EFFECT OF CONCRETE AGE ON PULLOUT STRENGTH OF HEADED STUDS

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ABSTRACT

Pullout strength of embedded items in precast elements is an important factor in the design of structural (beams, columns, panels, etc.) and architectural (cladding) elements. This is true for both transportation and installation of these elements and for their adequate performance throughout their service lives. Similarly, this property is also of great importance when considering the manufacturing process at many precast plants. In particular, when elements are to be removed from forms and stored or loaded for transportation, the bond strength/capacity of embedded lifting anchors is a major concern and needs to be well understood. Generally, pullout strength of such embedded items is estimated well enough, but most methods and testing to predict strength have been developed based on concrete strengths at ages greater than that when many elements are removed from forms and stored.

The study presented herein investigated the effect of age on pullout strength of embedded items. Test specimens and procedures were developed following ASTM C900 which generally results in a pullout failure mechanism that differs somewhat from that considered in design following ACI 318 Appendix D. Tests consisted of tensile loading (until failure) of single headed studs embedded in concrete samples across a range of compressive strengths (approximately 3 ksi to 7 ksi) attained at different target ages (1 day, 3 days, and 7 days). All concrete samples were fabricated using similar materials (aggregate type and size, etc.) but varying mix designs (cement content and type, admixtures, etc.) to obtain the desired strength and age combination. Results were analyzed to identify correlations between age, pullout strength, and concrete compressive strength. The results of the study indicate little influence of concrete age on the pullout strength of the single stud configuration used.

Keywords: Connections, research

INTRODUCTION

Pullout strength of embedded items in precast elements is an important factor in the design of structural (beams, columns, panels, etc.) and architectural (cladding) elements. This is true for both transportation and installation of these elements and for their adequate performance throughout their service lives. Similarly, this property is also of great importance when considering the manufacturing process at many precast plants. In particular, when elements are to be removed from forms and stored or loaded for transportation, the bond strength/capacity of embedded lifting anchors is a major concern and needs to be well understood. Generally, pullout strength of such embedded items is estimated well enough, but most methods and testing to predict strength have been developed based on concrete strengths at ages greater than that when many elements are removed from forms and stored.

Many design guidelines such as the PCI Design Handbook provide relationships for capacity of connections utilizing embedded items in cured concrete. Generally, when considering concrete failure, these guidelines require that the design capacity be taken as the minimum of three different mechanisms including breakout (failure cone), pullout (failure due to crushing of concrete adjacent to stud head), and side face blowout[1]. Other building codes and guidelines such as ACI 318 "*Building Code Requirements for Structural Concrete*" and ACI 530 "Building Code Requirements for Masonry Structures" provide similar design equations that allow calculation of capacities of embedded anchors[2,3]. Several similarities exist between these design guides. Most importantly, no consideration of age of concrete or masonry is required and the relationships commonly relate capacity of the connection to square root of concrete or masonry compressive strength (f'_c or f'_m).

This study investigated pullout strength generally following procedures outlined in ASTM C900[5]. Due to the required use of a bearing plate, which may restrain the concrete near the anchor during testing, the typical pullout failure mechanism throughout this study differs from the pullout failure mechanism considered in ACI 318 Appendix D[2]. This typical pullout failure mechanism was consistent throughout the study and is reflected in all results and analysis.

PURPOSE OF STUDY

The purpose of the study was to investigate the pullout capacity of headed studs in concrete samples across a variety of compressive strengths attained at different ages. This study was aimed at determining if the pullout capacity of stud connections is always a function of compressive strength regardless of age or if age was a contributing factor that should be included in design calculations. This study was not intended to verify or check the design equations frequently used, such as those provided in Appendix D of ACI 318 or in the PCI Design Manual, or to suggest that the current state-of-practice is incorrect.

METHODOLOGY

To investigate age effects on pullout strength of assemblages cast in concrete, headed studs were cast in concrete samples. All parameters (materials, mix procedure, testing, etc) were maintained throughout all specimen preparation and testing to reduce variability in test results. The test program consisted of single studs tested in tension across a range of compressive strengths at ages of 1 day, 3 days, and 7 days. Pullout loads from each of these age groups were investigated individually and then combined to highlight any differences evident because of concrete age at testing.

MIX DESIGNS

Many mix designs were utilized throughout the study. Although basic designs were formulated for the study, they were augmented to achieve the desired time and strength combinations. Augmentations included changes in cement type (Type I versus III), cement content, water to cement ratio (w/c), and admixtures (water reducer). All mix designs were non air entrained to reduce/eliminate a variable that would have impact on test results.

MATERIALS

Similar materials were used for each batch of concrete tested. Fine and coarse aggregates were obtained from a consistent source for all batches as was portland cement and admixtures. Fine and coarse aggregates were obtained from a local supplier. Fine aggregate was a natural sand meeting gradation requirements in ASTM C33[4]. Coarse aggregate consisted of a crushed limestone meeting the No. 67[4] gradation. Two different types of portland cement were used in the study. Both Type I and Type III portland cements were used to gain the target strength and age combinations representative of those found at many precast facilities. Each type of cement was obtained from one manufacturer/supplier to maintain consistency throughout the study.

STEEL STUDS

Standard steel studs were obtained from a local supplier. The studs were 4.1875 inches long with a 0.75 inch diameter shaft. The head thickness was 0.375 inches with a diameter of 1.25 inches. To facilitate accurate embedment depth of the studs, a plumb condition as compared to the surface of the specimen, and attachment of the loading device for testing, the first 2 inches of each stud shaft were machined with threads (16 per inch). Figure 1 illustrates a typical stud after fabrication and prior to concrete placement. Information from the stud supplier indicated that the studs met or exceeded the standard criteria including yield strength (51,000 psi @ 0.2% offset), tensile strength (65,000 psi minimum), and elongation (20% in 2 inches).

Fig. 1 Headed Stud after Fabrication

SPECIMENS

Specimen characteristics were developed with guidance from ASTM C900[5]. This information, along with information form previous studies, resulted in a stud embedment length of 2.25 inches (measured from concrete surface to extreme face of stud) in concrete specimens that were approximately 12 inches in each direction. This stud embedment length is slightly larger than that illustrated in ASTM C900 to ensure that testing could be completed up to actual stud failure. Specimens were cast in wood forms constructed of 0.75 inch thick material with studs cast in opposite sides (2 per specimen). To facilitate placement of each stud at the correct embedment depth, ensure that the stud projected perpendicular to the surface of the specimen, and provide adequate stability during casting, spacer blocks and 0.375 inch threaded washers were used. The washer was tapped with threads to match those on the studs. This arrangement held the studs in place and facilitated easy checking and setting of depth prior to concrete placement. An example of the spacer block/threaded washer combination is shown in Figure 2.

Each concrete mix used for study was batched and mixed in a similar manner using the same equipment with similar ambient temperatures and humidity. Although the mix designs were augmented to facilitate acquisition of the target compressive

Fig. 2 Embedment Length Apparatus

strengths at the desired ages, similar consistency was maintained for each batch mixed. After mixing, each specimen was cast following the same procedure. The basic procedure included filling the form in 2 layers, consolidating each layer by rodding 30 times and striking the outside of the form 5 times on each side with a rubber mallet. The top surface of each specimen was finished with a basic strike off with a standard steel trowel. Specimens were allowed to cure (1 day, 3 days 7 days,) in their respective forms at location of casting until removal for immediate testing. Test cylinders were cast simultaneously with specimens. Test cylinders were allowed to match cure, while remaining in plastic molds, directly adjacent to the test specimens with identical temperature and humidity. This step was taken to ensure that compressive strength results were representative of the concrete in each respective specimen at the time of testing.

TESTING

Specimens and test cylinders were removed from forms/molds immediately (~30 minutes) prior to testing. Care was taken not to disturb the embedded studs.

The test apparatus for pullout of embedded studs consisted of a bearing plate, center pull jack for load application, load cell to measure the applied tensile force, a data acquisition system to report the data, a steel rod to connect the load apparatus to the embedded stud, and spacer plates to reduce to stroke of the jack during each test. The bearing plate was steel, with a thickness of 0.375 inches with a 3 inch diameter center hole. The jack was rated at 60 kips and the load cell was rated at 50 kips. The steel connecting rod was threaded on one end to match a threaded insert on the bottom side of the load cell and drilled and tapped on the other end with threads to match those on the projection of the headed studs. This rod tied the entire system together and allowed the jack force to push against the concrete sample and the load cell. The spacer plates were steel with center holes slightly larger than the connecting rod.

The setup for performing a tensile test began by placing/centering the bearing plate around the embedded stud. The threaded rod was then tightened onto the headed stud. The jack was then placed over the steel rod and allowed to rest on the bearing plate with the threaded end of the connecting rod protruding from the top of the jack. Finally, the spacer plates were placed on the jack, the load cell was connected to the threaded end of the connecting rod and the data acquisition system was installed. Figure 3 illustrates this basic setup with the exception of the hydraulic pump that operated the jack and the data acquisition system (left out for clarity of picture).

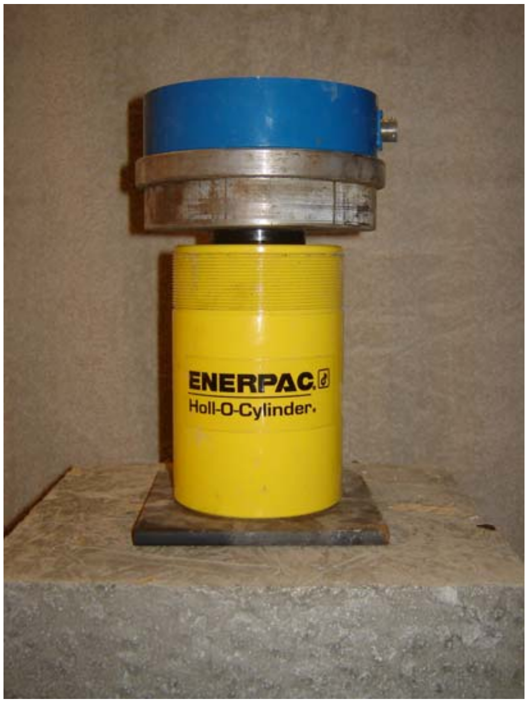

Fig. 3 Basic Testing Setup

After setup was complete, each stud was tested in tension until failure. Loading was applied through the use of a manual pump attached to the center pull jack. Great care was taken to maintain a constant loading rate during each test and across all tests completed to reduce data variability. Impact loading of the specimens was avoided. Testing of studs was completed within 1 hour (+/-) of their respective test age (1 day, 3 days or 7 days) and compressive strength testing of companion cylinders was completed concurrently with stud testing. Failures were typically as expected as a cone of concrete pulled from the specimen still attached to the steel stud. This failure type is illustrated in Figures 4 and 5.

Fig. 4 Typical Failure

Fig. 5 Typical Failure Cone

Several tests resulted in stud failure without concrete failure. This type of failure typically resulted in stretching of the stud where no increase in ultimate load could be applied to the stud. An example of stud failure (stretching) is shown in Figure 6.

One major challenge was encountered during the testing phase of the study. Using a manually operated load system presented minor initial problems maintaining a consistent loading rate. Preliminary tests were completed to gain experience in maintaining an appropriate and consistent loading rate. During the preliminary testing, it was evident that test results were quite sensitive to loading rate.

Fig. 6 Stud Failure

As expected, quick or impact loading of the stud almost always resulted in higher observed pullout load and slow loading resulted in the opposite. Several studs were tested during the preliminary testing to set an appropriate loading rate. This challenge may be avoided in future testing through the use of an electronic system controlling the loading rate and not an operator with a manual system. Although fluctuations in the loading rate were found to impact results considerably, enough preliminary testing was completed to set and meter an appropriate loading rate for all tests included in the analysis.

RESULTS

The compressive strength and pullout load test results for each stud tested are provided in Table 1. The results provided in Table 1 represent all studs tested except those (3) with problems that hindered proper testing (i.e. damaged threads) and those (8) where concrete strength was high enough that stud failure resulted. As shown in Table 1, compressive strengths ranged from 2,250 psi to 6,040 psi for the 7 day tests, 2,860 psi to 7,890 psi for the 3 day tests, and 2,410 psi and 6,910 psi for the 1 day tests. Likewise, pullout loads ranged from 16,016 lbs to 29,970 lbs, 19,646 lbs to 29,779 lbs, and 17,916 lbs to 27,244 lbs, for the 7 day, 3 day, and 1 day tests, respectively.

ANALYSIS OF RESULTS

Pullout loads for each set (by age) of tests were plotted versus square root of compressive strength. The plot for each of these data sets is provided in Figure 7. Regression analysis was completed for each of these data sets with the parameters that a linear relationship between pullout load and square root of compressive strength was required and that the resulting relationship would theoretically pass through the origin. The coefficients of determination (R^2) values were 0.8917, 0.7201, and 0.4216 for the 7 day, 3 day, and 1 day results, respectively. As indicated, the variability associated with the regression decreased with increased age at time of testing.

Table 1 Testing Results

Test No.	Comp. Strength	Load	Test No.	Comp. Strength	Load
---	(psi)	(lbs)	---	(psi)	(lbs)
	7 Day			3 Day (cont)	
1	2,250	16,016	16	4,860	25,727
2	2,340	16,505	17	5,400	29,778
3	2,360	16,914	18	6,530	29,779
4	2,370	16,533	19	6,910	29,421
5	3,970	24,730	20	6,940	29,372
6	4,120	23,115	21	7,890	29,618
7	4,160	23,591			
8	4,220	25,716		1 Day	
9	5,420	29,367			
10	5,490	26,862	1	2,410	17,985
11	5,510	25,450	2	2,500	19,679
12	5,590	24,193	3	2,540	19,716
13	6,010	28,297	4	2,620	19,672
14	5,650	29,826	5	2,640	20,302
15	5,800	29,970	6	2,900	20,389
16	6,040	29,824	7	2,910	21,036
			8	3,010	22,142
	3 Day		9	3,190	17,916
			10	3,210	19,399
1	2,860	23,768	11	3,320	22,091
2	3,110	22,762	12	3,350	22,890
3	3,170	20,496	13	3,370	25,601
4	3,270	19,964	14	3,490	24,746
5	3,280	22,712	15	3,520	23,750
6	3,360	19,904	16	3,530	23,135
7	3,590	22,714	17	3,610	24,494
8	3,630	19,646	18	3,750	26,663
9	4,380	24,016	19	3,760	23,383
10	4,400	24,727	20	3,800	24,428
11	4,440	24,555	21	5,910	25,274
12	4,470	25,249	22	6,210	26,672
13	4,620	28,362	23	6,630	27,114
14	4,760	26,179	24	6,910	27,244
15	4,800	26,629			

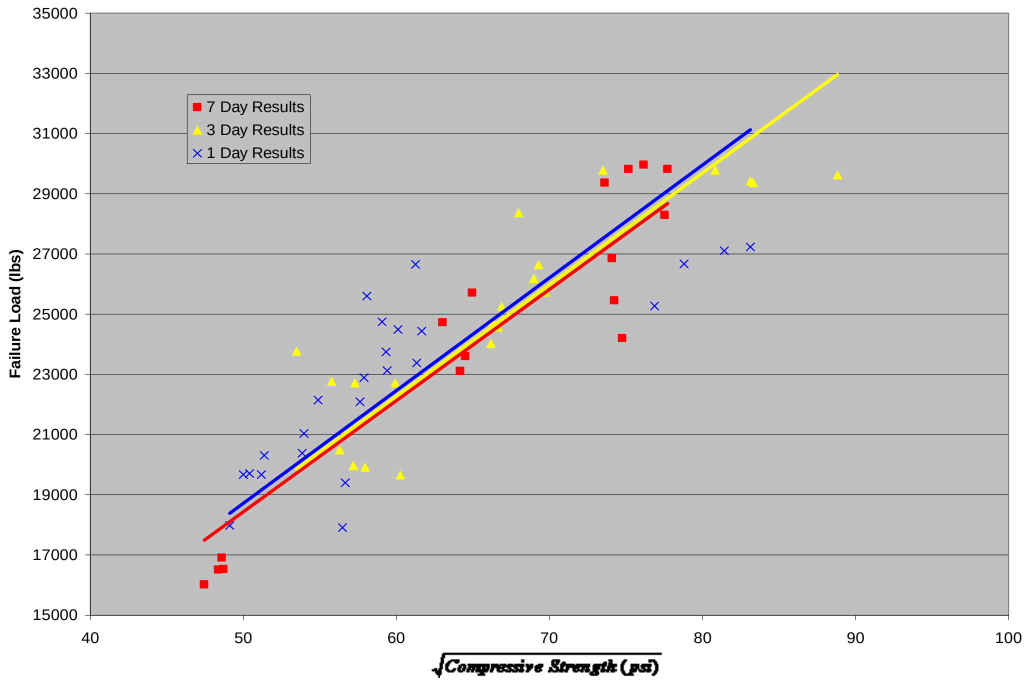

Fig. 7 Plotted Results and Regression for Each Data Set

The same group of data previously analyzed was combined into one data set and is similarly plotted in Figure 8 with the same regression analysis completed. The R^2 value for this regression analysis was 0.7987.

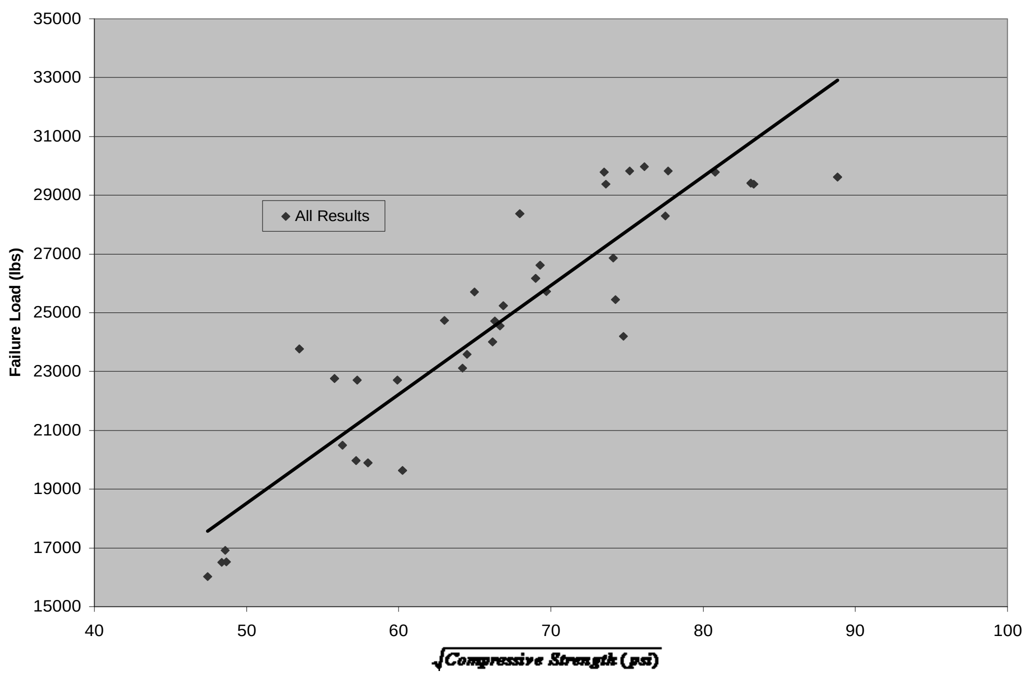

Fig. 8 Results and Regression for All Data

To compare the results from each testing age and the overall group, the prediction equations resulting from each regression analysis were compared. The equations from each analysis are provided in Table 2.

Table 2 Regression Prediction Equations

All Data	370.56 x (compressive strength)$^{1/2}$
7 Day	368.93 x (compressive strength)$^{1/2}$
3 Day	371.15 x (compressive strength)$^{1/2}$
1 Day	374.45 x (compressive strength)$^{1/2}$

As shown in Table 2, only small differences existed when comparing each of the prediction equations. The predictions resulting from each of the data sets were compared to that of the prediction when using “All Data” and to the maximum (1 day) and minimum (7 day) predictions from the entire group. As shown in Table 3, all predictions are quite similar with the extremes of 101.5% (1 day - % of Min. Prediction) and 98.53% (7 Day - % of Max. Prediction). Based on the information from the small data set analyzed, this analysis indicated that age may not be a factor in determining pullout strength.

Table 3 Comparison of Prediction Equations

Data Set	% of All Data Prediction	% of Min. Prediction	% of Max. Prediction
All Data	100.00	100.44	98.96
7 Day	99.56	100.00	98.53
3 Day	100.16	100.60	99.12
1 Day	101.05	101.50	100.00

CONCLUSIONS AND FUTURE WORK

Results from testing following procedures similar to those in ASTM C900 lead to a pullout failure mechanism different than that considered by ACI 318 Appendix D[1,2]. However, when following test procedures outlined in ASTM C900, the data generated in this study suggests that similar pullout loads for single headed studs are possible in concrete specimens with similar compressive strengths regardless of age (1 day thru 7 days). These results indicated that age may not be a necessary consideration for early age calculations but rather compressive strength is an adequate predictor. Also, based on preliminary work completed for this study, control of loading rate is an important factor in completing pullout tests and must be monitored carefully to generate uniform results. Additional work needs to be completed that includes specimens with a wider range of compressive strengths, different connection parameters (stud number, depth, and size), different failure mechanisms, and most importantly a wider range of ages (i.e. 8 hours thru 28 days).

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REFERENCES

1. Industry Handbook Committee. 2004. *PCI Design handbook: Precast and Prestressed Concrete*. 6th ed. MNL-120-04. Chicago, Il: PCI.

2. American Concrete Institute (ACI) Committee 318. 2008. *Building Code Requirements for Structural Concrete (ACI 318-08) and Commentary (ACI 318R-08)*. Farmington Hills, MI: ACI.

3. American Concrete Institute (ACI) Masonry Joint Standards Committee. 2008. *Building Code Requirements and Specification for Masonry Structures and Related Commentary (ACI 530-08).* Farmington Hills, MI: ACI.

4. "Design and Control of Concrete Mixtures," 14th Ed, Portland Cement Association, Skokie, IL, 2002.

5. .ASTM. C900-06, "Standard Test Method for Pullout Strength of Hardened Concrete," American Society for Testing and Materials, Annual Book of ASTM Standards, Vol. 04.02, 2008.