Examining the Applicability of Micro-pile for Bridge Foundation in Difficult Terrain using Pile Load Test

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Abstract - Construction of foundation of bridges in remote hilly terrain, in adverse climatic condition, is very difficult due to the limited working period and unavailability of transportation of machinery and equipment. In such situations where regular pile foundation is not feasible, micro-piles prove to be better solution. The study deals with the conditions in the field, field testing of micro-piles and their applicability as bridge foundation.

Keywords: Micro-pile, Field load-settlement test, Bridge Foundation.

1 INTRODUCTION

In remote areas and difficult hilly terrains there are several problems faced during construction of bridges. The hilly atmosphere has oxygen deficiency, negative temperatures, chilling cold, snowfall, frozen water bodies, lack of adequate transportation facilities and roads are some of the innumerable problems faced during construction. A number of environmental conditions allow only a limited period for construction which is hardly four-five hours a day. Considering the terrain and hydraulic factors at such sites there is limited option of foundation for the bridges. Usually such terrain has cobbles/gravels in the river bed. The seepage rate is likely to be very high. The high seepage rate requires heavy de-watering works while undertaking construction of substructure. Also such heavy concreting will be time consuming. Since, the time slot for construction is limited, regular procedures do not work.

Based on scour criteria, for such heavy loads as on bridges deep foundations are suitable but boulders, cobbles in such area do not allow sinking of well foundation, leaving us with only one option – piles. However, due to limited transportation facilities, roadways, it is not possible to transport such heavy rigs to such remote and inaccessible areas.

Therefore, micro-piles are the most suitable option for bridge foundation considering all the above factors and limitations. A micro-pile is a small-diameter drilled and grouted non-displacement pile that is typically reinforced. It is constructed by drilling a borehole, placing steel reinforcement, and grouting the hole and can bear axial loads as well as lateral loads. They are suitable and can be installed in restrictive areas and in all soil types and ground conditions. In India, the use of micro-piles has been restricted only to slope stabilization in hydro projects and earth retaining structures and not in bridge foundation and therefore, it will be a new area for future endeavors.

2 HISTORY OF MICRO-PILES

Micro-piles were first conceived in Italy in early in 1950s, in response to the demand for innovative techniques for underpinning historic buildings and monuments that sustained damage at that time. An Italian contractor, Fondedile and Dr Feranado Lizzi developed this technique, it was a reliable method support structural loads with minimal disturbances to the existing structures. Thereafter use of micro-piles gained significance and were used as units for foundation support to counter static and seismic loading conditions and as in situ reinforcements for slope and excavation stability.

Since then, micro-pile technology has evolved to cover a variety of applications: underpinning for existing foundations, in-situ soil reinforcement, and seismic retrofitting. In last 20 years, however, time has witnessed a significant expansion from use in low-capacity micro-pile networks to employment as single high-capacity foundations. One type of the popular micro-piles being used in the foundation industry nowadays is the hollow bar micro-pile, which facilitate fast installation with a high degree of ground improvement.

3 SUB-SURFACE INVESTIGATION

A case study for Leh - Ladakh region was taken up. The sub-surface investigation (SSI) was carried out by bore holes of 40m depth each at the planned abutments and intermediate pier locations for the SSI. It was planned for two test piles at each location to be driven up to a depth of 20m and tested for vertical static load which will be twice the design load or up-to the pre-mature failure limit. Results obtained from SSI and micro pile testing shall be utilized for the design and subsequent construction of micro pile foundation for design of appropriate substructure and superstructure.

The specifications of micro pile consist of 273 mm outer diameter steel casing with M-35 grade cement grout filled inside at a pressure of 4 to 5 bar, re-drilled to place four nos. 32 mm diameter longitudinal bars with a centralizer to maintain spacing. This micro pile shall be tested for static load as per IS 2219 Part IV. The bore holes were to be drilled. Standard penetration test (SPT) to be conducted in bore hole at the depth of every three meters or refusal. The collection of disturbed and un-disturbed soil sample for lab test was to be undertaken. And results were to be analyzed for type of soil strata, water table & safe allowable bearing capacity.

3.1 TESTS CONDUCTED

Field tests

(a) Boring at the proposed site to ascertain the type of soil strata at the requisite depth and collection of soil samples, both disturbed and undisturbed by boring tools.
(b) SPT conducted for measuring the penetration resistance of the soil, which is measure of its bearing capacity.
(c) Depth of Water Table was to be determined.

Laboratory test

(a) Bulk Density, Moisture content was determined for samples collected in field.
(b) Particle size analysis was carried out as per IS 2720 (Part-4).
(c) Atterberg's Limits were determined as per IS 2720 Part- 5 1985.

4 TEST RESULTS

The test result showed that stratum consists of coarse sand, gravel and rock. The results are tabulated below:

Table 1. Test Results

Depth Below G.L. in meter	Soil Classification on As per IS:1498	Standard Penetration Value (N)	Atterberg Limits of Fraction Passing 425 mic Sieve		Sieve Analysis			Shear Test	
			Liquid Limit	Plastic Limit	Gravel	Sand	Silt + Clay	Cohesion (C) Value Kg/cm^2	Angle of Internal friction
3	Sandy Gravel (GP)	76	22	NP	69.3	30.2	0.5	Nil	44
6	Sandy Gravel (GP)	110	23	NP	66.3	31.2	2.5	Nil	50
9	Sandy Gravel (GP)	81	24	NP	50.9	47.6	1.5	Nil	45
12	ROCK	>100 REFUSED	-	NP	100	-	-	Nil	-
15	ROCK	>100 REFUSED	-	NP	100	-	-	Nil	-
18	ROCK	>100 REFUSED	-	NP	100	-	-	Nil	-
21	ROCK	>100 REFUSED	-	NP	100	-	-	Nil	-
24	ROCK	>100 REFUSED	-	NP	100	-	-	Nil	-
27	ROCK	>100 REFUSED	-	NP	100	-	-	Nil	-
30	ROCK	>100 REFUSED	-	NP	100	-	-	Nil	-

Table 2. Results at ground level to 3-meter depth

S.N	Parameter	Unit	Test Methods	Result
1.	Sieve Analysis Sieve Size (mm) 20.0 10.0 4.75 2.0 0.425 0.075	**%**	IS:2386(P-1)-1963	Cumulative % passing by weight 86.9 78.2 67.1 53.8 16.7 3.2
2	Shear test			
	Cohesion (C) Value Angle Of Internal Friction	Kg/cm^2 Degree	IS:2720(P-13)-1986 (Reaffirmed 2002) ,----Do---------	Nil 38
	Chemical Test			
1	pH value at 25 degree Celcius	-	SRTL/SOP	7.54

2	Sulphate	%	SRTL/SOP	0.01
3	Chloride	%	SRTL/SOP	0.04

Table 3. Results at 12 meter to 15 meter

S.N	Parameter	Unit	Test Methods	Result
1.	Sieve Analysis Sieve Size (mm) 20.0 10.0 4.75 2.0 0.425 0.075	**%**	IS:2386(P-1)-1963	Cumulative % passing by wt 96.5 81.9 60.7 45.4 15.9 5.9
2	Shear test			
	Cohesion (C) Value Angle Of Internal Friction	Kg/cm^2 Degree	IS:2720(P-13)-1986 (Reaffirmed 2002) ,--------Do---------	Nil 40
	Chemical Test			
1	pH value at 25 degree Celcius	-	SRTL/SOP	7.54
2	Sulphate	%	SRTL/SOP	0.008
3	Chloride	%	SRTL/SOP	0.007

Table 4. Results at 15 meter to 33 meter (average values)

S.N	Parameter	Unit	Test Methods	Result
1.	Sieve Analysis Sieve Size (mm) 20.0 10.0 4.75 2.0 0.425 0.075	**%**	IS:2386(P-1)-1963	Cumulative % passing by wt 86.1 58.0 39.0 28.9 11.4 2.3
2	Shear test			
	Cohesion (C) Value Angle Of Internal Friction	Kg/cm^2 Degree	IS:2720(P-13)-1986 (Reaffirmed 2002) ,--------Do---------	Nil 42
	Chemical Test			
1	pH value at 25 degree Celcius	-	SRTL/SOP	7.54
2	Sulphate	%	SRTL/SOP	0.01
3	Chloride	%	SRTL/SOP	0.04

4.1 BEARING CAPACITY CALCULATION

Piles in Granular Soil

The ultimate load capacity (Qu) of piles, in kN, in granular soils is given by the following formula:

$$Q_u = A_p\left(\frac{1}{2}D\Upsilon N_\Upsilon + P_D N_q\right) + \sum_{i=1}^{n} K_i\, P_D \tan\delta_i A_{si} \quad (1)$$

L= length of pile = 21 m, Scour Depth= 5m, ϒ= submerged unit weight =10KN/m^3
d = diameter of pile = 0.273m, Φ= angle of internal friction = 40^0,
δ = angle of wall friction between pile and soil layer

As = surface area of pile shaft in the in
Nγ = bearing capacity factors depending upon
Nq the angle of internal friction, φ at pile tip
P_d= effective overburden pressure at pile tip, in KN/m^2
K = coefficient of earth pressure, L_c/d = critical depth ratio

BORE HOLE P-2
L=21m, Depth of Scour=5m,ϒ= submerged uint wt =10KN/m^3, Φ = 40^0, K=1.5, Nq=64.2, Nγ=109.4

Critical Depth:
Lc/d=19; Lc=19×0.273=5.187=5.2m
P_{d_i}= 5.2×10 = 52 KN/m^2
Skin friction Calculation
Q_{s1}=(1.5×$tan40^0$×$\frac{52}{2}$)×(π×0.273×5.2)= 15Tons
Skin Friction for remaining depth
Q_{s2}= (1.5 ×$tan40^0$× 52) × (π×0.273×10.8) = 61Tons

End bearing Calculation:
Q_p=(52×64.2)+(0.5×10×0.273×109.4)×($\frac{\pi}{4}$×0.273^2)= 20 tons
$Q_{ultimate}$= Q_s+Q_p = (15 + 61 + 20) = 96 Tons
Factor of Safety = 3
Q_{safe}= Safe load carrying capacity= $\frac{ultimate\ load}{FOS}$ = $\frac{96}{3}$= 32 Tons

4.2 LATERAL LOAD CALCULATION

The proposed foundation has to be comprised of micro-piles. The lateral load capacity as per FHWA is given by:

$$P=\frac{\delta}{F_\delta}\times\frac{E\times I}{T^3} \qquad (2)$$

Where,
P= lateral load capacity, N
δ= Lateral displacement, mm
F_δ= Factor
E= Young's modulus of material. N/mm^2
I= moment of Inertia of the material, mm^4
T= Stiffness factors = $\sqrt[5]{\frac{E\times I}{f}}$,m
F= Modulus of sub-grade reaction for dense sand
Lateral load required to produce a Deflection of 5 mm, in dense sand of micro-pile having External Dia, D_o= 273mm; Thickness = 8mm; Length of pile, L=21m
EI = (E_{casing} x I_{casing}) + (E_{grout} x I_{grout})
E_{casing}= 2×10^2 N/mm^2
I_{casing}= $\frac{\pi}{64}$ (D_o^4 - D_i^4)
E_{grout}= 5000$\sqrt{f_{ck}}$: f_{ck}= Characteristic comp. strength of Grout material= 30N/mm^2
I_{grout}= $\frac{\pi}{64}$ (D_i^4)
Therefore EI= 2×10^5 × $\frac{\pi}{64}$(273^4 - 257^4) + (5000$\sqrt{30}$) × $\frac{\pi}{64}$(257^4)
= 1.756×10^{13}N/mm^2
T= $\sqrt[5]{\frac{1.756\times10^{13}}{0.005}}$ = 1285.6 = 1.3m
As L > 5T it is considered as Long or Flexible pile
F_δ = 2.25
Substituting the above values in equation P=$\frac{\delta}{F_\delta}\times\frac{E\times I}{T^3}$
P = 1.7761 N = 1.77 = 1.8Ton

4.3 STATIC LOAD (LATERAL) TESTING ON PILE

Micro-pile Load Test Results:

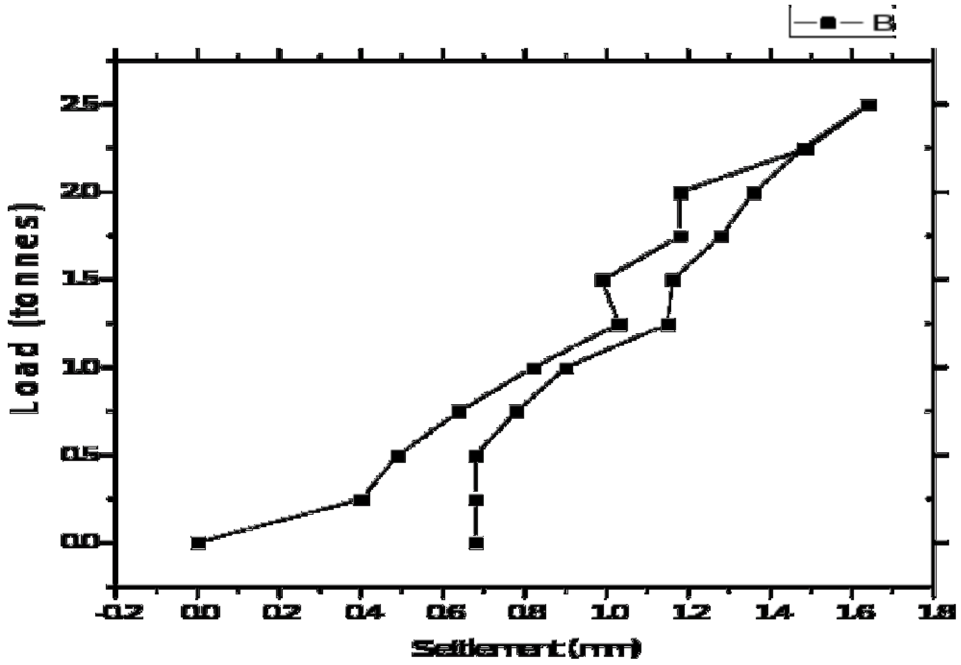

Fig.1. Graph: load vs settlement for single pile.

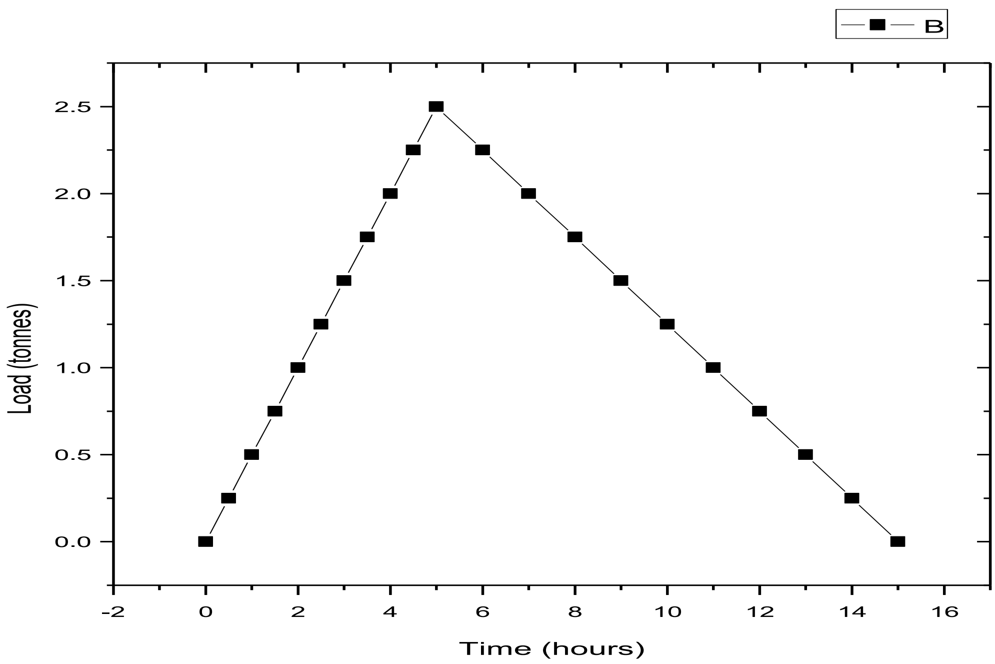

Fig.2. Graph: load vs time for single pile.

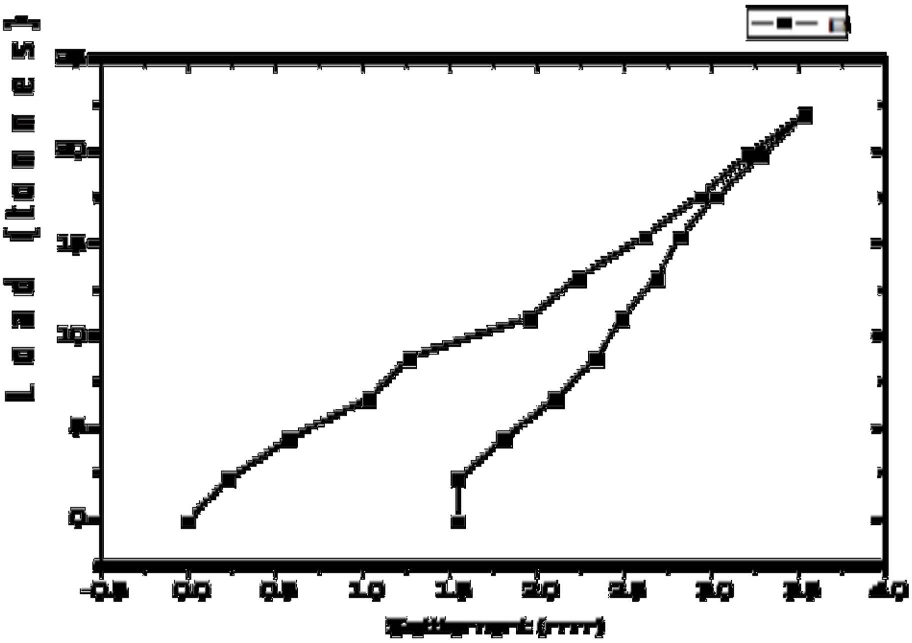

Fig.3. Graph: load vs settlement for pile group.

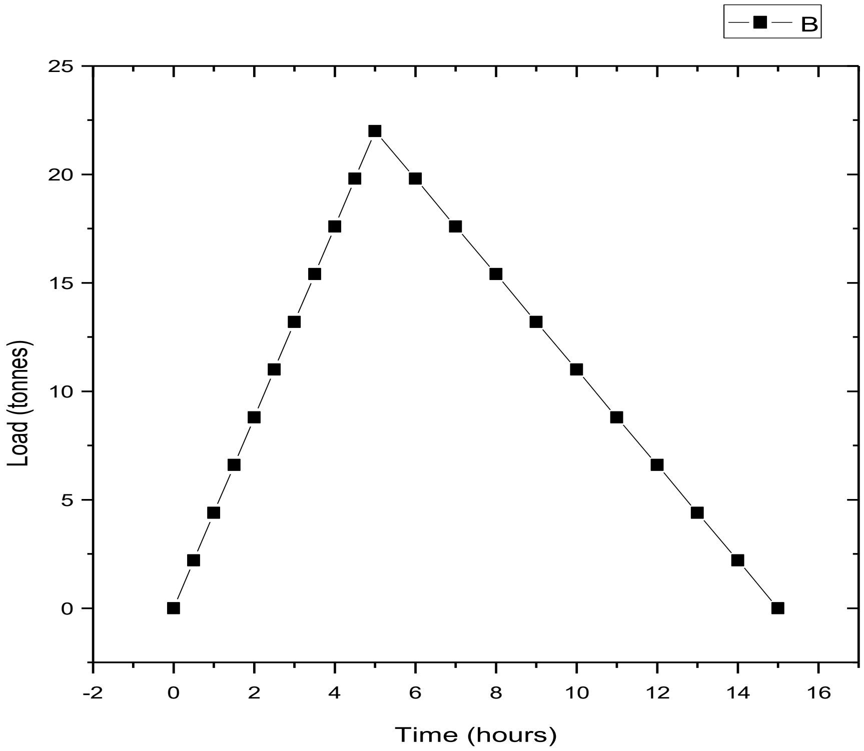

Fig.4. Graph: load vs time for pile group.

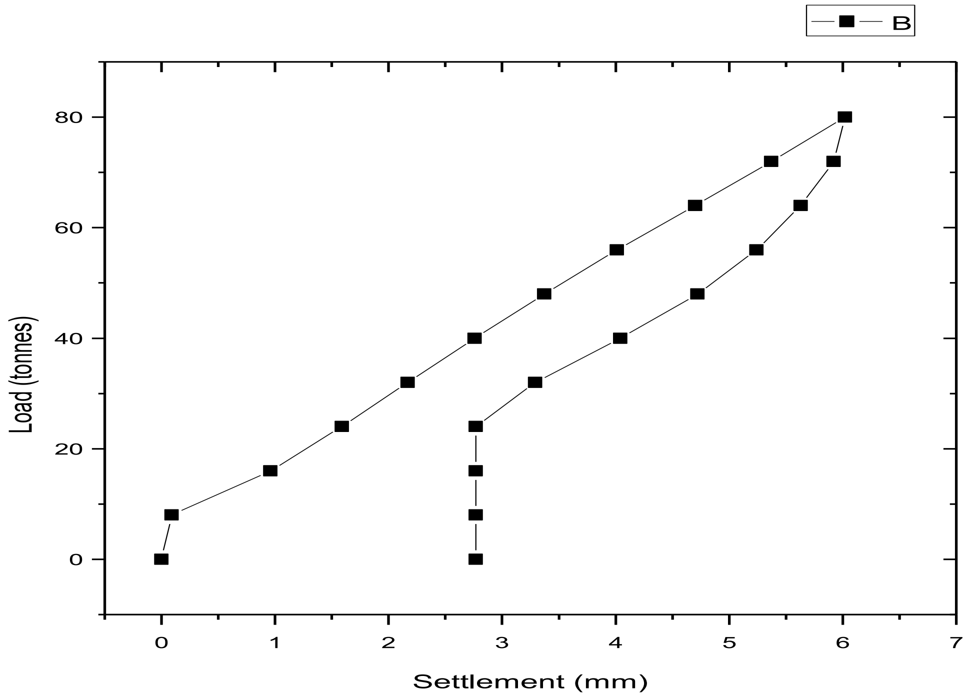

Fig.5. Graph: load vs settlement

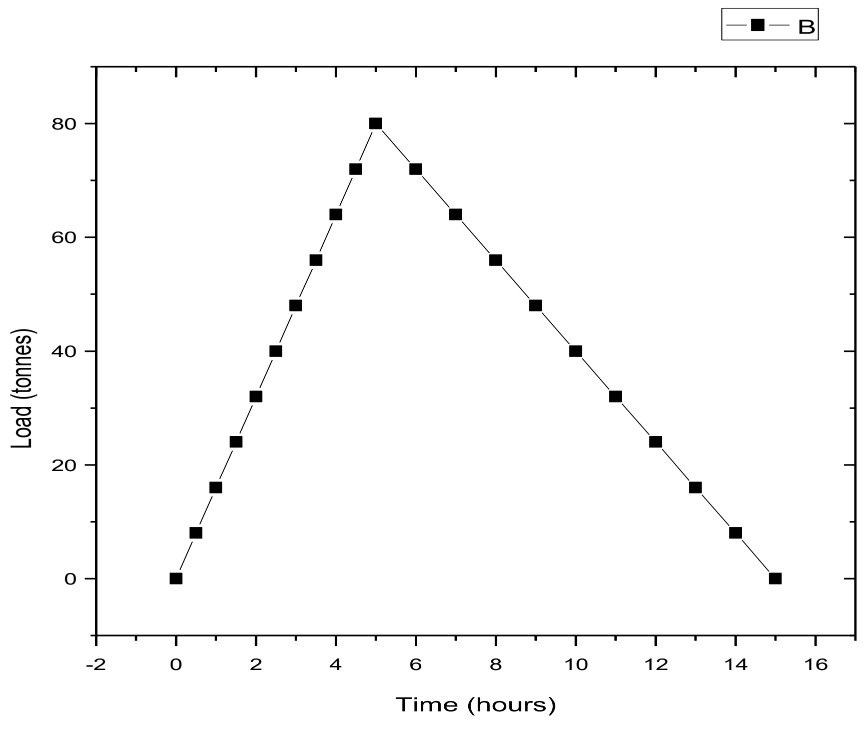

Fig.6. Graph: load vs time

5 RECOMMENDATION OF PILE LOAD TEST

5.1 FOR VERTICAL LOAD TEST

It is evident from load-settlement graph/ table that pile has attained 80MT load and the corresponding deflection achieved is less than 12 mm so the pile capacity may be taken as $80\times\frac{2}{3}$=**53.3 MT** as mentioned in IS2911:1985 PART-IV TH which may be safely adopted in design.

5.2 FOR LATERAL LOAD TEST

It is evident from load-settlement graph or table that load applied on pile is **2.5MT** and corresponding deflection achieved is less than 5mm as mentioned in IS2911:1985 PART-IV so pile capacity may be taken as 1.25 MT as a safe lateral load in the design.

5.3 FOR GROUP PILE LATERAL LOAD TEST

It can be observed from load-settlement graph or table that the load applied on the pile is **22MT**and deflection achieved is less than 5mm as mentioned in IS2911:1985 PART-IV. So pile capacity can be taken as 11MT which is safe lateral load and may be adopted in design.

6 RESULTS AND DISCUSSION

The design of substructure and foundation have been based on SSI report and pre-production micro-pile load test results:

6.1 **SSI REPORT**

The result of SSI reveals the fact as under-

- Normally the type of soil encountered is “Sandy Gravel” (GP) with average SPT value 80
- The average value of angle of internal friction Φ = 40^0
- Submerged density of soil is $10T/m^3$
- Relevant characteristics of ground water are as under: -
  - pH value = 7.54
  - Sulphate content = 0.01%
  - Chloride content = 0.04%

6.2 PILE LOAD TEST RESULT

The results of pre-production pile load test have been listed below. However, the micro-pile with length 21m, outer diameter = 273mm, casing thickness 8mm, given stiffness factor T = 1.3 is flexible and slender.

- Safe lateral load capacity of micro-pile is found to be 1.8 Ton and 11 Ton acting alone and in a group respectively
- The vertical load carrying capacity of pile is 32 Ton in normal conditions and 40 Ton in seismic condition.
- The worst vertical load expected on a pile is 23.4 Ton which is smaller than 32 Ton, hence safe.
- The micro-piles have been planned as flexible compression member and to take large lateral load and bending moment, the outer peripheral piles have been battered at 10^0 with vertical.

7 CONCLUSION

The problems owing to high altitude, remoteness, weather constraints and other difficulties as explained earlier can be overcome by micro-piles. Application of micro-pile for bridge foundation in submergence in river is debatable issue, as IRC78-2014 Section 9 Pile foundation in its clause 709.1.7 enumerates that minimum allowable diameter of bored pile should be 1000 mm for river water zone and 750 mm for bridge on land such as viaducts and ROBs etc. However, IRC: SP109-2015 permits use of small diameter pile in special circumstances. Based upon the success results, the design of micro-pile foundation and sub structure would be carried out. It is expected that this work would be considered as a distinguishing milestone in the era of bridge construction in similar difficult situations, repair and rehabilitation of endangered structures.

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