An Analysis of the Behaviour of Berthing Structures Under Stack, Crane, and Mooring Load Conditions

1.MALAKA SATISH 2. Dr.GIRI RAJA SEKHAR GUNNU 3. DUDDU HEMANTH KUMAR

Andhra University, Visakhapatnam-530003, Andhra Pradesh, INDIA

Abstract:

The increasing demand for oil, gas, and bulk cargo transportation necessitates larger vessels with deeper drafts.Constructing new ports in challenging environments exposes berthing structures to higher loads.This paper investigates the influence of varying stack, crane, and mooring forces on critical components of a berthing structure.Increased demand for oil, gas, and bulk cargo necessitates larger vessels with deeper drafts, putting higher stress on port structures. This paper investigates the impact of stack loads (cargo weight), crane loads (lifting equipment), and mooring forces (vessel tethering) on critical components of a berthing structure.Specifically, the study focuses on:Bending moment in the main crosshead beam of the deck slab.Behavior of the T-shaped diaphragm wall under varying loads.Axial forces experienced by vertical and racker piles supporting the deck slab.

The research aims to address the limited understanding of how these forces affect berthing structures modeled using STAAD. Pro software. It explores the behavior of these structures under various loading scenarios commonly encountered in marine environments.

Key Words: Berthing Structure, Stack Load, Crane Load and Mooring Load.

INTRODUCTION:

The rapid expansion of maritime transport systems necessitates the development of new port and harbor infrastructure. Berthing structures, essential for accommodating and servicing vessels, include various types such as quays, wharfs, piers, jetties, and dolphins. These structures provide essential services like berthing and mooring, cargo handling, and passenger embarkation/disembarkation.

The increasing demand for oil and gas has driven a substantial growth in maritime transportation over the past four decades. To ensure safe and efficient vessel berthing and cargo transfer, particularly for sensitive products like oil, gas, and petrochemicals, it is crucial to accurately predict and manage the dynamic forces and structural requirements involved. These factors include vessel motions, mooring loads, and the structural integrity of berthing facilities.

Fig.1.Berthing Structure

Sub Structure: Berthing structures supported by piles on marine soils are subjected to a combination of axial and lateral loads. Due to variations in ground slope, pile location, and pile geometry (length, diameter, and spacing), the lateral loads are not evenly distributed among the piles. To enhance structural stability and resist lateral deflection, anchors are incorporated into the design. These anchors help to counteract the lateral forces, ensuring the overall integrity of the berthing structure.

Fig2.Sub Structure

Role of Fenders in Berthing structure:

Marine fenders are essential components of port and dock infrastructure, designed to mitigate the impact energy of berthing vessels, thereby safeguarding both the vessels and the berthing structures. Common fender types include cell fenders, cone fenders, arch fenders, and pneumatic fenders, each offering distinct characteristics to absorb and dissipate the kinetic energy generated during docking maneuvers.

Fig3.Fender

METHODOLOGY:

The 255-meter-long berth is comprised of five modular units, each measuring 51 meters in length. Each unit incorporates a structural configuration consisting of 17 T-shaped diaphragm wall panels, 17 vertical piles, and 19 racker piles. The diaphragm walls are interconnected at the top by a 2.8-meter-deep cellular deck, forming a robust connection with the vertical piles (850 mm diameter) and racker piles (700 mm diameter). All substructure elements are founded on solid bedrock.

Material Properties

The material used for analysis Reinforced concrete with M-30 grade concrete and Fe-415 grade reinforcing steel.

The Stress-Strain relationship used is as per IS 456:2000. The basic materialproperties used are as follows: Modulus of Elasticity of steel, Es = 21,0000 MPaUltimate strain in bending, cu =0.0035 Characteristic strength of concrete, fck = 30 MPaYield stress for steel, fy = 415 MPa

Modelling of Structure

Each individual berthing unit is characterized by a deck slab measuring 51 meters by 17.2 meters. The entire berthing structure, consisting of five units, spans a total length of 255 meters. For analysis purposes, the structure is assumed to be rigidly connected at the interface between the diaphragm walls, piles, and main crosshead beam (MCHB). The overall deck thickness is set at 2.8 meters. All structural elements are considered to be homogeneous, isotropic materials with consistent elastic properties in both compression and tension and details shown in table.

Table1. Section details

MEMBER	SIZE (m)
longitudinal Beams	2.25 X 0.25 & 2.25 X 0.30
Cross Beams	2.25 X 0.6 & 2.25 X 0.25
Top Slab	0.30
Bottom Slab	0.25
T.D.W	3X3, t_W = 0.6, t_f = 0.6
Vertical pile	0.85
Racker pile	0.70

The behavior of the berthing structure is modeled using the Winkler foundation approach, which idealizes the underlying soil as a series of independent elastic springs. Spring constants for the diaphragm wall and anchor piles are calculated based on the soil's elastic modulus (refer to soil profile data). The supports at the ends of the diaphragm wall are fixed against horizontal movement (Y-direction), while the anchor pile supports are fixed in both horizontal directions (X and Y). Both restraints are assumed to be located at -28.00 meters depth. All other joints in the model have three degrees of freedom (can translate in X, Y, and rotate). The connection between the deck and both the diaphragm wall and anchor piles is assumed to be rigid. Due to the presence of soft marine clay, mobilization of passive soil resistance (beyond -17 meters) is neglected in the analysis. The structural analysis software "STAAD.Pro" is employed to model and analyze the behavior of the berthing structure under various loading conditions. A Typical model of Berthing structure as shown in fig 4.

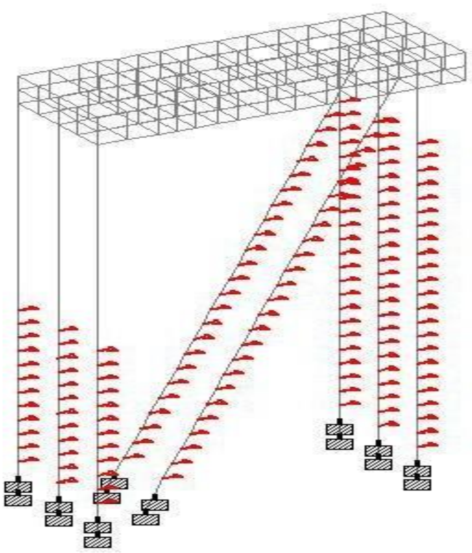

Fig 4. View of Berthing structure

Load combination consider for Berthing structure:

From among the various live loads indicated the following live combinations are considered in the design of the Berthing structure.

Dead Load+ Live Load (Stack load+ Crane Load+ BGML +Concentrated load 20 T+IRC 70R+Bottom slab Load+ Earth pressure+ lateral pressure due to surcharge+ Mooring+ Lateral)

RESULTS AND DISCUSSIONS:

This study utilizes STAAD.Pro software to analyze the influence of varying crane loads, stack loads (cargo weight), and mooring forces on a berthing structure.The analysis focuses on the impact of these forces on three key structural components:
Main Crosshead Beam (MCHB): The bending moment acting on the MCHB, a critical element of the deck slab, is investigated under different loading scenarios.
T-Shaped Diaphragm Wall: The behavior of the diaphragm wall, a crucial component for lateral stability, is evaluated under varying load conditions.
Vertical and Raker Piles: The axial forces experienced by these piles, which provide vertical and lateral support to the structure, are analyzed.
By analyzing these factors, the study aims to gain a deeper understanding of how crane operations, cargo weight distribution, and vessel mooring affect the structural integrity of berthing structures. This knowledge can be valuable for optimizing design and ensuring the safety and longevity of these critical marine facilities.

NOTE: While crane and stack loads are inherently point loads, the design process typically converts them into equivalent uniformly distributed loads (UDLs) for simplified analysis. This conversion is based on established methodologies that distribute the concentrated load over a specified area, ensuring that the overall effect on the structure remains equivalent. By representing these loads as UDLs, the structural analysis becomes more manageable and efficient, facilitating the evaluation of stresses and deflections within the berthing structure.

Berthing structure with different loading conditions as follows: The structure was analyzed
for linear static analysis for the following Loads. Stack load

Crane loadBGML
load IRC
70R load
Concentrated loadMooring force of
90Tons

The results obtained are shown in Table No.2, 3 and 4 for variable stack,crane and mooring load.

VARIABLE STACK LOAD:

Table No.2.Details of Bending Moment of Main Cross Head beam of Deck Slab,“T” Shaped Diaphragm wall and the axial forces of vertical & racker piles for Stack load, keeping other loads constant.

Table.2

S. No	Stack Load (Tons/m^2)	Max. B.M of M.C.H.B(Tons-m)	Max. B.M of T.D.W (Tons- m)	Axial Force (R.P) (Tons)	Axial Force (V.P) (Tons)
1	5	2071	4901	644	1612
2	5.25	2082	4967	650	1627
3	5.5	2093	5007	654	1636
4	5.75	2105	5039	657	1644
5	6	2116	5069	659	1651

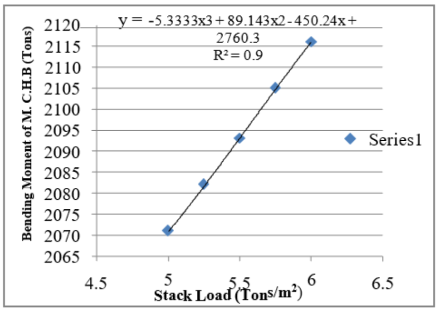

Fig5. Stack Load v/s BM of M.C.H.B

Bending moment of M.C.H.B variation was in the polynomial of order 3 with respect to Stack load.

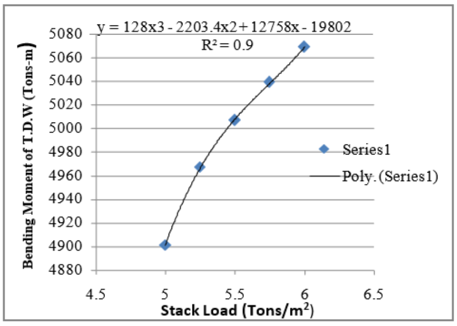

Fig6. Stack Load v/s BM of T.D.W

Bending moment of T.D.W variation was in the polynomial of order 3 with respect to Stack load.

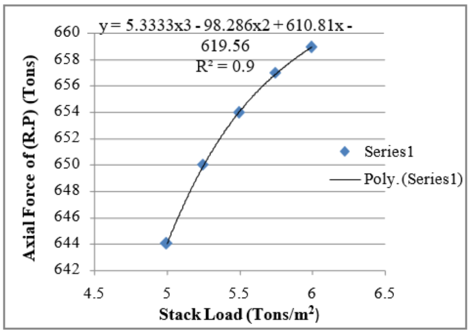

Fig7. Stack Load v/s Axial force of (R.P)

Axial force of raker pile was in the polynomial of order 3 with respect to stack load.

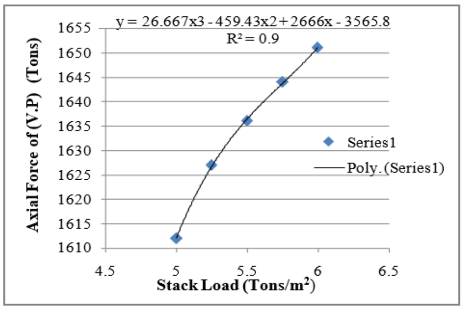

Fig8. Stack Load v/s Axial force of (V.P)

Axial force of vertical pile was in the polynomial of order 3 with respect to stack load.

VARIABLE CRANE LOAD:

Table No3.Details of Bending Moment of Main Cross Head beam of Deck Slab,“T”Shaped Diaphragm wall and the axial forces of vertical & racker piles for Crane load, keeping other loads constant.

Table.3

S. No	Crane Load (Tons)	Max. B.M of M.C.H.B (Tons- m)	Max. B.M of T.D.W (Tons- m)	Axial Force (R.P) (Tons)	Axial Force (V.P) (Tons)
1	20	2071	4901	644	1612
2	21	2103	4933	647	1619
3	22	2136	4972	650	1628
4	23	2163	5004	653	1635
5	24	2190	5035	656	1643

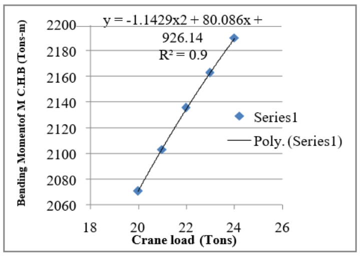

Fig9. Crane Load v/s BM of M.C.H.B

Bending moment of M.C.H.B variation was in the polynomial of order 2 with respect to Crane Load.

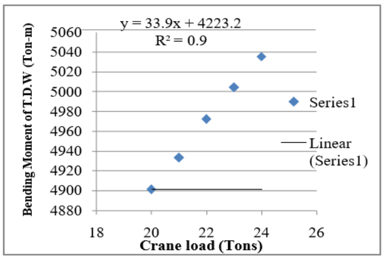

Fig10. Crane Load v/s BM of T.D.W

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Bending moment of T.D.W variation was linear with respect to Crane Load.

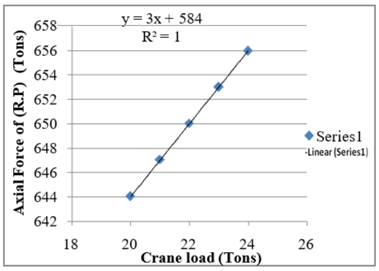

Fig11. Crane Load v/s Axial force of (R.P)

Axial force of raker pile was linear with respect to crane load.

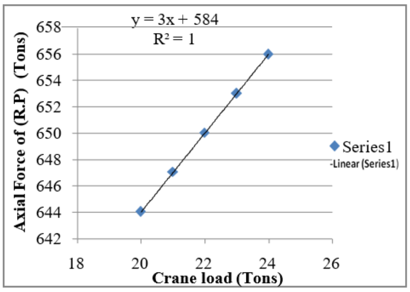

Fig12. Crane Load v/s Axial force of (V.P)

Axial force of vertical pile was linear with respect to stack load.

VARIABLE MOORING LOAD:

Table No4.Details of Bending Moment of Main Cross Head beam of Deck Slab,"T"Shaped Diaphragm wall and the axial forces of vertical & racker piles for Mooring load, keeping other loads constant.

Table.4

S. No	Mooring Load (Tons)	Max. B.M of M.C.H.B (Tons- m)	Max. B.M of T.D.W (Tons- m)	Axial Force (R.P) (Tons)	Axial Force (V.P) (Tons)
1	90	2071	4901	644	1612
2	100	2083	4930	645	1615
3	120	2105	5005	647	1620
4	150	2132	5105	650	1627

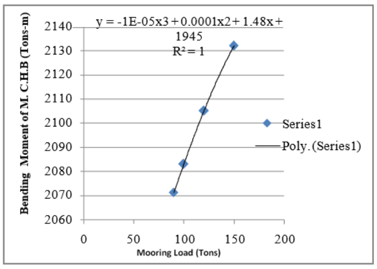

Fig13. Mooring Load v/s BM of M.C.H.B

Bending moment of M.C.H.B variation was in the polynomial of order 4 with respectto Mooring Load.

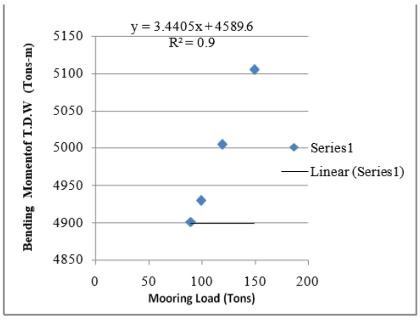

Fig14. Mooring Load v/s BM of T.D.W

Bending moment of T.D.W variation was Linear with respect to Mooring Load.

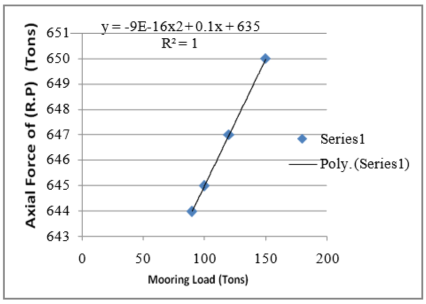

Fig15. Mooring Load v/s Axial force of (R.P)

Axial force of raker pile was in the polynomial of order 3 with respect to MooringForce.

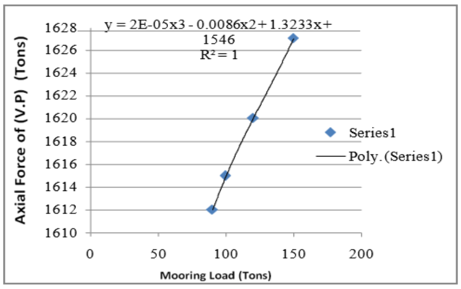

Fig16. Mooring Load v/s Axial force of (V.P)

Axial force of vertical pile was in the polynomial of order 4 with respect to MooringForce.

CONCLUSIONS:

The following conclusions are obtained from the STADD.Pro analysis for variablestack, crane and mooring loads.

STACK LOAD:

On increasing the stack load of 5%, 10%,15%, 20% and 25% on $5T/m^2$

a)The percentage of increase in the bending moment of M.C.H.B 0.52, 1.05, 1.61, 2.12 and 2.68 respectively.

b)The percentage of increase in the bending moment of T.D.W were 1.32, 2.11, 2.73, 3.31 and3.89 respectively.

c)The percentage of increase in the Axial force of racker pile were 0.92,1.52,1.97,2.27 and2.72 respectively.
d)The percentage of increase in the Axial force of vertical pile were0.92,1.46,1.94,2.36 and 2.84 respectively.

CRANE LOAD:

On increasing the Crane load 5%, 10%,15%, 20% and 25% on 20T

a)The percentage of increase in the bending moment of M.C.H.B were 1.52, 3.04, 4.25, 5.43, and6.64 respectively.
b)The percentage of increase in the bending moment of T.D. were 0.64, 1.42, 2.05, 2.64 and 3.27 respectively.
c)The percentage of increase in the Axial force of racker pile were 0.46,0.92,1.37,1.82, and2.27 respectively.
d)The percentage of increase in the Axial force of vertical pile were 0.43,0.98,1.40,1.88 and 2.32 respectively.

MOORING LOAD:

On increasing 90T mooring load to 100T, 120T and 150T
a)The percentage of increase in the bending moment of M.C.H.B were 0.57,1.61and 2.86 respectively.
b)The percentage of increase in the bending moment of T.D.W were 0.58, 2.07 and 3.99 respectively.
c)The percentage of increase in the Axial force of racker pile were 0.15,0.46 and
0.92 respectively.
d)The percentage of increase in the Axial force of vertical pile were 0.18, 0.49 and 0.92 respectively.

The influence of varying loads on the berthing structure is significant, with distinct effects on different structural components:

Stack Load: Variations in stack load primarily impact the axial forces experienced by the vertical and racker piles.
Crane Load: Changes in crane load exert a major influence on the bending moment within the main crosshead beam.
Mooring Load: Fluctuations in mooring forces predominantly affect the bending moment in the T-shaped diaphragm wall.
These findings highlight the importance of considering the specific loading scenarios and their relative impacts on different structural elements when designing and evaluating berthing structures.

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