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16. Abstract In the presence of ground water or caving soils, the slurry displacement method may be used to place concrete for CIDH piles to ensure the stability of the drilled hole. As concrete is placed under slurry, anomalies may occur around the reinforcement, affecting the structural integrity of the pile. Hence, the construction of CIDH piles under wet conditions requires the installation of inspection tubes for the non-destructive detection of potential anomalies in concrete. Current Caltrans practice requires that the clear spacing between an inspection tube and an adjacent longitudinal bar be at least three inches, which is less than the 5-in. minimum clear spacing required for rebar cages of piles. Hence, concrete mixtures used for CIDH piles must have good passing ability to avoid anomalies or voids. Caltrans developed a field test method, called the California Bar (C-Bar) test, for assessing the passing ability of concrete used in CIDH piles poured with the slurry displacement method. This study was to examine if results of C-Bar tests could be used to determine whether the concrete mix has sufficient passing ability to result in good quality concrete in CIDH piles. L-Box tests were also conducted for comparison purposes. The passing ability of several concrete mixes was tested with trial batches, and mixes with different levels of passing ability were selected for trial pours of pile specimens. Twelve 24-in. diameter piles were cast with the selected mixes using the slurry displacement method. The quality of the cast concrete piles was inspected visually, and the passing ability of the mixes was assessed with C-Bar and L-Box tests. The study has found that concrete mixes with C-Bar passability ratios of 1.82 or lower resulted in piles that were free of voids on the exterior surface except for some small voids near the base of the piles. However, the concrete mix that had a passability ratio of 1.82 barely flowed beyond the rebars in the C-bar test. The results have shown that 1.80 is a reasonable upper limit for the passability ratio. Furthermore, the concrete should have a minimum slump of 10 inches. None of the concrete mixes used for the pile specimens passed the L-Box tests. Hence, this is not a good test for the passing ability.		13. Type of Report and Period Covered  Final Report	
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**Characterization of Passing Ability  
of Concrete in CIDH Piles with Wet Conditions**

by

**Jeffery Sun  
P. Benson Shing**

Report Submitted to the California Department of Transportation under  
Contract No. 65A0369

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Department of Structural Engineering  
University of California, San Diego  
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## Abstract

In the presence of ground water or caving soils, the slurry displacement method may be used to place concrete for CIDH piles to ensure the stability of the drilled hole. As concrete is placed under slurry, anomalies may occur around the reinforcement, affecting the structural integrity of the pile. Hence, the construction of CIDH piles under wet conditions requires the installation of inspection tubes for the non-destructive detection of potential anomalies in concrete. Current Caltrans practice requires that the clear spacing between an inspection tube and an adjacent longitudinal bar be at least three inches, which is less than the 5-in. minimum clear spacing required for rebar cages of piles. Hence, concrete mixtures used for CIDH piles must have good passing ability to avoid anomalies or voids. Caltrans developed a field test method, called the California Bar (C-Bar) test, for assessing the passing ability of concrete used in CIDH piles poured with the slurry displacement method. This study was to examine if results of C-Bar tests could be used to determine whether the concrete mix has sufficient passing ability to result in good quality concrete in CIDH piles. L-Box tests were also conducted for comparison purposes. The passing ability of several concrete mixes was tested with trial batches, and mixes with different levels of passing ability were selected for trial pours of pile specimens. Twelve 24-in. diameter piles were cast with the selected mixes using the slurry displacement method. The quality of the cast concrete piles was inspected visually, and the passing ability of the mixes was assessed with C-Bar and L-Box tests. The study has found that concrete mixes with C-Bar passability ratios of 1.82 or lower resulted in piles that were free of voids on the exterior surface except for some small voids near the base of the piles. However, the concrete mix that had a passability ratio of 1.82 barely flowed beyond the rebars in the C-bar test. The results have shown that 1.80 is a reasonable upper limit for the passability ratio. Furthermore, the concrete should have a minimum slump of 10 inches. None of the concrete mixes used for the pile specimens passed the L-Box tests. Hence, this is not a good test for the passing ability.



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# **1. Introduction**

## **1.1 Background**

In the presence of ground water or caving soils, the slurry displacement method may be used to place concrete for CIDH piles to ensure the stability of the drilled hole. As concrete is placed under slurry, anomalies may occur around the reinforcement, affecting the structural integrity of the pile. Hence, the construction of CIDH piles under wet conditions requires the installation of inspection (PVC) tubes for the non-destructive detection of potential anomalies in concrete. Normally, one 2-in.-diameter inspection tube is required per one foot of pile diameter. Inspection tubes are placed between the longitudinal bars in the reinforcement cage of the pile. Current Caltrans practice is to have the clear spacing between a tube and an adjacent rebar be at least 3 in., which is less than the 5-in. minimum clear spacing required for rebar cages of piles (Caltrans 2003). Hence, concrete mixtures placed in CIDH piles with the slurry displacement method must have good workability to avoid anomalies or voids.

The workability of a concrete mixture includes its flowability, stability, and passing ability. Caltrans developed a field test method, called the California Bar (C-Bar) test, for assessing the passing ability of concrete mixes to be placed in CIDH piles using the slurry displacement method and for screening out unsuitable concrete batches (Caltrans 2009). The apparatus for this test, as shown in Figure 1.1, resembles the arrangement of longitudinal reinforcement in a CIDH pile, including the inspection tubes used for post installation testing. A primary benefit of the test is that it allows for easy and direct assessment of the concrete's passing ability. In the C-Bar test, the passing ability ratio of the concrete mix is determined and compared to the set criteria. The C-Bar test could be a better measure of the passing ability of concrete than the slump tests. However, the sensitivity of the method has not been validated.



Figure 1.1 – C-Bar Test

The study documented in this report was the second phase of a two-phase research aimed to develop guidelines that will ensure the good workability of concrete used for CIDH piles. The Phase-1 study was carried out at Oregon State University (Trejo and Hendrix 2014) to assess the influence of different constituent materials (e.g., aggregate type or aggregate size) and mix proportions on the flowability and passing ability of concrete mixtures, and to assess the adequacy of different test procedures for quantifying the passing ability. The Phase-2 study reported here was to investigate the reliability of the C-Bar test method, and in particular, to examine if results of C-Bar tests could be used to determine whether the concrete mix has sufficient passing ability to result in good quality concrete in CIDH piles constructed with the slurry displacement method.

## **1.2 Scope of this Study and Organization of the Report**

Based on the Phase-1 study (Trejo and Hendrix 2014), the Oregon State University research team proposed six concrete mix designs (as shown in Table A.1 in Appendix A) for possible investigation in Phase 2. In this study, four of these six mix designs were selected for investigation. Some of the mixes were expected to have low passing ability, while the others had adequate passing ability. The mixtures were prepared in trial batches with varying dosages of chemical admixtures in the Structural Components Laboratory of the Powell Structural Engineering Laboratories at UC San Diego, and tested using the slump, L-Box, and C-



Bar test methods.

After the trial batch tests, twelve 2-ft.-diameter pile specimens were cast in the laboratory using the slurry displacement method to investigate the correlation between results of the C-Bar and L-Box tests and the quality of concrete placement. Ten of the pile specimens had three of the concrete mixes used in the trial batches. Each mix was selected from the trial batches based on having either unacceptable, questionable, or passable performance according to the C-Bar test criteria (Caltrans 2009). Two additional pile specimens were cast using a mix design used by Caltrans for a project with CIDH piles poured under slurry. All twelve specimens had the same amount of reinforcement but varied in the spacing of the longitudinal bars. Each specimen had four 2-in. PVC inspection tubes, while only two were actually required for a 2-ft.-diameter pile (Caltrans 2015). The piles were cast above ground using form tubes, which were removed after construction allowing the quality of the concrete to be examined.

Chapter 2 of this report describes the experimental program, including the results of the concrete trial batch tests, and the design and construction of the pile specimens. Chapter 3 describes the observations pertaining to the quality of concrete placement for the pile specimens. The summary and conclusions of the study are presented in Chapter 4.



## **2. Test program**

The workability of four mix designs proposed by Oregon State University (OSU) was evaluated with trial batches. In this process, right amounts of admixtures required to attain the target performance were determined. Three of the mixes were expected to be workable and one was expected to have low flowability according to the study of Terejo and Hendrix (2014). The quality of the mixes was judged by visual inspection to see if any segregation or bleeding. The passing ability of the concrete mixes was evaluated with C-Bar and L-Box tests. Based on the test results, three of the mixes were selected for trial pours of pile specimens. A total of twelve pile specimens were cast using the slurry displacement method. Ten of them were cast with three of the mixes evaluated in the trial batches. Each of these mixes displayed either low, marginal, or high passing ability. In addition, two of the pile specimens had a mix design that is commonly used by Caltrans for CIDH pile applications.

The pile specimens were intended to investigate the ability of the C-Bar and L-Box tests to determine the suitability of a concrete mixture for CIDH piles cast with the slurry displacement method, and in particular, the correlation between the passing ability measured and the quality of concrete placement. Results and observations from the pile specimens are presented in Chapter 3.

### **2.1 Trial Batches**

The four mix designs used for the trial batches and their anticipated performance are shown in Table 2.1. Aggregate weights shown in Table 2.1 are based on the saturated-surface-dry (SSD) condition. The concrete was machine mixed in accordance with the ASTM C192-14 standard for making concrete in a laboratory setting. Each of the mixtures had a water-to-cementitious material ratio (w/c) of 0.39 and a maximum aggregate (MSA) size of 3/8 in. The cement paste volume of the mixes varied from 35 to 41 percent. The moisture content of the aggregate was corrected to achieve the target w/c ratio. In addition, different dosages of a polycarboxylate-based (PCB) high range water reducing (HRWR) chemical admixture and set retarding admixture were used in each trial batch to reach a target level of concrete flowability. The admixture

dosages were initially selected based on the manufacture’s recommendations and then modified based on trial and error. The amounts of the admixtures used for different batches are shown in Table 2.2. Once concrete was mixed, a slump test was performed, and the C-Bar and L-Box tests were each conducted three times and the results were averaged.

Table 2.1 – Trial batch mix proportions provided by Oregon State University

	Mix 2	Mix 3	Mix 4	Mix 5
Anticipated Performance	Workable	Workable	Low Flowability	Workable
Water (lbs/cy)	325.6	354.7	300.1	327.4
Fly Ash Class F (lbs/cy)	231.1	251.7	213	232.3
Cement (lbs/cy)	593.4	646.4	547	596.7
Coarse Aggregate (lbs/cy)	1148	1089	1323	1256
Fine Aggregate (lbs/cy)	1608	1525	1587	1507
FA/CA	1.4	1.4	1.2	1.2
% Paste Volume	38	41	35	38

The passing criteria used for the C-Bar tests were developed by Caltrans (Caltrans 2009). They are shown in Table 2.3. A schematic of the plan view of the C-Bar test apparatus is shown in Figure 2.1. To pass the C-Bar test, the concrete must first flow at least 9 inches from the center of the concrete patty in each direction along the two axes. The C-Bar passability ratio of the concrete is the ratio of the effective flow of concrete in the X-direction to the effective flow in the Y-direction. The effective flow is the length of the concrete patty along one axis minus the outer diameter of the C-bar assembly, which was 14 in. The mixture passes the test if the passability ratio is less than 1.67, the passing ability is questionable if the ratio is between 1.67 and 2.0, and it is unacceptable if the ratio is greater than 2.0.

Table 2.2 – Trial batch C-Bar and L-Box test data

Proposed OSU Mix	Anticipated Performance	Trial Batch Date	C-Bar Passability Ratio	L-Box Passing Ability Ratio	Slump Value (in)	Type-F HRWR admixture dosage (oz/cwt): BASF, MasterGlenium 7500	Type-D water reducing and retarding admixture dosage (oz/cwt): BASF, MasterSet Delvo	Type-F HRWR admixture dosage (oz/cwt): WR Grace, ADVA 190	Type-D water reducing and retarding admixture dosage (oz/cwt): WR Grace, Recover
3	Workable	6/4/2015	1.48	0.83	10.5	8	4		
2	Workable	5/14/2015	2.1	0	10	5	4		
2	Workable	5/19/2015	1.59	0.64	10.5	8	4		
2	Workable	5/28/2015	1.91	0.31	9.75	8	4		
2	Workable	12/17/2015	1.42	0.4	10.25			4.5	3
4	Low Flowability	10/20/2015	1.69	0.53	10.5			8	1
4	Low Flowability	10/23/2015	2.16	0	9			7.5	1
4	Low Flowability	11/4/2015	1.81	0	8.5			9.5	1
5	Workable	7/17/2015	1.79	0	9.75	8	4		
5	Workable	7/21/2015	1.56	0.39	10.25	8	4		
5	Workable	7/23/2015	1.56	0.85	10.5	8	4		

Table 2.3 – Passability criteria for the C-Bar test

Passability Ratio (p)	Passability
Less than 1.67	Passable (Unrestricted Flow)
1.67 - 2.0	Questionable (Partial Restriction)
Greater than 2.0	Unacceptable (Restricted Flow)

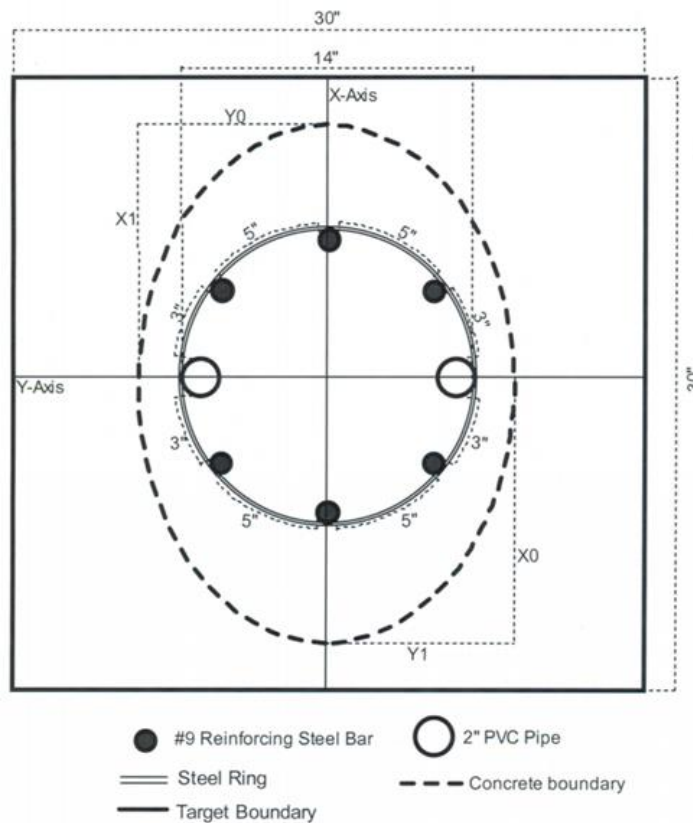


Figure 2.1 – C-Bar Assembly Plan View (from Caltrans draft document)

In the L-Box test, the mean depth of concrete is measured at both the beginning and the end of the box. The passing ability ratio is the ratio of the depth of the concrete at the end of the box to the depth at the beginning of the box. To pass the L-Box test, the passing ability ratio must be at least 0.8 (University of Paisley 2005).

Table 2.2 shows the average C-Bar and L-Box test results for concrete mixes that were able to satisfy the minimum passing criteria required by the C-Bar test, along with the slump values. Pictures of the C-Bar and L-Box tests on select batches of Mixes 4, 5, and 2 are shown in Figure 2.2 through Figure 2.4, respectively. Except for two cases, data for trial batches that did not meet the minimum C-Bar flow requirements (a passability ratio of 2.0 and a minimum flow of 9 in.) are not provided in this report since their corresponding L-Box tests had passing ability ratios way below the acceptable value. Trial batches that were able to pass the L-Box test also passed the C-Bar test but not vice versa. The variation of the test results for each mix design was caused by changes in the water reducing admixture dosage, which is shown in Table 2.2. However, there is a lack of consistent correlation between the C-Bar and L-Box test results. In general, mixes with slump values of 10.25 in. or greater passed the C-Bar test.



Figure 2.2 – C-Bar and L-Box tests for Mix 4, Trial Batch on 10/23/15



Figure 2.3 – C-Bar and L-Box tests for Mix 5, Trial Batch on 7/17/15



Figure 2.4 – C-Bar and L-Box tests for Mix 2, Trial Batch on 12/17/15

Mix 2 (trial batch on 12/17/15), Mix 4 (trial batch on 10/23/15), and Mix 5 (trial batch on 7/17/15) were selected as starting points for the pile specimens. They were selected to provide a range of passing ability properties varying from low to marginal to high based on the C-Bar test results. Mix 4 had low passing ability, Mix 5 had marginal passing ability, and Mix 2 had high flowability, as shown in Table 2.2 and in Figures 2.2 through 2.4, respectively. However, the actual amounts of admixtures added were varied because the volume and the source of the concrete mixes used for the piles differed from the trial batches.



## 2.2 Pile Specimens

The pile specimens were not tested under any form of loading as the quality of concrete placement is more a durability issue than an immediate load resistance issue. The influence of the spacing of longitudinal reinforcement in a pile on the structural performance was studied in a separate task of this project as reported in Papadopoulos and Shing (2014, 2015). The height of each pile studied here was 6 ft. and the diameter was 24 in. The design and reinforcement details of the specimens are summarized in Table 2.4 and shown in Figure 2.5 through Figure 2.9. The steel cages of the pile specimens before casting are shown in Figure 2.10.

Table 2.4 – Reinforcement details of specimens

	Shaft Diameter (in.)	Diameter of Confined Core* (in.)	Long. Bars	Angular Spacing of Long. Bars (deg.)	Clear spacing between Long. Bars (in.)	Inspection Pipes	Clear spacing between inspection pipe and Long. Bars (in.)
Rebar Configuration 1	24	20	6 #8	60	8.25	4	3, 2.5, 3.375
Rebar Configuration 2	24	18	6 #8	61, 36	8.375, 5	4	3

\*Out-to-out diameter of hoops

The twelve pile specimens had two different reinforcing bar configurations. The first eight specimens were cast with “Rebar Configuration 1” and the last four specimens were cast with “Rebar Configuration 2”. Rebar Configuration 1 had a concrete cover of 2 in. and Rebar Configuration 2 had a concrete cover of 3 in. Both configurations consisted of 6 #8 bars for the longitudinal reinforcement and a #5 spiral with a spacing of 5.625 in. on center for the transverse reinforcement. A primary difference between the two configurations is the spacing between the longitudinal bars. In Rebar Configuration 1, the longitudinal bars had an even clear spacing of 8.25 in., whereas in Rebar Configuration 2, the longitudinal bars had a varied clear spacing of 8.375 in. and 5 in., as shown in Figures 2.6 and 2.7. The minimum clear spacing permitted by Caltrans for shaft reinforcement is 5 in. (Caltrans 2003). Furthermore, in Rebar Configuration 1, the smallest clear spacing between a longitudinal bar and an inspection tubes was 2.5 in., which violated the

minimum clear spacing of 3 in. permitted by Caltrans specifications (Caltrans 2015), while the minimum clear spacing in Rebar Configuration 2 is 3 in.

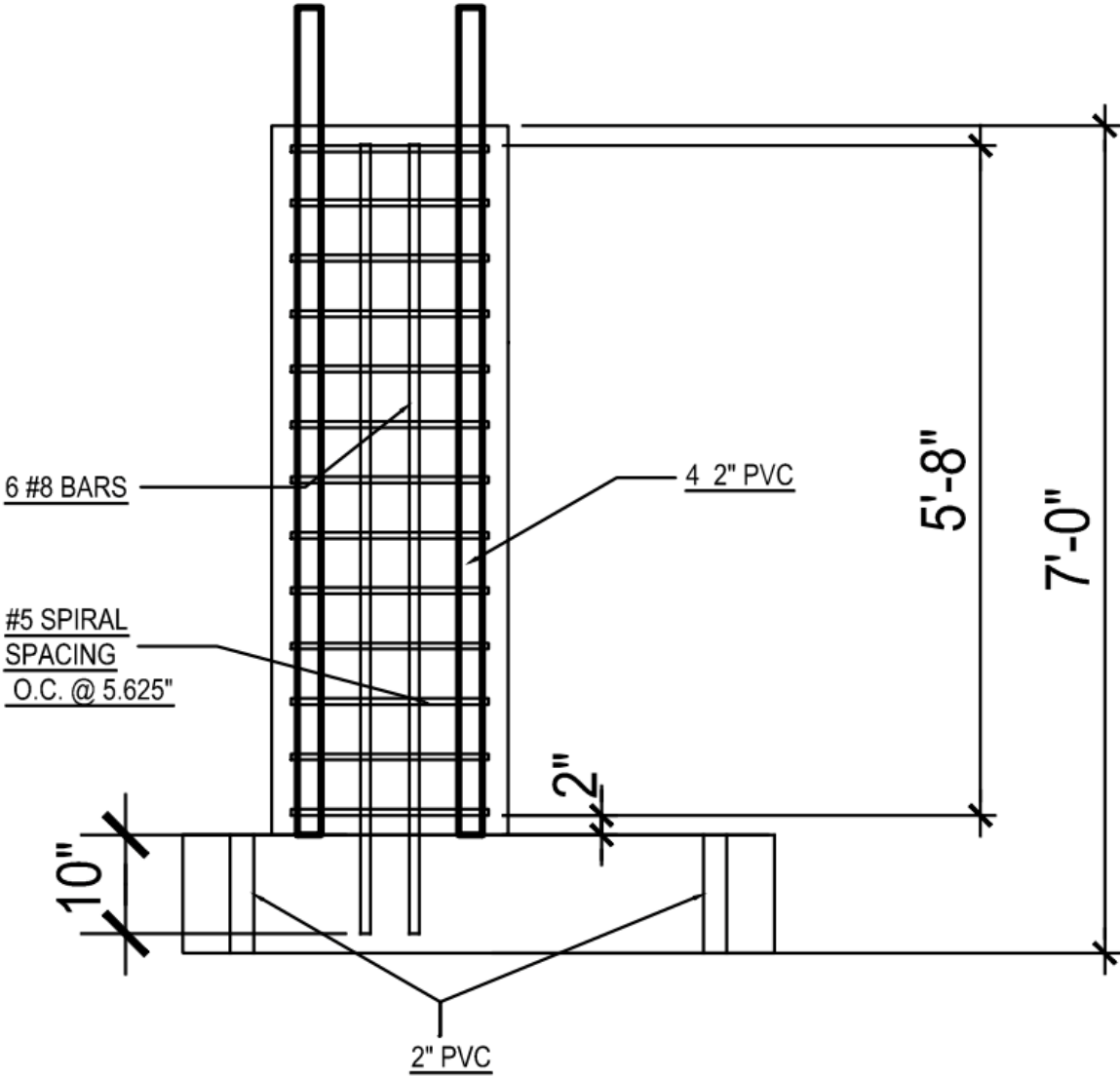


Figure 2.5 – Elevation view of a pile specimen

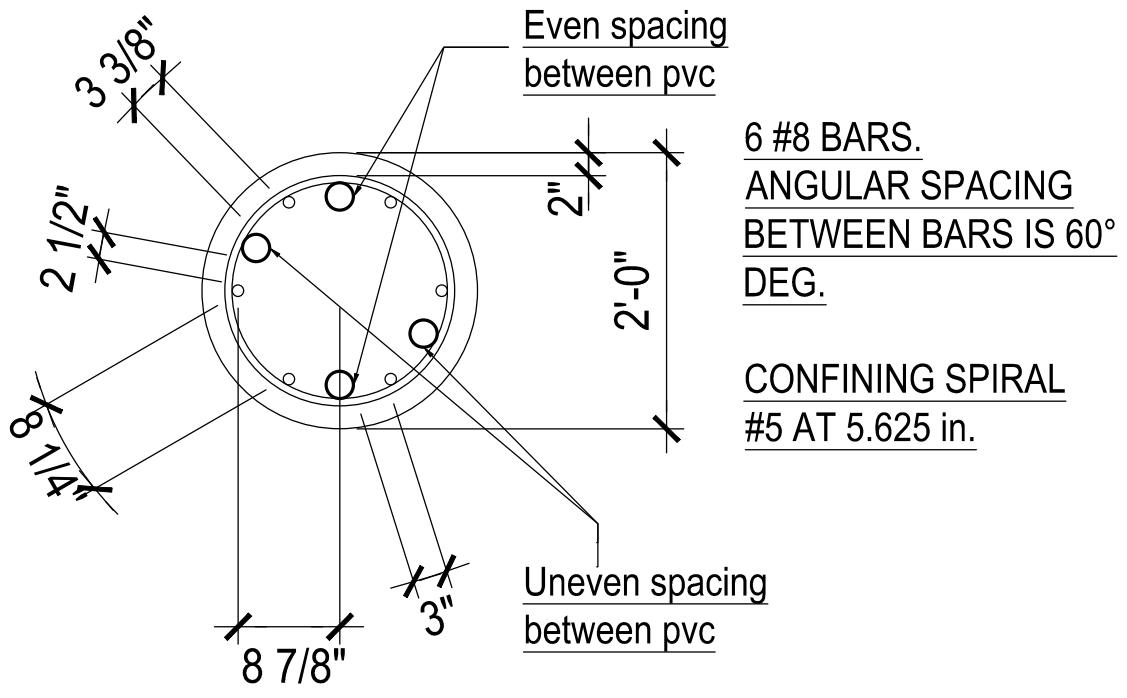


Figure 2.6 – Cross-sectional view of Specimens #1 through #8 showing rebar and inspection tube spacing (Rebar Configuration 1)

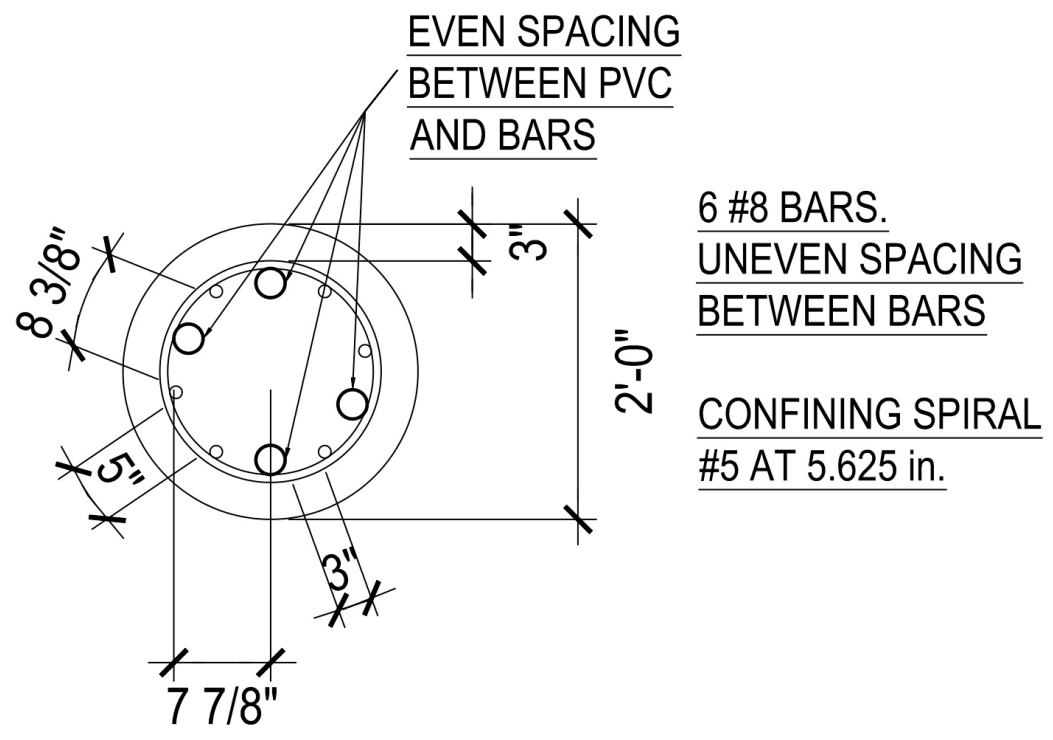


Figure 2.7 – Cross-sectional view of Specimens #9 through #12 showing rebar and inspection tube spacing (Rebar Configuration 2)

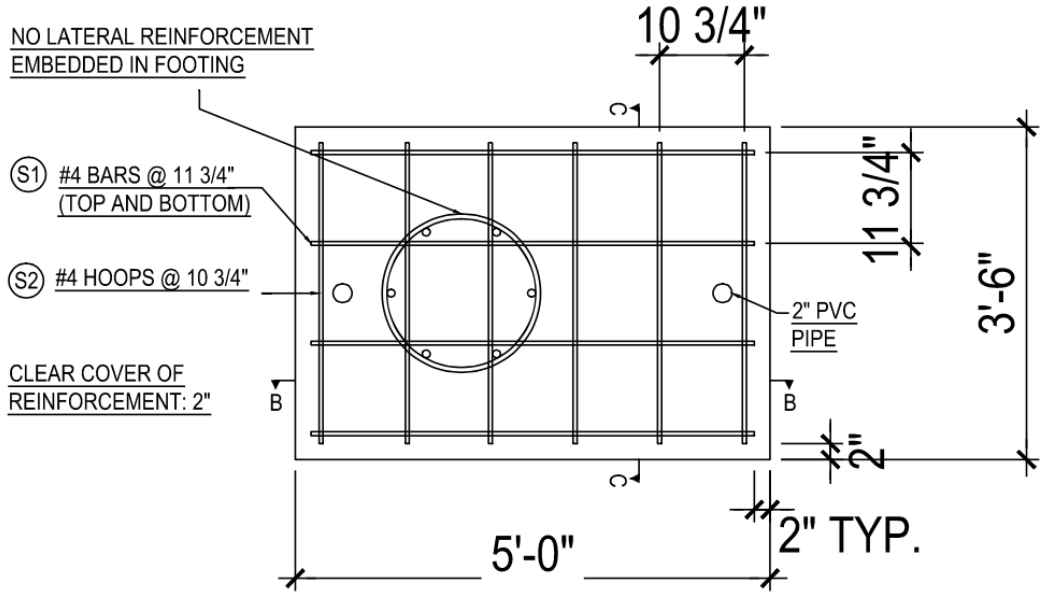


Figure 2.8 – Plan view of footing details

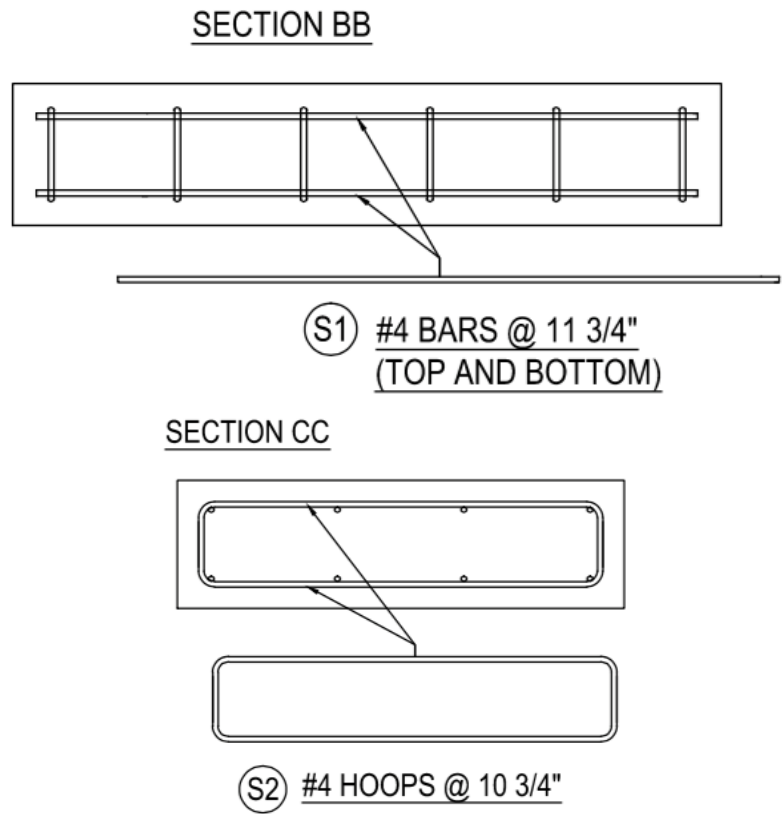


Figure 2.9 – Elevation view of footing details (see Figure 2.8 for section locations)



Figure 2.10 – Casting the footings

Each specimen had four 2-in.-nominal diameter PVC inspection tubes placed parallel to the longitudinal reinforcement. Caltrans requires that one inspection tube be placed for every one foot of pile diameter; however, two additional inspection tubes were added to each specimen in order to have a number of different clear spacings between a tube and a rebar. As shown in Figure 2.6, Rebar Configuration 1 had two tubes placed evenly between the longitudinal bars at a 3-in. clear spacing, and two tubes placed unevenly between the longitudinal bars resulting in a minimum clear spacing of 2.5 inches to provide a more severe condition. The 2.5-in. spacing introduced here was to mimic a construction error. In Rebar Configuration 2, all four inspection tubes were placed with an even clear spacing of 3 in. between the longitudinal bars, as shown in Figure 2.7.

Table 2.5 summarizes the concrete mix designs and placement methods for the pile specimens. Three of the mixes (Mixes 2, 4, and 5) were proposed by Oregon State University and one was a mix commonly used by Caltrans for CIDH piles poured with the slurry displacement method. Based on the trial batches, Mix 4 was expected to have low passing ability, Mix 5 had marginal passing ability, and Mix 2 had high flowability. However, except for the Mix 4 used in Specimens 1 and 2, the amounts of admixtures added differed from those for the trial batches in order to attain these properties, because the concrete was provided

by a commercial supplier in much larger volumes. Tables A.1 and A.2 in Appendix A provide the details for the mix designs. After completing the first eight specimens, Mixes 2 and 4 were used again for Specimens #9 through #12. An increased admixture dosage was used in the Mix 4 for Specimens #11 and #12.

Table 2.5 – Summary of pile specimen pours

Proposed Mix (Pile specimen #'s)	Mix 4 (1 & 2)	Mix 5 (3 & 4)	Mix 2 (5 & 6)	Caltrans Mix (7 & 8)	Mix 2 (9 & 10)	Mix 4 (11 & 12)
Date Poured	12/8/15	12/18/15	1/15/16	3/16/16	4/11/16	4/28/16
Type-F HRWR admixture dosage (oz/cwt): WR Grace, ADVA 190	7.5	5	7.5	13	7.5	10, 11**
Type-D water reducing and retarding admixture dosage (oz/cwt): WR Grace, Recover	1	1	2	14	2	2, 2
Type-A water reducing admixture dosage (oz/cwt): WR Grace, WRDA 64	0	0	0	4	0	0
Air-Entraining admixture dosage (oz/cwt): WR Grace, Daravair 1000	0	0	0	0.14	0	0
Gravity-fed tremie	Yes	Yes	Yes			
Pump-fed tremie				Yes	Yes	Yes
Rebar Configuration	1	1	1	1	2	2
C-Bar Passability Ratio	See note*	See note*	1.48	1.40	1.35	1.82, 1.50
L-Box Passing Ability Ratio	0	0	0.49	0.40	0.59	0, 0.46
Slump Value (in)	8.5	8.75	10	10	10.25	9.75, 10
28-Day Compressive Strength (ksi)	4.72	3.97	6.05	5.11	5.34	5.01, 5.45

\*Concrete did not meet the minimum flow requirements of the C-Bar test

\*\*The HRWR dosage was increased for the second pile specimen poured on 4/28/15

## 2.3 Specimen Construction Procedure

The twelve pile specimens were constructed two at a time by the laboratory staff. A different mix design was used for each pair of pile specimens. As shown in Table 2.5, the variations in the mix designs include the volume of the cement paste and the percentage of the admixtures. First, the reinforcement cages were assembled and the forms for the footing were constructed. The footings were cast first and the piles were cast next on a later day. After the footings were cast, black lines were marked on top of the footings so that the locations of the longitudinal bars and PVC inspection tubes could be identified after the piles had been cast.

The piles were cast above ground in form tubes using the slurry displacement method in accordance with

the Caltrans Standard Specifications, Section 49-3.02C(9) (Caltrans 2015). For many specimens, an approximate 1-in. layer of hydrostone was added at the base of the form tubes and allowed to harden prior to filling the tubes with slurry. The hydrostone was used to help prevent slurry leakage at the base of the form tube. To prepare the slurry, Cetco Shore Pac synthetic slurry mix and soda ash were mixed with water according to the manufacturer's specifications. In each specimen, slurry was added to a height of 5 ft. inside the 6 ft. tall form. Before the concrete pour, the slurry was tested once for its pH value and several times for its Marsh Funnel Viscosity at the midpoint and bottom of the form. The density and sand contents were not taken into account while testing the slurry since no sand or fines were introduced into the form tube. In addition, clean out of the bottom of the form tube was not necessary since there were no debris introduced into the slurry.

Concrete was placed into the form tubes using two different methods. Pictures of the placement processes are in Figures 2.11 and 2.12. The first method, which was used for the first three pours (i.e., the first six pile specimens), had the concrete flow by gravity through a tremie tube, which was a PVC tube of 8-in. nominal diameter. The tremie tube was lowered into the form tube filled with slurry, and the bottom of the tremie tube was plugged with a rubber ball to prevent the slurry from entering the tube. Concrete was poured into the tremie tube from a bucket, as shown in Figure 2.11c, and the concrete pushed out the ball, which floated to the top of the slurry. The concrete bucket was filled with enough concrete to pour one pile specimen continuously before being refilled to pour another pile specimen. The second method, which was used for the last three pours (i.e., the last 6 pile specimens), used a 4-in. diameter steel tremie tube and had a pump truck to expel concrete through the tube, whose bottom end was initially plugged with a foam cylinder, as shown in Figure 2.12. In both methods, the tremie tube was extended to the bottom of the form before charging the tube with concrete. After filling the tube with concrete, the tube was lifted 6-in. to release the plug and induce the flow of concrete. The tube remained embedded in the concrete at this height for the entire pour.

In order to contain the displaced slurry during the pour, an additional form tube of 36-in. diameter was

placed around the form tube for the pile specimen, as shown in Figure 2.11a. The slurry was allowed to flow out of the top of the inner form tube into the outer form tube. The slurry then flowed into a drum underneath the strong floor of the laboratory through a tube that passed through the footing and a tie-down hole in the strong floor.

Prior to concrete placement, C-Bar, L-Box, and slump tests were performed on the concrete mix. Six-inch-diameter concrete cylinders were prepared for compression tests. Compression tests were performed on the concrete cylinders after 28 days of curing, and the results are shown in Table 2.5. The forms for the piles were removed a few days after the casting of the specimens to allow inspection.



(a)



(b)



(c)



(d)





(e)



(f)



(g)

Figure 2.11 – Concrete placement using gravity-fed tremie: (a) form tube for pile and outer form tube for catching slurry, (b) slurry inside form tube, (c) tremie tube system, (d) concrete poured through tremie tube, (e) slurry level rising, (f) slurry flowing over form, and (g) removal of the tremie tube



Figure 2.12 – Concrete placement using pump-fed tremie



### **3. Results and Observations from Pile Specimens**

This chapter presents the results and observations from the 12 pile specimens. Specimens #1 through #8 were cast with Rebar Configuration 1 and Specimens #9 through #12 were cast with Rebar Configuration 2. For each of these specimens, the mix design, main observations, and the C-Bar, L-Box, and slump test results are presented in Table 2.5.

#### **3.1 Specimens #1 and #2**

Specimens #1 and #2 were cast using the Mix 4 proportions provided by Oregon State University (see Table 2.5). Rebar Configuration 1 (see Figure 2.6) was used and the concrete was placed using a gravity-fed tremie tube. The target C-bar passability ratio was a value above 2, based on the results from the Mix 4 trial batch on 10/23/15 (see Table 2.2). However, upon delivery, the concrete did not possess adequate flowability to give a measurable value for the C-Bar test, i.e., it did not have a flow of at least 9 in. from the center of the concrete patty in each direction along the two axes. As shown in Figure 3.1, the concrete flowed to the edge of the ring, but not passing the vertical bars in the C-Bar test apparatus. Furthermore, the concrete displayed a noticeable difference in height between the center of the patty and at the outer edge. During the L-Box test, the concrete only flowed a few inches into the horizontal section of the box. However, the concrete had a slump value of 8.25 in.

As shown in Figures 3.2 and 3.3, both Specimens #1 and #2 appeared very similar to each other after the removal of the form tubes. The surface of the specimens appeared rough with small bumps. This was possibly caused by not overflowing the concrete at the end of the pile pour, which could have flushed out contaminated concrete at the side. In both specimens, major voids appeared in the bottom two feet or more. Vertically oriented voids, with the appearance of cracks, appeared in front of the PVC inspection tubes and longitudinal bars, whose locations were identified by black lines on top of the footing. The vertical voids were up to 0.5 in. wide at the surface of the piles and are most likely a result of poor concrete flowability.



Figure 3.1 – C-Bar and L-Box Tests on Mix 4 for Pile Specimens #1 and #2



Figure 3.2 – Pile Specimen #1



Figure 3.3 – Pile Specimen #2

Both specimens had a gap between the bottom of the pile and the footing near the pile surface. The width of the gaps varied from 0.25 in. to 2.5 in., with the worst locations exposing reinforcement bars, as shown in Figure 3.4. During the removal of the form tubes, trapped slurry was released from these gaps.



Figure 3.4 – Bottom of Pile Specimen #1 showing exposed reinforcement

### 3.2 Specimens #3 and #4

Specimens #3 and #4 were cast using the Mix 5 proportions (Table 2.5). Rebar Configuration 1 was used and the concrete was placed using a gravity-fed tremie tube. The target C-bar passability ratio for the mix was between 1.67 and 2, based on the results from the Mix 5 trial batch on 7/17/15 (see Table 2.2). However, similar to the concrete mix for Specimens #1 and #2, the concrete did not possess adequate flowability to give a measurable value for the C-Bar test. The concrete was able to flow past the C-Bar ring edge, but only partially around the vertical bars and PVC tubes as shown in Figure 3.5. The maximum length of the patty measured along the axis through the PVC tubes was 16 in. (measured within 15 degrees from each side of the axis). Along the axis perpendicular to the line through the PVC tubes, the maximum length of the patty measured was 18 in. Hence, the flow in one direction did not satisfy the minimum required distance of 9 in. from the center, which was needed to make the measurement reliable for assessing passing ability. During the L-Box test, the concrete flowed about half the length of the horizontal box, as shown in Figure 3.5. The slump measured was 8.5 in.

As shown in Figures 3.6 and 3.7, Specimens #3 and #4 appeared similar to Specimens #1 and #2 in terms of the size of the voids both vertically and at the base of the piles. Reinforcement bars were also visible in the worst gaps at the base of both piles. Part of the surface of the pile specimens appeared to be rough and bumpy, and part of the surface appeared smooth. The roughness could be caused by slurry trapped in some areas.



Figure 3.5 – C-Bar and L-Box tests on Mix 5 for Pile Specimens #3 and #4



Figure 3.6 – Pile Specimen #3



Figure 3.7 – Pile Specimen #4

### 3.3 Specimens #5 and #6

Specimens #5 and #6 were cast using the Mix 2 proportions (see Table 2.5). Rebar Configuration 1 was used and the concrete was placed using a gravity-fed tremie tube. The C-Bar passability ratio for this mix was 1.48, categorizing the concrete as “passable” according to Table 2.3. Here, the concrete was able to completely flow around both the PVC tubes and vertical bars in the C-Bar test as shown in Figure 3.8. For the L-Box test, the concrete had a passing ability ratio of 0.49. The slump value was 10 in.

As shown in Figures 3.9 and 3.10, both specimens appeared to have vertical voids up to 0.25 in. wide in the bottom one foot of each pile. Specimen #5 had two major voids at the base of the pile. Otherwise, the base was in full contact with the footing. As shown in Figure 3.11, one void at the base of Specimen #5 was close to 2 in. wide and had trapped slurry. The void, located between a PVC tube and a longitudinal bar,



exposed a transverse rebar. Specimen #6 did not have any significant voids and had only a few gaps at the base. Otherwise, the base was in full contact with the footing.



Figure 3.8 – C-Bar and L-Box tests on Mix 2 for Pile Specimens #5 and #6



Figure 3.9 – Pile Specimen #5



Figure 3.10 – Pile Specimen #6



Figure 3.11 – Bottom of Pile Specimen #5 showing void at base

### 3.4 Specimens #7 and #8

Specimens #7 and #8 were cast with a concrete mix used by Caltrans for a project with CIDH piles poured with the slurry displacement method. The mix proportions are listed in Table A.2 in Appendix A. It had a lower paste volume compared to all other mixes considered here. Rebar Configuration 1 was used and the concrete was placed with a pump-fed tremie tube. The C-bar passability ratio for the mix was measured to be 1.40, and the L-Box passing ability ratio was 0.40. The slump value was 10 in. Pictures of these tests are shown in Figure 3.12.

As shown in Figures 3.13 and 3.14, Specimen #7 and #8 did not have voids. However, at the base of both piles, there were gaps up to 0.5 in. wide in some places. In the upper four feet of Specimen #8, there were vertically oriented streaks where aggregate was exposed on the surface as shown in Figure 3.15. This might be attributed to the fact that the concrete did not overflow during the pour to flush away the concrete contaminated by the slurry. In the bottom two feet of both pile specimens, white streaks were present on the surface due to hydrostone residue that was unintentionally left on the form tube prior to the concrete placement.



Figure 3.12 – C-Bar and L-Box tests on Caltrans Mix for Pile Specimens #7 and #8

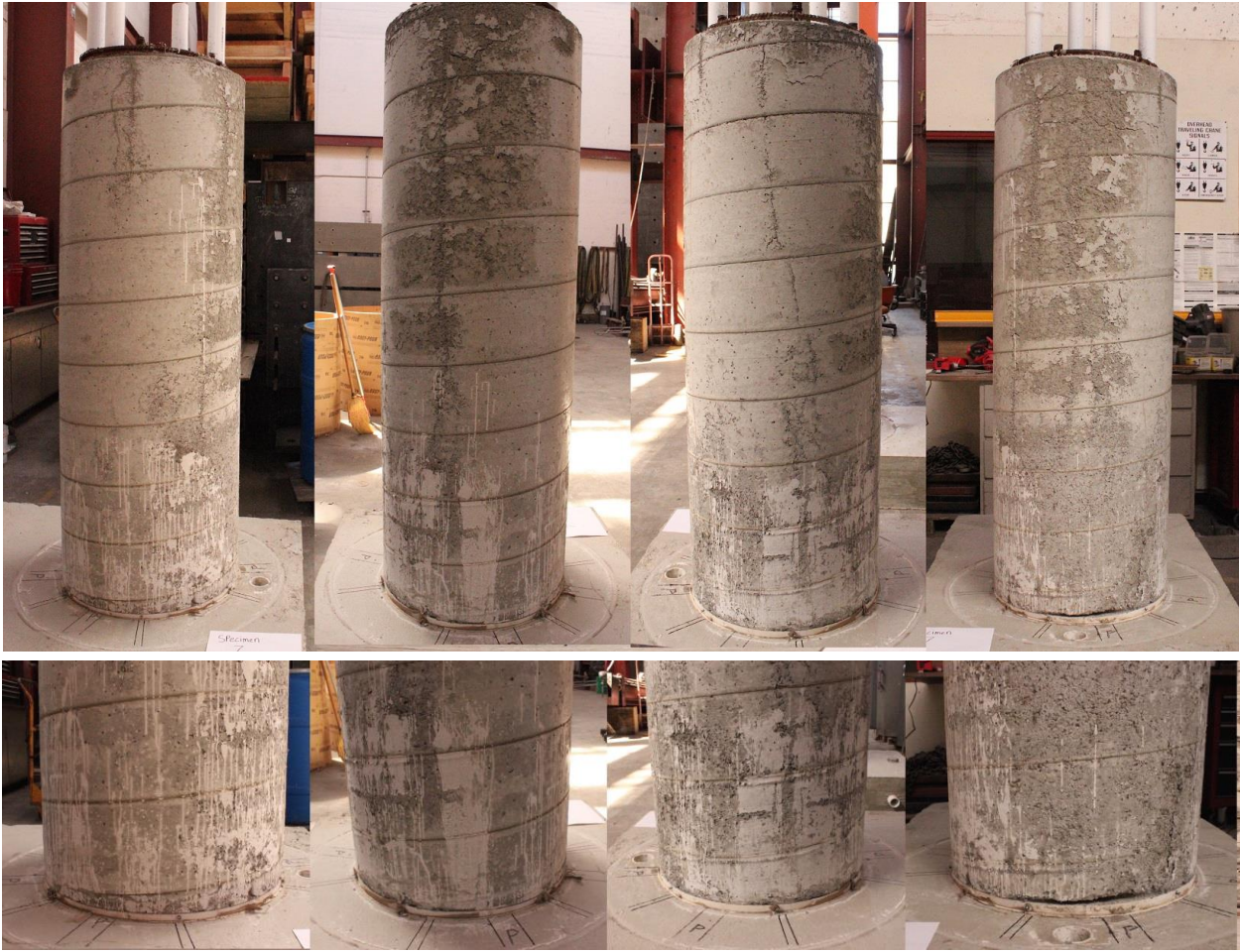


Figure 3.13 – Pile Specimen #7



Figure 3.14 – Pile Specimen #8



Figure 3.15 – Exposed aggregate in Pile Specimen #8

### 3.5 Specimens #9 and #10

Specimens #9 and #10 were cast using the Mix 2 proportions (see Table 2.5). It had the same mix proportions as Specimens #5 and #6. However, Rebar Configuration 2 was used and the concrete was placed using a pump-fed tremie tube. The C-bar passability ratio measured was 1.35, which was a little less than that for Specimens #5 and #6, and the L-Box Passing Ability Ratio was 0.59. The slump value was 10 in. Slight bleeding and segregation was observed in the concrete paste, as shown in Figure 3.16.

As shown in Figure 3.17, Specimen #9 had vertical voids near the base and gaps between the base and the footing. As shown in Figure 3.18, specimen #10 did not have voids, but had gaps at the base. In Specimen #9, the width of the gaps varied from 0.25 in. to 1.5 in., as shown in Figure 3.19. In Specimen #10, the width of the gaps varied from 0.25 in. to 1 in. The surface of both specimens appeared to be smooth.



Figure 3.16 – C-Bar and L-Box tests on Mix 2 for Pile Specimens #9 and #10



Figure 3.17 – Pile Specimen #9



Figure 3.18 – Specimen #10



Figure 3.19 – Bottom of Pile Specimen #9 showing gap at base



### 3.6 Specimens #11 and #12

Specimens #11 and #12 were cast using the Mix 4 proportions (see Table 2.5). In comparison to Specimens #1 and #2, which were cast with the same mix, Specimens #11 and #12 had an increased admixture dosage. Specimen #12 had a higher admixture dosage than Specimen #11. For both specimens, Rebar Configuration 2 was used and the concrete was placed using a pump-fed tremie tube. For Specimen #11, the C-bar passability ratio measured was 1.82, and the L-Box passing ability ratio was 0. The concrete flow stopped about 3 in. away from the end of the horizontal section of the L-Box, as shown in Figure 3.20. For Specimen #12, the C-bar passability ratio measured was 1.50, and the L-Box passing ability ratio was 0.46. Pictures of these tests are shown in Figure 3.21. The slump values were 9.5 in. and 9.75 in. for Specimens #11 and #12, respectively.

As shown in Figures 3.22 and 3.23, Specimen #11 had a few voids and gaps at the base. The base of the pile was mostly in contact with the footing, and the width of the gaps varied from 0.25 in to 1 in. As shown in Figures 3.24 and 3.25, Specimen #12 had no voids or gaps except for one 1-in.-deep small rectangular-shaped void near the mid-height of the specimen. The surface of Specimen #11 was rough at some locations, while the surface of Specimen #12 was mostly rough. Among all the mixes used here, Mix 4 had the lowest paste volume at 35 percent (see Table A.1). In comparison, both Mix 2 and Mix 5 had a paste volume of 38 percent. Despite a lower paste volume in Specimens #11 and #12, and the marginal C-Bar passability ratio for Specimen 11, the quality of concrete appeared adequate.



Figure 3.20 – C-Bar and L-Box tests on Mix 4 for Pile Specimen #11



Figure 3.21 – C-Bar and L-Box tests on Mix 4 for Pile Specimen #12



Figure 3.22 – Pile Specimen #11



Figure 3.23 – Bottom of Pile Specimen #11 showing gaps



Figure 3.24 – Pile Specimen #12



Figure 3.25 – Bottom of Pile Specimen #12

### 3.7 Comparison of Specimen Appearance

Specimens #1 through #4 had severe narrow, vertically oriented, voids with widths up to 0.5 in. over two-third of the height of the specimens. This was the result of poor concrete flowability. Specimens #1 and #2 had Mix 4, while Specimens #3 and #4 had Mix 5. The concrete for these piles did not flow enough (a minimum of 9 in. from the center) to provide measurable results in the C-Bar tests. Specimens #5, #6, and #9, which had Mix 2, had better quality than Specimens #1 through #4 but had vertical voids, approximately 0.25 in. wide, at the bottom of the piles. However, the voids were not significant and localized at the bottom. The concrete for Specimens #5 and #6 had a C-Bar passability ratio of 1.48, and Specimen #9 had a passability ratio of 1.35, which were all well below the upper limit of 1.67 recommended in the Caltrans proposal (Caltrans 2009) to have unrestricted flow. Specimen #10, which had concrete from the same batch as Specimen #9, had no voids. Specimens #7 and #8, which had a mix used by Caltrans for CIDH piles, had no voids but had some exposed aggregate in some areas over the surface of the piles. This concrete had a relatively low volume of cement as compared to the other mixes (Mix 2, Mix 4, and Mix 5) considered here but had larger dosages of water reducing admixtures. The C-Bar passability ratio for the concrete was 1.40. Specimens #11 and #12 had the same mix (Mix 4) as Specimens #1 and #2, but had a higher dosage of water reducing admixtures. These specimens had acceptable concrete quality without any vertical voids on the exterior surface. However, Specimen #11, which had slightly less water reducing admixture than

Specimen #12, showed some gaps at the base of the pile. The C-Bar passability ratio for the concrete for Specimen #11 was 1.82, while that for Specimen #12 was 1.50.

In the L-Box tests, none of the specimens had a concrete flow that achieved the minimum passing ability ratio of 0.8. For all the concrete that passed the C-Bar test (with the passability ratio below 1.67), the slump value was 10 in. or above.

No major difference could be observed between the quality of concrete in Specimens #5 and #6, and that in Specimens #9 and #10. All these specimens had Mix 2, but Specimens #5 and #6 had concrete placed with a gravity-fed tremie tube, while Specimens #9 and #10 were cast with a pump fed-tremie tube. Furthermore, Specimens #5 and #6 had Rebar Configuration 1, while Specimens #9 and #10 had Rebar Configuration 2.



## **4. Summary and Conclusions**

### **4.1 Summary**

This study examined the reliability of C-Bar and L-Box tests in determining the passing ability of concrete, and whether results of these tests could be used to determine the quality of concrete placed in CIDH piles using the slurry displacement method. The workability of several concrete mix proportions provided by Oregon State University based on a study reported in Trejo and Hendrix (2014) was examined with trial batches. In addition, twelve 24-in. diameter piles were cast using the slurry displacement method. For these piles, two rebar configurations were used, and concrete was placed through a tremie tube using either the gravity-fed method or the pump-fed method. The two rebar configurations had the same transverse and longitudinal reinforcing bars, but had a 2-in. and a 3-in. concrete cover, respectively, and different spacings between a longitudinal bar and an inspection tube. In Rebar Configuration 1, the smallest clear spacing between a longitudinal bar and an inspection tube was 2.5 in., which violated the minimum spacing of 3 in. permitted by Caltrans Standard Specifications (2015). The main observations and conclusions of this study are summarized below.

### **4.2 Conclusions**

This study has found that concrete mixes with C-Bar passability ratios of 1.82 or lower resulted in piles that were free of voids on the exterior surface except for some small voids near the base of the piles. In the Caltrans proposal (Caltrans 2009), a passability ratio between 1.67 and 2.0 is considered questionable. In this study, none of the piles had concrete with a measurable passability ratio beyond 1.82. Concrete mixes that did not have enough flowability to give measurable C-Bar test values resulted in piles having severe voids on a significant portion of the surface. The concrete mix that had a passability ratio of 1.82 barely flowed beyond the rebars in the C-bar test. This concrete had a slump value of 9.75 in. For the concrete that passed the C-Bar test, the slump value was 10 in. or above. However, one of the trial batches had a slump of 10 in. and yet had a passability ratio of 2.1. This could be considered an outlier. Hence, 1.80 can be

considered as a reasonable upper limit for the passability ratio. Furthermore, a slump value of 10 in. or more also appears to be a good indicator.

None of the concrete mixes used for the pile specimens passed the L-Box tests, which requires a minimum passing ability ratio of 0.8. This is consistent with the findings of Trejo and Hendrix (2014) that concrete mixes showing an adequate passability ratio in C-Bar tests typically failed L-Box tests.

No major difference could be observed between the quality of concrete placed with the gravity-fed tremie tube and that with the pump fed-tremie tube.

### **4.3 Recommendations for Future Study**

The pile specimens studied here were much shorter than the actual piles normally used in bridges. They were also cast in clean forms instead of drilled holes in soil. No gamma-gamma tests were conducted in this study to see if the anomaly observed in some of the piles could be detected by these tests. Therefore, further studies are recommended to confirm if the results and observations of this study would apply to the actual field condition. These studies will require the casting of long piles (20 to 30 ft.) in drilled holes, the conduction of gamma-gamma tests, and the extraction of the pile specimens from the holes for inspection.

However, it is believed that the length of a pile will not affect the results of this study. The change in hydrostatic pressure will occur in both the concrete mix in the tremie tube and the slurry as the height of a pile changes.



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## Appendix A

Table A.1 – Concrete mix design proportions recommended by Oregon State University

	Mixture 1	Mixture 2	Mixture 3	Mixture 4	Mixture 5	Mixture 6
Anticipated Performance	Low Flowability	Workable	Workable	Low Flowability	Workable	Unstable
Meets Caltrans Combined Aggregate Gradation Specifications	No - #4 is slightly out of range (note)	No - #4 is slightly out of range (note)	No - #4 is slightly out of range (note)	Yes	Yes	Yes
Meets Caltrans Individual Gradation Specifications	Yes	Yes	Yes	Yes	Yes	Yes
Use in CIDH Piles with Diameter > 8 feet	Yes	No, exceeds cm limit by 74.5 lbs	No, exceeds cm limit by 148 lbs	Yes	No, exceeds cm limit by 74.5 lbs	No, exceeds cm limit by 148 lbs
Water (lb/cy)	295.6	325.6	354.7	300.1	327.4	354.7
Fly Ash Class F (lb/cy)	209.8	231.1	251.7	213	232.3	251.7
Cement (lb/cy)	538.7	593.4	646.4	547	596.7	646.4
Coarse Aggregate (lb/cy)	1209	1148	1089	1323	1256	1191
Fine Aggregate (lb/cy)	1693	1608	1525	1587	1507	1430
FA/CA	1.4	1.4	1.4	1.2	1.2	1.2
% Paste Volume	35	38	41	35	38	41

Table A.2 – Caltrans wet CIDH pile mix

Specified compressive strength = 4.0 ksi		
Material	Quantity (lbs/cy)	Admixture dosage (oz/cwt)
Water (W/C)	302.6 (0.42)	
Fly Ash Class F	210	
Cement	506	
Coarse Aggregate	1460	
Fine Aggregate	1346	
Daravair 1000		0.14
WRDA 64		4
ADVA 190		13
Recover		14
Air	0.81 (CF)	