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Study on Design and Construction of Offshore Structure Foundation

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Abstract:

The study on the design and construction of offshore foundations is crucial for the successful deployment and long-term stability of offshore structures such as oil rigs, wind turbines, and bridges. Offshore foundations must withstand a unique set of environmental and geotechnical challenges, including dynamic loading from waves and wind, corrosive saltwater environments, and the complex behaviour of seabed soils. This abstract provides an overview of the critical aspects involved in the design and construction of offshore foundations, with a focus on different types of foundations, site investigation techniques, material selection, construction methodologies, and the impact of environmental factors.

Keywords **—Offshore Foundation, Jetty, Loads, Underwater Foundation, Design and Analysis .**

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I. INTRODUCTION

The development of offshore foundations in India began in the 1960s with the discovery of Mumbai High and has since expanded to include various offshore oil and gas fields and, more recently, offshore wind energy projects. Driven by the need to harness domestic energy resources and technological advancements, India's offshore foundation engineering has evolved to address the unique challenges posed by the marine environment. Through continuous innovation and adherence to rigorous standards, offshore foundations in India continue to play a critical role in supporting the country's energy infrastructure and economic growth.The development of offshore foundations in India incorporated several technological innovations to address the unique challenges posed by the marine environment:

- Pile Foundations: Driven piles, made of steel or concrete, were used extensively. These piles were driven deep into the seabed using hydraulic hammers, providing the necessary load-bearing capacity and resistance to environmental forces such as waves, currents, and wind.
- Jacket Structures: Steel jacket structures, anchored to the seabed with piles, became a common design for offshore platforms. These structures provided a stable base for the platform deck and equipment.
- Suction Caissons and Gravity-Based Structures: In addition to pile foundations, other types of foundations, such as suction caissons and gravity-based structures, were explored and used in suitable locations.

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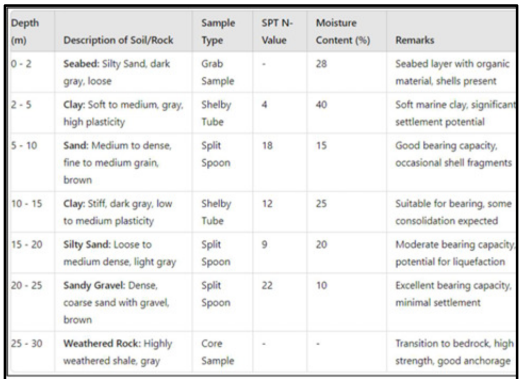
continue to play a critical role in supporting the country's energy infrastructure and economic growth.

II. GEOTECHNICAL CONSIDERATION

a) **Site investigation:**The objective of a site investigation for the construction and design of offshore structure foundations is to gather comprehensive data about the subsurface conditions at the proposed site. This data is crucial for designing safe, efficient, and cost-effective foundations. Determine the physical and mechanical properties of the seabed materials, such as strength, density, porosity, and compressibility. These properties influence the design of foundation systems and the selection of construction methods. Assess the hydrodynamic conditions, including water depths, tidal ranges, wave heights, and currents. This information is vital for designing structures that can withstand the forces exerted by the marine environment. Evaluate the seismicity of the area to design foundations that can withstand potential earthquake forces. This includes understanding the potential for liquefaction and other earthquake-related phenomena. Investigate the potential environmental impacts of the construction and operation of the offshore structure. This includes understanding the local marine ecosystem and ensuring compliance with environmental regulations.

b) **Borelog Analysis**: This investigation is performed to study the physical properties of soil and the strength properties of the seabed soil. These results can be used to determine soil-bearing capacity of the underlying soil.

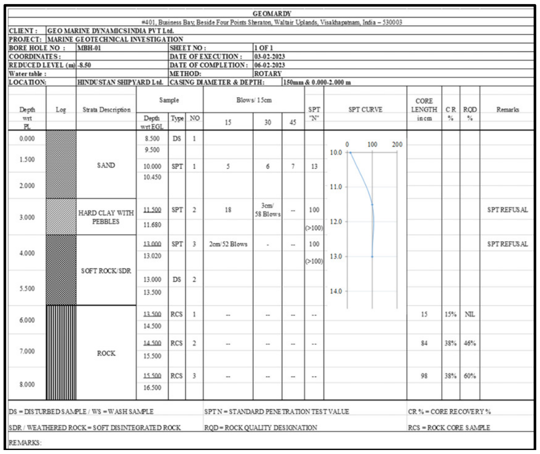
TABLE 1
SOIL SAMPLE RECEIVED THROUGH BOREHOLE



Depth (m)	Description of Soil/Rock	Sample Type	SPT N-Value	Moisture Content (%)	Remarks
0 - 2	**Seabed:** Silty Sand, dark gray, loose	Grab Sample	-	28	Seabed layer with organic material, shells present
2 - 5	**Clay:** Soft to medium, gray, high plasticity	Shelby Tube	4	40	Soft marine clay, significant settlement potential
5 - 10	**Sand:** Medium to dense, fine to medium grain, brown	Split Spoon	18	15	Good bearing capacity, occasional shell fragments
10 - 15	**Clay:** Stiff, dark gray, low to medium plasticity	Shelby Tube	12	25	Suitable for bearing, some consolidation expected
15 - 20	**Silty Sand:** Loose to medium dense, light gray	Split Spoon	9	20	Moderate bearing capacity, potential for liquefaction
20 - 25	**Sandy Gravel:** Dense, coarse sand with gravel, brown	Split Spoon	22	10	Excellent bearing capacity, minimal settlement
25 - 30	**Weathered Rock:** Highly weathered shale, gray	Core Sample	-	-	Transition to bedrock, high strength, good anchorage

c) **Laboratory Testing:**To the extent that site assessment is not complete until all engineering design parameters are obtained, many of the retrieved soil/rock samples undergo laboratory testing. The laboratory testing program should be tailored to obtain engineering parameters for preliminary design of the intended foundation system. For example, both monotonic and cyclic shear strength profiles are needed for determining the holding capacity of suction caissons. The types of soil (and/or rock) laboratory tests conducted for underwater foundations should accomplish the following objectives: (a) material identification and classification, (b) behaviour under anticipated field levels of stress and strain, (c) compressibility characteristics under sustained loading, and (d) stress-strain characteristics and pore-pressure response under cyclic loading. The tests on soil materials should include index properties (submerged unit weight, Atterberg limits, mineralogy, grain-size analysis, moisture content, chemical composition, and specific gravity). Strength tests should be conducted using either “undisturbed” or remoulded sample specimens. Unconsolidated undrained (UU) tests can be conducted to assess short-term behaviour, whereas consolidated-drained (CD) or consolidated-undrained (CU-bar) tests with pore pressure measurements are needed to assess the long-term behaviour. Conventional soil strength tests imply static (monotonic) loading conditions and include direct simple shear tests, unconfined compression triaxial tests, UU triaxial tests, miniature shear vane, fall cone, and hand penetrometer, among others. Computed strength and stiffness parameters (cu, u Eu) from these test data establish the undrained shear strengths of the soil specimens.

FIGURE1
BORELOG OF MARINE PILE



GEOMARDY
#401, Business Bay, Beside Four Points Sheraton, Waltair Uplands, Visakhapatnam, India – 530003

CLIENT :	GEO MARINE DYNAMICSINDIA PVT Ltd.		
PROJECT:	MARINE GEOTECHNICAL INVESTIGATION		
BORE HOLE NO :	MBH-01	SHEET NO :	1 OF 1
COORDINATES :		DATE OF EXECUTION :	03-02-2023
REDUCED LEVEL (m)	-8.50	DATE OF COMPLETION :	06-02-2023
Water table :		METHOD:	ROTARY
LOCATION:	HINDUSTAN SHIPYARD Ltd.	CASING DIAMETER & DEPTH:	150mm & 0.000-2.000 m

Depth wrt PL	Log	Strata Description	Sample			Blows/ 15cm			SPT "N"	SPT CURVE	CORE LENGTH in cm	C R %	RQD %	Remarks
			Depth wrt EGL	Type	NO	15	30	45						
0.000		SAND	8.500	DS	1									
1.500			9.500											
			10.000	SPT	1	5	6	7	13					
2.000			10.450											
3.000		HARD CLAY WITH PEBBLES	11.500	SPT	2	18	3cm/ 58 Blows	--	100					SPT REFUSAL
			11.680						(>100)					
4.000		SOFT ROCK/SDR	13.000	SPT	3	2cm/52 Blows	-	--	100					SPT REFUSAL
			13.020						(>100)					
5.500			13.000	DS	2									
			13.500											
6.000		ROCK	13.500	RCS	1	--	--	--	--		15	15%	NIL	
			14.500											
7.000			14.500	RCS	2	--	--	--	--		84	38%	46%	
			15.500											
8.000			15.500	RCS	3	--	--	--	--		98	38%	60%	
			16.500											

DS = DISTURBED SAMPLE / WS = WASH SAMPLE
SPT N = STANDARD PENETRATION TEST VALUE
CR % = CORE RECOVERY %
SDR / WEATHERED ROCK = SOFT DISINTEGRATED ROCK
RQD = ROCK QUALITY DESIGNATION
RCS = ROCK CORE SAMPLE
REMARKS:

d) **Wave and Current Data:**In coastal areas, surface gravity waves and ocean currents are often experienced at the same time. The waves are usually generated by wind, while the currents can be generated by, for example, waves, density variations, and tides. The interaction between waves and currents are of vital significance to coastal engineers concerned with hydrodynamics in near-shore regions. Hydrodynamic loading of coastal structures, scouring around offshore structures, flow fields near pipelines, and dispersal of pollutants are all typical examples which require an enhanced understanding of wave-current interaction. In nature, currents are normally turbulent; a turbulent boundary layer is characterized by its ability to mix and transport fluid across several layers. Physically, the interaction of ocean waves with a turbulent current is complicated by the various temporal and spatial scales created by the two processes.The vertical distance between the crest (top) and trough (bottom) of a wave.The time it takes for two successive wave crests to pass a fixed point is wave period.The direction from which waves are coming is a wave direction. Distribution of wave energy over different frequencies and directions is a wave spectrum.The velocity at which water flows in a particular direction is current speed. The direction in which the water is moving is called current direction.Regular, predictable currents caused by the rise and fall of tides is a tidal current.Large-scale water movements influenced by wind, salinity, and temperature gradients is called and current is called ocean current.

e) **Seismic Data Analysis:** Seismic analysis is essential for several reasons. First, seismic events, including earthquakes and underwater landslides, generate ground motions and vibrations that can induce significant stresses in underwater foundations. These dynamic forces can cause structural damage or failure if not properly accounted for in the design. Second, seismic activity can trigger soil liquefaction, a phenomenon where saturated soil loses its strength and stiffness due to earthquake shaking. This can lead to the sinking or tilting of piles, compromising the stability of the entire structure. Finally, understanding seismic hazards allows engineers to design foundations that can withstand both the immediate impacts of seismic events and their aftereffects. This is crucial for ensuring the long-term safety and operational continuity of offshore installations. These maps provide information on the probability of different levels of seismic activity in a region over a specific period. They are essential for assessing the likelihood and potential severity of seismic events. This includes measurements of ground acceleration, velocity, and displacement during seismic events. Ground motion data is crucial for understanding the forces that will be transmitted to the underwater foundation.

Data on the geotechnical properties of the seabed materials, such as shear strength, density, and stiffness. This information is vital for evaluating how the soil will behave during seismic shaking and for assessing the potential for liquefaction.

III. ASPECTS OF DESIGN

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 consists 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 Harbour Loading.

Load Calculation:

a) 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.

b) 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.

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

$P_z = 0.6xV_z^2$

Where:

Where, $V_z=V_b x\ K_1 \text{ x } K_2 \text{ x } K_3$

Pz = Design wind pressure in N/m2 at height z.

Vz = 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

d) 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 center 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:

$$A_h = \frac{Z \text{ x } I \text{ x } S}{2.R.g}$$

Z= Zone Factor
I= Importance Factor
S_a / g = Average response acceleration coefficient
R= Response reduction factor
$V_b = A_h \text{ x } W$

V_b= Base Shear
W=Seismic weight of the structure

e) 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.

f) 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.

g) 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 $w.v^2.g$ per square meter of area, where v is the velocity in m/s and w is the unit weight of water in tones/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.

h) 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.

i) 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:

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

j) 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

k) Depth of fixity:Fixity on offshore structure foundations refers to the condition where a structural element (such as a pile or caisson) is embedded in the seabed to a depth sufficient to provide stability against lateral and vertical loads. It ensures that the foundation resists movement and rotation under the influence of environmental forces such as waves, wind, and currents. The recommended values of k1 are given in Table 4 of IS 2911 (Part 1/Sec 2): 2010.[11]

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.).

IV. SELECTION OF DESIGN LIFE

Most port structures are designed and constructed for a specific design life. The design life of a structure is taken to be its intended useful life and will depend on the purpose for which it is required. The choice of the design life is a matter to be decided in relation to each project since changes in circumstances and operational practices can make the structure redundant or in need of substantial reconstruction before the end of its physical life. The design life will also be selected based on economic factors, such as the cost of replacement, cost of downtime and availability of other berths during the repair.For example, a wave height with a return period of 50 years has an annual likelihood of occurring or being exceeded of 0.02 or 2%.For design events, the return period should be significantly longer than the design life. It is important to emphasize here that due to the stochastic nature of wave conditions and water levels there is still a risk that the design event will be exceeded during the design life. This likelihood of exceedance of the design event during the design life of the structure is termed the encounter probability. As the return period of the design event increases, the encounter probability decreases.

Design event return period:Structures are usually designed to withstand a specific hydraulic design event (or a number of extreme events of different severity). Each such event will probably be a combination of a wave condition and water level, and will have an associated return period T_R, which indicates the annual likelihood of the design event being exceeded.Guidance is given in BS 6349 Part 1, BSI (2000), on determining the encounter probability of an event of duration T_R. The encounter probability, p, of an event of a return period, T_R, during the design life, N, can be calculated:

$$p = 1-(1-1/T_R)^N$$

This function is plotted in BS 6349 Part 7, BSI (1991) (see Figure 3.2)

For example, for an oil terminal with a design life of 25 years and a design event with a 1 in 100-year return period, the probability of that event occurring during the life of the structure is just under 25%.

For structures exposed to loads on a frequent basis, e.g. breakwaters, it is normally not economical or even feasible to design a structure to fully resist such loads with no damage, so the designer should identify a suitable level of risk of exceedance and design the structure for an event with the corresponding return period. For example, for a breakwater with a design life of 50 years, the 1000 year. event has a 5% probability of exceedance. If the structure were to be designed for the return period equal to the design life, then this would have a 63% chance of exceedance. Selection of an appropriate design condition should also be based on an assessment of the consequences of exceedance as this may not always be catastrophic. This forms the basis of risk-based design by evaluating the frequency of occurrence of a certain event against the consequences. It is the designer's responsibility to define, in discussion with the eventual owner and operator, the acceptable risk for the structure. In general, it can be seen that the return period of the design condition will exceed the given period over which costs are to be optimized. Structures designed to withstand large events may be more expensive to construct than weaker structures for which the cost of periodical repair has been included. By optimizing whole life costs, including downtime, against benefits, it may be possible to establish an acceptable level of risk. This type of cost optimization is, however, difficult to achieve in jetty structures, as the degree of damage is difficult to predict, and the consequences of subjecting the jetty deck to unanticipated wave loads may be much more severe than for other classes of structure. In this case, probabilistic simulations may be needed to address the 'air gap' problem. Definition of design conditions becomes more complicated when two or more variables (e.g. wave height and water level) need to be considered. In this case, the return period represents the likelihood that both (or all) variables are exceeded at the same time. Some simple guidance on establishing joint probabilities is given in CIRIA (1996). However, specialist studies may be required to establish this joint probability.

V. MODEL DEVELOPMENT

The design and engineering of coastal structures encounter specific obstacles in marine environments, which require for thorough research and creative design solutions. A jetty is typically a platform built from a shoreline into the water, extending beyond the shallow waters to accommodate ships and boats. In India, jetties are essential components of ports, harbours, and coastal areas where maritime activities are concentrated. They serve as berthing points for cargo vessels, fishing boats, and passenger ferries, allowing for safe and efficient movement of goods and people between land and sea. Jetties also support various coastal industries such as fisheries, aquaculture and tourism. Jetties in India are vital for coastal defense and protection against natural forces like waves and currents. They act as barriers, mitigating erosion and protecting coastal areas from the impacts of cyclones and storm surges. Among these essential constructions, concrete jetties are crucial for supporting marine activities since they operate as berthing locations for ships and offer vital land-sea connectivity. For concrete jetties to remain long-lasting, safe, and functional, a thorough understanding of the structural behaviour is necessary due to the dynamic interaction of coastal factors, such as tides, waves, and currents. The research aims to investigate in detail the environmental pressures acting on concrete jetties, the dynamic responses of the structures, and the creation of design criteria that strike a balance between sustainability objectives and structural strength. The main objective of this research is to identify critical points of jetty by analyzing the structure in software by referring load combination as per is code4651:2014 for normal and severe conditions and comparing those results with the design performed as per IS 4651:1989.
Here we are going to consider forces acting on jetty for example to study the forces acting on and the load combinations carried out

a) DETAILS OF JETTY STRUCTURE

Jetty size: 56 m × 32 m Slab Thickness: 600 mm Longitudinal Beams: 1400 mm × 2200 mm Transverse Beams: 1500 mm × 1850 mm Crane Beams: 2500 mm × 1950 mm Sea-face Beam and Landside beam: 2200 mm × 1950 mm Right edge and left edge Beam: 1800 mm × 2000 mm Deck Slab Top: (+) 7.10 m RL Sea bed level: General (–) 13.0 m Rock encountered at: (-) 20 m

Founding Level of Piles: (-) 26 m.

b) **Loads Acting On Jetty Structure:** Weight of Deck slab =15 KN/m2 Wearing coat weight =5 KN/m2
Beams: Longitudinal beams =77 KN/m Transverse beams =70 KN/m Sea-face beam & Landside Beam =108 KN/m Right edge & Left Edge beam = 90 KN/m Crane beam =122 KN/m Marine growth =1.5 KN/m2 (IS 4651, Part 4:2014)

c) **Live Load:** Live load is based functioning of berth and truck loading on berth as per IS 4651 (Part 3)-2020. The function of berth is related to truck. Loading A or AA or 70R (Heavy cargo Berth) so we are adopted 50 KN/m2

d) **Berthing Load:** When a ship or other vessel comes into contact with a jetty structure in order to dock, forces and loads are applied to the structure. This is known as the berthing load. Several dynamic forces are at work when a ship approaches the jetty to dock; in order to guarantee safe and secure berthing, the jetty needs to be built to bear these loads.

Design vessel size = 2,00,000 DWT
Length of Ship = 235 M
Width of Ship = 32.5 M
Height = 16.2 M
Draft/laden weight D = 15.2 M
Unit weight of sea water γ = 1.03 T/m3
Angle of approach θ = 10 Degrees
Velocity of approach = 0.2 m/s
Factor of safety = 1.4
DT/DWT factor = 1.26
Mass co-efficient Cm, = 1.385
Eccentricity coefficient, Ce, = 0.51
Softness co-efficient, Cs = 0.9
Berthing Energy, E = 85 Tm
Design Berthing Energy, Ed = 120 Tm

$E = W_D . V^2/2g.(Cm)(Cs)(Ce)$

e) **Mooring Load:** The lateral masses that the mooring lines create as they draw the ship into or onto the dock or stabilize it against the forces of wind or current are referred to as the mooring masses. Adopted Design load for Mooring is 900KN.

f) **Wind load:** Wind Contributes primarily to the lateral loading on a pier. It Blows from many directions and can change without notice.IS 875 (Part 3):2015.

Design wind speed, Vz = Vb x k1 x k2 x k3
Vb = 44 m/s

k1 = 1.07 k2 = 1 k3 = 1.3 Vz = 2.247 KN/m2 = 0.6 (Vz)2 P = 2.247 KN/M2 Now the design wind pressure is resolved as nodal loads on structure = 9 KN

g) **Seismic load:** The forces and vibrations that a jetty structure experiences during an earthquake are referred to as seismic loading. Jetties and other waterfront constructions are susceptible to ground changes and dynamic forces during earthquakes, which could jeopardize their stability. It is essential to design jetty constructions to withstand seismic loads in areas where earthquakes are common.

Design seismic base shear Vb = Ah W Ah = (Z/2) x (Sa/g) x (I/R) Zone factor Z = 0.24 Importance factor I = 1.75 Sa/g = 2.5 Hard soil Ah = 0.105

h) **Earth pressure:** A crucial factor in the design and analysis of the jetty's structural stability is the ground pressure exerted on the piles supporting its superstructure. The jetty's foundation is supported by piles, which are susceptible to a number of factors, including lateral earth pressure. The force that the soil applies to a pile or other retaining structure is known as lateral earth pressure. Design Active Earth pressure, Pa = K ɣ h Pa = 171.6 KN/m2 Uniform Load, Pa = 686.4 KN/m

i) **Water pressure/hydrostatic pressur**e: Water pressure affects jetties that reach out into bodies of water. Loads that are vertical and lateral may be influenced by the water's hydrostatic pressure. The pressure rises with depth and is inversely related to the water's density and gravitational acceleration. An RCC jetty structure experiences an increase in hydrostatic pressure that is linear in depth. The pressure is constant at whatever depth and perpendicular to the jetty's surface in all directions.

Design Water Pressure P = ɣ h

P = 260 KN/m2

Load on each Pile P = 390 KN/m

j) **Crane loads:** The forces and loads applied by cranes that are attached to or utilized in connection with jetty structures are referred to as crane loads on jetty structures. Cranes are frequently installed on jetties to help with cargo handling, ship loading and unloading, and other marine tasks. Dynamic motions occur during crane operations, so dynamic impacts need to be taken into account. Wide-span Crane Gantry span 40 - 50 m Outreach 30 – 40 m Back-reach 15 – 20 m Crane weight Capacity (A) 40 T Crane weight Capacity (B) 30 T

VI. LOADS COMBINATIONS

Load Combinations for Extreme/Severe Condition (IS 4651, Part 4:2014)

1.2 (DL+ DyL+ LL) +1.0 EP + 1.0 (HyF + CL) + 1.0 BF

1.2 (DL+ DyL+ LL) +1.0 EP + 1.0 (HyF + CL) + 1.0 EL

1.2 (DL+ DyL+ LL) +1.0 EP + 1.0 (HyF + CL) + 1.0 TL

1.2 (DL+ DyL+ LL) +1.0 EP + 1.0 (HyF + CL) + 1.0 E-WiF

Load Combinations for Normal Condition (IS 4651, Part 4:2014)

1.5 (DL+ DYL+ LL) +1.0 EP + 1.0 (HYF) + 1.2(WL + CL) + 1.5 BF + 1.0 (WWIF)

1.5 (DL+ DYL+ LL) +1.0 EP + 1.0 (HYF) + 1.2 (WL + CL) + 1.5 MF + 1.0 (WIF)

DL – Dead Load

LL – Live Load

EP – Earth Pressure

WL – Wave Force

CL – Current Force

BF – Berthing Force

MF – Mooring Force

WWIF – Working Wind Force

EWIF – Extreme Wind Force

HYF – Hydrostatic Force

DYL – Dynamic Load

TL – Tsunami Load

EL – Seismic Force

Load combinations for Normal Condition (IS 4651, 1989)

1.5DL + 1.5LL + 1EP + 1HYD PRESSURE + 1.5B + 1.5M

1.2DL + 1.2LL + 1.0 EP + 1.2 HYD PRESSURE

0.9DL + 0.9LL + 1.0 EP + 1.0 HYD PRESSURE

1.2DL + 1.2LL + 1EP + 1HYD PRESSURE + 1.5WL

0.9DL + 0.9LL + 1EP + 1HYD PRESSURE + 1.5WL

1.2DL+1.2LL+1.0EP+1.0HYD PRESSURE + 1.5 EQ

0.9DL+0.9LL+1.0EP+1.0HYD PRESSURE + 1.5 EQ

1.2DL+1.2LL+1.0EP+1.0HYD PRESSURE + 1.5 DQ

0.9DL+0.9LL+1.0EP+1.0HYD PRESSURE + 1.5 DQ

VII. ANALYSIS OF THE MOMENT ULTIMATE OF PILE

The lateral load generated by vessels is designed to be supported by the structure of the pile contained in the pier structure. The parameters that affect the structure of the pile due to the lateral load of vessel are the stiffness of the pile structure, and the cross-sections of the pile. The types of piles used in this study are piles with spun pile types and diameter of pile are 40 cm, 60 cm, and 80 cm. In addition, the quality of concrete pile is K-500. The results of the moment ultimate of the pile that obtained for the configuration of the pile diameter are 40 cm, 60 cm, and 80 cm are presented

TABLE 2
MOMENT ULTIMATE ANALYSIS OF PILE

Description	Pile Structures		
	D40 cm	D60 cm	D80 cm
Eccentricity of The Pile (m^3)	0,0035	0,011	0,024
Modulus of Elasticity of Concrete (kN/m^2)	957462,79	957462,79	957462,79
Modulus of Cohesive Soil (n_h) (kN/m^3)	600	600	600
Rigidity of Pile (m)	1,024	1,39	1,73
Type of Pile (Lp≥4T)	19,51≥4 (Unrigid pile)	14,38≥4 (Unrigid pile)	11,56≥4 (Unrigid pile)
Moment Ultimate of Pile (kNm)	87,15	273,9	597,6

VIII. ANALYSIS OF LATERAL FORCE

The structure by using the equation of the ship's impact energy when the ship hits the pier with the slope angle of the 10^o vessel to the centre of the ship. In this calculation, the maximum load from the specifications of Table 3

TABLE 3
ANALYSIS OF LATERAL FORCE

Description	Piles Structure		
	D40 cm	D60 cm	D80 cm
Dead Weight Tonnage (ton)	75000	75000	75000
Maximum Mass Displacement(Δm)	117000	117000	117000
The length of the vessel's surface line (Loa (m))	288	288	288
The length of the vessel's parallel to the water (Lpp (m))	274	274	274
Width (B (m))	49	49	49
Draft (T (m))	11,5	11,5	11,5
Coefficient of block (Cb)	0,74	0,74	0,74
Displacement Tonnage(DT (ton))	98301,14	98301,14	98301,14
Coefficient of mass (Cm)	1,99	1,99	1,99
Coefficient of eccentricity (Ce)	0,48	0,48	0,48
Coefficient of hardness (Cs)	1	1	1
Coefficient of berthing (Cc)	1	1	1
Energy of berthing (E (kNm))	1173,2	1173,2	1173,2
Energy of absorded (Ef (kNm))	586,86	586,86	586,86
Berthing Force($F_{berthing}$ (kN))	4915,05	4915,05	4915,05

IX. ALLOWABLE ULTIMATE LATERAL FORCE OF PILE

The empirical Brooms method is adopted to determine the value of the ultimate lateral force of the allowable pile positions under different pile diameter. The calculation is based on the Standard Pile Design and Construction Practice, for soft soil types, the position of pile (Zf) is 1.5 m. The results of the calculation of the allowable of ultimate lateral force of pile based on the pile position obtained for the configuration of the pile diameter of 40 cm, 60 cm, and 80 cm are presented in Table

TABLE 4
ANALYSIS OF LATERAL FORCE

Description	Pile Structure		
	D40 cm	D60 cm	D80 cm
Eccentricity of Lateral Load (e) (m)	12	12	12
Value of Pile Position (Zr) (m)	1,5	1,5	1,5
Moment of Inertia of Pile (I) (m^4)	0,0007	0,0033	0,0096
Allowable of Lateral Force (H_{all}) (kN)	2,58	12,18	35,08
Allowable of Pile Deflection (δ) (cm)	70,8	79,04	78,98

X. THE RESULT OF NUMERICAL ANALYSIS USING SAP2000 PROGRAM

After loading and loading combinations are obtained and input to 3D pier structure modeling using the SAP2000 program, Table 7 shows the results of deflection analysis obtained from the SAP2000 program for configuration of pile diameter 40 cm, 60 cm, and 80 cm with distance between piles 2,5 m and 5 m.

TABLE 5
DEFLECTION ANALYSIS WITH PILE SPACING 2.5M

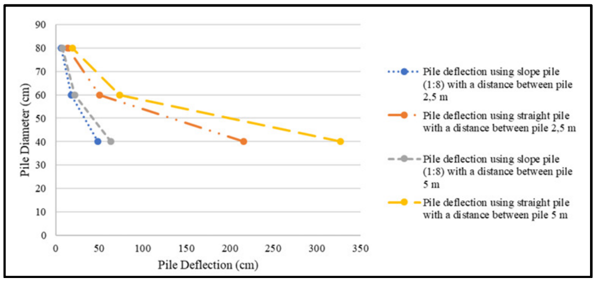
Diameter (cm)	Allowable of Pile Deflection ($\delta_{allowable}$) (cm)	Deflection Result from SAP2000 Program (δ) (cm)	
		Sloped Pile (1:8)	Straight Pile
40	70,8	48,2	215,6
60	79,04	17,4	50
80	78,25	6,13	13,62

TABLE 6
DEFLECTION ANALYSIS WITH PILE SPACING 5M

Diameter (cm)	Allowable of Pile Deflection ($\delta_{allowable}$) (cm)	Deflection Result from SAP2000 Program (δ) (cm)	
		Sloped Pile (1:8)	Straight Pile
40	70,8	63,15	326,83
60	79,04	21,86	73,57
80	78,25	7,28	18,7

From the results obtained in Table 4.4.1 and Table 4.4.2, the following is a graph of the relationship between the deflection of the piles on the diameter of the piles in the pile configuration diameter 40 cm, 60 cm, and 80 cm for the distance between the piles 2.5 m and 5 m using the sloped pile (1: 8) and straight pile:

TABLE 4
ANALYSIS OF LATERAL FORCE



The graph in Figure 4.4.3 shows that the deflection results caused by vessels on variations in diameter of pile 40 cm, 60 cm, and 80 cm and variations in distance between poles 2.5 m and 5 m, with modeling of pile structure using pile combinations with sloped pile (1: 8) is smaller than using a pile structure model using a straight pile.

Relation Between the Parameter of Pile Deflection (δ), Allowable of Pile Deflection (δallowable), Pile Diameter (D), and Pile Spacing (S)

From the results of the pile deflection analysis then the results can be re-analyzed to find the value of the theoretical development equation of the relationship between deflection parameters of the pile to the pole diameter and the distance between the piles caused by vessel load of 75000 DWT. To determine the theoretical development equation of the relationship between pile deflection (δ), allowable of pile deflection (δallowable), pile diameter (D), and pile spacing (S), need a cross-section ratio of jetty pile structure (D / S) and stability ratio jetty structure (δallowable/δ). The cross-section jetty pile structure ratio (D/S) is the ratio between the effect of pile inertia diameter (D) on the distance between the piles (S). The greater the cross-sectional ratio of the jetty structure, the more rigid the pile structure is. This is influenced by the larger the diameter of the pile used and makes the moment of inertia more enlarged resulting in a more rigid and stable pile structure. Conversely, the smaller the ratio of the jetty pile structure cross section, the pile is easy to flex and results in a deformation of the mast structure. This is influenced by the smaller the diameter of the pile used and makes the moment of inertia also smaller and causes the pile structure to be easily deformed (deflected) and unstable. In addition to the cross-section ratio of the jetty pile structure (D/S), the stability ratio of the jetty structure (δallowable/δ) is also needed to determine whether the jetty structure is stable or not depends on the large or small cross-sectional ratio of the jetty (D/S) pile structure. The jetty structure is declared stable if the stability ratio of the jetty structure is greater or equal to 1 ($\delta allowable/\delta \geq 1$).

XI. RESULTS AND DISCUSSIONS

From the Studies and available data, it is determined that the offshore construction aspects can be taken into two aspects: a) Deterministic Approach b) Probabilistic Approach.

Deterministic design: Traditionally, deterministic methods have been adopted for design. An accepted level of loading, termed the Limit State condition, will be determined for the structure. This limit state will correspond to a particular strength of the structure. This may be the Serviceability Limit State (SLS) or the Ultimate Limit State (ULS). Exceedance of the SLS indicates that the structure is not meeting the required performance. Exceedance of the ULS may result in damage to, or failure of, the structure. It may not be economical to design a structure to resist the most extreme loads. In practice, an acceptable probability of exceedance of the Limit State will be decided upon, by balancing the likelihood of exceedance and consequences of failure. This is the essence of risk-based design. Consequences are usually quantified in monetary terms. However, there are often less tangible consequences that cannot be easily quantified in monetary terms, such as the loss of human life or natural habitats. An acceptable annual probability of exceedance of the design loading will be determined. The reciprocal of this exceedance probability is the return period, T_R of the design event. The design loading for this return period can then be determined from a statistical analysis. Uncertainties in the loading and strength are accounted for by a safety factor, which should always be greater than 1. The loading is a function of a number of variables. These variables are often stochastic in nature. It is important to note that deterministic methods can be described as being partially probabilistic and risk-based as they are based on design loading at a selected return period, T_R, where the return period is a statistical entity. A limitation of deterministic methods is that no account is made of loading on the structure other than at a single design level. Other loading cases will have a range of effects on the structure, but will not be identified, nor will their contributions to the overall chance of failure. Events exceeding the design load will obviously affect the structure, but loading below the Limit State can have a cumulative effect on the structure, contributing to structural failure over time.

Probabilistic design: The alternative to the use of simple deterministic methods is to use probabilistic methods. These extend the deterministic approach by using statistical methods to describe the stochastic nature of strength and load instead of applying a safety factor. There are various different types of probabilistic methods each with varying degrees of complexity. The basic principle of full probabilistic methods is that the distributions of strength and loading are considered instead of single design values, to account for uncertainty and variability in these parameters. This method avoids unnecessary conservatism and can lead to savings in comparison with designs based on deterministic methods. Generally, the methods used in this manual are strongly deterministic, as interactions between elements and failure modes are important but not quantified, and there are very few statistical data available on the uncertainties in loading. Some discussion is given where appropriate on probabilistic methods. Often uncertainties in the design process can be partially examined using deterministic methods by undertaking sensitivity testing, varying input parameters to assess the impact on response. This might include looking at a range of combinations of wave height and water level with the same joint probability (probability of exceedance of a certain wave height and water level combination).While deterministic design methods are most common, the input parameters used are often stochastic in nature, with associated probabilities of exceedance, e.g. sea state parameters such as wave height, wave period and water level.

XII. CONCLUSIONS

This research study performed for several load combinations and critical load cases were taken into consideration for analysis of beams and deck slab as per loading suggested by Indian code IS 4651:PART 4 :2014 and compared those results with the loading and load combinations given as per IS 4651:1989 to identify the difference in the analytical results for particular jetty structure and to undergo better performance of jetty structure, worst load combinations are adopted [2] As per Clause 5.1 and 7..1 from IS 4651:Part4:2014,Load combination for Normal Conditions and severe condition were introduced, which represent performance of jetty structure in worst scenario. [3] The Result show the difference of 3.6%, 0.6%, 2.8% decrease in maximum moment for sea-face and land face beam, Right and Left edge beam and for Crane Beams, and decrease in 2%, 5% for Transverse Beam and Longitudinal Beam. The difference is less than 5% for structure analyzed by referring both the IS codes [4] The Normal load combination and Severe Load combination for strength analysis of beam shows 37%, 33%, 41%, 40.6%, 42.25% increase in moment for severe condition in sea-face & Land-face beam, Right & Land edge beams, Crane Beams, Transverse Main Beam, Longitudinal Main Beam. [5] The Berthing Forces, Crane load Dynamic loading and Seismic effects shows the Maximum moment values for worst load combination considered for Design of Jetty structures. In this research, the issues and prevention methods of pile foundation at waterfront development were determined. From the analysis, all respondents agreed that the wave condition and tide condition were the main issues of pile foundation at waterfront development. For the prevention methods, coating system and concrete cover has been chosen by the respondents as the main prevention methods of pile foundation at waterfront development. In contrast, all respondents also mentioned that the workmanship and check and balance were some other prevention methods of pile foundation issues which means they believed that during construction and installation, the workmanship can control the quality of work. The check and balance determined the work after completing the installation following the requirements and standards have been set in the design stage. In conclusion, this research has been successfully implemented with both the objectives being achieved which identifying issues of pile foundation at waterfront development and determines the prevention methods of pile foundation issues at waterfront development. From this research, issues and prevention methods of pile foundation at waterfront development was identified through interviews with the respondents whom involved in the process of analyzed data that had been obtained. Data analysis and discussions in chapters 4 and 5 has provided a clear understanding with an explanation of the objectives and results for this research. Lastly, this research is very important for developers and contractors so that they know and understand the issues of pile foundation at waterfront development as well as in determining the prevention methods of pile foundation issues at waterfront development.

Furthermore, the selection of materials and construction techniques is critical in ensuring the durability and longevity of offshore structures. Corrosion resistance, structural integrity, and maintenance requirements are carefully evaluated to mitigate risks and minimize lifecycle costs. Advanced materials such as high-strength steel, fiber-reinforced composites, and corrosion-resistant alloys have revolutionized offshore construction, enabling lighter and more robust structures capable of withstanding harsh environmental conditions. Moreover, the safety and operational efficiency of offshore platforms heavily rely on comprehensive risk assessment and management strategies. From conceptual design stages to operational phases, rigorous safety protocols and emergency response plans are implemented to protect personnel and assets against potential hazards, including fire, structural failure, and environmental disasters.

The study has also underscored the importance of adopting sustainable practices in offshore engineering. As the industry continues to expand into deeper waters and more challenging environments, minimizing environmental impact and adhering to regulatory standards are paramount. Innovations in renewable energy integration, such as offshore wind farms and wave energy converters, highlight the industry's commitment to reducing carbon footprints and promoting environmental stewardship. Collaboration among multidisciplinary teams, including engineers, architects, environmental scientists, and regulatory experts, is essential for the successful execution of offshore projects. By fostering a culture of innovation and knowledge sharing, stakeholders can address complex challenges and capitalize on emerging technologies to push the boundaries of offshore engineering. Looking ahead, the future of offshore structures will likely be shaped by advancements in digitalization, automation, and artificial intelligence. Real-time monitoring systems, predictive maintenance algorithms, and autonomous robots are poised to revolutionize asset management and operational efficiency, enhancing safety and reducing downtime.

In conclusion, the study on the design and construction of offshore structures has illuminated the intricate interplay between engineering, technology, and environmental stewardship. By continuously advancing our understanding and capabilities, we can unlock new opportunities for sustainable development and economic growth in the offshore industry. As we navigate towards a future of deeper waters and renewable energy solutions, collaboration, innovation, and a steadfast commitment to safety and sustainability will remain the cornerstones of offshore engineering excellence.

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