Application of Methacrylate Polymers for Seismic ABC Connections

Quarterly Progress Report
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Submitted by:
PI- Mohamed Moustafa
Graduate Student- Mohamed Abokifa

Department of Civil and Environmental Engineering
University of Nevada, Reno

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ABC-UTC

Florida International University

Miami, FL

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1. PROJECT ABSTRACT

Previous research has demonstrated the validity and effectiveness of grouted ducts filled with advanced materials such as UHPC for seismic ABC column-to-footing and column-to-cap beam connections. Accordingly, State DOTs such as Caltrans considered this connection type in ABC pilot project in high seismic areas in California. This connection type was first demonstrated using robust proprietary UHPC mixes. Nonetheless, in an ongoing Caltrans project, UNR has developed non-proprietary UHPC mix for this specific connection type. Non-proprietary UHPC has also been demonstrated feasible and effective for this connection. However, recent concerns about domestic steel fibers availability and UHPC compliance with the Buy America act are motivating the need to find and validate the use of alternative materials that provide superior bond and anchorage behavior without relying on steel fibers. Polymer-based materials can provide a good candidate for this application, but more research is needed to identify best polymer-based materials and demonstrate its validity using large-scale testing. The aforementioned knowledge gap is the reason for undertaking this project.

2. RESEARCH PLAN

2.1. STATEMENT OF PROBLEM

As previously mentioned, several research projects have been conducted to study the seismic behavior of grouted duct connections with UHPC (e.g. Tazarv and Saiidi 2015; 2016). Figure 1 illustrated the precast column to footing grouted duct connection. More recently, PI Moustafa worked with a team at UNR on a Caltrans project to develop and use non-proprietary UHPC with domestic and local California materials for the same connection. The recent tests at UNR confirm that only good anchorage behavior is needed for the filler material where a 15-ksi non-proprietary UHPC was demonstrated to provide comparable behavior as the 28-ksi UHPC. Thus, using polymer-based materials with relatively lower compression strength as compared to UHPC but superior bond behavior can make a good candidate for the referenced connection type and is the focus of this proposed study.

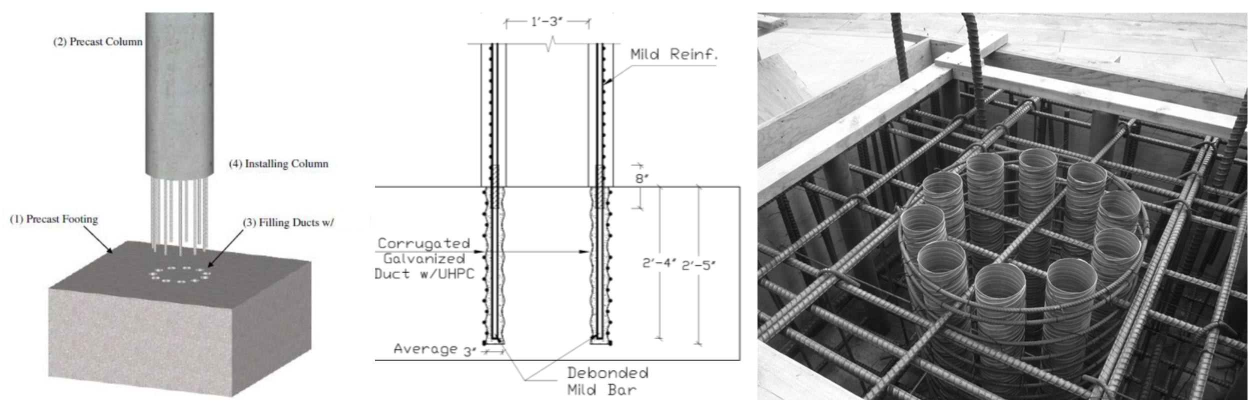

Fig. 1 – Typical grouted duct base connection and view of ducts and footing detail before concrete casting and column plunging (adopted from Tazarv and Saiidi 2015)

One potential material that could be good candidate for such connections is the methacrylate family of polymers, which is also used for polymer concretes. Polymer concrete (PC) has been recently used for full-depth deck panel connections and demonstrated to have comparable results to UHPC (Abokifa and Moustafa 2020). PC has also been considered by others for bridge applications (e.g.

Mantawy et al. 2019; Whitney and Fowler 2015). Thus, methacrylate polymers and methacrylate polymer concrete are tentatively proposed to use for this study.

2.2. RESEARCH APPROACH AND OBJECTIVES

Our approach for this proposed study is mainly an experimental approach with the main activity is large-scale structural test at UNR Earthquake Engineering Laboratory. The specific research objective of this study is to identify and select a polymer-based material with superior anchorage and bond behavior to apply and demonstrate using large-scale testing for seismic ABC connections. This project will leverage a recently completed Caltrans project. The results from this study will be compared to results from the Caltrans tests that used non-proprietary UHPC for seismic grouted ducts connections. A summary of the proposed tasks and brief description of each task is provided next.

2.2.1. SUMMARY OF PROJECT ACTIVITIES

An experimental approach will be used and several research activities will be executed to accomplish the objective of this study. A summary of the proposed research tasks is as follows:

- Task 1 – Conduct literature search on polymer-based materials (e.g. methacrylate and polymer concrete) for bridge applications
- Task 2 – Development of experimental program and specimen design
- Task 3 – Experimental testing of column with polymer seismic grouted duct connection
- Task 4 – Summarize the results in a final report

2.2.2. DETAILED WORK PLAN

A detailed description of the proposed research tasks is presented in this section.

Task 1 – Conduct literature search on polymer-based materials for bridge applications

A detailed literature search was conducted to determine possible and potential alternatives of polymer-based materials and identify best material for the proposed application. This task focused on materials that have been already used by different State DOTs and currently specified such as the Methacrylate polymers, which is specified by Caltrans and has been used for various applications such as overlays. The literature search was divided into two main sections. First, searching for a proper alternative material for ABC column seismic connections. Second, reviewing the previous experimental studies that focused in the experimental testing of ABC column seismic connections.

- *Alternative Materials for Use in ABC Seismic Column Connections*

The main aim of this section was to select an alternative material to be used in the ABC seismic column connections. The literature search concluded that many advanced materials have been tested inside the ABC seismic column connections. Examples of these material included advanced grouts, UHPC, and non-proprietary UHPC. However, none of the previous research efforts focused on trying the polymer based materials for such connections. PC in general has a high bond strength, high early strength, high shear strength, adequate flowability, and high freeze and thaw resistance (ACI 548.1R, 2009; Ribeiro et al., 2003). Moreover, PC is corrosion resistant, fast curing, has very low permeability and superior cracking resistance (ACI 548.1R, 2009; Ribeiro et al., 2002; Reis and Ferreira, 2003). The superior properties of PC make it a popular material for use in bridge deck overlays (Whitney and Fowler, 2015) and make it a very attractive material for use in structural engineering applications and in many industries (ACI 548.1R, 2009; Fowler and Paul, 1978; Fontana et al., 1978; Kukacka and Fontana, 1977; Fowler et al., 1983). Among the different types of PC, the Poly-Methyl Methacrylate (PMMA) PC has been selected as a potential alternative for testing inside such connections due to its high bond properties. The minimum development length required for the steel rebars embedded in PMMA-PC is almost one-half that of the UHPC and ranges between 3.6 and 4.1 times the reinforcing bar diameter (d_b) (Mantawy et al., 2019). One other advantage for the PMMA-PC that it has a high early strength as it can cure to full-hardness in about 24 hours which can accelerate the bridge superstructure erection almost one or two days after placing the precast columns. Table 1 shows some of the mechanical properties of the PMMA-PC that was proposed for use in this study.

Table 1 – mechanical properties of "T-17" polymer concrete.

T-17 Mortar (No Extension)		
Compressive Strength	8000 – 9000 psi (55 – 62 MPa)	ASTM C579 Method B
Flexural Strength	1800 – 2500 psi (13-17 MPa)	ASTM D790
Linear Shrinkage	<0.2%	DuPont
Tensile Strength	1000 – 1200 psi (6.90-8.25 MPa)	ASTM D638 Type I
Compressive Modulus	1.1-1.2 x 10^6 (7.50-8.50 GPa)	ASTM C579 Method B
Tensile Adhesion (pull-off concrete)	>250 psi (>1.7 MPa)	ACI 503R

- *Literature Work Focused on Experimental Testing of ABC Column Seismic Connections*

As mentioned earlier, the current experimental work will leverage a recently completed Caltrans project done by Aboukifa et al. The results from this study will be compared to results from the Caltrans tests that used non-proprietary UHPC for seismic grouted ducts connections. Furthermore, one other study that was done by Tazarv and Saiidi will be taken as reference for further comparison with our test results. Tazarv and Saiidi tested UHPC for the seismic grouted ducts connections. Table 2 shows the structural details and test parameters of the specimens that were tested in the previous two studies.

Table 2 – Structural details and test parameters of previous test specimens in literature.

Test		Previous Research at UNR		Present study	
Column model		CIP	PNC	S1-Bond	S2-Debond
Researchers		Haber et al. 2014	Tazarv & Saiidi 2015	Aboukifa et al. 2019	
Column-footing connection		Monolithic connection	Proprietary UHPC filled ducts	Non-Proprietary UHPC filled ducts	
Debonding		Doesn't exist	Exist	Doesn't exist	Exist
Column Dimensions	Diameter [in.]	24	24	20	20
	Height [in.]	108	108	87	87
	Aspect ratio	4.5	4.5	4.35	4.35
	Clear Cover [in.]	1.75	1.5	1	1
	Anchorage Length [in.]	N/A	28	28	28
Reinforcement	Longitudinal	11-#8	11-#8	8-#8	8-#8
	Ratio ρ_l (%)	1.92	1.92	2.01	2.01
	Transverse	#3 @2in.	#3 @2in.	#3 @2.5in.	#3 @2.5in.
	Ratio ρ_v (%)	1.03	1.03	0.998	0.998
Design Axial Load	Load (kips)	226	200	157	157
	Ratio	10	10	10	10

Task 2 – Development of experimental program and specimen design/construction

The objective of this task was to finalize the design of the test specimen that will be used to explore the validity of polymer-based materials for ABC seismic connection, i.e. column-to-footing grouted duct connection. As mentioned before, this project will leverage a recently completed Caltrans project for developing and testing non-proprietary UHPC for grouted duct connections. Thus, exact specimen design that represent a 1/3-scale bridge column will be used for comparison purposes. Table 3 and Figure 2 show the design details of the specimen that will be tested in our study. It is worth noting that the construction of the specimen was suspended for the almost five months because of the Covid-19 pandemic and the associated campus closure. Figures 3 and 4 shows the construction process of the test specimen at UNR.

Table 3 – Design details of the test specimen.

	Longitudinal Reinforcement			Transverse Reinforcement		
Specimen	% of Ag	RFT.	Grade	% of Ag	RFT.	Grade
S1	2.01%	8 # 8	Gr 60	0.998%	# 3@ 2.5 in spirals	Gr 60

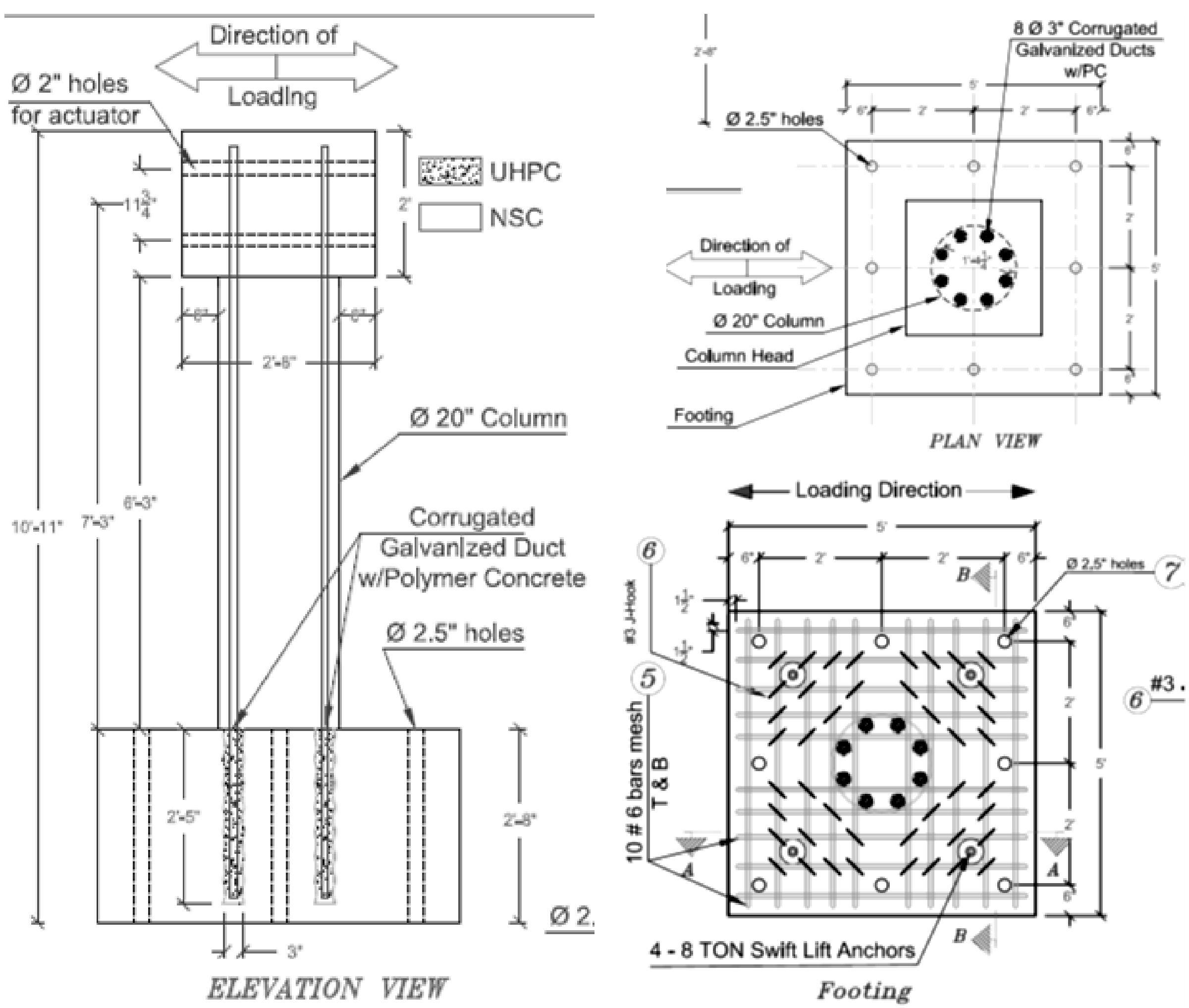

Fig. 2 – Overall dimensions and structural details of the test specimen.

Fig. 3 – Form work of the footing of the test specimens.

Fig. 4 – Construction process of the test specimen at UNR.

Task 3 – Conduct experimental testing of column with methacrylate or polymer concrete

As previously mentioned, a similar test setup and specimen as previous project will be used for testing the validity of polymer-based materials in seismic ABC connections. The specimen and ABC connection with polymer-based material used in precast column-to-footing connection will be tested under combined axial load (8% axial load index) and cyclic lateral loading up to 10% drift ratios. The test setup and specimen dimensions are illustrated in Figure 5. The objective of the test is to test the column until failure to verify whether a full plastic hinge will be developed in the column outside the ABC connection. In other words, it is desired to verify experimentally that the new polymer-based material that will be used in this study can provide sufficient anchorage for the column reinforcement so that no bars will slip or have anchorage failure while the column develop the full plastic hinge. Figure 6 shows picture of actual previous column test setup and successful plastic hinging in column outside the ABC connection that was filled using non-proprietary UHPC. The experimental testing of the test specimen will be done at early October, 2020.

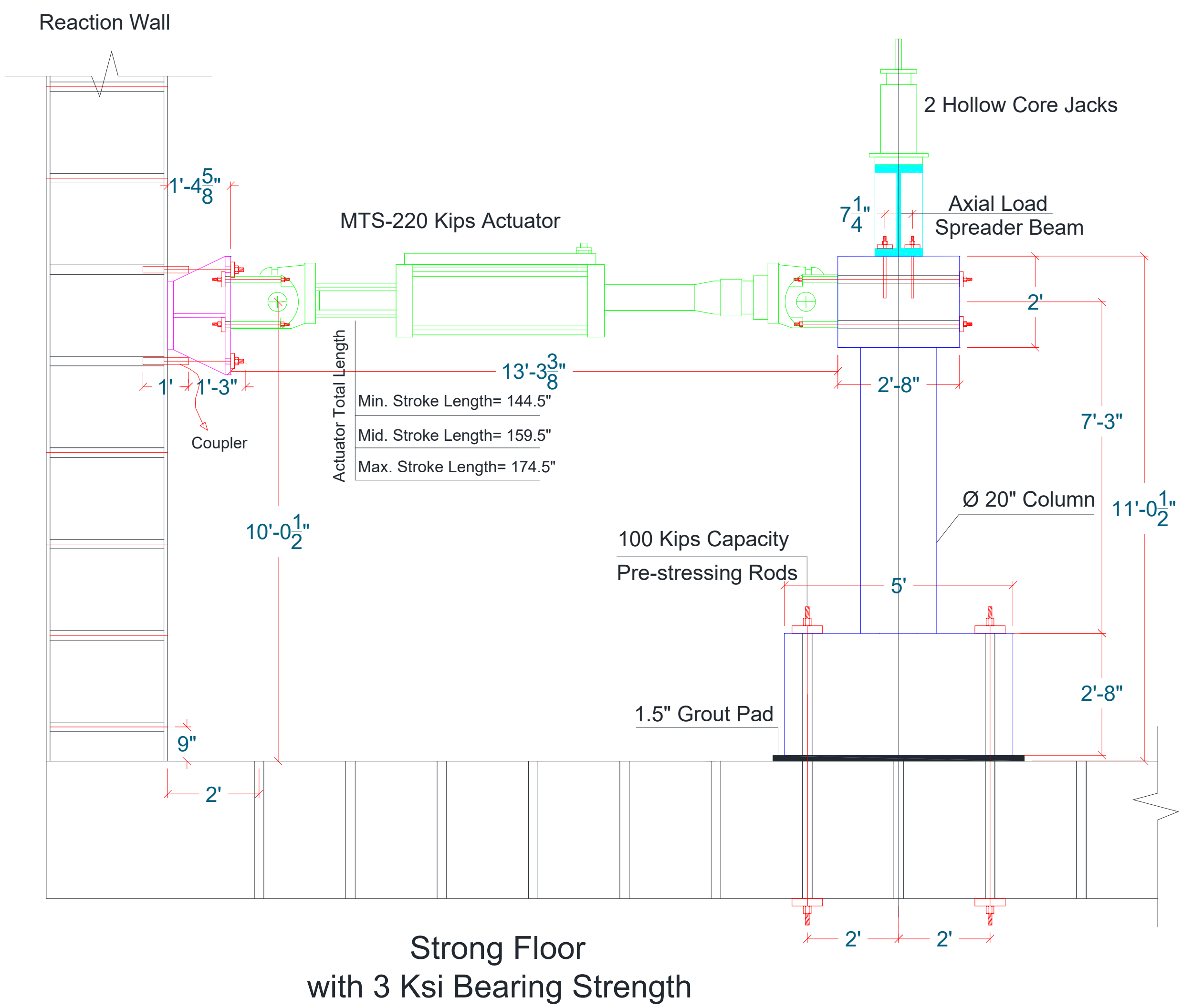

Fig. 5 – Proposed test setup and specimen dimensions

Fig. 6 – Pictures for test setup from previous test and progression of column damage

Task 4 – Summarize the investigation and the results in a draft final report

A final report describing the details of different tasks will be prepared and submitted to the ABC-UTC steering committee for review and comments. Upon addressing the review comments, the report will be finalized and made widely available for dissemination.

2.3. ANTICIPATED RESEARCH RESULTS AND DELIVERABLES

- Final Report and ABC-UTC guide on design of grouted ducts seismic connections using Methacrylate polymers or other polymer-based materials such as polymer concrete
- One comprehensive manuscript that compares the experimental results of two columns with UHPC and methacrylate polymer grouted ducts connections
- Five-minute video summarizing research study and findings

2.4. APPLICABILITY OF RESULTS TO PRACTICE

The results from this project are expected to immediately benefit different states DOTs. Specifically, the results of this project along with the companion Caltrans project on using non-proprietary UHPC will have the potential to be included in Caltrans Bridge Specifications.

3. TIME REQUIREMENTS (GANT CHART)

To allow for the completion of all the project tasks, the study will be conducted over a period of 12 months (4 quarters) following the schedule in Table 4.

Table 4 – Gant schedule of major project tasks

Task	2020											
	1	2	3	4	5	6	7	8	9	10	11	12
1. Literature search on methacryate polymers												
2. Specimens design/construction												
3. Column test/comparison with UHPC tests												
4. Final report & dissemination												

	Completed or work in progress		Remaining

Percent work completed: 45%

Remaining work: 55%