Investigation on Causes of Failure and Design of Remedial Measures of Pile Foundation Supporting Transmission Line Tower.

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ABSTRACT

The deficiencies in cast in-situ pile are detrimental for long term satisfactory performance of the foundation. The general deficiency found in these piles are reduction in area, discontinuity in pile length, shorter length of pile, quality of concrete and reinforcement. The cast in-situ pile foundation are invariably used as foundation system of power transmission lines towers. One such transmission line was investigated between Mahilpur-Jamsher in Punjab, consist of 143 number of towers, among which 56 number of towers are supported by bored cast in-situ underream pile under each leg. These pile have following design parameters: diameter 400 mm, length 3800 mm, depth 3500 mm from the top and diameter of the underream 2.5 times the shaft diameter. One such tower of this transmission line was uprooted along with the pile foundation. Present study investigates the probable reason (s) of failure of pile foundation through the low strain integrity test. A total of 224 numbers of piles were tested and 34 % of piles were found to be defective. Remedial measures in the form of additional piles were suggested for defective pile (s) based on the pile integrity test results, subsoil profile of the site and the load carrying capacity of the foundation system.

INTRODUCTION

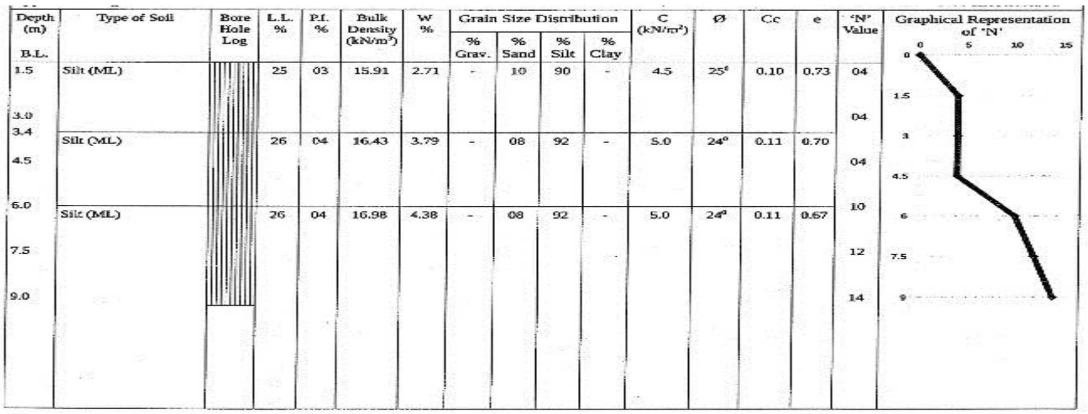
The use of cast-in-situ/bored piles in sub-structure have always been a great concern for geotechnical engineers. Due to deficiencies in quality of concrete and as-built length for new as well as in-service piles, their use as foundation system below the transmission line tower have always been apprehensive. For satisfactory long tern performance of this piles foundation, their geometry and parameters conceived during design should be ensured during construction stage. For quality assessment of the in-service piles, low strain integrity tests are used successfully. The integrity test of existing or in-service piles helps in ensuring the length, discontinuity in geometry of pile (necking, cracking and void) and quality assessment of concrete (Ni et al. 2006 & 2008). The advantages and disadvantages of different nondestructive testing method for piles and their application in field problems for determining the defects and exact length of the piles were carried out by Paikowsky and Chernauskas (2003). Prakash et al. (2003) applied low strain pile integrity test to determine the quality of concrete, shape and length of existing in-service pile below transmission line tower.

A failure in foundation system of Mahilpur-Jamsher transmission line in Punjab was occurred in the year of 2013. One of the towers of this line was uprooted in storm, causing total disruption of power supply of Punjab (Figure 1). The transmission line is about 47 km in length and consists of 143 numbers of towers. The design and drawings of the transmission tower foundation suggested that it is supported by underream piles as well isolated footing system. The transmission line was commissioned in the year of 1994-95. The objective of the project was to investigate the cause (s) of the failure and a suggestion of strengthening/remedial measure to the existing in-service pile foundation. Low strain pile integrity test was carried out to assess the existing conditions and as-built length of the existing piles. The present study discusses the use of the pile integrity test for ascertaining the deficiencies in the piles and strengthening/remedial measures for in-service pile at present conditions.

Figure 1. Uprooted pile foundation with tower

Sub-Soil Condition

The Mahilpur-Jamsher transmission line was commissioned more than 22 years back, the details related to sub-soil investigation carried out at the time of commissioning was not available. In general, this line passes through the cultivated agriculture land in most places. To establish the sub-soil strata of the stretch, geotechnical investigation was carried out at 14 different locations where change in sub-strata was noticed. The investigation work includes drilling of 14 nos. borehole upto 9 m depth and laboratory investigations on disturbed and undisturbed samples. Also, Standard Penetration Test (SPT) were carried out in the boreholes as per IS 2131 (1981). Investigation revealed, the sub soil strata predominantly of silt/ silty sand in top few meters followed by sandy strata. At other locations, the silty sand strata started from the top itself. The laboratory investigations carried out on the UDS and DS samples collected during drilling of borehole reveals that the sub-soil strata are similar in general and consist of predominantly coarse silt/ silty sand /poorly graded sand layers. The observed standard penetration value ‘N’ varies in the range of 4 to15 for a depth of 9 m. The observed N values indicate strata of low compactness. In general, the water table was found to be at a depth of 1.5 m- 4.5 m below NGL. Figure 2 shows the typical borelog with SPT ‘N’ value. These soil properties were used to estimate the capacity of the existing piles.



Depth (m) B.L.	Type of Soil	Bore Hole Log	L.L. %	P.I. %	Bulk Density (kN/m³)	W %	Grain Size Distribution % Grav.	% Sand	% Silt	% Clay	C (kN/m²)	Ø	Cc	e	'N' Value
1.5	Silt (ML)		25	03	15.91	2.71	-	10	90	-	4.5	25°	0.10	0.73	04
3.0															04
3.4	Silt (ML)		26	04	16.43	3.79	-	08	92	-	5.0	24°	0.11	0.70	
4.5															04
6.0	Silt (ML)		26	04	16.98	4.38	-	08	92	-	5.0	24°	0.11	0.67	10
7.5															12
9.0															14

Figure 2. Typical borelog with SPT values

Design Details

Each transmission line tower consists of four leg. Under each leg, one 400 mm in diameter and 3500 mm in length (below NGL), single under reamed pile was provided. Overall length of the pile is 3800 mm and bulb is at a depth of 3500 mm from top of the pile with diameter to pile shaft ratio of 2.5. M15 grade of concrete was used in the piles. The main reinforcement consists of 3-16 mm and 3-20 mm tor steel bars and rings of 6 mm diameter M.S. bars are provided @ 250 mm c/c.

FIELD INVESTIGATIONS

Visual inspection of individual transmission tower foundation was carried out before the low strain integrity test for examining the present conditions and simultaneously, the diameter of the piles with surrounding conditions were also recorded (Figure3). The visual inspection of the physical conditions were then used to decide the stress wave velocity of the pile foundation.

Figure 3. Present condition of the in-service piles

Field procedure

The low strain integrity tests have been conducted on the pile heads (about 300 mm above NGL) under each individual leg of all the towers. Each pile head was cleaned of any earth, loose particles of concrete and dust. The integrity test was conducted by striking the pile head with a small manual hammer in the axial direction. The wave response consisting of reflections from the locations in variation of pile section such as increase or decrease in the cross-section, cracks, necking or inclusion from the pile toe are picked up by an accelerometer placed on pile head close to the hammer blow. At each pile, at least a set of 3 signals were taken to obtain repetitive and good representative signals. Impact of hammer blow was given at two to three locations on pile head to assess the overall condition. To arrive at the most appropriate stress wave velocity and corresponding lengths for proper assessment of structural condition of piles, the maximum stress wave velocity has been taken as 3600 m/s considering grade of concrete, its method of mixing along with its placement and aging. The lower limit for the same was considered as 2400 m/s. These records are stored on the computer for subsequent processing and analysis.

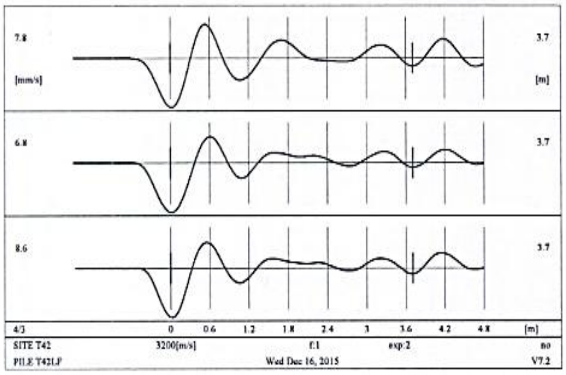
Figure 4. Pile integrity test in progress

RESULT OF INTEGRITY TESTS

Structural condition assessment of piles

Close examination of the failed piles reveals that the pile have improper bulb formation and shorter as-built length than design one. The integrity test results obtained in the field were post-processed subsequently, keeping in mind the observations made during field tests such as soil data, construction of piles and other common features associated with these type of piles. Other features such as projection of pile 300 mm above NGL, variation in soil strata due to cultivation and bracings joints with piles at about 600 mm below the pile top etc. were also considered in final assessment of structural condition of piles. More weightage in the final assessment was given to the shape and length of pile rather than the variations in stress wave velocity which is indicative of average concrete strength over the entire length of pile. This helps in creation of six scale category for the assessed piles vis-à-vis; 'Good', 'Satisfactory', 'Fair', 'Fairly Poor' 'Poor' and 'Very Poor' which are discussed below:

Good - The piles whose signals showed local variations in the sections or reflection of any common features resulting due to sub-soil variations and the other features as mentioned above with proper bulb formation as well as length more than or equal to 3.6 m from test level as shown in Figure 5.



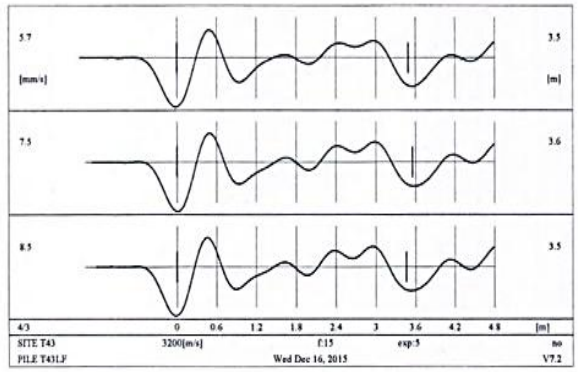
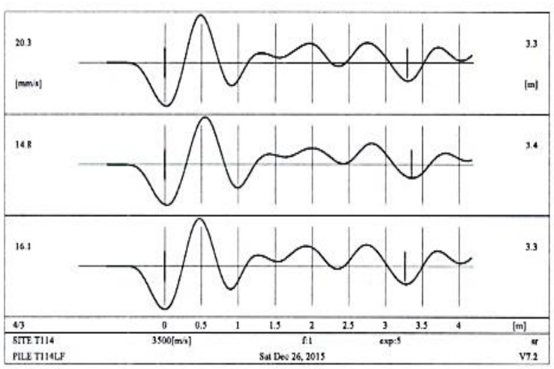


Figure 5. Reflectogram considered as good **Figure 6. Reflectogram considered as satisfactory**

Satisfactory - The piles whose signal showed minor variations in section, increase/enlargement in section above the designed bulb formation level with bulb formation fairly clear and length in between 3.4 m - 3.5 m from the test level as shown in Figure 6. In these cases also, it is expected that the performance of pile shall not be affcted under load.

Fair – The pile whose signal reveals length in between 3.2 m to 3.4 m from test level with reflections of bulb formation fairly clear; irregular/variations (enlargements) in sections as shown in Figure 7. In these cases also, it is expected that the performance of pile shall be affcted marginally (10% to 15%) under load.



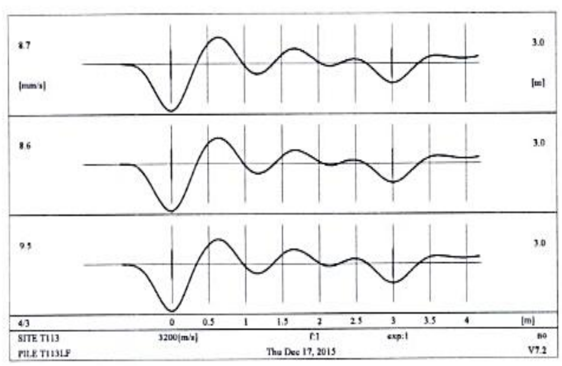
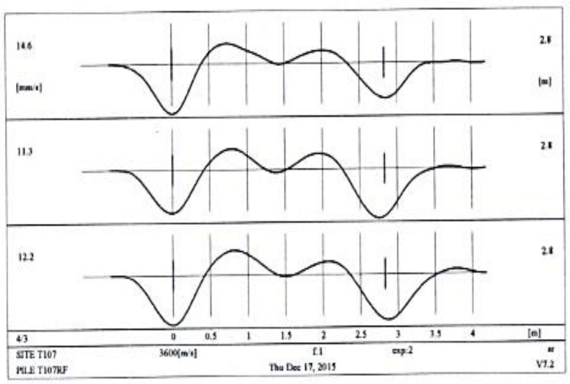


Figure 7. Reflectogram considered as poor **Figure 8. Reflectogram considered as fairly poor**

Fairly Poor – The piles whose signal reveals length in the range of 3.1 m - 3.2 m form test level with reflections of bulb formations not very clear, irregular variations in sections as shown in Figure 8. In these cases, it is expected that the performance of the pile shall be affected under loads.

Poor – The piles whoose signal reveals length less than 3.0 m with no clear reflection of bulb formations, only minor incraese in sections at bulb locations, variations in sections as shown in

Figure 9. In these cases, it is expected that the performance of the piles shall considerably affected under load.



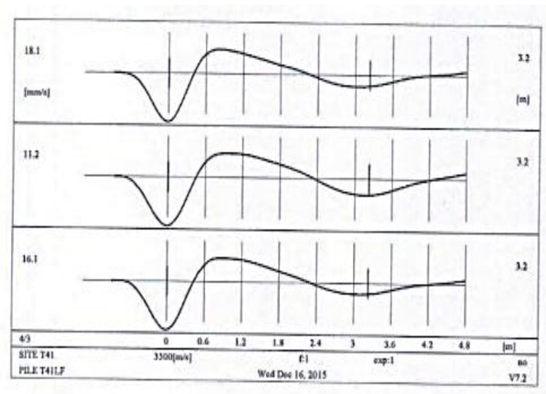


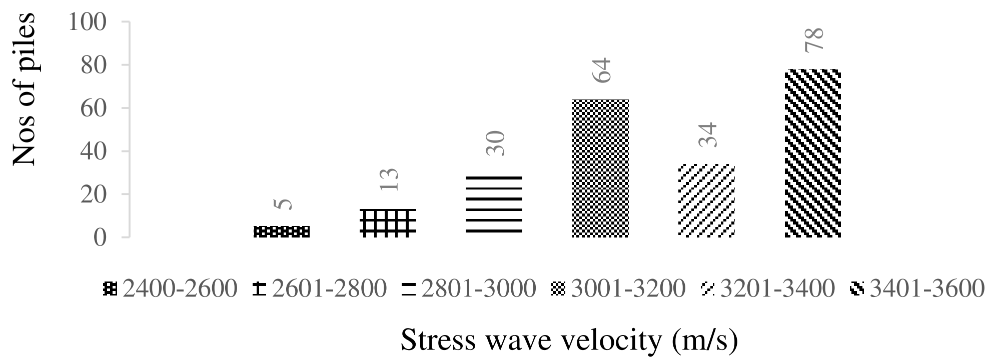
Figure 9. Reflectogram considered as poor Figure 10. Reflectogram considered as very poor

Very Poor – The piles whoose signal reveals significantly less than the designed length with no reflection of bulb formation, defective shaft, almost no increase in section as shown in Fig.10. In this case, it is expected that the performance of piles are greatly affected under loads.

Statistics of stress wave velocity & structural conditions of pile

The statistics of structural condition (Figure 11) of piles show that the out of 224 numbers of underreamed pile tested 15 piles (7%), 57 piles (25%), 75 piles (34%), 50 piles (22%), 9 piles (4%) and 18 piles (8%) fall under the category of Good, Satisfactory, Fairly Poor, Poor and Very Poor respectively.

The statistics of stress wave variation (Figure 11) reveals that out of 224 underream pile tested, 18 piles (8%) with the stress wave velocity 2400 -2800 m/s shows the quality of the concrete is poor to fair; 94 piles (42%) with the stress wave velocity 2800 -3200 m/s show the quality of the concrete is satisfactory; 142 piles (63 %) with the stress wave velocity 3200-3600 m/s shows concrete is of good quality.



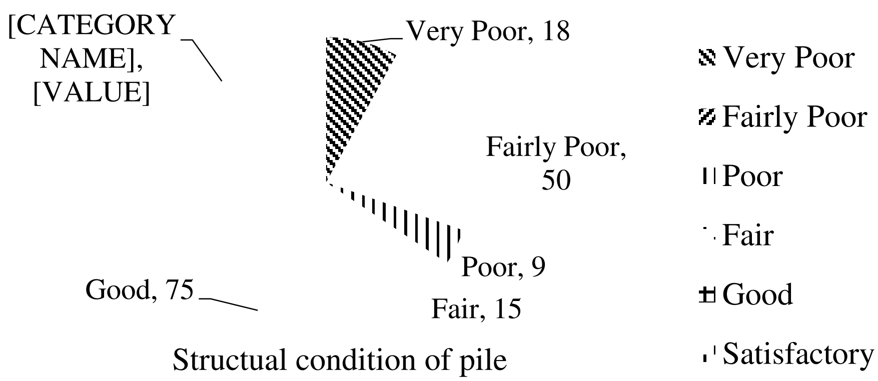


Figure 11. Stress wave velocity & structual condition of underream pile below existing tower

Capacity of piles in existing condition

The design of piles under the tower is mainly governed by the uplift (pullout) loads. Hence, the pile capacity have been asseseed under uplift condition and then checked against vertical and lateral load. In view of the difficulties in assessing capcity of each individual pile considering the actual variations in shape as observed, the capacities have been assessed with the following variations in pile shape and length for the piles corresponding to various catergories of strcutural conditions as already described above. The shaft daimeter (D) is taken as 400 mm while diameter of bulb was taken as 2.5D (100%), 2.125D (75%), 1.75D (50%), 1.375D (25%) & 1D (0%) respectively.The length of piles were taken as 3.5 m, 3.0 m & 2.5 m for the various categories of piles in Good to Very Poor conditions. The results show that the piles falling in the group ‘Fairly Poor’ ‘Poor’ and ‘Very Poor’ requires 40%, 58% and 78% capacity augementation in existing condition to support the towers.

REMEDIAL MEASURES SUGGESTED

The remedial measures to be provided for the piles falling under the structural condition categories,'Fairly Poor', 'Poor', and 'Very Poor' to achieve the additional capacities. The details of remedial measures using additional piles suggested is presented below in Figure 12.

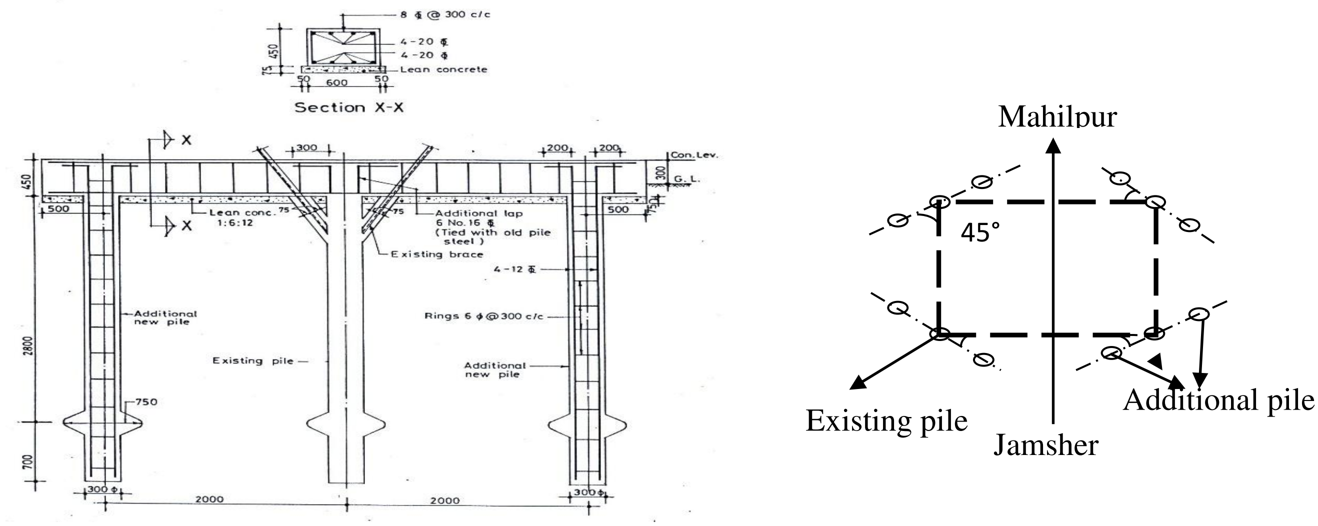


Figure 12. Remedial measures for strengthening foundation system under existing tower

CONCLUSIONS

Low strain pile integrity test was carried out to investigate the present condition of the in-service piles. The as built length and geometry of the underream pile foundation supporting transmission line tower can be estimated through the integrity test. Variation in section along the length of the pile with improper bulb formation can be predicted by pile integrity testing. For the present case study, among 224 number of piles tested, 34% piles needs capacity augmentation in the present condition to support the tansmission line tower. Installation of additional piles with due care ensuring the length and geometry will strengthen the existing piles in present conditons and will ensure the long term satisfactory performance of the tower foundations.

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