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Effect of Earthquakes in Marshy Lands and Alluvial Soils: Case Histories

Saripalli Suryanarayana
Kranthi Constructions, Erragadda, Hyderabad , India

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Saripalli Suryanarayana
Consultant, Kranthi Constructions,
208, Ram's Enclave, Erragadda,
Hyderabad – 500 018, INDIA

ABSTRACT

This paper presents a case study of the various factors effecting foundations and piling in marsy lands and alluvial soils. Various aspects regarding these types of soils are presented in context of the Indian sub-continent. Various case studies are shown and practical inferences are drawn from them on the correct methodology of piling and foundation work to be performed in marshy and alluvial soils. Also examples from recent earthquakes in Gujarat, India are analyzed. . Precautionary measures such as light structures, with no cantilever, and no high-rise buildings are a preliminary step. Further the overstressing of ground need to be avoided by spacing structures well apart. The eccentricity of center of gravity should not be allowed. In construction all joints shall have same stiffness. The billion-dollar loss equation is an assuming an SPT value for marsh depths of 7 to 9m [which really does not exist].

INTRODUCTION

Civilization requires Ports, Docks, Harbors, and Naval - Establishments nearer to shores. Also to ease on cost Billion Dollars are spent to set up shore industries such as Petroleum Refineries etc. Back history of Gujarat in INDIA, shows that these marshy and alluvial deposit areas [like RAN OF KUTCH] are effected by earth quakes, due to plate movements, since ages. Example of DWARAKA-CITY in water and hundreds of Gujaratis fled ages back to EAST AFRICA, are constant reminders of problems in marshy lands. Geological formations undergoing metamorphism with KILMANJARO-LAVA are also in great threat and are likely to disintegrate, in the process to create an earthquake like situation. The tides in November or December shall be maximum, while rock formations tend to pass the vibrations directly, the Marshy and Alluvial Soils act like plastic medium.

This medium is like a geo textile membrane and is susceptible for water table fluctuations. Water or Tide Tables vary during the year. Daily fluctuations being about 1 Mt, and the lowest of the low tide happening in march[generally]. The decrease in Tide starts in Dec 25th and increase starts after June 23 rd. Hence the effect of quakes in this period, due to plate movement, on the marshy lands, shall be minimum. The effect of EARTH QAKE when occurred in July PHENOMENA OF SIOLS: - The soils as a plastic medium try to compress and absorb the effect of plate movements. However this is not true when huge overburden of 2 to 3 meters is added to keep the land above tide effects. In these cases we observe 1] the structure is sinking, then tilting in the first vibration and then not able to come back to original position. Given the same stiffness all joints and given the hinge or fixed support to soil the structure is enormously dangerous with further addition of cyclone tides and cyclone wind loads, unless the structure is made to wind direction and not against it.

Hence the combination of loads for such a hinge shall be 1] Flotation 2] Negative Skin Friction 3] Eccentricity in Vibration [relative to the height of structure and combination of loads on base area] 4] Finite modules of 10 to 20 Mt long in independent units-With independent stress free foundation zone in soils.5] The approach Velocity [Reynolds number and pore pressure etc] ROCKY AREAS; The structures with anchored foundation in solid medium are to be assumed as fixed at bottom and designed for same stiffness, so that vibrations are uniform. While stress relief at foundations is not necessary, finite elements of 30 Mt may be necessary. A case study using matrices for soil parameters in submergence and in semi submergence needs to be done in marshy areas, to give a conclusion on BILLION DOLLAR LOSS equation.

GEO TECHNICAL FEATURES OF FOUNDATION

We discuss only the adequacy of foundations and natural calamities. These natural calamities are a combination of (a) high tides associated with or without cyclones, and a passing earthquake. It is generally understood that the North Pole attraction on the earth surface is higher, thus allowing the continents to drift and concentrate towards this pole. The classic features of Sumatra, Jawa and other islands are part of this pull force. The Himalayan plateau is rising thus shrinking the length of India. The vulnerable zones in India, yet to be classified are definitely Gujarat (Saurastra-Raan of Kutch) Assam (Arunachal

Pradesh) parts along Nagapur - Vidarbha - Paradeep line. No substraction can be made to these only addition of Mumbai and Pondicherry can at best be decided.
While the Ganga brings lots of silt every year, the settlement is taking place at the mouth of Godavari near Kakinada. Future land mass can be expected in this area. The faulty deccan area stretching from Nagapur, Vidarbha, Kothagudem has to be actually ascertained (The presence of coal in these areas without rivers is an indication of an earth quake or a fault in the area.)

East African Continent:

Applying the analogy of surplus lava of Kilmanjaro and underneath coal deposits, the East Africa is (1) increasing in its size by way of addition of new land at Somali. (2) However the rocks are yet to crystalline or metamorphize. In this process the shrinkage of the rocks gives way to an earth quake like situation needing either (a) very light structures (b) strong rigid foundations.

Indian context of Research:

The Govt., institutions such as "Survey of India" is more associated with making maps. The "Geological survey of India" is more immersed in finding metals and minerals. The Central Ground Water Dept. is on look out for sources of depleting ground water.

There is now an agency created to monitor earth Quakes head quartered at Bhuvaneswar might have been established a couple of years ago. The faulty rock formations, the origin of laterite deposits at Hyderabad, Orissa and Kerala are yet to be classified and established.

The research or the co-ordination in these parts starting from Gulf to Burma, after the Vanish of British Empire is negligible. All maps still depict the recordings by Surveyor General at Karachi, done between 1920 to 1940. I was astonished to find such a map in use at Saudi Aramco. Jaihmah off shore platform in 1998.

OBSERVATIONS IN FOUNDATION ENGINEERING

From late 60's to till today, I had seen people lost lives, lost their positions their pensions, lost precious production and precious money of the people, either through Govt., or through Private Corporation, because of faulty foundations.

Still the structural engineer is the more qualified foundation expert-only to pass- on- the- buck, in deciding the foundation type. The truth being, for unknown soils the factor of safety is less than 2, while for man- made items like steel and cement the factor is above 3.

History of Marshy lands

Marshy lands are marine deposit slushy soils with high P.I and low LL. Hence, all marine deposits are not marshy in nature. Here the soil heaves up when water table rises. This phenomena was greatly observed at Visakhapatnam, India Naval Project in end sixties. When dredged slush was used to elevate the land. To a great extent alluvial fine silts and black cotton soils act in the similar way. While this phenomena was seen to a little extent in Reliance, Hazira site, where the filling was with fine dredged sands form Tapati River.

Construction in Marshy Lands

To a great extent even laying of Roads in marshy land in Godavari delta area (S. Yanam, Amalapuram) was of great difficulty. No medium including boulders, Morrum was able to arrest the swell and sink process of these soils. The construction was achieved only after putting pieces of pulpy coconut, palmera or palmtree cuts. The top of the road was made using lime as a mixture, or binding agent to morrum.

Pile Foundation in Marshy Lands

Difficult theories of floatation, and -ve skin friction are added, for these structures. However an accurate analysis by now, if a real investigation with out personal vendetta, is made could have indicated that there is no negative skin friction and forget about any friction offered by these skeleton soils. The blame for this bleak research shall go to govt institutions, and private consultants who offer economic packages. This phenomenon of friction piles sinking is happening from 1969 to till date in all places of marshy lands in India. Be it buildings, in naval dockyard in vizag. bridges in Goa or Docks in Jamnagar etc.,

In majority of the cases the overburden added is acting as a dead load for achieving, consolidation in the floating solids underneath. Thus squeezing of water from pores of the soils in time of low water tables. This process of settlement can be observed in Docks, ports and Aerodromes built in sea. The settlement being the underneath natural consolidation achieved. The floating mass of overburden is anchored to bottom rigid layers by way of piles. Hence, for all practical purposes it is necessary, that this load transfer shall be done in to solid rock by at least 2 M. This was done for Naval docks and harbors at Visakhapatnam and for Bombay Port trust, modernization at Pirpau.

In sufficient Friction files in Marshy Lands

However reck-less founding is done assuming skin friction for buildings at Naval Docks, Vizag and at Essar pellet plant at Vizag. This demanded more costly stabilization for floors and ball mill foundations. The piles when driven and tested in dry season showed not only n=100,[SPT] but also showed the required load
carrying capacity.

On left open for one season and then after adding the 2 M over burden, the dead load of foundations started making the piles to give away. Thus showing that all the earlier estimates tend to zero in marshy areas where filled up soil also is dredged Marsh. The n was 35 and load was ¼ of tested load, after a year.

	Original Area level	Dredge &filling	Ground filling	Weathered Surface Below 0.0 m	Hand Rock Surface	Ref :
Pellet Plant Area	-4.00m	0.00m	+2.5m	-13 to -17m	-25 to 28m	Fig 1
DGN Para (Buildings)	-2.00m	0.00m	+1.5m	-12m to15m	-18m to -30m	Fig 2-3

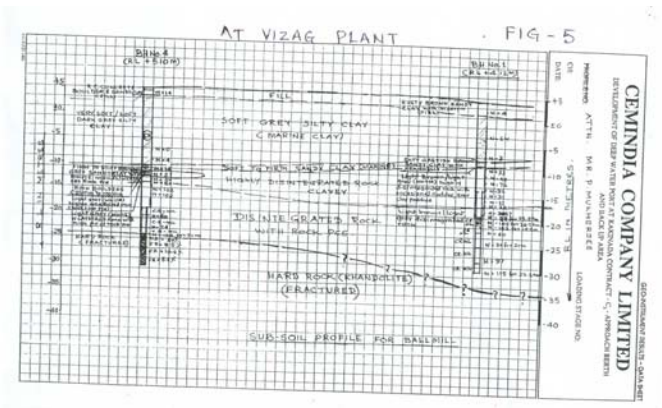

Figure 1: Pellet Plant Area Visakhapatnam

The piling engineering book published by Surrey University Press of Dr.WGK Fleming & others, in page 116 chapters of 13, 3rd Para. 'In weathered rock careful monitoring of driving records is essential ,owing to the wide variability in strength exhibited by soft rocks ,such as chalk and marl in a weathered state. Refusal of piles may not be achieved and the contribution of the pile shaft to its overall capacity may need to be relied upon. Accurate estimation of skin friction around pile driven in soft rock is difficult owing to the disruption of the structure of the rock as the pile penetrates.

For bored piles in chalk (as weathered rock, with n=100 & 1mtr shaft drilling). The skin friction is as low as 8kn/m^2 (Hodges and Pink 1971). This also has to be correlated for chemical bonding of bentonite (which is also like marsh, or-marine-organic matter – in reality.) with chalk both make the end of bearing capacity also freak. Thus the N=100 for 0.3m penetration need to be correlated as per page 104 & 105 of same book'.

In case of Naval Project (DGNP) all marine work were taken to hard rock and 2mtr socketing at around 20 to 25m depth, in hard rock was done.

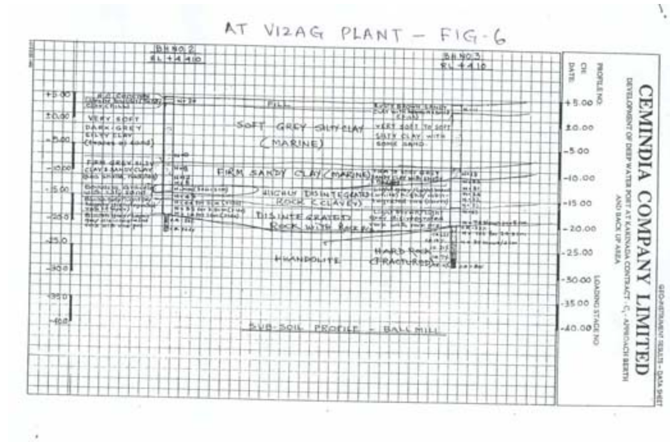

Figure 2 Soil Conditions

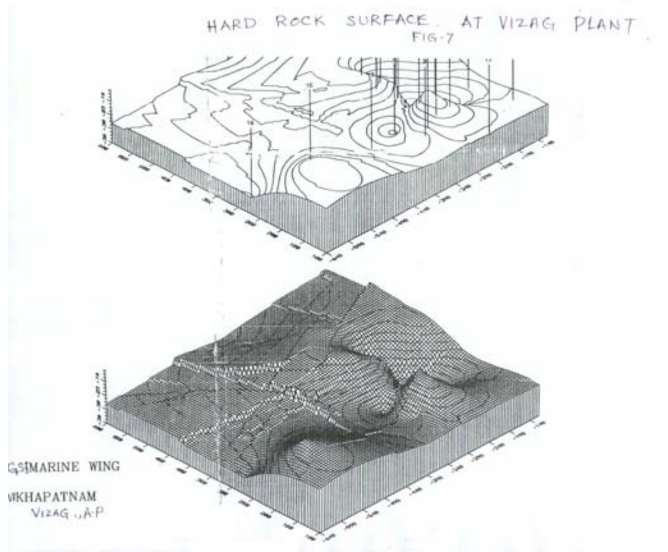

Figure 3 Hard Rock Surface at Visakhaptnam Plant

Same was suggested by Keverner RJ Brown, [SINGAPORE] Mumbai for BPCL, and Pirpau modernization in scheme. Hard rock and 6m penetration was necessity for docking vessels (Project of Bombay Port Trust on Western India). Again in 1988-90 piling on west coast on Hazira (Surat) for Petro Industry was N=50 or 7.5m from G.L, 6T capacity 600mm- 1m bulb under reamed piles,&Precast 500*500 or 600*600[square] piles were driven upto 18 to 25m.(Source Humphry-Glawscow consultants-&Constructors Gannam Dunkerley & Co Ltd. Contractor) (Refer Figures 4 – 8).

Further studies in East Indian – marsh soils shows many industries has gone for n=100,' [which was clayey highly disintegrated Rock] @ approximately -15m. And actual hard rock is at 21 to -22m approximately. (Source CEMINDIA -1995, &OTHERS). At Gangavaram Port. At port facilities the weathered Rock is available ft -21.50m (L & T Romboll). At port area of Vishakapatnam for an oil bearth in 2000 has shown N=100 at 20m approx, while hard Rock at some places was at-39m

Soil liquefaction in Marshy lands and the effects on Dwaraka temple and latest 'Bhuj" Earth Quake – in Gujarat:

'Todorvoska in his 1998 paper states that liquefaction of water saturated sands is believed to occur when the wave pressure approaches the confining pore pressure. It can initiate large blocks of soil (lateral spreading) causing extensive damage to man made structures.'

He also states that 'there is uncertainty in estimation of critical SPT for liquefaction to occur, when the thickness of the sedimentary layer at site is[h] not available. The possibility of amplification of strong ground motion by sedimentary deposits is demonstrated time and again.'. Thus Raan of Kutch near Bhuj and Dwaraka areas are very much the marshy lands reflecting all these uncertainties associated with yearly 4 m tidal variations &another 2 meter cyclonic storm water waves. An account of these in near marshy areas [nearer to sea exposure] needs to be accounted for, in design calculations.

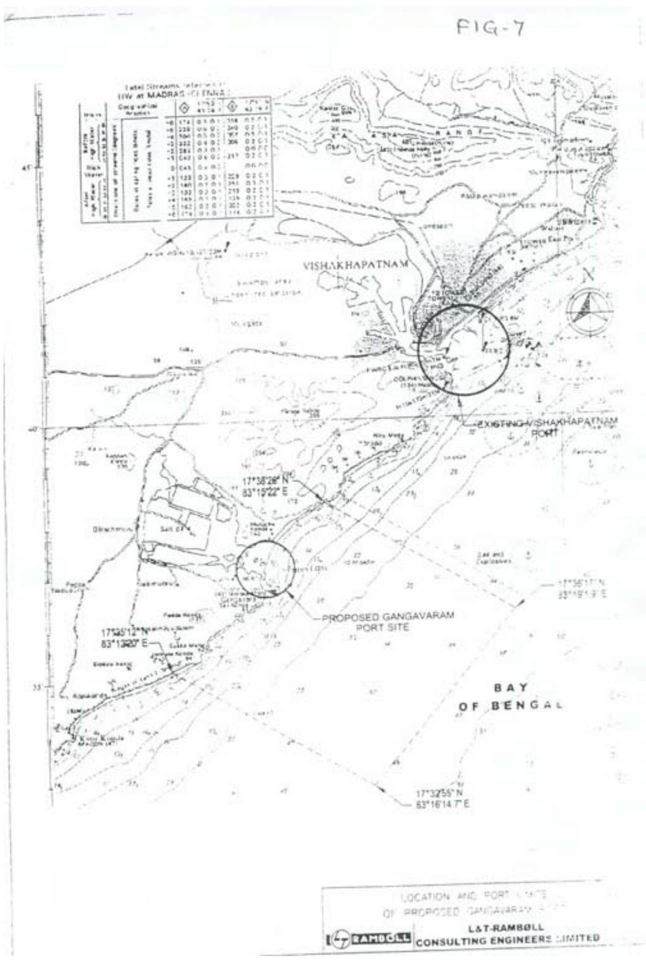

Figure 4 Location of Visakhapatnam Port

Right Piling:

However the friction piles at Relience Hazira on the banks of Tapati contained fine filled up sands of 3 to 4 M. below that a small layer of fine silts. The 3rd layer was of 2 M black cotton soil, followed by other natural soils, such as stiff clay. The alluvial soils were behind the scenes as the site is 7 Km. from the shoreline. Hence, even under reamed piles of 7.5M length and 500mm dia offered good resistance and were successful.

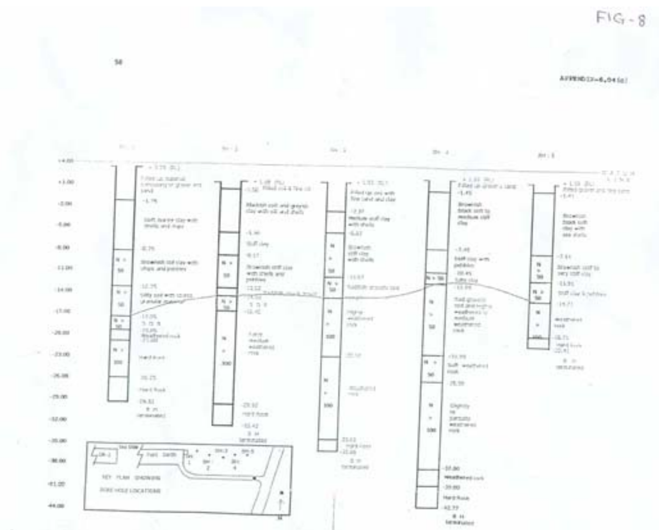

Figure 5 Bore Hole Locations for Pelletization Plant

These observations tend to suggest that though the area is dry, and confined, please do not assume any strength for the marshy soils either in load bearing or in friction (2) The SPT tests has to be done year long during tide variations for at least 3 years (2) The structures need to be designed as floating foundations, which are estimated for settlement, or as rigid foundations anchored 2 M in to rock, like that of Docks.

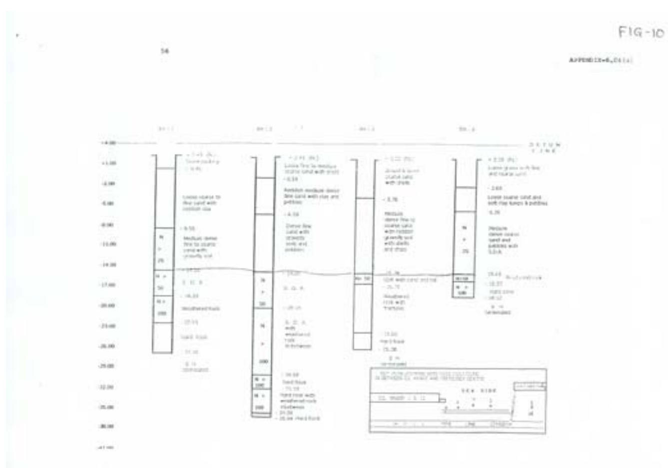

Figure 6 Bore Hole Locations (part 2)

The dynamics of the fluids are the influencing factor. The soil particles are assumed as suspended matter and irreverent in all calculations for stability. The depth of such layers may be 5 to 10 M. The silts add viscosity to the fluid. When water is drawn out in low tides the sedimentary solids try to consolidate forming a boundary layer.

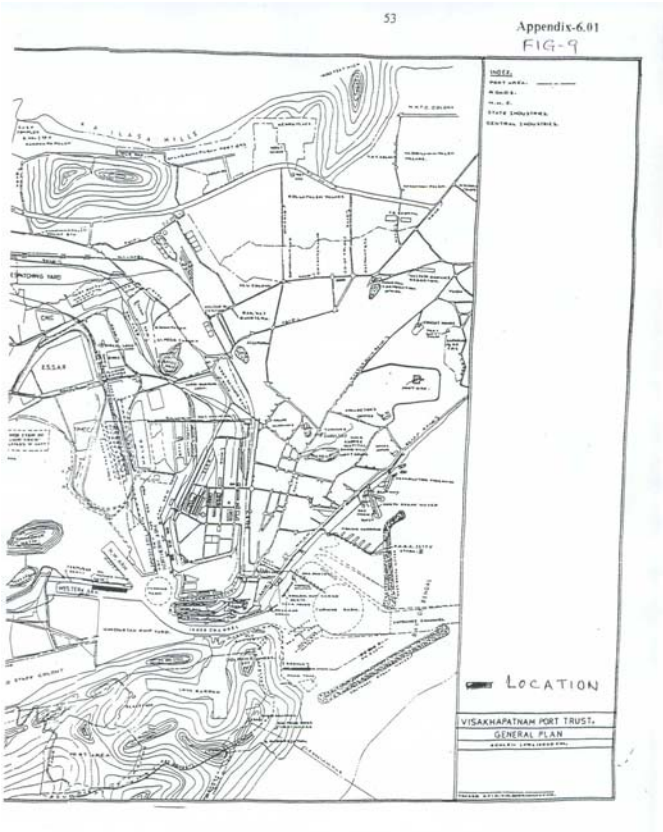

Figure 7 Location of Pellet Plant (Detailed Drawing)

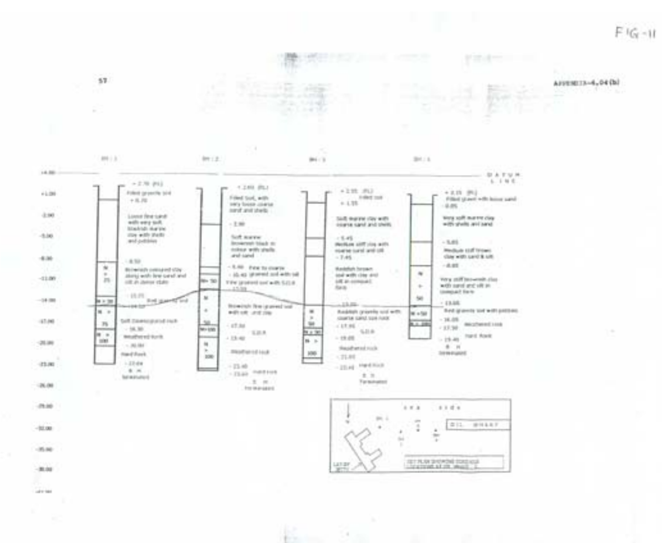

Figure 8 Locations of Bore Holes

The effects of friction and erosion are confined to a very thin adjoining boundary layer, making it more viscous. This cantilever effect on the end soils by drag and boundary layer cannot be neglected, as cavitation, bubble formation are also associated with it. The match number (Equation No 1)

$$M = \frac{V}{C} \tag{1}$$

in high tides of Cyclone (and earth quakes) also can be more than 1 where V is Velocity of flow and C is velocity of sound in fluid.

Applying momentum equation at times of tide increase (Equation No 2)

$$F.dt = \partial(mv) \tag{2}$$

where

impulse of tide force in a given time =
Change of momentum in the vertical direction of the force

The impulse of tide force acting over a short interval of time is equal to change of momentum in the direction of force. Here the change being the uplift pressure of water on the marshy soils.

Similarly applying dimensional similarity the equivalent drag force acting on these soils as up lift force depends on Reynolds number, Freud's number, and density of water and Viscosity of the fluid mass acting from below. (Equation No 3)

$$F = \rho l^2 V^2 \phi(RFE) \tag{3}$$

where

ρ = density of fluid (salt water)

l = linear dimension on the coast line

V = Velocity of flow (with tides)

R = Reynolds number $R = \frac{\rho Vl}{\nu}$

ν = viscosity of fluid

f = freud's number = $\frac{V^2}{\lg}$

g = gravitational constant

E = Relative roughness of area $\frac{K}{L}$ = 1 (for marshy lands)

At the time of earth quake the factor dia (RFE) Needs to be ascertained

<u>Ports & Harbors – Suggestions:</u>

Be it ports or Industrial Structures including gas pipelines in these areas stand for great risk. The theories of pore pressure, flow nets do not stand in the saturated marshy soils. Also either friction or – ve skin friction does not arise unless it is naturally consolidated for 100 years. My experience on 30 years naturally consolidated marsh is already described.

Due to tidal variations high viscous fluids are formed and the bottom layers tend to (1) bulge and soften (b) Create movement among soils with slight load application (c) do not show same SPT number when piling is completed and load is applied (d) The ultimate aim of a foundation gets nullified.

This necessities continuous draining bores of depth about 6 to 10 M on the periphery to decrease the pressure of tides on the reclaimed marshy lands.

CONCLUSIONS

The earth Quakes, known and unknown in all these marshy lands have created havocs. Loss of life, property and prosperity sinking of Dwaraka, unknown calamities at Porbandar, Kandla, Paradeep, Mahabalipuram and known earth Quakes at Bhuj reflect the colossal attitude and lack of interest in research in the foundations in these marshy lands or alluvial soils nearer to shore line. Precautionary measures such as light structures, with no cantilever, and no high rise buildings are a preliminary step. Further the overstressing of ground need to be avoided by spacing structures well apart. The eccentricity of center of gravity should not be allowed.

In construction all joints shall have same stiffness. The billion dollar loss equation is an assuming an SPT value for marsh depths of 7 to 9m [which really does not exist].The economics are more in loss than in gain

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