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Estimation of Marine loads on Jetty Structure

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Abstract—*Port and Harbor gives access to water ways through which can load and unload goods, raw material, and it is useful for the public transportation at very low cost. So these structures are the back bone of the economic growth of the country. Jetties are the most important structure of transporting the large quantities of goods, raw material and fuel. Jetty is structure which gives an easy way of transportation and economical thorough waterway which will Inland waterway or through sea. This paper consist the process of calculation of forces on jetty in additional marine loads like Current load, Wave Load, Berthing Load, Mooring Load IS4651-1974 of Planning and Design of Port and Harbor(Part 3)-Loading.*

Keywords*: Jetty, Berthing, Mooring, Current, Wave, Depth of Fixity.*

1. INTRODUCTION

Jetties are mostly built on pile foundation. In India most common practice is bored cast in situ piles which gives maximum stability and ability to berth the ships on a Jetty Structure. Jetty design should have to be in such manner that it will stand in any worst load combination within permissible limit, because Jetty plays a very important role in natural disasters like earthquake and tsunami to provide the relief material and evacuation of people.

Generally jetties are built in water with sufficient depth for the anchorage of ships and parallel to the navigation of the channel. It will help to berth a ship smoothly.

2. LOAD CALCULATION

2.1 Dead Load

The dead load coming on the Berthing structure is mainly due to the self-weight of the members including slab, beams, piles, pile cap, fender block, retaining wall etc. In SAP-2000 Modeling, floor load is defined separately, while member load is directly defined as self-weight.

2.2 Live Load

Surcharges due to stored and stacked material, such as general cargo, bulk cargo, containers and loads from vehicular traffic of all kinds, including trucks, trailers, railway, cranes, containers handling equipment and construction plant constitute vertical live loads.

2.3 Wind Force

Wind force on structure shall be taken in accordance with IS: 875-1987 as applicable. Wind force pressure is given by,

$$P_z = 0.6 \times V_z^2$$

Where,

$$V_z = V_b.K_1.K_2.K_3$$

P_Z = Design wind pressure in N/m^2 at height z.

V_Z = Design wind speed at any height in m/s

V_b = Basic wind speed at any height in m/s

K_1 = Probability factor (risk coefficient)

K_2 = Terrain height and structure size factor

K_3 = Topographic factor

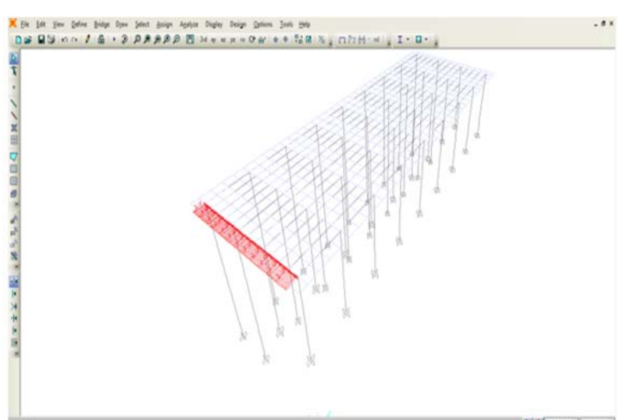

Fig. 1: Applied Wind Force in X-Direction

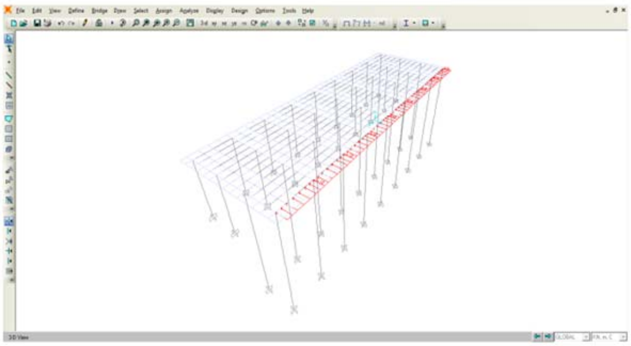

Fig. 2: Applied Wind Force in Y-Direction

2.4 Seismic Force

Jetty should sustain in earthquake so for the calculation of seismic force IS1893 – 2002 is followed. In areas susceptible to seismic disturbance horizontal force equal to a fraction of the acceleration of gravity times the weight applied as its centre of gravity should be taken. The fraction will be depending upon the likely seismic intensity of the area. The weight to be used is the total dead load plus one half of the live load. The design horizontal seismic coefficient (A_h) for a structure shall be determined by the following expression:

$$A_h = \frac{Z.I.S_a}{2.R.g}$$

Z= Zone Factor.

I= Importance Factor.

$\frac{S_a}{g}$ = Average response acceleration coefficient.

R= Response reduction factor.

$$V_B = A_h.W$$

W=Seismic weight of the structure.

V_B= Base Shear.

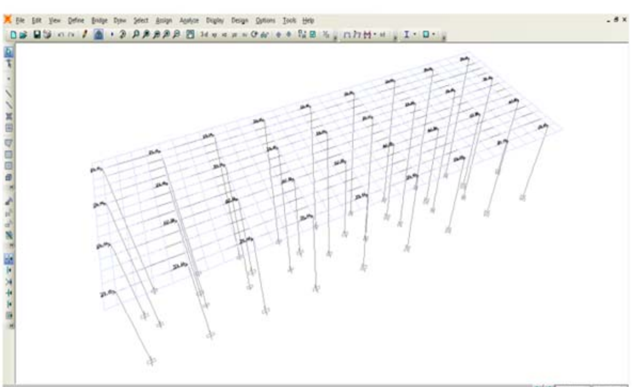

Fig. 3: Applied Seismic Force in X-Direction

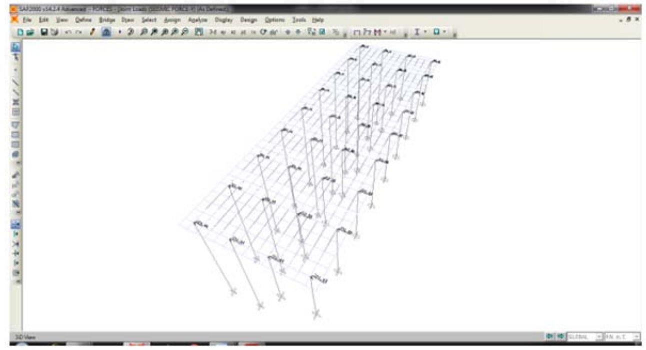

Fig. 4: Applied Seismic Force in Y-Direction

2.5 Wave Force

For deep water waves, the most important processes in the development of the wave field are usually energy growth from the wind, deep water wave propagation and eventual decay of wave energy. The seabed generally does not have an influence on the wave field in deep water. When waves encounter an island, headland or obstacles during their propagation, they diffract through these obstructions and such phenomenon should be account for in wave analysis.(Refer, Chakrabarti S.K(1987),“ Hydrodynamics Of Offshore Structure”, Computational Mechanics Publications, Southampton Boston, USA[6,8]

Analysis of wave force using Morison equation,

$$dF_I = C_m.\rho(\frac{\Pi D^2}{4}).\dot{U}.dz \quad dF_D = \frac{1}{2}.C_D.\rho.D.|U|.U.dz$$

Where,

$\dot{U}$ = Water Particle Acceleration

dF_I = Inertial force on the segment ‘dz’ of the vertical cylinder

D= Cylinder Dia.

C_M= Inertia coefficient (for uniformly accelerated flow)

ρ = Mass density

dF_D= Drag force on an incremental segment ‘dz’ of the cylinder

U=Instantaneous water particle velocity.

C_D= Drag Coeff

$$\{F_T \cong F_D + F_I\}$$

$$F_T = C_m.\rho\frac{\pi D^2}{4}.\int_{-d}^{0}(\frac{-2\pi^2 H}{T^2}.\frac{\cosh k(z+d)}{\sinh kd}.\cos\theta).dz$$

$$+ \frac{1}{2}.C_D.\rho.D\int_{-d}^{0}(\frac{\pi^2 H^2}{T^2}.\frac{\sin\theta.|\sin\theta|}{\sinh^2 kd}.\cos^2 kd(z+d)).dz$$

$$= -C_m.\rho\frac{\pi D^2}{4}.\frac{2\pi^2 H}{T^2}.\frac{\cos\theta}{\sinh kd}.\frac{\sinh kd}{k}$$
$$+\frac{1}{2}.C_D.\rho.D.\frac{\pi^2 H^2}{T^2}.\frac{\sin\theta.|\sin\theta|}{\sinh^2 kd}\left\{\frac{d}{2}+\frac{\sinh 2kd)}{4k}\right\}$$

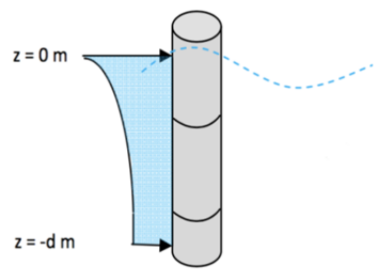

Fig. 5: Wave force profile along the depth of pile

2.6 Tsunami Force

Tsunami forces on slender piles have been determined by the Morison equation. It has been assumed that the largest loads will be included during the passage of the tsunami crest. Therefore, inertia force has not been considered.

2.7 Current Force

Pressure due to current will be applied to the area of the vessel below the water line when fully loaded. It is approximately equal to $w.v^2/2.g$ per square meter of area, where v is the velocity in m/s and w is the unit weight of water in tonnes/m3. The ship is generally berthed parallel to the current. With strong currents and where berth alignment materially deviates from the direction of the current, the likely force should be calculated by any recognized method and taken into account. For the calculation of the velocity along the depth of pile at each specified location.[6] $U_{TZ} = U_{TS} \times \left(\frac{z}{d}\right)^{\frac{1}{7}}$

Where U_{TZ} is the surface current, z is distance above the bottom measured positive upward & d is the total depth of pile.

$$P = \frac{k.w.v^2}{2.g}$$

Where,

P= Pressure force

w=unit wt. of water in tonnes/m^3

g=acceleration due to gravity

k= for circular c/s=0.70

v=current velocity

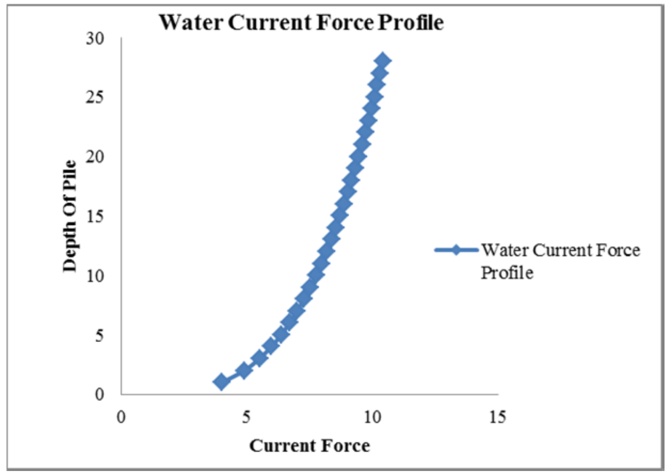

Fig. 6: Graph shows Water Current Force Profile

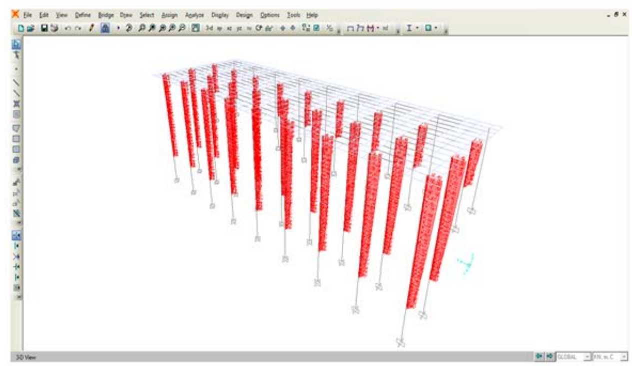

Fig. 7: Applied Current Pressure along the depth of the Pile in X-direction.

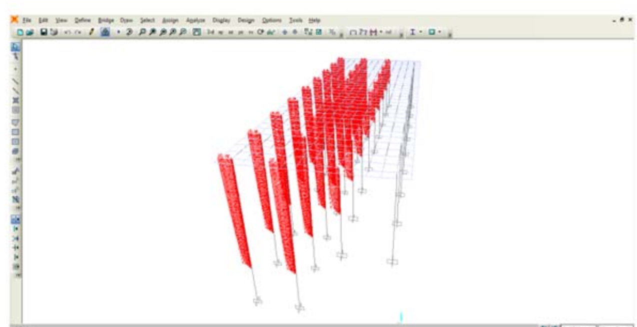

Fig. 8: Applied Current Pressure along the depth of the Pile in Y-direction.

2.8 Earth Pressure

This type of force is applicable only if the berth has a retaining wall at the landside and it retains the earth. Thus active earth pressure can be defined as, if the wall moves sufficiently away from the backfill by translatory motion or rotation about the base or their combination, lateral pressure of the backfill is reduced and is termed as Active earth pressure.

Soil Data-

γ_{soil} = Unit wt. of soil (KN/m^3),

Surcharge Load= q (KN/m^2),

ϕ= Internal Friction Angle,

K_a=Coeff. Of active earth pressure= $= \frac{1+\sin\phi}{1-\sin\phi}$

Lateral earth pressure due to soil (P_1) => $P_1 = K_a.\gamma.H$

Lateral Pressure due to Surcharge (P_2) => P_2=K_a x q

Resultant of both soil and surcharge as shown in below,

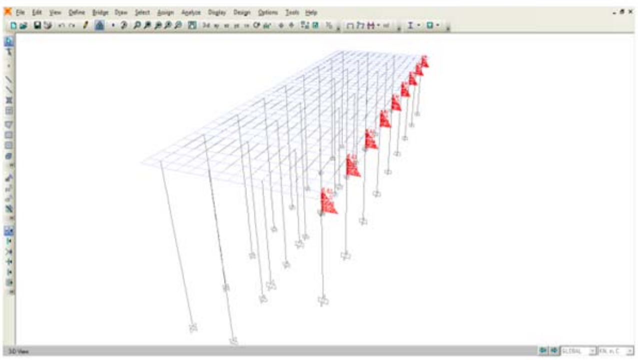

Fig. 9: Applied Earth Pressure on land side of Jetty

2.9 Berthing Energy

When an approaching vessel strikes a berth a horizontal force acts on the berth. The magnitude of this force depends on the kinetic energy that can be absorbed by the fendering system. The reaction force for which the berth is to be designed can be obtained and deflection-reaction diagrams of the fendering system chosen. These diagrams are obtainable from fender manufacturers. The kinetic energy, E, imparted to a fendering system, by a vessel moving with velocity V m/s is & given by:[3]

$$E = \frac{W_D.V^2}{2g} x C_m x C_e x C_s$$

Where,

V = Vessel moving with velocity

W_D = Displacement tonnage (DT) of the vessel in Tonnes.

g = Acceleration due to gravity in (m/sec^2)

C_m = Mass Coefficient

C_e = Eccentricity Coefficient

C_s = Softness Coefficient

2.9.1 Mass Coefficient. When a vessel approaches a berth and as its motion is suddenly checked, the force of impact which the vessel imparts comprises of the weight of the vessel and an effect from the water moving along with the moving vessel. Such an effect, expressed in terms of weight of water moving with the vessel, is called the additional weight (W_A) of the vessel or the hydrodynamic weight of the vessel. Thus the effective weight in berthing is-the sum of displacement tonnage of a vessel and its additional weight, which is known as virtual weight (W_V) of a vessel.[3]

$$W_v = W_D.C_m$$

W_v = Virtual weight of the vessel in tonnes

W_D = Displacement tonnage of the vessel in tonnes

I. The mass coefficient C_m should be calculated as follows:

$$C_m = 1 + \frac{2D}{B}$$

Where,
D = draught of the vessel in m,
B = beam of the vessel in m.

II. Alternative to (I) in case of a vessel which has a length much greater than its beam or draught generally for vessels with displacement tonnage greater than 20,000 the additional weight may be approximated to the weight of a cylindrical column of water of height equal to the length of vessel and diameter equal to the draught of vessel, then

$$C_m = 1 + \frac{(\pi/4 \, x D^2 x L x w)}{W_D}$$

Where,
D = Draught of the vessel in m,
L = Length of the vessel in m,
w = Unit weight of water (1.03 tonnes/m^2 for sea water),
W_D=Displacement tonnage of the vessel in tonnes

2.9.2 Eccentricity Coefficient. A vessel generally approaches a berth at an angle, denoted by 'θ' and touches it at a point either near the bow or stern of the vessel. In such eccentric cases the vessel is imparted a rotational force at the moment of contact, and the kinetic energy of the vessel is partially expended in its rotational motion. [3]

The eccentricity coefficient (C_e) may then be derived as follows:

$$C_e = \frac{1+(l/r)^2.\mathrm{Sin}^2\theta}{1+(l/r)^2}$$

Where,

l = distance from the Centre of gravity of the vessel to the point of contact projected along the water line of the berth (m)

r = radius of gyration of rotational radius on the plane of the vessel from its Centre of gravity (m)

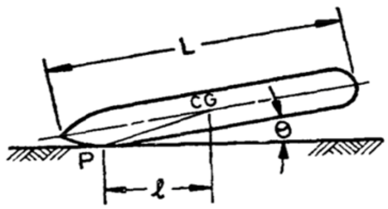

Fig. 10: Vessel approaching berth at an angle[3]

Table 1: Values of eccentricity coefficient[3]

l/r	Angle θ		
	0°	10°	20°
1	0·50	0·51	0·56
1·25	0·39	0·41	0·46

2.9.3 Softness Coefficient This softness coefficient (C_s) indicates the relation between the rigidity of the vessel and, that of the fender, and hence also that between the energy absorbed by the vessel and by the fender. Since the ship is relatively rigid compared with the usually yielding fendering systems, a value of 0.9 is generally applied for this factor or 0.95 if higher safety margin is thought desirable.[3]

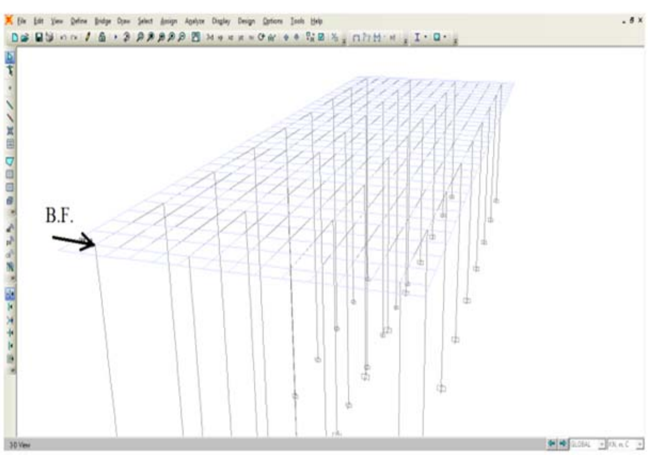

Fig. 11: Applied Berthing Force on a Jetty

2.10 Mooring Force

The mooring loads are the lateral loads caused by the mooring lines when they pull the ship into or along the dock or hold it against the forces of wind or current. The maximum mooring loads are due to the wind forces on exposed area on the broad side of the ship in light condition:[3]

$$F = C_w . A_w . P$$

F = Force due to wind in kg

C_w = Shape Factor =1.3 to 1.6

A_w = Windage Area in m^2

P = Wind pressure in kg/m^2 to be taken in procedure with IS875-1987

The windage area (A_w) can be estimated as follows:

$$A_w = 1.175 L_p (D_M - D_L)$$

Where,

L_p = Length between perpendiculars in m

D_M = mould depth in m

D_L = average light draft in m

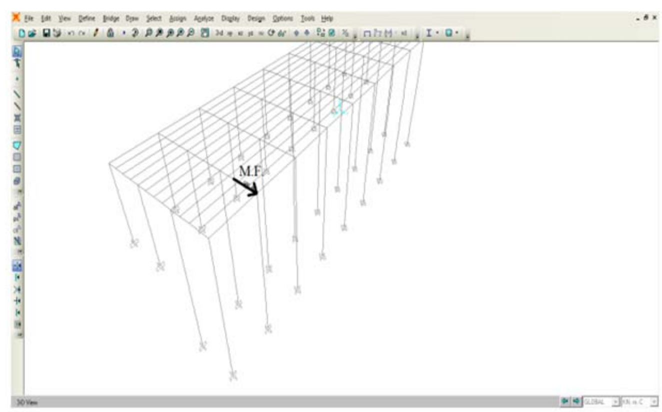

Fig. 12: Applied Mooring Force on a Jetty

2.11 Temperature Stress

Temperature stresses makes very big impact on Jetty structure mostly along the length of the structure. Temperature change cause additional strain to structural element. For unconstrained structural element temperature change cause zero stress, but for constrained structural element that temperature change cause stress. For this reason expansion joints are provided so that the joint is free to expand. Expansion joint is provided at 150 m to reduce temperature stresses. Temperature force will be in form of expansion and contraction.

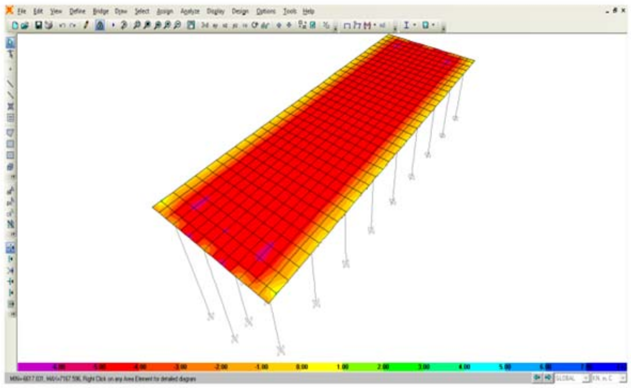

Fig. 13: Applied Temperature Stress on a Jetty

2.12 Shrinkage and Creep

There are several similarities and dissimilarities between creep and shrinkage. First, the source for both the effects is the same, which is loss of adsorbed moisture from the hydrated cement paste. In shrinkage, the loss is due to difference in the relative humidity of concrete and the environment, in creep it is due to sustained applied stress. Second, the strain-time curves of both the phenomenon are very similar.

When concrete is subjected to compressive loading it deforms instantaneously. This immediate deformation is called instantaneous strain. Now, if the load is maintained for a considerable period of time, concrete undergoes additional deformations even without any increase in the load. This time-dependent strain is termed as creep.

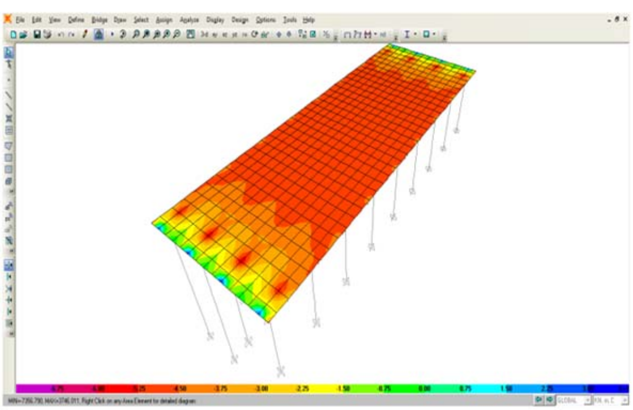

Fig. 14: Shrinkage stress due to material of a Jetty

3. DEPTH OF FIXITY

The recommended values of k_1 are given in Table 4 of IS 2911 (Part 1/Sec 2): 2010.[11]

Stiffness Factors –

For piles in sand and normally loaded clays $T = \sqrt[5]{\frac{EI}{\eta_h}}$

For Piles in Preloaded Clays

$$R = \sqrt[4]{\frac{EI}{KB}}$$

$$K = \frac{k_1}{1.5} X \frac{0.3}{B}$$

Where,

E = Young's modulus of pile material, in MN/m2;

I = moment of inertia of the pile cross- section, in m4

B = width of pile shaft (diameter in case of circular piles), in m.

η_h = modulus of subgrade reaction, in MN/m3 (*see* Table 3 of IS 2911 (Part 1/Sec 2): 2010.).

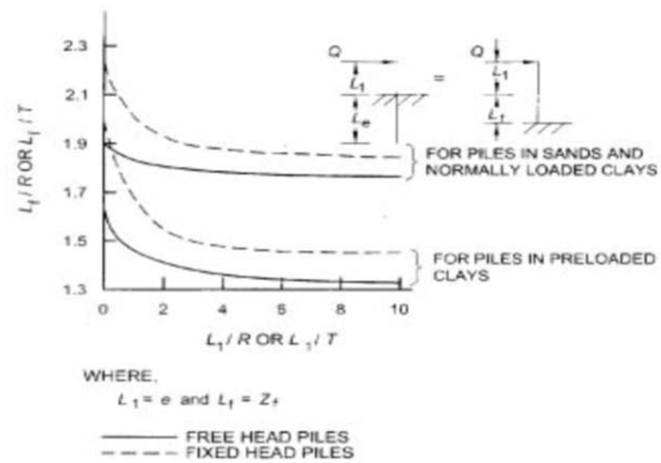

Fig. 15: Depth of fixity (Source: - IS 2911 (Part 1/Sec 2): 2010)

4. DISCUSSION

It's very difficult to do the analysis of Wave Force and Current Force because the nature of currents and waves is unpredictable.

Wave force and Current are never been uniform along the depth of pile, the profile of both forces as shown in above.

The conversion of Berthing energy to Berthing force is dependent on the type of Fender and the material type which is used.

5. ACKNOWLEDGEMENTS

Special thanks to AFCONS Infra. Ltd. Andheri (W) for providing guidance.

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