete spalling was evident at similar drifts.

7 CONCLUSIONS

Previous researches carried out on segmental self-centering piers using ultra-high performance concrete as the construction material have been summarized in this review paper. Since many existing bridges have reached the end of their service life, they need to be repaired, retrofitted or demolished so that new bridges can be built in their places. In this modern era of civilization, it is not possible to close down roads for a long time, and accelerated bridge construction is a necessity. Segmental prefabricated unbounded post-tensioned bridge is a solution to this problem which not only ensures acceleration and quality control of the work but is also able to perform really well in seismic areas as it can withstand large lateral drift angles with minimum damage and residual displacements.

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