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STEEL PIPE PILE: COMPARATIVE CASE STUDY WITH API RP2A (WSD) AND IS: 2911 RECOMMENDED PROVISIONS

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ABSTRACT: Due to lack of provisions in form of codes and considerable experience especially in the steel pipe piles in the India, clients and designers frequently hesitate in adopting the pipe piles. The present paper is an attempt to get insight for the pipe pile design compared to international experience. Typical soil profile of west coast of India is selected for the present study. The design provisions made by API RP-WSD are compared with the Indian code IS: 2911 recommendations for typical pipe pile design case. The axial capacities and lateral load capacities are calculated using both provisions and compared at the end of the paper.

INTRODUCTION

Despite the large of research carried out on the bearing capacity of piles in India and the considerable experience in the installation of deep foundations, the offshore-near shore many uncertainties are still need to be addressed. Due to unavailability of updated provisions in form of codes, lack of experience especially in the steel pipe piles and economic criteria, clients and designers frequently hesitate in adopting the pipe piles in India. Compared to the code of practice of piling of India [1], the API RP2A (WSD) [2] is frequently updated and encourage the designer to use the provisions more confidently. The world wide designers use the API RP2A [2] provisions more frequently for axial (vertical) capacities and lateral capacities of pile foundations. The pile capacities estimated using API provisions and IS: 2911[1] provisions are compared using one representative soil profiles selected from Mundra port of the west coast region of India. The present study aims to append the confidence in the Indian designers to adopt the API 2P2A(WSD) provisions for offshore –near shore pile installations.

TYPICAL PORT SITE

Mundra port site (latitude: 22.740N; longitude: 69.710E) located at 60 km west of Gandhidham in Kutch district of Gujarat, India, is selected as typical port site for present study. The port was initiated in 1998 by the Adani Group as logistics base for their international trade operations when the port sector in India was opened for private sectors. The generalized soil profile obtained though borehole details are presented in Table 1. The soil profile consists of the clay layer sandwiched between of loose to medium dense sand layers. The assumed soil-pile geometry is described in the Fig.1. The SPT N-value observed at the site is presented in Fig. 2.

API RP2A (WSD)

The API RP2A recommendation for calculation of the pile capacities are described in the section 6.2 of [2] which describes the methods to calculate skin friction and end bearing resistance in cohesive and cohesionless soils. The siliceous sand is assumed as the cohesionless soils in present study as [2]describes siliceous sand as cohesionless material for pile capacity calculations. API standard i.e. [2] recommends other suitable methods for other type of sand formations.

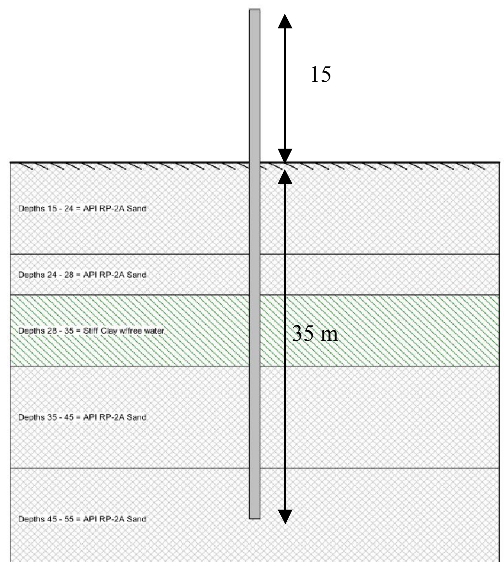

Fig. 1 Soil –Pile geometry for present analysis.

Table: 1 Typical soil profile at Mundra port site.

Layer no	Thk m	Unit wt. kN/m^3	Avg. SPT-value	Description	C_u (kPa)	Ø
1	9	17	8	Loose to medium dense silty sand	---	25
2	4	18.5	10-35	Yellow to grey dense sand	---	27
3	7	17	28-39	Stiff clay with sand and silt	75-100	---
4	10	18.5	30-50	Very dense to dense silty sand	---	35
5	8	20	40-50	Completely to highly weathered yellow sandstone	---	38

It is not possible to discuss all the provisions describe in the section 6.2 of [2]; the focus in the present paper is given to highlight the provisions made for cohesionless soils (siliceous sands). Table 2 describes the chronological changes made in the API RP2A [2] for calculation of axial pile capacity to highlight the modifications made in the sequential publication of the standard. It is notable that for calculation of the skin friction in the cohesive soils, it recommends the use of α method which was modified in 16th (1987) edition. The comparative α value in the previous version are given in the Fig. 3. For lateral load capacity estimation, [2]recommends the nonlinear p-y curves which are very popular in offshore pile design and installations. The procedure for lateral load estimation outlined in [2]is beyond the scope of this paper but may be referred from section 6.8 of [2].

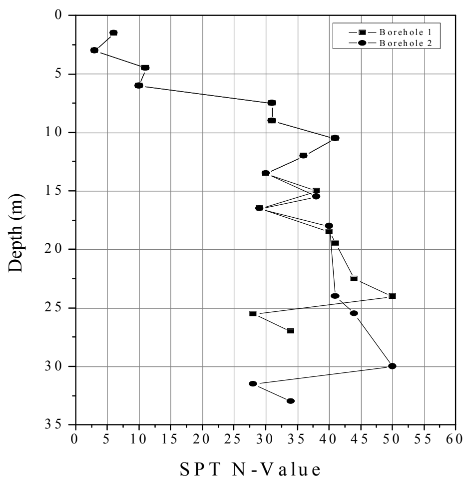

Fig. 2 SPT N-value of site selected

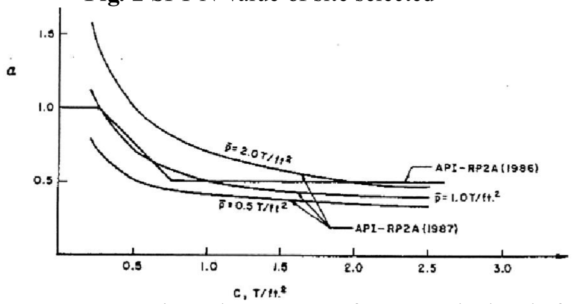

Fig. 3 Comparison between α factors calculated for different edition of the API RP2A [2] (2007 edition uses the α values as per 1987)

IS: 2911 (COP for Design and Construction of Pile Foundation)

In India, methodology for construction and design of pile foundations are laid down in IS: 2911 [1] and widely followed in India. The section 1 and section 3 of [1] describe the procedure for Driven piles whereas for Bored piles section 2 and section 4 is followed. Appendix A in the relevant sections i.e. [1] gives static formula for the ultimate load carrying capacity both in cohesionless and cohesive soil, considering both end bearing and skin resistance. The important comparison of the IS: 2911 [1] and API RP2A [2] is given in subsequent sections revealing the influencing parameters for pile capacity estimations.

DISCUSSION

Adhesion factor (α-value)

Both IS: 2911[1] and API RP2A[2] uses α method for estimation of the skin friction in the cohesive soils. However the values recommended are different in some sense. The IS: 2911[1] recommends the α-value based on the consistency of the soil and SPT N-value. It is prudent to note that the SPT N-value is widely used in India for characterization of the soils irrespective of international opinion of using it cautiously in cohesive soils. The recommended α-value is tabulated in Table 3. In the upcoming second revision of the[1], the addition of the cohesion value (C_u) in the recommendation makes IS: 2911 more comparable with other international practices (i.e. similar to API RP 2A- method 2, 1986 version; see Fig. 3)

Table: 2 Chronology of changes to API RP2A [2]recommendations for shaft resistance of piles in Sand.

API RP2A edition	Year of Publication	Soil Type	δ (deg)	$\tau_{max\,(kPa)}$	Earth pressure coefficient, K	
					C	T
1st	1969	Clean Sand	30	96	0.7	0.5
		Silty sand	25	82		
		Sandy Silt	20	67		
		Silt	15	48		
3rd	1972	u/c	u/c	w/d*	0.7	0.5-1.0
15th	1984	Dense gravel/ very dense sand	35	115	0.8	0.8
		Dense sand/very dense sand silt	30	96		
		Medium dense sand dense sand-silt	25	81		
		Loose sand, M. Dense sand silt, Dense silt	20	67		
		Very loose sand, loose sand silt, Medium dense silt	15	48		
20th/	2000	u/c	u/c	u/c	u/c	u/c
21st	2007	Very loose sand, Loose sand, loose sand-silt, medium desne silt, dense silt	N.A.	N.A.	N.A.	
		Medium dense sand-silt	0.29*	67		
		Medium Dense sand, Dense Sand Silt	0.37*	81		
		Dense Sand, Very Dense Sand-Silt	0.46*	96		
		Very Dense Sand	0.56*	115		

Note: * K.tanδ value

The 1986 method of the [2] for computing the skin friction in cohesive soil is based on types of clays. For normal, consolidated, highly plastic clays, [2] Method 1 (1986) (based on the depth v/s α- value) was generally used. For other types of clay, [2] Method 2 (1986) based on C_u method) was recommended for design. Further research studies have led API RP2A (1987) to combine method 1 and method 2 into revised API method i.e. [2]. The current API method recommended in API RP2A 1993 and 2007 is still the same revised method introduced in 1987. The α-value, recommended by API can be computed by the equation:

$$\alpha = 0.5\psi^{-0.5} \quad \text{if}\ \psi \le 1.0$$
$$\alpha = 0.5\psi^{-0.25} \quad \text{if}\ \psi > 1.0 \qquad (1)$$

With constraint that, $\alpha \le 1$. Where $\psi = C_u/p'$ for the depth of interest. p' =effective overburden pressure, and C_u= undrained shear strength of soil. The same can be visualized from the Fig. 3 for the comparison between old and revised method.

Table: 3. α-vlue recommended in IS:2911 –part I [2], section 1.

Consistency	SPT N-value	Range of C_u (kPa)	Value of α
Soft to very soft	<4	25	1
Medium Stiff	4 to 8	25 to 50	0.7 to 0.4
Stiff	8 to 16	50 to 100	0.4 to 0.3
Stiff to Hard	>16	>100	0.25

Bearing Capacity factor (Nq) for cohesionless soils

For end bearing capacity calculation in cohesionless soils, the IS: 2911 (Part 1) recommends the bearing capacity factor N_q which is based on Vesic's recommendations [3]. However, API RP2A recommends different N_q value which is tabulated in Table 2. It is notable that the IS: 2911 recommends the value in form of graph describing Ø (angle of internal friction of soil) v/s N_q whereas, API RP2A specifies the N_q value directly based on the consistency of soil/type of soil. The comparison of the recommended N_q values for both the codes is presented in Fig 4.

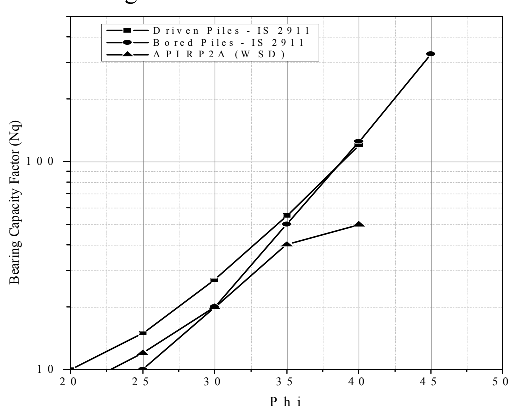

Fig. 4 Comparison of the recommended N_q value for IS:2911 and API RP2A.

It is also important to note that the bearing capacity factor (N_q) developed by [4] (Fig 5) are widely adopted by many engineers in the piling industry. However, the reason for this preference over the other more rigorous and justifiable theories is difficult to explain, as the Berezantzev method tends to give more conservative values (Fig 5). Authors feel that the continued use of a bearing capacity theory (factor) that was developed more than 30 years ago ([3]; [4]) is difficult to justify, particularly as it based on a somewhat questionable theoretical background and does not implicitly include for the effects of soil compressibility or variation in Ø'. Alternative methods based on cavity expansion theory seem to be most promising area for further development in this direction.

Earth pressure Co-efficient (K)

The earth pressure co-efficient to be used for skin friction calculation for cohesionless soils are specified by the IS: 2911 in Appendix A. It is interesting to note that IS: 2911 is the only code which allows the coefficient of earth pressure in the range of 1 to 3 for loose to medium sands. However Note 2 of Appendix A of IS: 2911 states that K should depend on the nature of soil strata, type of pile and its method of construction but no further guidance given on this parameters. API RP2A prior to 2000 (20th Edition) recommends K value as per described in Table 2. There is also provision for using different K value for piles in tension. However, in the present API RP2A (2007 version), the practice of specifying K is abandoned and the coefficient Ktanδ is now directly specified in API code (see Table 2). It is important to note that K value greater than 2 is generally not recommended by various researchers worldwide even for large displacement piles i.e. [5]; Table 4.10.

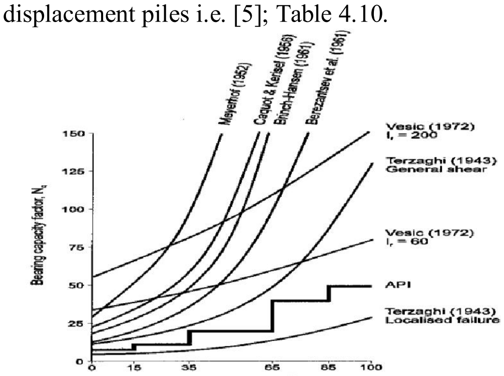

Fig. 5 Bearing Capacity factor N_q according to various authors compared with API RP 2A.

Angle of pile to soil friction (δ)

The angle of pile to soil friction (δ) for calculation of skin friction in cohesionless soils is generally obtained from the angle of internal friction (Ø') value. IS: 2911 allows to take δ as Ø' directly irrespective of installation method and interface material. However, it is recommended worldwide to use δ less than the Ø'-value (see [5]; Table 4.11). This is taken care by specifying δ= (Ø'-5) in API code prior to 21st Edition. As stated earlier, present API RP2A [2] specifies Ktanδ coefficient directly which further eliminate the confusion on selection of K and δ.

Impact on overall pile capacities

The pile capacities calculated for the pile geometry shown in the Fig. 1 considering the soil properties given in Table 1 using both IS: 2911 part I [1], section 1 and API RP2A [2]. The computed axial pile capacities are plotted in Fig 6. It is observed that skin friction capacities are very much comparable and more or less despite of the discrepancy on the various interaction parameters as discussed in above sections. However, there is significant difference in end bearing values computed for the pile. The total capacity, skin friction and end bearing are 4016, 3763, 7779 for API RP2A and for 4340, 4958, 9298kN for IS: 2911. The main reason for the differing the end bearing capacity is [2] recommends much lower N_q value. The difference is wide for medium to dense sand (i.e. $\emptyset > 35^0$) which is clear from the Fig 4. The reason behind difference in skin capacity is mostly due to variation in earth pressure coefficient.

The Lateral capacities may not be comparable as axial capacities due to the fact that [1] does not specify to use nonlinear p-y approach but not restrict designer to strictly follow the procedure given in the Appendix B of Amendment 3 of [1]. However, due to lack of specific guidance on p-y spring approach designers are generally avoiding it and follow the procedure given in the code. For the present case the pile capacity estimate is 80 kN for IS:2911 whereas 100 kN for API RP2A considering fixed head condition and 50mm deck displacement as offshore piles. It is interesting to note that IS: 2911 gives the formula for the computations of the lateral displacement (or lateral force causing admissible displacement) using equivalent cantilever approach which is actually structural approach presuming that soil will not fail in any case. It may be argued that the difference is low in capacity computations but this 20% difference in lateral capacity is comparatively huge in offshore installations where lateral pile capacity governs the number of pile installations and vary case by case. It is important to note that the factor of safety recommended by [1] is 2.5 where as for API RP2A is 2 which results comparable safe capacities.

Conclusions

The API RP2A and IS: 2911 are comparable in some sense for computation of the pile capacities (Axial and Lateral) and [1] generally estimates higher ultimate axial capacity compared to API RP2A. The API RP2A specifies the very low end bearing capacity factor (N_q) and which is clearly observed from the Fig 4. This difference is large for medium to dense sand formations. The earth pressure coefficient recommended in the [1] should be revisited as it may influence the skin capacity. Authors feel that picking the upper limit of K value designers may end up the higher capacity which may not be fact. Calibration of the computed capacity based on the pile load test is still a dream in India due to difficulty in pile load testing facilities in the Indian offshore industry. There is obvious need to revise the lateral capacity computations in [1] to make use of present day computer computations to optimize the safe lateral load on piles especially for partially embedded piles for offshore and near shore installations. The limiting values for skin friction and end bearing for the particular soil types needs to be specify clearly in the [1] similar to API RP2A [2]. It is fact that various codes are not prediction tools for the pile behaviour instead they should ensure the safe behaviour of piles in any ultimate limit states during span of their use therefore certain degree of conservation is acceptable in provisions made in codes. It is also important to recall that provisions in API RP2A for cohesionless soils are essentially for silicisous sands and one should use appropriate provisions for other types of Sand.

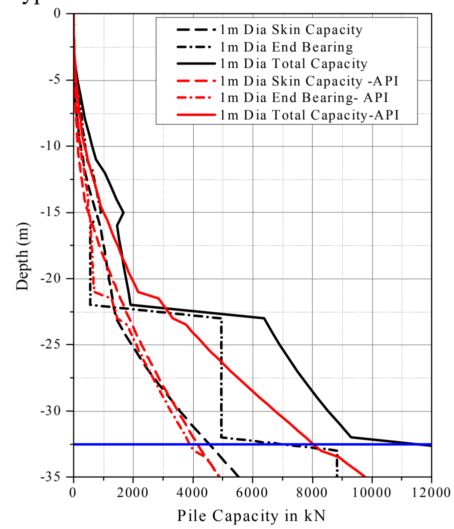

Fig. 6 Comparative pile bearing capacity estimate for IS:2911 and API RP 2A (WSD)

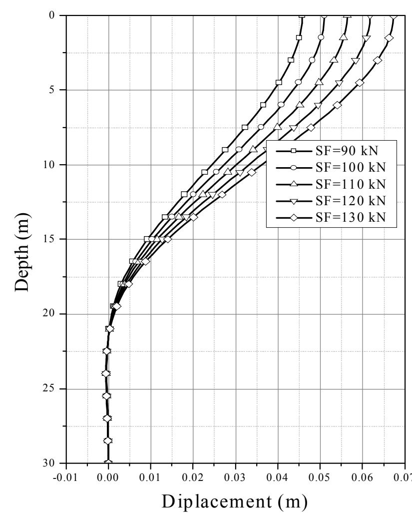

Fig. 7 Lateral response of pile for various shear force applied at pile head.

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