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A Study on Geotechnical Investigation and Tests on Pile

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***Abstract*: This paper gives details of test conducted during geotechnical investigation and recommendations based on test results for two sites as case studies for A J Institute of Engineering & Technology, Mangalore and Sridevi College Hostel Building, Mangalore of 6 Storey. The region situated at western India where piles passes clayey deposit and highly weathered strata. From construction sites, the data of pile load test were collected for the detailed study.**

Pile load tests like Pull out load test, Lateral load test, Vertical load test and Pile integrity test were conducted for the proposed sites and covered in this study. The detailed pile load test results were shown and these tests give conventional load settlement curve for load upto failure. The pile load tests were done based on Codal provision of IS 2911 (Part 4): 2013. Example of Pile load capacity as per IS 2911 (Part 1/Sec 2): 2010 for both granular and cohesive soil of 750mm diameter, depth of 15m and 6m respectively by static analysis were shown.

***Keywords*: Geotechnical Investigation, Borehole log, Pile tests, CAPWAP analysis, Pile load capacity.**

1. Introduction

Foundation is the key for strength of building. Construction of poor foundation gives dangerous alarm for the occupants and neighborhood. Nowadays the high rise building reaches the sky is very important for strong foundation. When comes to coastal region, the formation of unconsolidated material composed of sand, gravel, silt, clay and laterite. Based on the type of soil and type of foundation, piling been done and certain tests related to pile were carried out for safer side.

A. Scope of study

This paper report comprises of,

- Introductory and background information of contracting agencies.
- Case studies of two 6 storied college building.
- Detailed geotechnical investigation consists of observation and results related to laboratory and field testing.
- Preparation of geotechnical bore logs for the proposed site.
- Based on SPT and compressive strength of rock, type of foundation and drainage related issues are recommended by the experts are shown.
- Various type of tests for a pile along with detailed observation, results and graphically shown.

2. Literature Review

Rajan Kataria, et.al, (2003), High strain dynamic pile load test were done to access the settlement under loading, structural integrity of pile and pile capacity in a limited time at Delhi Metro Rail project. The friction cum end bearing piles was tested using pile driven analyzer and the data collected were subjected to case pile wave analysis program. It was concluded that when compared with information obtained from high strain dynamic pile load test is more than static pile load test, which also saves time and early completion of project.

H. S Thilakasiri, (2006), To identify the defective piles, pile integrity test using sonic pulse echo method were used in srilanka for bored piles. The wave equation method gives variation that observed when blowing a hammer on a pile. Based on stiffness of soil, some of the observations given by PIT records at the toe of the pile give a positive or negative velocity reflection. When the stiffness of the soil at the toe of pile shaft is soft, relatively records a positive velocity reflection where defect is identified enormously at the pile shaft. PIT observations were explained qualitatively by using wave equation method.

K. P Dash, et.al, (2014), Soil investigation on the bank of nallah and selection of foundation for superstructure were carried out. Laboratory test and field test were conducted to know what type of foundation is suitable for the soil. Detailed characteristics of each borehole at a depth of 10.0m were shown. Based on investigation, deep foundation holds good for the stratum. It was concluded that for less load forms shrinkage, high swelling and compressibility of pressure bulb in soil.

3. Case Study – 1

A. Geotechnical Investigation report

A.J. Shetty, Mangalore were requested to carry out "Geotechnical Investigation for proposed construction of A J Institute of Engineering & Technology of 6 storeyed (G+5 Floors) building at Kulur, Mangalore during the year 2013.

They approached the Department of Civil Engineering, National Institute of Technology Karnataka for boring and Standard Penetration Tests (SPT).

1) Observation

Some of the observations are,

- Bore holes were done at two locations.
- It was terminated at a depth of 12.0m and 6.8m respectively.
- It was reported that water table situated at ground level.
- According to Bureau of Indian Standards, SPT for soil/ rock samples were conducted at suitable depth levels within the bore holes as shown in Fig 1 (a) and (b).
- Compressive strength for rock sample from bore holes 1 and 2 was found to be 38,000 kN/m^2 and 42,000 kN/m^2 respectively.

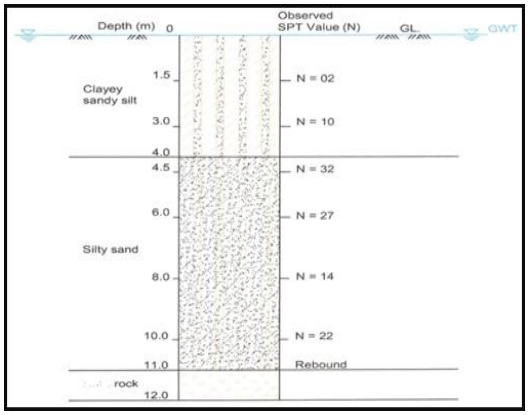


Fig. 1(a). Borehole no. 1

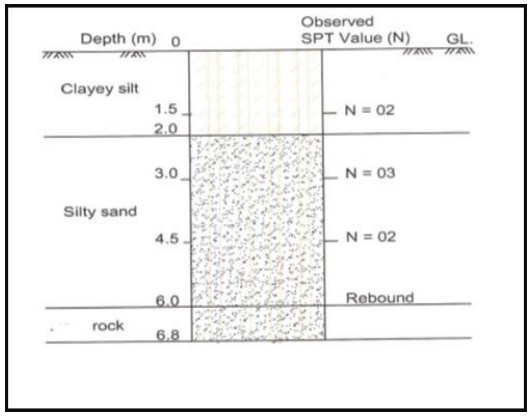


Fig. 1(b). Borehole no. 2

2) Recommendation

Due to water table at ground level, availability of rock and poor soil condition at shallow depth for the proposed structure, pile foundation was recommended. Good drainage facility shall be provided at site. Piles are embedded into the hard rock properly. The compressive strength of rock given shall be made use to ascertain the bearing capacity of piles in rock.

B. Tests on pile

The safe load capacity of piles is performed based on the load test on piles. There are two types of load tests namely Initial and routine tests. But in this proposed site, Lateral load test, pull out test, vertical load test and High strain dynamic load test were done. These tests were conducted by M/s RAMSONS INFRASTRUCTURE.

1) Lateral load test

Lateral load test shall be performed as per IS: 2911(Part 4) – 1985. Hydraulic jack was introduced of suitable capacity along with pressure gauge placed horizontally abutting the pile. The jack is placed between two piles and from the adjacent pile, reaction shall be obtained. With the help of calibrated pressure gauge placed on the jack, lateral load applied shall be measured. The details of equipment and test pile were shown in Table 1. This test is conducted at cut off level where the pile head will be chipped off 300mm above this level. On pile surface, the dial gauges are fitted with 25mm square piece of glass. On central position of glass plate, the dial tips shall be rested.

Table 1
Details of Lateral Load Test and Test Pile

TEST PILE DETAILS	
Pile No	B 3 b (College Block)
Size	750 mm Dia
Depth of Pile	6.40 m from EGL
Date of Concreting	23.05.2014
Date of Testing	17.09.2014
Designated Lateral capacity of Pile	10.00 MT
Test Load	15.00 MT
Grade of Concrete	M-30
HYDRAULIC JACK DETAILS	
Make	HYDROPACK
Capacity/ No of Jacks	50 MT/ One
Ram diameter	80 mm
Ram Area	50.2857 cm^2
HYDRAULIC PUMP DETAILS	
Make	HYDROLINE
Capacity	750 Kg/cm^2
PRESSURE GAUGE DETAILS	
Make	AKVALO
Range	0 – 420 Kg/cm^2
DAIL GAUGE DETAILS	
Make	Baker
Least Count	0.01 mm
Range	0 – 25 mm
Numbers	2
PILE REINFORCEMENT DETAILS	
Main Bars	8 Nos 20 tor
Rings/ Helicals	8 tor @ 150 c/c
Stiffners	16 tor rings @ 1500 c/c

At the cut off levels, the loads shall be applied in increments of about 20% of the estimated safe load.

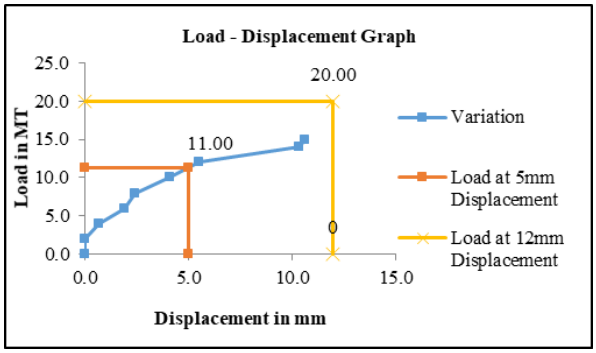
The next load increment shall be applied after the rate of displacement of two dial gauges is near to 0.1 mm per 30minutes. Unless failure occurs first, 150% shall be loaded for the test pile of the designed load. The detailed observation and test results were shown in Table 2.

To measure displacement, one dial gauge shall be placed exactly at the cut off level when it is approachable. If the cut off level is unapproachable, two dial gauges shall be set up horizontally one above the other with least count 0.01mm sensitivity and spaced 30cm apart to calculate lateral

Table 2
Detailed Observations and Results on Lateral Load Test

Date/ Time	Increment Details %	Actual Pressure (Kg/cm^2)	Load in Tonnes	Dial Gauge Readings		Displacements (mm)		Displacements at COL		Average Displacement at COL
				A	B	A	B	w.r.t Dial A (88.52 %)	w.r.t Dial B (84.37%)	
26/06/2010										
12:10	0	0.00	0.000	0	0	0.00	0.00	0.0000	0.0000	0.0000
12:10	20	40.00	2.011	0	0	0.00	0.00	0.0000	0.0000	0.0000
	20	40.00	2.011	0	0	0.00	0.00			
12:40	40	80.00	4.023	69	60	0.69	0.60	0.6993	0.5906	0.6450
13:10	40	80.00	4.023	79	70	0.79	0.70			
13:10	60	120.00	6.034	151	135	1.51	1.35	2.0800	1.7465	1.9133
13:40	60	120.00	6.034	205	179	2.05	1.79			
14:10	60	120.00	6.034	235	207	2.35	2.07			
14:10	80	160.00	8.046	250	210	2.50	2.10	2.3370	2.5734	2.4552
14:40	80	160.00	8.046	250	280	2.50	2.80			
15:10	80	160.00	8.046	264	305	2.64	3.05			
15:10	100	200.00	10.057	446	387	4.46	3.87	4.5145	3.6703	4.0924
15:40	100	200.00	10.057	480	406	4.80	4.06			
16:10	100	200.00	10.057	510	435	5.10	4.35			
16:10	120	240.00	12.069	635	646	6.35	6.46	5.6298	5.4675	5.5487
16:40	120	240.00	12.069	636	648	6.36	6.48			
16:40	140	279.00	14.030	825	819	8.25	8.19	10.7200	9.9647	10.3424
17:10	140	279.00	14.030	1109	1083	11.09	10.83			
17:40	140	279.00	14.030	1212	1181	12.12	11.81			
17:40	150	299..00	15.035	1246	121	12.46	12.11	11.0300	10.2178	10.6239

displacement. Variations on load – Displacement were graphically represented on Graph 1.



Graph 1: Variations on Load – Displacement by Lateral Load Test

2) Pull out load test

Pull out load test shall be performed as per IS: 2911(Part 4) – 1985. Pile head shall be chipped off till sound concrete and pile cap is casted to place jack. Three Rolled steel joist (R.S.J) are used. One over jack on the pile cap and other two shall rest on the ground as concrete block or two dummy piles are casted at a minimum distance of 2.5 times the diameter of piles. When jack is operated, the pile gets pulled up and the reaction transfers to the ground through concrete block or dummy piles. As R.S.J frame attached on top of pile cap and the jack reacts against the frame. This frame work is connected with the help of steel bars shall be threaded. The details of equipment and test pile were shown in Table 3.

The calibrated pressure gauge measures load that applied by the jack. The test pile is loaded with 20% incremental and 200% of design load, unless the failure occurs first.

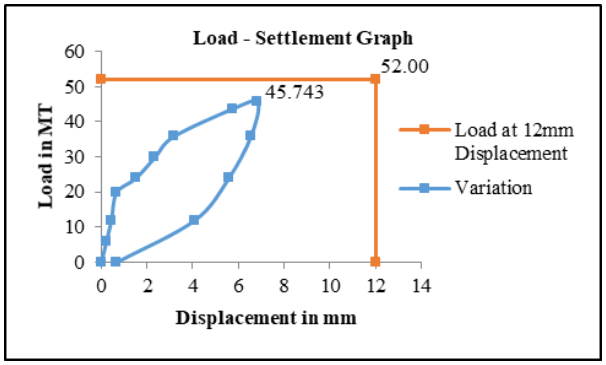
The detailed observation and test results were shown in Table 4. To measure displacement, minimum of two dial gauges are fixed to datum bar with least count of 0.01mm sensitivity placed diametrically opposite provided with rigid supports. Variations on load–Displacement were graphically represented on Graph 2.

Table 3
Details of Pull Out Load Test and Test Pile

TEST PILE DETAILS	
Pile No	K 5 a (College Block)
Size	600 mm Dia
Depth of Pile	6.40 m from EGL
Date of Concreting	26.05.2014
Date of Testing	09.10.2014
Designated Pull Out capacity of Pile	30.00 MT
Test Load	45.00 MT
Grade of Concrete	M-30
HYDRAULIC JACK DETAILS	
Make	HYDROPACK
Capacity/ No of Jacks	300 MT/ One
Ram diameter	225 mm
Ram Area	397.76785 cm^2
HYDRAULIC PUMP DETAILS	
Make	HYDROLINE
Capacity	750 Kg/cm^2
PRESSURE GAUGE DETAILS	
Make	AKVALO
Range	0 – 420 Kg/cm^2
DAIL GAUGE DETAILS	
Make	Baker
Least Count	0.01 mm
Range	0 – 25 mm
Numbers	2
PILE REINFORCEMENT DETAILS	
Main Bars	8 Nos 16 tor
Rings/ Helicals	8 tor @ 150 c/c
Stiffners	16 tor rings @ 1500 c/c

Table 4
Detailed Observations and Results on Pull out Load Test

Date/ Time	Increment Details %	Actual Pressure (Kg/cm^2)	Load in Tonnes	Dial Gauge Readings		Displacements (mm)		Average Displacement at COL
				A	B	A	B	
26/06/2010								
11:20	0	0.00	0.000	0	0	0.00	0.00	0.0000
11:25	20	15.00	5.967	19	25	0.19	0.25	0.2200
11:55	20	15.00	5.967	19	25	0.19	0.25	0.2200
11:55	40	30.00	11.933	39	47	0.39	0.47	0.4300
12:25	40	30.00	11.933	39	47	0.39	0.47	0.4300
12:25	60	50.00	19.888	62	70	0.62	0.70	0.6600
12:55	60	50.00	19.888	62	70	0.62	0.70	0.6600
12:55	80	60.00	23.866	145	153	1.45	1.53	1.4900
13:25	80	60.00	23.866	145	153	1.45	1.53	1.4900
13:25	100	75.00	29.833	187	275	1.87	2.75	2.3100
13:55	100	75.00	29.833	188	275	1.88	2.75	2.3500
13:55	120	90.00	35.799	205	418	2.05	4.18	3.1150
14:25	120	90.00	35.799	206	432	2.06	4.32	3.1900
14:25	140	110.00	43.754	392	755	3.92	7.55	5.7350
14:55	140	110.00	43.754	393	760	3.93	7.60	5.7650
14:55	150	115.00	45.743	560	770	5.60	7.70	6.6500
15:25	150	115.00	45.743	580	827	5.80	8.27	7.0350
Release of Load								
15:30	120	90.00	35.799	525	827	5.25	8.27	6.7600
16:00	120	90.00	35.799	524	740	5.24	7.40	6.3200
16:00	80	60.00	23.866	495	680	4.95	6.80	5.8750
16:30	80	60.00	23.866	480	570	4.80	5.70	5.2500
16:30	40	30.00	11.933	369	449	3.69	4.49	4.0900
17:00	40	30.00	11.933	365	448	3.65	4.48	4.0650
17:00	0	0.00	0.000	95	55	0.95	0.55	0.7500
17:30	0	0.00	0.000	95	25	0.95	0.25	0.6000
Gross Settlement								**7.0350 mm**
Net Settlement								**0.600 mm**
Rebound								**6.4350 mm**



Graph 2: Variations on Load – Displacement by Pull out Load Test

3) *Vertical load test*

Table 5
Details of Vertical Load Test and Test Pile

TEST PILE DETAILS	
Pile No	C 32 c
Size	600 mm Dia
Depth of Pile	6.40 m from EGL
Date of Concreting	07.04.2014 – Tremie Method
Date of Testing	26.11.2014 – 27.11.2014
Designated capacity of Pile	130.00 MT
Test Load	195.00 MT
Grade of Concrete	M-30
HYDRAULIC JACK DETAILS	
Make	HYDROPACK
Capacity/ No of Jacks	300 MT/ Two
Ram diameter	225 mm
Ram Area	795.536 cm^2
HYDRAULIC PUMP DETAILS	
Make	PLY HYDRON
Capacity	750 Kg/cm^2
PRESSURE GAUGE DETAILS	
Make	AKVALO
Range	0 – 400 Kg/cm^2
DAIL GAUGE DETAILS	
Make	Baker
Least Count	0.01 mm
Range	0 – 25 mm
Numbers	4
PLATFORM DIMENSIONS	
Bottom	10.00 m x 9.00 m
Middle @ 1.50m	10.00 m x 9.00 m
Top @ 2.10m	9.50 m x 8.50 m
Volume of fill	186.187 cum
Weight of fill @ 1.5/m^3	279.300 MT
Weight of plates & girders	18.00 MT
Weight of Kentledge platform	297.300 MT

Table 6
Detailed Observations and Results on Vertical Load Test

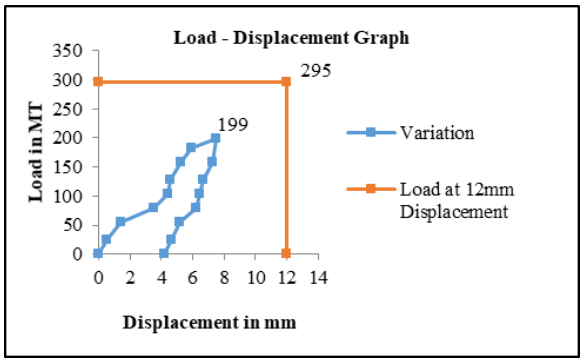
Date/ Time	Increment Details %	Actual Pressure (Kg/cm^2)	Load in Tonnes	Dial Gauge Readings				Displacements (mm)				Average Displacement at COL	Remarks
				A	B	C	D	A	B	C	D		
26/11/2014													
	0	0.00	0.000	0	0	0	0	0	0	0	0	0.00	
10:45	20	30.02	23.882	30	32	47	48	0.30	0.32	0.47	0.48	0.3925	
11:15	20	30.02	23.882	41	38	60	60	0.41	0.38	0.60	0.60	0.4975	0.1050
												Increment Given	<0.1 mm
11:20	40	70.06	55.735	153	140	124	137	1.53	1.40	1.24	1.37	1.3850	
11:50	40	70.06	55.735	161	145	128	141	1.61	1.45	1.28	1.41	1.4375	0.0525
												Increment Given	<0.1 mm
12:00	60	100.10	79.633	351	319	342	371	3.51	3.19	3.42	3.71	3.4575	
12:30	60	100.10	79.633	363	321	352	388	3.63	3.21	3.52	3.88	3.5600	0.1025
												Increment Given	<0.1 mm
12:35	80	130.13	103.523	458	428	428	441	4.58	4.28	4.28	4.41	4.3875	
13:05	80	130.13	103.523	460	430	436	446	4.60	4.30	4.36	4.46	4.4300	0.0425
												Increment Given	<0.1 mm
13:10	100	160.13	127.389	466	445	451	453	4.66	4.45	4.51	4.53	4.5375	
13:40	100	160.13	127.389	469	451	454	458	4.69	4.51	4.54	4.58	4.5800	0.0425
												Increment Given	<0.1 mm
13:45	120	200.15	159.226	530	526	516	513	5.30	5.26	5.16	5.13	5.2125	
14:15	120	200.15	159.226	538	531	522	520	5.38	5.31	5.22	5.20	5.2775	0.0650
												Increment Given	<0.1 mm
14:20	140	230.17	183.108	598	610	531	604	5.98	6.10	5.31	6.04	5.8575	
14:50	140	230.17	183.108	603	613	538	610	6.03	6.13	5.38	6.10	5.9100	0.0525
												Increment Given	<0.1 mm
14:55	150	250.18	199.027	641	651	567	655	6.41	6.51	5.67	6.55	6.2850	
15:55	150	250.18	199.027	647	659	569	660	6.47	6.59	5.69	6.60	6.3375	0.0525
16:55	150	250.18	199.027	654	663	576	665	6.54	6.63	5.76	6.65	6.3950	
17:55	150	250.18	199.027	657	668	580	669	6.57	6.68	5.80	6.69	6.4350	
18:55	150	250.18	199.027	662	674	587	673	6.62	6.74	5.87	6.73	6.4900	
19:55	150	250.18	199.027	666	678	593	679	6.66	6.78	5.93	6.79	6.5400	
20:55	150	250.18	199.027	671	684	600	683	6.71	6.84	6.00	6.83	6.5950	
21:55	150	250.18	199.027	677	689	604	690	6.77	6.89	6.04	6.90	6.6500	
22:55	150	250.18	199.027	681	696	610	695	6.81	6.96	6.10	6.95	6.7050	
23:55	150	250.18	199.027	686	700	617	701	6.86	7.00	6.17	7.01	6.7600	
27/11/2014													
00:55	150	250.18	199.027	693	705	621	707	6.93	7.05	6.21	7.07	6.8150	
01:55	150	250.18	199.027	698	709	628	713	6.98	7.09	6.28	7.13	6.8700	
02:55	150	250.18	199.027	702	715	635	718	7.02	7.15	6.35	7.18	6.9250	
03:55	150	250.18	199.027	708	718	639	725	7.08	7.18	6.39	7.25	6.9750	
04:55	150	250.18	199.027	713	724	646	729	7.13	7.24	6.46	7.29	7.0300	
05:55	150	250.18	199.027	718	731	652	735	7.18	7.31	6.52	7.35	7.0900	
06:55	150	250.18	199.027	724	738	660	741	7.24	7.38	6.60	7.41	7.1575	
07:55	150	250.18	199.027	732	741	663	745	7.32	7.41	6.63	7.45	7.2025	
08:55	150	250.18	199.027	736	745	668	750	7.36	7.45	6.68	7.50	7.2475	
09:55	150	250.18	199.027	741	748	668	753	7.41	7.48	6.68	7.53	7.2750	
10:55	150	250.18	199.027	744	754	671	756	7.44	7.54	6.71	7.56	7.3125	
11:55	150	250.18	199.027	749	757	675	759	7.49	7.57	6.75	7.59	7.3500	
12:55	150	250.18	199.027	753	762	675	762	7.53	7.62	6.75	7.62	7.3800	
13:55	150	250.18	199.027	757	765	679	765	7.57	7.65	6.79	7.65	7.4150	
14:55	150	250.18	199.027	761	770	682	769	7.61	7.70	6.82	7.69	**7.4550**	

Release of Load													
14:45	120	200.15	159.23	758	762	674	761	7.58	7.62	6.74	7.61	7.388	
16:15	120	200.15	159.23	746	750	667	753	7.46	7.50	6.67	7.53	7.290	
16:20	100	160.13	127.39	721	695	604	643	7.21	6.95	6.04	6.43	6.658	
16:50	80	130.13	103.52	684	662	602	621	6.84	6.62	6.02	6.21	6.423	
17:20	60	100.10	79.63	661	624	600	600	6.61	6.24	6.00	6.00	6.213	
17:50	40	70.06	55.74	508	521	526	513	5.08	5.21	5.26	5.13	5.170	
18:20	20	30.12	23.88	485	463	453	463	5.85	4.63	4.53	4.63	4.660	
18:50	0	0.00	0.00	430	422	416	403	5.30	4.22	4.16	4.03	4.178	
Gross Settlement												7.455	
Net Settlement												4.1775	
Rebound												3.2775	

Compression load is applied to the pile top with the help of hydraulic jack against suitable frame or it can be Rolled Steel Joist (R.S.J) where the reaction is provided and consisted in Kentledge. Displacement in the pile can be recorded by dial gauges which are suitably positioned. 25% of dead weight is applied more than the maximum force required by jack. The kentledge C.G shall be on the axis of pile. The jack load shall be co-axial with pile. Around the piles, position of dial gauges should be at equal distances and rested on rigid supports at 5D away from the test piles. The details of equipment and test pile were shown in Table 5.

The test pile is loaded with 20% incremental and 200% - 250% for initial test and 150% for routine test of design load, unless the failure occurs first. The detailed observation and test results were shown in Table 6. To measure displacement, 3 dial gauges for single pile and 4 dial gauges for group of piles of 0.01/0.02mm sensitivity. Percentage of loading should be maintained such that the displacement of pile top shall not be more than 0.1mm per 30 min whichever is earlier or 0.2mm per one hour or maximum of 2 hours. Same as loading, unloading shall be carried out.

Record about 24 hours of final rebound after whole test load has removed. Variations on load – Displacement were graphically represented on Graph 3.



Graph 3: Variations on Load – Displacement by Vertical Load Test

4) High Strain Dynamic load test

This test was conducted by the agency Struct Geotech Research Laboratories Private Limited. It measures settlement under the load and quantitative evaluation of static pile capacity. Details of Pile installation and Location as shown in Table 7.

Table 7
Details of Pile installation and Location

Pile No	H 5B
Date of Concreting	25.05.2014
Grade of Concrete	M - 30
Equipment	Hydraulic Rig
Pile length below gauges	8.05 m
Hammer Weight	30 kN
Drop Height	0.5 m
Working Load	3000 kN
Testing Load	4500 kN
Actual Volume	6.00 m^3

A Pile driving Analyzer (PDA) – model PAK, velocity and force transducers were used to conduct the high strain dynamic pile test. Two accelerometers and four strain transducers were attached to the pile head. During each strike of the hammer, bending effects are cancelled when they are mounted on opposite sides of the pile. The PDA is a micro-processor based signal conditioner and digital computer.

During each strike of the hammer, signals of the pile top surface and velocity are measured, analyzed and stored in analyzer as shown in Table 8. On instrument screen itself the force and velocity-time curves of pile top were displayed. This PDA onsite uses program based to compute pile static capacity and checked with the computer program CAPWAP to confirm the result obtained on the site.

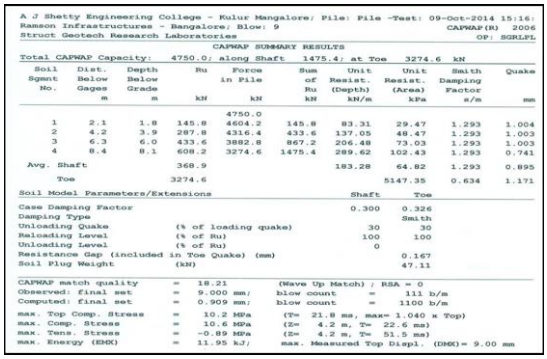
Table 8
Details of PDA field results

Pile Identification	H 5 B				
Height of fall (m)	0.5m	1.00m	1.50m	2.00m	2.50m
Maximum Compressive force (kN)	857	2015	2180	2163	3037
Maximum Resistance (kN)	316	862	1072	1424	1419

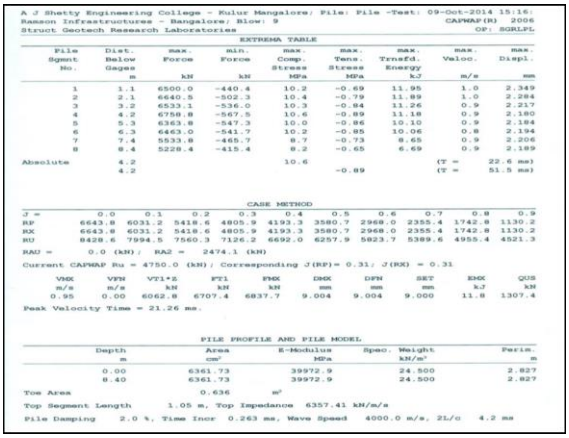
CAPWAP (Case Pile Wave analysis program) is a computer software. The analysis involved applying the measured pile top velocity time record to the top of a lumped mass and spring wave equation model of the pile. The program calculates the pile top force – time record and then compared to the actual measured force – time record. The adjustments were done until a good match is obtained between measured and computed forces from the pile and soil resistance model. After this adjustments, the estimated static load – settlement curve are determined. The CAPWAP Analysis results are shown in Table 9 and detailed results were shown in Fig. 2(a), (b) and (c).

Table 9
CAPWAP Analysis result

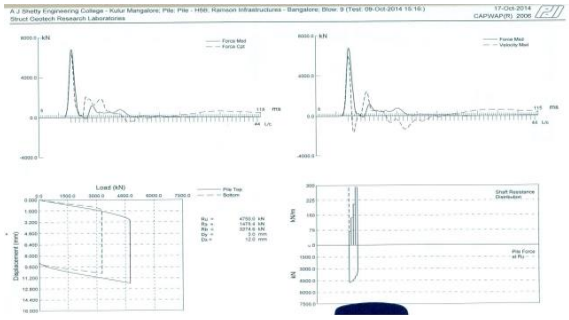
Pile Identification	H 5B
Pile Capacity	4750 kN
Skin Friction	1475.4 kN
End Bearing	3274.6 kN
Net Displacement	3.00 mm
Total Displacement	12.00 mm
Compressive Stress	10.60 N/mm^2
Tensile Stress	0.89 N/mm^2
Pile Integrity	100 %



(a)



(b)



(c)

Fig. 2. Detailed Results of CAPWAP Analysis

C. Conclusion

In lateral load test, at 12 mm of total displacement, fifty percent of the final load for safe lateral load and the maximum test load shall be observed.

In Pull out load test, at 12mm of total displacement, two-third of final load and clear break (downward trend) of fifty percent of load shows in load – displacement curve.

In Vertical load test, at 12mm of total displacement, two-third of final load. The total displacement for final load of 50 percent equal to 10 percent for uniform diameter piles and 7.5 percent for bulb diameter of piles.

The CAPWAP analysis results on the tested pile showed that the pile had achieved total activated static capacity of more than 1.65 times the working load at the time of testing. The pile integrity was observed to be satisfactory for the tested piles. The stresses in the piles were within the code limits during any stage of testing.

4. Case Study – 2

A. Geotechnical Investigation report

M/s. Sridevi College, Mangalore were requested to carry out "Geotechnical Investigation for proposed construction of 6 storeyed (BF+GF+4 Floors) Hostel building at Ballalbagh, Mangalore during the year 2017. They approached the Department of Civil Engineering, National Institute of Technology Karnataka for boring and Standard Penetration Tests (SPT).

1) Observation

Some of the observations are,

- Bore holes were done at two locations.
- It was reported that during the time of boring water table was at 2.0m depth.
- For basement, 3.0m was lowered the site.
- In Borehole 1, rock was encountered between 7.5m and 8.5m depth.
- In Borehole 2, rebound is at 15m depth.
- According to Bureau of Indian Standards, SPT for soil/ rock samples were conducted at suitable depth levels within the bore holes as shown in fig 3(a) and (b).
- The compressive strength of rock sample for bore hole 1 was found to be 37,000 kN/m^2

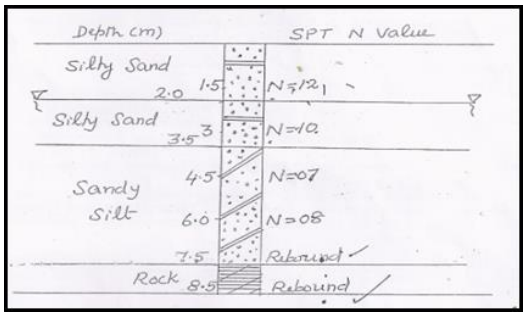


Fig. 3(a). Borehole no. 1

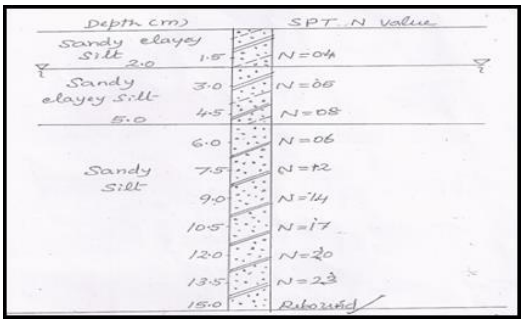


Fig. 3(b). Borehole no. 2

B. Recommendation

Water table is found to be at shallow depth. Due to very poor soil condition for a location of Borehole 1 and 2 at a depth of 7.5m and 10.5m, pile foundation was recommended. At a depth of one time the pile diameter, bored cast-in-situ shall be properly embedded into the hard rock. Good drainage facility shall be provided at site to avoid water stagnation. The compressive strength of rock given shall be made use to ascertain the bearing capacity of piles in rock. Raft foundation can be taken for the basement floor level below 2.0m depth and at foundation level the total load intensity is limited to 85 kN/m2. By ramming well compaction shall be done at the bottom of excavation. 45cms of compacted thickness of sand packing and boulder of two layers shall be provided. For all sides of PCC bed, 30cms of these layers are extended. For the

above compacted boulder and sand layers, foundation PCC bed shall be provided. For the design of raft foundation, it is recommended that the safe bearing capacity (SBC) shall be 85 kN/m^2.

C. Test on pile

Pile Integrity test (PIT) also known as Low Strain Impact Integrity Test was conducted for the proposed site by M/s GEO DYNAMICS in accordance with ASTM D5882. The purpose of this test is to estimate the pile integrity for some of problems like changes in cross section, quality of concrete, honeycombing etc. this test were conducted on 6-7-2018.

This test was comprised of most advance system to estimate the pile integrity by impact method. Basically it consists of PIT collector, accelerometer connected with USB cable and nylon hammer. The PIT Collector detects the pile impedance change of wave reflections. It grabs, intensify and display the data. The accelerometer has 100 mV/V sensitivity which attaches on the pile top having 30 kHz resonant frequency and 50 kHz sampling frequency. The details of equipment and test pile were shown in Table 10.

Table 10
Details of Pile Integrity Test and Test Pile

Type of pile	R.C Bored
Method of Piling	Tripod & Winch
Pile depth from test level	5.18m – 13.36m
Concrete Grade	M 25
Period of Casting	6/7/2018
Pile Diameter	600 mm

With the help of nylon tipped hammer by generating a moderate force for several times on the pile top, low strain compressive wave that travels to the toe of pile. Accelerometer records acceleration and velocity along with reflection from the pile toe any discontinuities are displayed graphically. Number of blows on pile top gives several records. By averaging the signal record gives results based on velocity against time curve. The signals from accelerometer are transferred through USB cable where a portable computer is monitored by a program and signals being analyzed further.

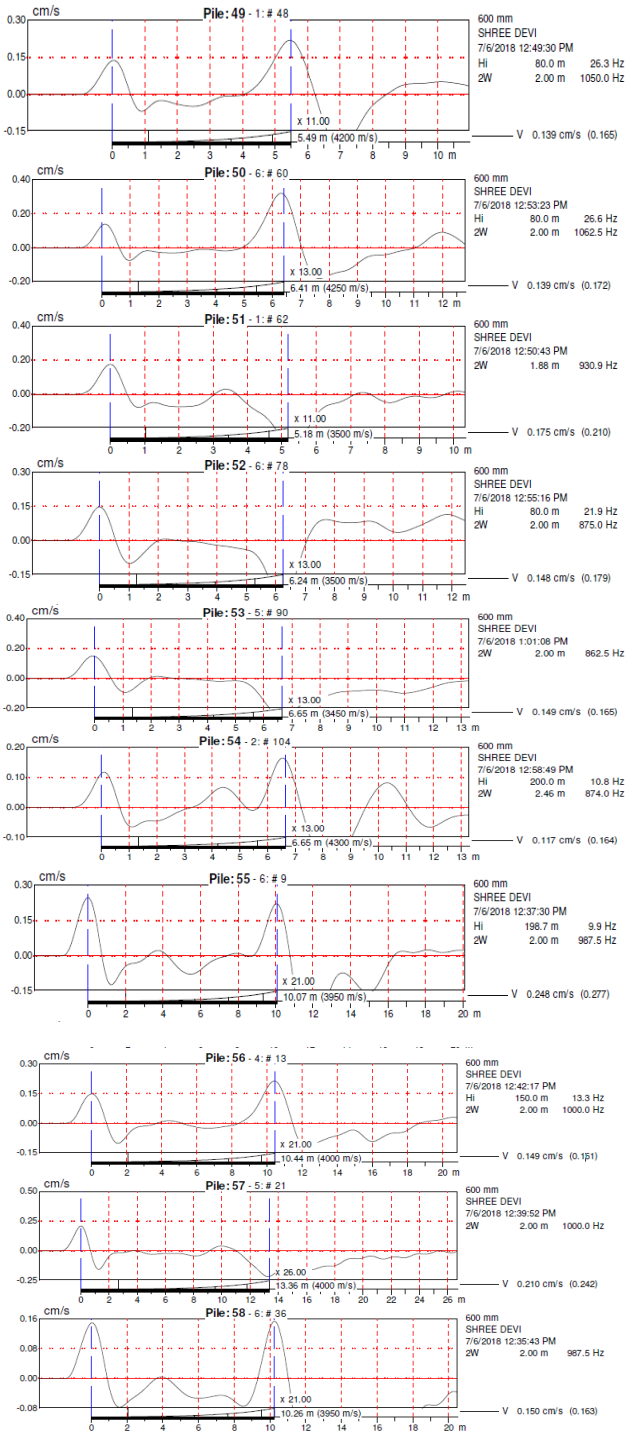
1) Limitation of test system

- This test generally considers piles upto ratio L/D of 45-50. This method also reduces the signals which depend on soil resistance.
- The piles in layered soils of varying greatly in cross sectional area give difficulty in distinguishing reflection by construction method and localized discontinuities.
- This method is suitable only for R.C bored piles and not for jointed pre-cast piles, micro piles, steel piles etc. It cannot detect multiple defects inside the pile.
- This method also evaluates pile length approximate range within 5% - 10% due to concrete density variation.

2) Test result

Pile integrity test were conducted on pile shafts. Considering 10 piles are tested at the proposed site. The detailed observation and test results were shown in Table 9.

From the test, wave speed varies from 3450 m/sec to 4300 m/sec for piles are considered as consistent concrete quality. Pile integrity showing soft toe condition for pile no's 49, 50, 54, 56 and 58 need to conduct high strain Dynamic pile load test for atleast 1 to 2 piles for actual pile capacity evaluation. The piles tested were evident and no defects were found. Graph 4 shows variation of wave transfers from pile shaft to pile toe during pile integrity test.



Graph 4: Pile Integrity Results for 10 Piles during Analysis

Table 11
Detailed Observations and Results on Pile Integrity Test

S. No	Pile No.	Toe Response	Length of Pile from test level (m)	Wave Speed (m/sec)	Shaft Cross Section and Soil Changes (From test level)	Pile Integrity
1	49	Evident	5.49	4200	Fairly uniform pile shaft	Soft toe
2	50	Evident	6.41	4250	Fairly uniform pile shaft	Soft toe
3	51	Evident	5.18	3500	Fairly uniform pile shaft	OK
4	52	Evident	6.24	3500	Fairly uniform pile shaft	OK
5	53	Evident	6.65	3450	Fairly uniform pile shaft	OK
6	54	Evident	6.65	4300	Fairly uniform pile shaft, Bulge/ increase in soil resistance seems evident around 2m from test level	Soft toe
7	55	Evident	10.07	3950	Fairly uniform pile shaft, Bulge/ increase in soil resistance seems evident around 5m from test level	OK
8	56	Evident	10.44	4000	Fairly uniform pile shaft	Soft toe
9	57	Evident	13.36	4000	Fairly uniform pile shaft	OK
10	58	Evident	10.26	3950	Fairly uniform pile shaft	Soft toe

D. Conclusion

The method of testing cannot detect the nature of defect. Some of the classified defects such as soil variations honeycombs, voids in concrete filling, necking and termite choke etc. but bulbs are not considered as defect. Thus the defected piles are considered as doubtful or needs further replacement or testing or remedial action or re-design based on actual load carrying capacity. The second cycle of wave is the curve after the response of pile toe. Some of the secondary reflection where the piles having major bulb which is similar to defect but such deflection should not consider as defect. To evaluate wave speed, it is necessary to input the length into the system. For good consistent concrete the wave speed range from 3500 m/sec – 4200 m/sec. If it is less than 3500 m/sec but upto 3200 m/sec considered as less quality control or have very low reinforcement percentage. It is difficult to identify the pile defects at half the pile length to evaluate magnitude defect.

5. Design of pile load capacity

A pile of 750mm diameter and 15m length is driven in a sand deposit having angle of internal friction of 30°, effective unit weight of soil at pile tip is 16.5kN/m^2 and Υ_{sat} = 18.5 kN/m^2. According to IS 2911 (Part 1/sec 2): 2010, the critical depth shall be taken as 15 times the diameter of pile shaft if $\phi \leq 30°$. From IS code fig 1, for $\phi = 30°$, the bearing capacity factor (N_q) is taken as 35, the coefficient of earth pressure depend on soil strata, spacing of pile and method of construction range to K=3.2 and angle of wall friction shall be taken which is equal to friction angle of soil $\delta = 30°$. The water table is at depth of 1.5m from ground level and factor of safety as 2. The unconfined compressive strength of clay is 0.9x10^4 kN/m^2, from fig 2, the adhesion factor α=0.75 and depth of 6m. Factor of safety as 3.

A. For Granular soil

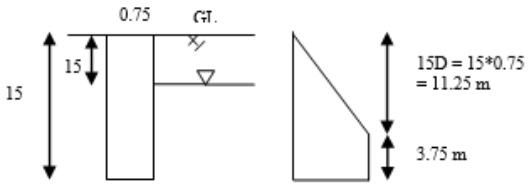
The ultimate load capacity (Qu) of piles for granular soil is given as,

$Q_u = A_p * \sigma_v * N_q + \Sigma As * \sigma_a * K * Tan\delta$

Where, A_p = Cross sectional area of pile = $\frac{\pi}{4}$ * (dia of pile)^2

= $\frac{\pi}{4}$ * (0.75)^2 = 0.441 m^2

σ_V = Effective overburden pressure at tip of pile



Pressure at the top is zero till the critical depth, pressure increase linearly. After critical depth, pressure is constant.

$\sigma_V = (1.5 * \Upsilon_{dy}) + (\Upsilon_{sat} - \Upsilon_w * (1.5\text{-}11.25))$
$= (1.5 * 16.5) + (18.5 - 10 * 9.75)$
$= 103.75$ kN/m^2

1st term gives end bearing resistance

As = Surface area of pile = $\pi * D * L$
$= \pi * 0.75 * 3.75$
$= 8.83$ m^2

Average pressure = 103.75 kN/m^2

2nd term gives skin friction resistance. Here total length of pile 15m. But here we need to consider till critical depth.

As = $\pi * D * L = \pi * 0.75 * 11.25$
$= 26.49$ m^2

Average pressure from 0 to 11.25m upto critical depth = $\frac{0+103.75}{2}$ = 51.875 kN/m^2

K = Coefficient of earth pressure = 3.2
δ = Angle of wall friction = 30°
N_q = Bearing capacity factor = 35

$Q_u = (0.441 * 103.75 * 35) + (8.83 * 3.2 * \tan 30° * 103.75) + (26.49 * 3.2 * \tan 30° * 51.875)$
$= 1601.38 + 1694.5 + 2537.2$
$= 5833.08$ kN

Safe Load = $\frac{Qu}{FOS} = \frac{5833.08}{2}$ = 2916.54 kN

B. For Cohesive soil

The ultimate load capacity (Q_u) of piles for cohesive soils is given by,

$Q_u = A_p * N_c * C_p + A_s * \alpha * C_s$

Where, Ap = Cross sectional area of pile = $\frac{\pi}{4}$ * (dia of pile)^2

= $\frac{\pi}{4}$ * $(0.75)^2$ = 0.441 m^2

N_c = Bearing capacity factor as 9.

C_p = Average cohesionat pile toe

$= \frac{\text{Unconfined Compressive Strength}}{2}$

= (0.9 x 10^4)/2 = 0.45x10^4 kN/m^2

A_s = Surface area of pile shaft = π * D * L = π * 0.75 * 6

= 14.13 m^2

Q_u = (0.441 * 9 * 0.45x10^4) + (14.13 * 0.75 * 0.45x10^4)

= 65549.25 kN

Safe Load = $\frac{Qu}{FOS} = \frac{65549.25}{3}$ = 21849.75 kN = 21.84 T

6. Conclusion

This paper presented a study on study on geotechnical investigation and tests on pile.

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