Uplift Resistance of Coated Driven Steel Piles

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ABSTRACT: Results of axial tension (uplift) tests on driven open-end pipe piles and H-Piles with difference surface coatings are presented. Piles included plain steel, galvanized steel and piles coated with Slickcoat™, a silicone epoxy surface coating. Open-end pipe piles with outside diameters of 2.875 in. and 4.5 in. and H-piles consisting of standard steel W6x9 sections were evaluated. Piles were installed using a simple gravity drop hammer. Uplift tests were conducted at four sites consisting of both clay and sand to evaluate the influence of surface coating on the short-term behavior and long-term behavior. Short-term tests were performed seven to ten days after driving; long-term tests were performed on the same piles 200 to 400 days after driving. Axial tension tests were performed to failure for each pile. A comparison of the installation driving records is presented which shows a similarity in driving resistance for the different surface coatings. Load tests are also presented and show that the Slickcoat™ coated piles gave a substantial decrease in shaft resistance for both short-term and long-term behavior as compared with plain or galvanized piles.

INTRODUCTION

Some foundation design situations require the need to consider reducing side resistance of driven steel piles. For example, there may be a need to reduce downdrag resulting from consolidation of soft clay or to reduce uplift forces from adfreeze resulting from frost heave or from swelling of expansive clays. Historically, bitumen and other materials have been used as surface coatings to reduce pile side resistance. In the present study, a silicone epoxy surface coating was applied to a series of round pipe piles and H-piles to evaluate the short-term and long-term influence of the coating on side resistance. The coatings were evaluated by performing axial tension tests on the piles which were driven at four sites. The results were compared to adjacent load tests conducted on plain steel (uncoated) piles and galvanized piles. Overall the coated piles showed a reduction in side resistance from the load tests.

TEST SITES

Tests were performed at four test sites where the senior author has previously performed other field tests.

Site-1: AgFarm-Solar: Site-1 is located in South Deerfield Massachusetts on property owned by the University of Massachusetts and consists of an unsaturated silty fine sand site overlying medium stiff clay at a depth of about 26 ft. Standard Penetration Test (SPT) N_{60} values range from about 8 to 15 in the upper 15 ft. The ground water level is seasonally at a depth greater than 10 ft.

Site-2: Taylor Field: Site-2 is located in North Amherst, Massachusetts on property owned by the University of Massachusetts. Soils at the site consist of about 6 ft. of saturated medium dense coarse to medium sand overlying clay. Standard Penetration Test (SPT) N60 values range from about 20 to 25 in the sand and about 6 to 8 in the clay. The ground water table at this site is seasonally at or near the ground surface.

Site-3: UMass DOE: Site-3 is located in Hadley, Massachusetts on property owned by the University of Massachusetts. The soils consist of approximately 1.5 m of stiff silty-clay fill overlying a thick deposit of late Pleistocene Connecticut Valley Varved Clay. The fill at the site consists of CVVC placed about 40 years ago after excavations at the Town of Amherst Wastewater Treatment Plant, adjacent to the site. Below the clay fill, the CVVC has a well-developed stiff overconsolidated crust. Figure 1 shows the soil profile and characteristics near the location of the pile tests.

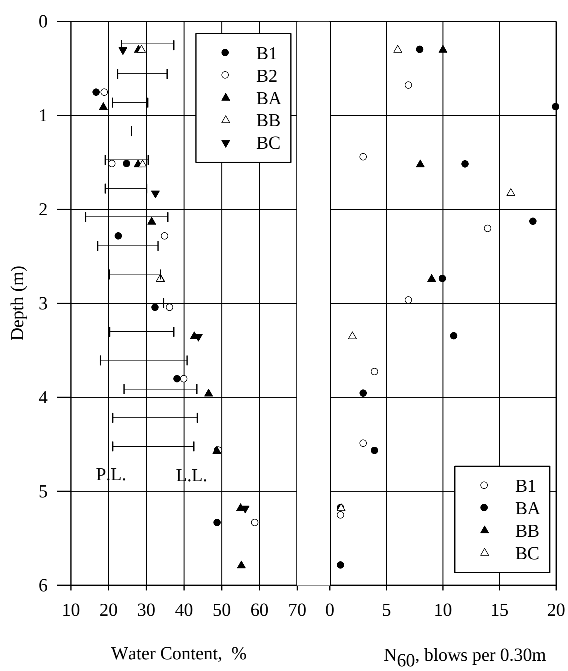

FIG. 1. Site-3 UMass DOE Site Characteristics.

Site-4: UMass HHF: Site-4 is located in Hadley, Massachusetts approximately 1 mile west of the University of Massachusetts on property owned by the University of Massachusetts. The site consists of a thick deposit of Connecticut Valley Varved Clay and does not appear to have ever had any construction at the site. The clay is medium stiff and the Sensitivity is around 5. The water table at this site is generally located within 1 to 2 ft. of the ground surface, or at the ground surface, most of the time.

Pile Sections Tested

Tests were performed on piles with three different surface preparations; 1) untreated, plain black steel; 2) hot-dipped galvanized steel; and 3) Slickcoat™ coated. Tests were initially performed at a single site, Site-1, on 2.875 in. and 4.5 in. O.D. Schedule 40 driven pipe piles. Based on the results obtained from these tests, the scope of the work was expanded to include three other sites and prototype-scale steel driven H-piles (W6x9). The coated H-piles were only compared with plain steel H-piles of the same section. Table 1 gives a summary of the piles installed and tested at each site.

Table 1. Summary of Piles Installed and Tested.

Site	Test No.	Pile	Coating	Length (ft.)	Total Number of Hammer Drops
1	1	2.875	P	8	10
	2	2.875	G	8	19
	3	2.875	REG	8	16
	4	2.875	NC	8	17
	5	4.5	P	8	21
	6	4.5	G	8	31
	7	4.5	REG	8	31
	8	4.5	NC	8	26
	9	W6x9	P	8	15
	10	W6x9	NC	8	15
	11	W6x9	NC	8	13
	12	4.5	P	8	28
	13	4.5	G	8	38
	14	4.5	REG	8	36
	15	4.5	NC	8	34
2	16	W6x9	P	10	88
	17	W6x9	REG	10	89
	18	W6x9	REG	10	91
3	19	W6x9	P	8	77
	20	W6x9	REG	8	65

	21	4.5	P	10	119
	22	4.5	REG	10	111
4	23	W6x9	P	8	70
	24	W6x9	REG	8	72
	25	4.5	P	10	113
	26	4.5	REG	10	108

Note: P = Plain; G = Galvanized; REG & NC = Coated.

Pile Installation Method

All piles were installed using a mechanical drop-weight drive hammer with a mass of 550 lbs. and a drop height of 44 in. Care was taken during pile installation to keep the pile and hammer vertical and prevent whipping of the pile to maintain contact with the soil over the full driving length. During installation a record was taken of the pile penetration for each hammer drop for all piles and the total number of hammer drops for full installation.

SHORT-TERM AND LONG-TERM LOAD TESTS

The plan for the field tests initially included load tests performed after a short aging period between installation and testing of either 1 to 10 days and after a longer aging period of approximately 200 or 400 days. Short term aging tests were initially conducted at Site-1. After testing the piles were then removed and reinstalled at a different location on the site adjacent to the first series of tests. A total of 26 tests were performed.

Load Test Procedure

Load tests were performed using the incremental maintained load method using the general procedures described in ASTM D3689 *Standard Test Method for Individual Piles Under Static Axial Tensile Load*. Load was applied by a single acting hollow ram 250kN hydraulic jack placed on top of two reaction beams centered over the anchor and resting on wood cribbing. Load was transferred from the jack to the anchor using a threaded rod. The load was measured using a digital load cell placed over the threaded rod on top of the hydraulic jack and was read using an electronic digital indicator. Deformation measurements were made using a digital dial indicator with a resolution of 0.0127 mm (0.0005 in.) attached to an independent reference beam. The dial indicator was referenced directly to a steel plate attached to the side of the pile with a worm-gear clamp. Loads were applied incrementally in the range of approximately 5 to 10% of the estimated ultimate capacity of each anchor. Each increment of load was maintained for 2.5 minutes giving a time to reach failure on the order of 50 to 60 min. Loads were applied until a relative displacement of approximately 3 in. of the was achieved or the piles failed by plunging, whichever occurred first. Smaller load increments were used in order to better define the load-displacement curve and to accurately define the ultimate capacity or failure load.

RESULTS

Pile Installation

Figure 2 shows installation driving records in the form of Pile Penetration vs. Cumulative Hammer Drops for the initial series of tests 2.875 and 4.5 in. O.D. pipe piles installed for the first set of tests at Site-1. These results show very little difference in the driving energy required to install Plain (New) steel, Galvanized or Coated piles to the same depth at the same site. This may be related to the short length of the piles used but is also probably more related to the dynamic impact driving installation. Surface texture appears to have very little influence on driving resistance simply because the energy is so great that the impact overcomes any influence of surface texture.

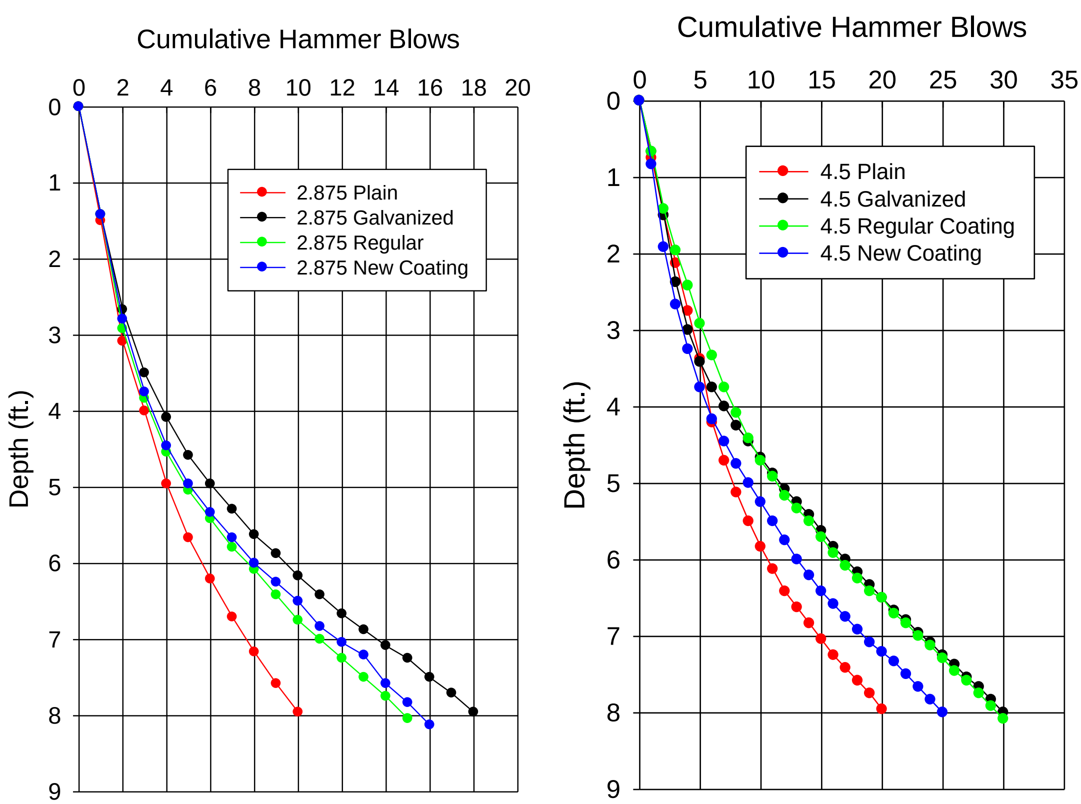

FIG. 2. Typical Driving Records for 2.875 in. and 4.5 in. Pipe Piles at Site-1

These results are typical of observations obtained at all four sites. In some cases the Plain piles required less driving resistance and in some cases the coated piles required less driving resistance. There was no consistent trend obvious at all four sites. Table 1 gives a summary of the total driving energy, in terms of total hammer drops required to install all piles in this study. Since all piles were installed using the same equipment, it is possible to make a general comparison using these results. Figure 3 shows a comparison between the Total Driving Energy of Plain Piles and Coated Piles for all sites, independent of pile geometry. Overall, there is effectively no significant difference in the driving resistance between the plain (uncoated) piles and the coated piles at three of the sites. The galvanized piles showed the highest driving resistance for the three comparisons made at Site-1.

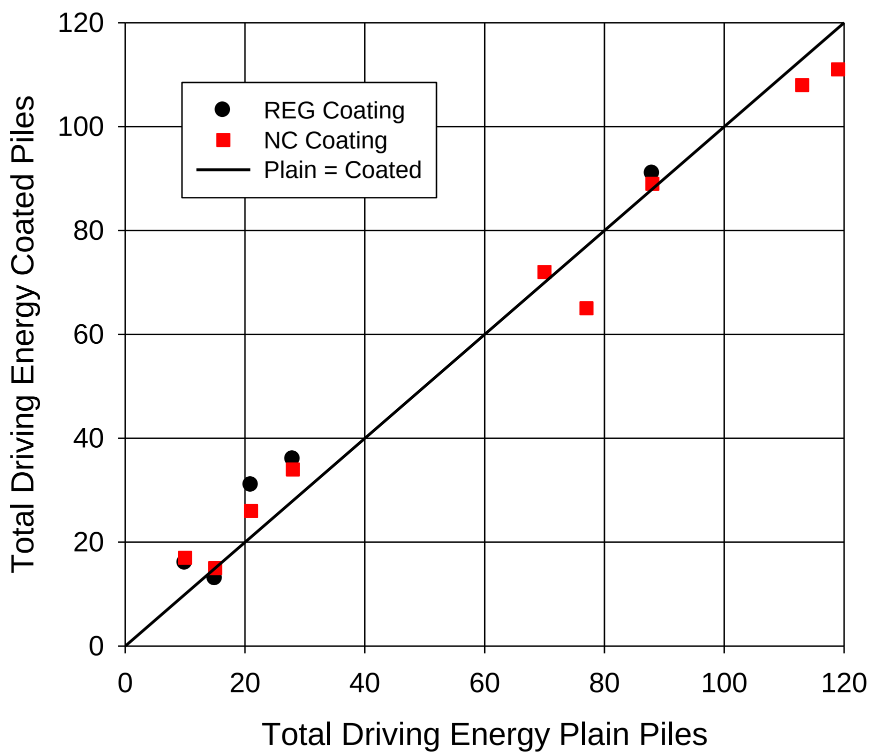

FIG 3. Comparison Between Total Driving Energy of Plain and Coated Piles.

Load Tests Results

Table 2 gives a summary of the load test results from this study in terms of the interpreted ultimate load capacity for each test. The interpretation of the ultimate load was very straightforward for these tension tests as all piles showed a rapid failure in uplift. Plain H sections showed less of a dramatic plunging failure than did coated piles which may be related to the plugging in between the flanges. Once the ultimate load was reached the pile essentially moved rapidly and could not maintain the applied load. Also given in Table 2 is the ratio of ultimate load of a coated pile to the ultimate load of a plain pile. Figure 4 shows typical load test results.

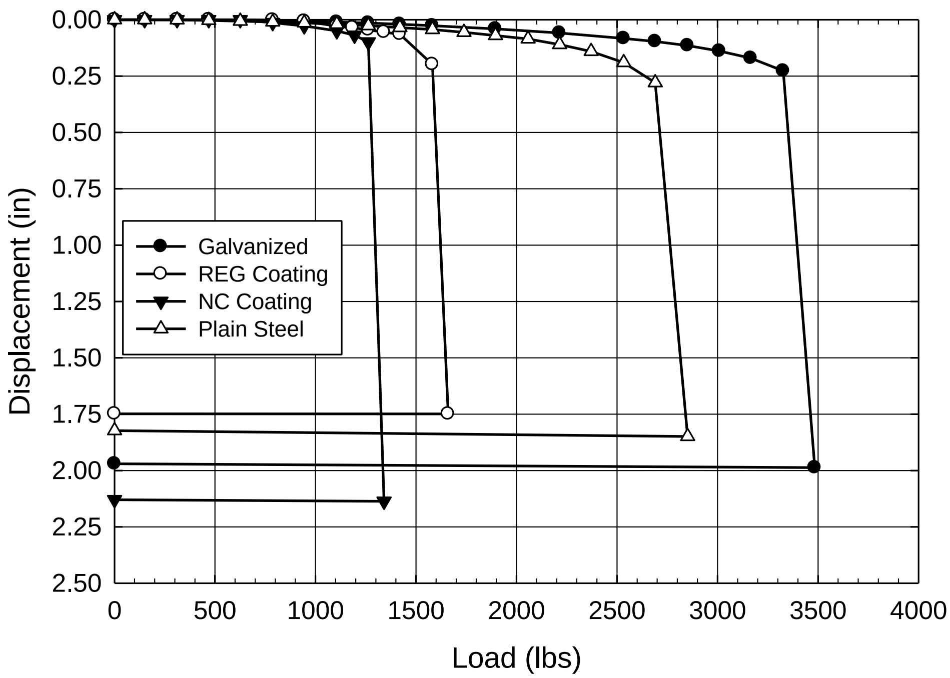

FIG. 4. Typical Load Test Results on 4.5 in. Piles at Site-1.

Table 2. Summary of Coated Pile Load Test Results

Site-1: AF-Solar (8 ft. Piles)				
Pile No.	**Pile Type**	**Age (Days)**	**Q_{ult} (lbs)**	**C/P**
1	2.875 Plain Steel	10	1050	2.86
2	2.875 Galvanized	10	3000	
3	2.875 Regular Coated	10	950	0.90
4	2.875 Normal Coated	10	1150	1.10
5	4.5 in. Plain Steel	9	2700	1.24
6	4.5 in. Galvanized	9	3350	
7	4.5 in. Regular Coated	9	1600	0.59
8	4.5 in. Normal Coated	9	1300	0.48
9	W6X9 Plain Steel	1	1600	
		202	3200	
10	W6X9 Blue Coated	1	2700	1.69
		202	2050	0.64
11	W6X9 Regular Coated	1	2700	1.69

		202	2200	0.69
12	4.5 in. Plain Steel	1	3400	
		200	2850	
13	4.5 in. Galvanized	1	3714	1.09
		243	1314	0.46
14	4.5 in. Regular Coated	1	2364	0.70
		231	2100	0.74
15	4.5 in. Normal Coated	1	2014	0.59
		231	1900	0.67

Site 2: Taylor Field (10 ft. Piles)				
	Pile Type	**Age (Days)**	**Q_{ult} (lbs)**	**C/P**
16	W6X9 Plain Steel	8	7700	
		175	8600	
		393	7700	
17	W6X9 Blue Coated	8	3400	0.44
		175	2750	0.32
		393	2880	0.37
18	W6X9 Regular Coated	8	3600	0.47
		175	2700	0.31
		393	3750	0.49
Site-3: DOE (8 ft. Piles)				
	Pile Type	**Age (Days)**	**Q_{ult} (lbs)**	**C/P**
19	W6X9 Plain Steel	7	8080	0.69
20	W6X9 Blue Coated	7	5550	
21	4.5 in. Plain Steel	10	7830	0.71
22	4.5 in Blue Coated	7	5555	
Site-4: HHF (8 ft. Piles)				
	Pile Type	**Age (Days)**	**Q_{ult} (lbs)**	**C/P**
23	W6X9 Plain Steel	10	8330	0.69
24	W6X9 Blue Coated	7	5800	
25	4.5 in. Plain Steel	7	9600	0.61
26	4.5 in. Blue Coated	7	5900	

Short-Term Tests

In most cases the coated piles produced lower ultimate capacities than plain piles for short-term tests, Figure 5. At Site-1, the small diameter coated pipe piles actually gave essentially the same short-term capacity as the plain steel pile. Also at Site-1 the two short-term tests on coated W6x9 piles gave considerably higher capacities as compared with the plain pile. In all other cases, for both sandy soils and clays, the epoxy coated piles gave lower short-term capacities as compared to plain piles.

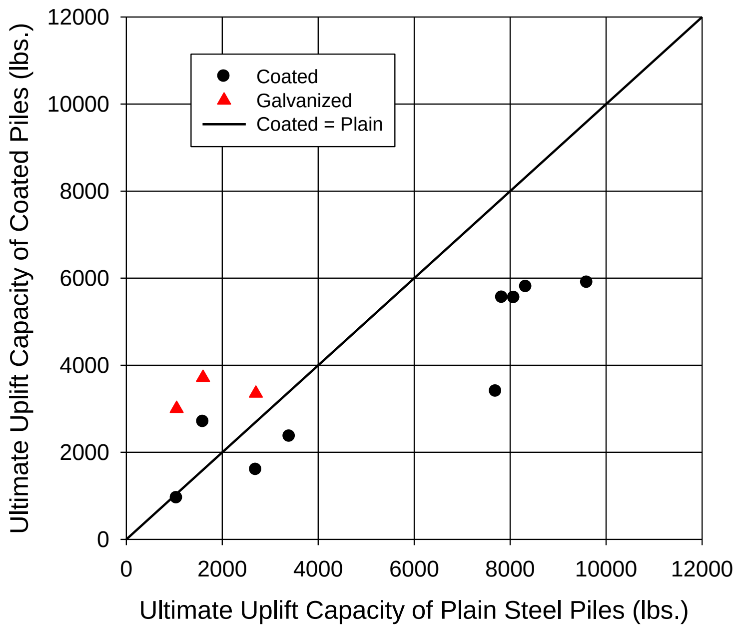

FIG.5. Comparison of Ultimate Capacities for Short-Term Tests.

Long-Term Tests

When the piles were left in place and aged for longer periods of time, in all cases, for both sandy soils and clays, the epoxy coated piles gave lower long-term capacities as compared to plain piles as shown in Figure 6. The difference was more dramatic for long-term tests with the epoxy coated piles giving an average of about 52% of the load capacity of the plain piles for nine long-term tests.

It was observed during the uplift testing that the plain H-piles produced significant heave in the soil in between the flanges of the pile, suggesting that the soil was lodged in between the flanges and moved with the pile. This means that the failure occurred in both the soil within the web and along the pile-soil interface on the outside of the flanges. During uplift testing of the coated H-piles no vertical soil heave was observed suggesting that the failure took place as slippage at the pile-soil interface. Therefore, it is possible that two different failure mechanisms are taking place during static loading.

As previously noted there was little difference in the driving resistance between plain and coated piles. Since the load tests show a lower side resistance for the coated piles, this means that in the case driving resistance is not a good indicator of load resistance. Long-term load tests on plain pipe piles showed a more gradual development of the load capacity, whereas the load tests on the coated piles showed a more rapid plunging. This may suggest that for the plain piles, the failure takes place in the soil away from the pile face while for the coated piles, the failure is an interface failure.

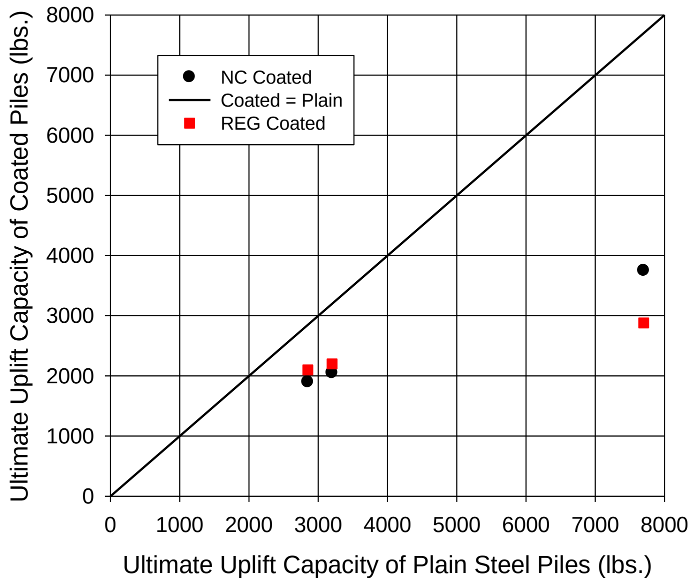

FIG.6. Comparison of Ultimate Capacities for Long-Term Tests.

SUMMARY

Results of a series of pile uplift tests performed at four sites using plain, galvanized and coated piles have been presented. The results indicate that there was little difference in dynamic installation energy required to install both open pipe piles and H-piles as compared to plain steel piles of identical geometry. At one site, the plain uncoated pile did show a somewhat higher driving resistance however this may only be the result of site variability. Galvanized piles appeared to show higher driving energy and higher load capacities, most likely related to the surface roughness produced by galvanization. Results of static uplift (tension) tests showed that the capacity of coated piles was lower than for uncoated piles. This difference appears to be accentuated for long-term tests where piles were left in the ground to age for periods ranging from 200 to 400 days. In summary, epoxy coated piles produce lower capacities ranging from about 35% to 70% of uncoated plain steel piles.

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