

Evaluation of Grout Strength Gain within Augered Cast-in-Place Piles using Concrete Maturity Meter

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ABSTRACT

The rate of strength gain for concrete or grout is essential information when determining the load carrying capacity of a recently placed structure. New technology in maturity meters allows for embedded components to be used in lieu of external recording devices, making the use of these instruments more feasible on job sites.

This paper presents the results of strength gain data collected from grout used to construct augered cast-in-place (ACIP) piles for load testing and production on a Houston area project. Strength gain within the ACIP piles was evaluated using a Engius IntelliRock™ Maturity Meter that had been calibrated using standard ASTM procedures for compressive strength testing of grout cubes and cylinders for the grout mix design used in construction.

INTRODUCTION

One of the primary concerns of structural engineers when designing a foundation system is the strength of the in-situ concrete. Knowledge of the in-situ concrete strength can assist the structural engineer in evaluating whether a foundation system is capable of supporting design loads at a given time during construction. Construction costs are often driven by schedules that are dependent upon the length of time it takes for concrete to achieve a desired strength. Therefore, evaluating in-situ concrete strength in a timely fashion can reduce construction time and cost for a project.

Typically, the strength of concrete is evaluated by casting 6-in. by 12-in. test cylinders and compression testing the cylinders at 7 and 28 days. This method assumes that the strength of the cylinders is indicative of the concrete placed in the field. However, recent concrete failures have shown that concrete strength is a function of site temperature as well as time. The site temperature component has generally been neglected in testing the early strength of concrete. The discrepancy in concrete strength as a function of time and temperature is especially pronounced when the ambient air temperature is significantly below the temperature of approximately 70 degrees Fahrenheit found in most laboratory curing rooms. Concrete maturity testing was developed to more accurately evaluate the early strength of concrete as it cures in the field under ambient temperature conditions.

Similar to concrete, grout strength is also typically evaluated through compressive strength testing of samples at 7 and 28 days. In order to better evaluate the early strength gain of grout used in augered cast-in-place (ACIP) piles, a study was performed using concrete maturity meter testing for grout placed within test and production ACIP piles installed on a project in Houston, Texas.

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PROJECT DESCRIPTION

Augered Cast-in-Place (ACIP) piles continue to see significant growth in the market due to their unique combination of speed of installation and high capacity that results in one of the most cost effective deep foundation systems available. ACIP piles were first introduced in the 1940's, and are also known by a variety of names including auger cast, auger pressure grouted, and continuous flight auger piles. In the 1990's the Deep Foundations Institute came up with the generic term Augered Cast-In-Place piles to describe this type of deep foundation system.

ACIP piles were installed for a mid-rise apartment building located adjacent to Buffalo Bayou in central Houston. The scope of the project included installing approximately 450, 14-inch-diameter by 75-ft-long ACIP piles. The design capacity of the pile was 135 tons (270 kips). A pile load test was also performed to verify the capacity of the pile.

The soil conditions consisted of loose to medium dense sand in the upper 20 ft, very stiff clay from 20 ft to 50 ft, and dense sand below 50 ft. The groundwater level at this site was about 5 ft below grade.

PILE INSTALLATION

ACIP piles are constructed by rotating a continuous flight auger into the ground to depth required by project design or performance requirements (see Figure 1). When the required depth is reached, a high strength flowable cement-based grout is pumped under pressure through the hollow stem auger, exiting below the cutting teeth of the auger tip. The grout is forced into the opening formed by the auger and around the auger flights, creating a head of grout on the outside of the auger.



Figure 1. ACIP Installation

As pumping continues, the auger is withdrawn in a manner to maintain the head of grout to avoid intrusion of soil or water into the grout column. The pumping is stopped after the auger is fully withdrawn from the ground. The upper portion of the pile is then screened of any debris

that may have fallen into the grout during spoil cleanup. The steel reinforcing is then installed by dropping it through the fluid column of grout. The reinforcing can take the form of a partial length cage, full-length center bar or combination of both.

GROUT MIX DESIGN

The grout used for ACIP piles generally consists of Portland cement, flyash, sand, water and a grouting aid. These materials are batched at a local ready mix operation to produce a homogenous fluid mixture that can be pumped without difficulty and stay in suspension. The mix design for the grout used on this project consisted of the following proportions.

Material	Proportion (lb/cy)
Portland Cement	705
Flyash	225
Sand	2333
Water	416 (50 gal)
Grout Aid	3

The water/cement ratio for this mix is 0.45 and the design 28 day compressive strength is 4,000 psi.

PILE LOAD TEST RESULTS

The pile load test was conducted in general accordance with the procedures outlined in ASTM D1143, section 5.6 (Quick Load Test Method for Individual Piles). Loads were applied in 15-ton increments and held for 5 minutes each up to twice the design load of 270 tons. The load was then removed in four equal decrements. The pile top deflection measured at the design load of 135 tons was about 0.2 inches. The total movement of the pile top at twice the design load was about 0.8 inches, which did not exceed the “Davisson” failure criteria for this test. A plot of the load versus deflection curve for the test pile is shown the figure below.

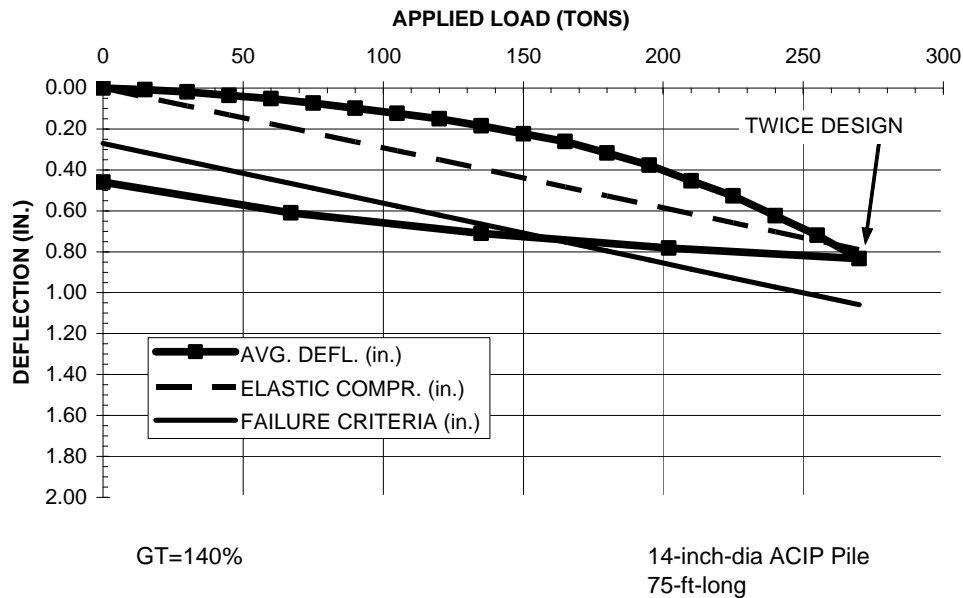


Figure 2. Pile Load Test Results - 14-inch Diameter ACIP Pile Compression Test

HISTORY OF MATURITY METHOD

(Engius, 2003)

The maturity method for measuring concrete strength has been in use for over fifty years and became an American Society for Testing and Materials (ASTM) standard in 1987 (ASTM C 1074) and an American Association of State Highway and Transportation Officials (AASHTO) provisional standard in 1995 (TP 52). The general principle behind the maturity method is the relationship between chemical reaction rates and temperature. For concrete, the specific application involves the rate of curing as a function of time and temperature as evaluated in the field and laboratory. Typically, the rate of curing in concrete increases with elevated temperature.

CONCRETE MATURITY METHOD

(Engius, 2003)

The maturity method accounts for the effects of time and temperature on the strength development of concrete in structures. This method allows for a continuous evaluation of concrete strength during the curing period. This information can be used to accelerate the construction process, and can also be used as a very powerful quality control tool.

The strength-maturity relationship is generated in the lab for each mix design to be used in the field. Samples of the design mix are cast for compression testing along with instrumentation with IntelliRock™ maturity loggers. The maturity loggers are imbedded within

representative concrete samples and are read periodically with an IntelliRock™ maturity reader (see Figure 3) to record a “maturity” value (time-temperature history) of the concrete.



Figure 3. IntelliRock™ Maturity Reader and Maturity Loggers

Other samples of the concrete are then tested in compression, and a plot of maturity value versus compressive strength is generated. Once the plot of maturity value versus compressive strength for a mix design has been generated, maturity loggers can then be installed within concrete in the field to evaluate strength gain of the in-place structures (see Figure 4).

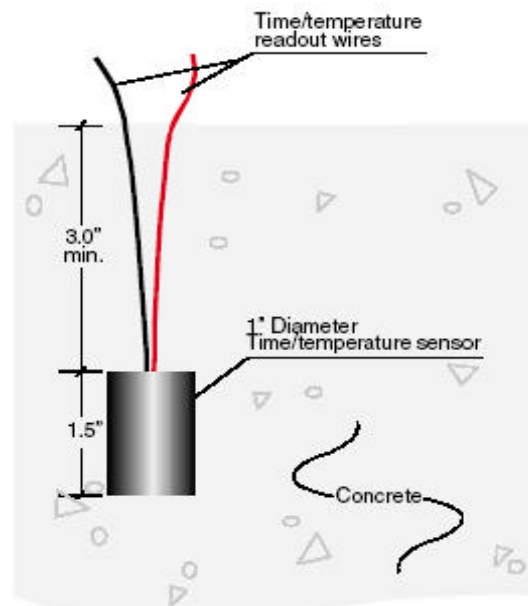


Figure 4. In-Situ Maturity Logger

MATURITY METHOD - ACIP PILES

During placement of test piles and production piles for the new mid-rise apartment building, IntelliRock™ maturity loggers were installed within the several ACIP piles at depths ranging between 18 inches and 24 inches (upper pile) and 15 ft and 20 ft (lower pile). The maturity loggers were secured to the reinforcement cages that were inserted into the grout columns of the ACIP piles, once the auger had been withdrawn.

In addition to installing maturity loggers into the ACIP piles, grout samples were collected for calibration testing, and maturity loggers were inserted within a representative number of samples and read with the IntelliRock™ maturity reader (see Figure 5). A total of 24, 2-inch by 2-inch square grout cubes (2 installed with maturity loggers) and 24, 3-inch diameter by 6-inch tall grout cylinders (2 installed with maturity loggers) were sampled.




Figure 5. Collecting Grout Samples and Recording Maturity Readings

Grout samples were transported back to the laboratory after initial set (approximately 24 hours), and stored in a controlled environment curing room. Maturity readings were taken for the samples embedded with maturity loggers on a daily basis up to 7 days, then at 14 days, 21 days, and 28 days. Samples of grout were tested in compression corresponding to the maturity readings for comparison of compressive strength with maturity. Additionally, readings were taken from the in-place maturity loggers installed within the ACIP piles onsite (see Figure 6).



Figure 6. Maturity Readings of In-Situ Grout within ACIP Pile

The data recorded from the maturity loggers is compiled and then plotted to compare compressive strength versus maturity (see Figures 7 and 8).

Project Number:				FUGRO SOUTH, INC.						
Concrete Producer:				6100 Hillcroft						
Contractor:		Berkel & Company		Houston, Texas 77081						
Mix Design Code:				Phone: 713 369-5400						
Batch Date:				Fax: 713 369-5518						
Batch Time:										
Ambient Temperature:										
Concrete Temperature:										
Concrete Slump:										
Concrete Unit Weight:										
Concrete Air Content:										
Strength Test Method:		Compressive								
Strength Units:		psi								
Datum Temperature:		0 °C								
Maturity Scale:		Normal								

Maturity Level	Specimen #	Specimen Strength ()	Average Strength ()	Maturity Logger Serial Number	Maturity Elapsed Time (hh:mm)	Specimen Maturity (I°C-Hrs)	Temperature (°C)	Average Maturity (I°C-Hrs)	Average Temperature (°C)	Average Age (days)
1	1	2,180	2,853	2,006,085	72:00	1,544	19	1,149	22	3.00
1	2	2,260		2,006,082	72:00	1,417	21			
1	3	3,280		2,006,179	72:00	799	24			
1	4	3,690		2,006,177	72:00	835	23			
2	5	2,910	3,518	2,006,085	96:00	2,034	20	1,655	20	4.00
2	6	3,100		2,006,082	96:00	1,946	20			
2	7	4,010		2,006,179	96:00	1,300	20			
2	8	4,050		2,006,177	96:00	1,341	20			
3	9	4,020	4,318	2,006,085	120:00	2,538	20	2,151	20	5.00
3	10	3,450		2,006,082	120:00	2,440	20			
3	11	4,800		2,006,179	120:00	1,790	20			
3	12	5,000		2,006,177	120:00	1,836	20			
4	13	4,250	4,800	2,006,085	168:00	3,497	20	3,138	19	7.00
4	14	4,600		2,006,082	168:00	3,443	19			
4	15	5,080		2,006,179	168:00	2,775	18			
4	16	5,270		2,006,177	168:00	2,838	19			

Figure 7. Compressive Strength and Maturity Data

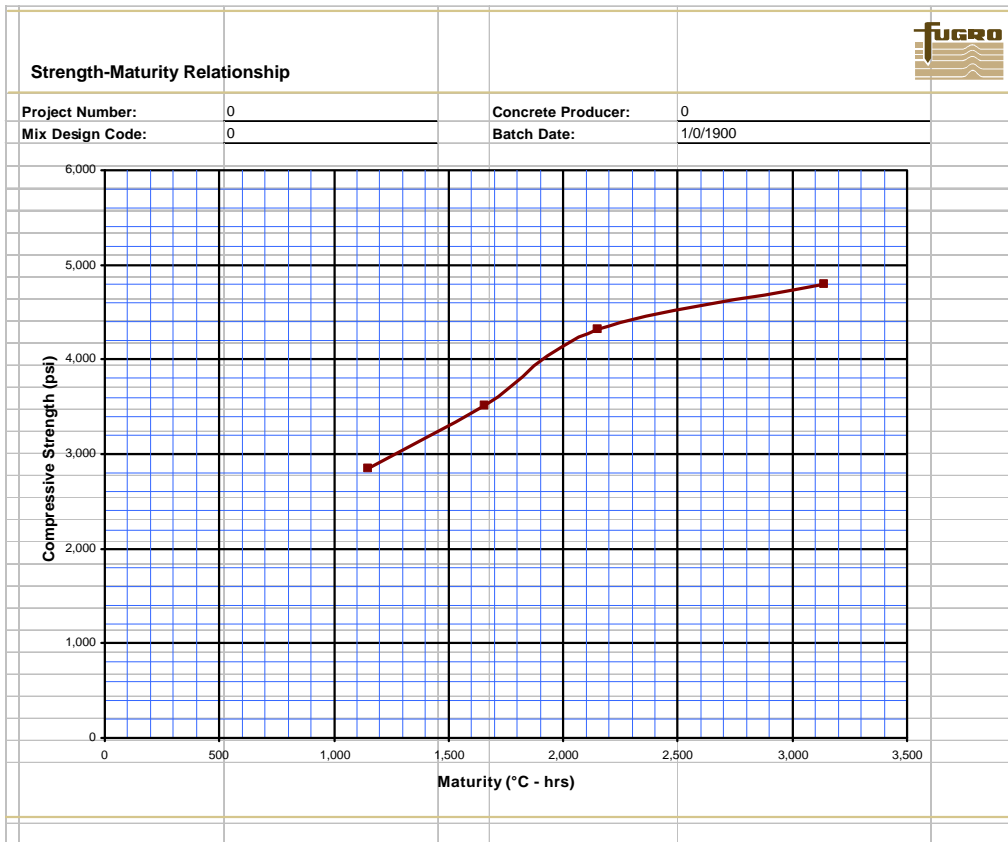


Figure 8. Plot of Maturity versus Compressive Strength – 2-inch by 2-inch Grout Cubes

As indicated in Figure 8, the design compressive strength of 4,000 psi for the grout used in the ACIP piles is achieved at a maturity of about 1,900 °C-hrs. Based upon laboratory compression data, a maturity of 1,900 °C-hrs was achieved 5 days after placement of the grout. However, data collected from the loggers installed within the ACIP piles themselves indicate that maturity of in-place grout for this project achieve a value of 1,900 °C-hrs in less than 3 days. The reason for this increase in the rate of maturity is the elevated temperature of the in-situ grout relative to the controlled temperature of a concrete curing room. Figure 9 illustrates the relationship of temperature with time for in-place grout at a depth of about 2 ft below grade in an ACIP pile.

The plot of time versus temperature in Figure 9 illustrates the increase in temperature during the initial curing process, followed by the gradual decline to a uniform temperature within the grout. As stated earlier, elevated temperatures increase the rate of maturity within the grout mix, resulting in early strength gain that is measurable using the Maturity Method.

Another interesting point identified during this study was the increase in temperature with depth within the ACIP pile. It has long been assumed that grout cures more quickly with depth in ACIP piles, and comparison of data retrieved from the maturity loggers within the ACIP piles for this project confirm that there was an increase in temperature (and thus maturity) measured from the maturity loggers placed at about 20 ft depth over maturity loggers placed at 2 ft depth. Based upon this information, the use of the Maturity Method to identify in-situ strength of ACIP piles would necessitate placement of maturity loggers in the upper portion of the pile as this would be the critical location where strength gain would require the longest period of time.

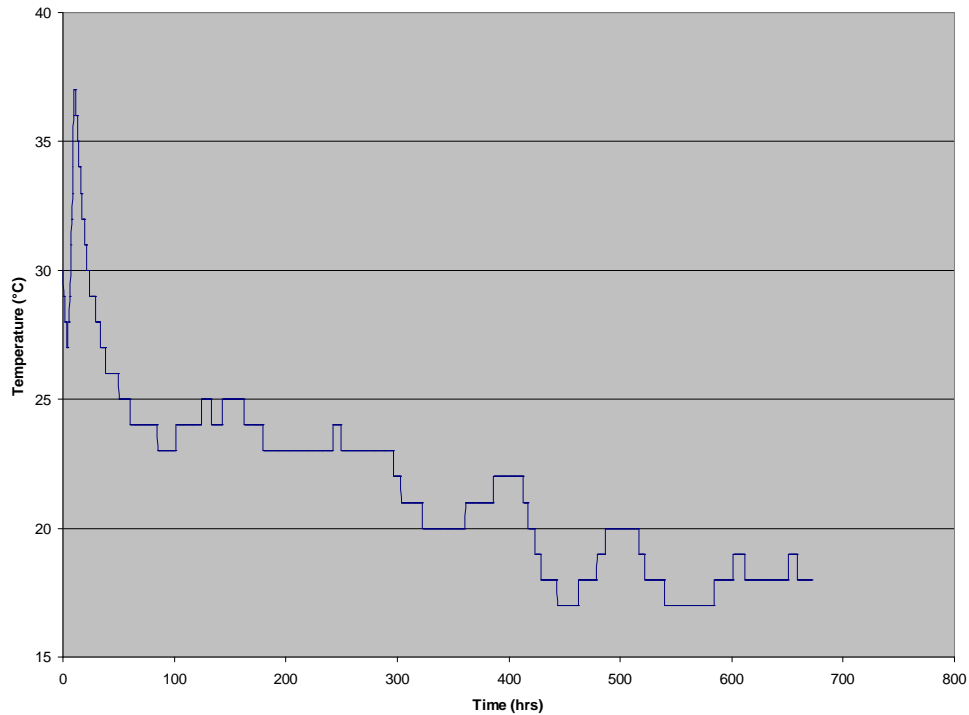


Figure 9. Time versus Temperature - In-Situ Grout 2 feet below Grade in ACIP Pile

CONCLUSIONS

Based upon the results of field and laboratory tests, including maturity readings and compressive strength testing, the use of the Maturity Method is a valid technique to evaluate strength gain of grout within ACIP piles. Results of maturity readings indicate that grout strength gain within ACIP piles occurs at a more rapid rate than in laboratory samples due to an elevated in-situ temperature during field curing relative to laboratory curing. Data collected from maturity loggers embedded within ACIP piles indicate that curing temperatures are greater with depth in the ACIP piles, thus correlating to a more rapid grout strength gain in the lower portion of the ACIP piles.

The Maturity Method can be a powerful tool in evaluating early strength gain of grout within ACIP piles, which can accelerate construction schedules by allowing loads to be placed on these foundations earlier than by destructive testing means alone. Additionally, the Maturity Method provides for better quality control and quality assurance of the grout used on ACIP pile projects. The Maturity Method can be used to supplement or reduce traditional grout cube testing performed during production pile installation.

REFERENCES

Engius (2003); IntelliRock™ Concrete Facts•Superior Results; Concrete Maturity Resource Guide. Version VIII; Engius, Inc. Stillwater, Oklahoma.