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Study on the Structural Behaviour of Berthing Structure due to Variable Stack Load

G. T. Naidu[1*], K. V. G. D. Balaji[2], M. Pavan Kumar[1] and B. Siddharth Rao[2]

[1]Department of Civil Engineering, S.V.P. Engineering College, PM Palem, Visakhapatnam - 530041, Andhra Pradesh, India; gtpnaaidu@gmail.com, pavanidea@gmail.com
[2]Department of Civil Engineering, GITAM University, Rushikonda, Visakhapatnam - 530045, Andhra Pradesh, India; balajigitam@gmail.com, rao.siddharth19@gmail.com

Abstract

Objectives: To study the structural behavior of the components of berthing structure subjected to variable stack load with and without mooring force conditions. **Methods/Statistical Analysis:** Linear static analysis was performed on the berthing structure subjected to variable stack load with and without mooring effects. Based on this study, equations related to bending moment and axial force of structural members of berthing structure has been obtained. A Monte Carlo simulation method was adopted for generation of random numbers using MATLAB software. From the obtained results, analysis was performed to obtain characteristics of load effects of the components of the berthing structure. **Findings**: The influence of variable Stack load has an effect on the Bending Moment and Axial Force of structural components of the berthing structure. It was also found that there was a significant variation of results of load effects between with and without mooring force condition in case of Vertical Pile (VP) but there was no significant variation of results of load effects on Main Cross Head Beam (MCHB), T-shaped Diaphragm Wall (TDW) and Raker Pile (RP) due to stack load. **Applications/ Improvement:** This study helps to predict the behavior of berthing structure subjected to varying stack load caused due to lack of awareness of end user on the loading specifications that have been assessed by the designer.

Keywords: Berthing Structure, Linear Static Analysis, Mooring force, Stack load

1. Introduction

Berthing structure is a marine structure for the mooring of vessels, for loading and unloading of cargo, for embarking and disembarking passengers. Berthing structures that are most widely used were quays, wharfs, piers, jetties, and dolphins. Berthing structures vary from port to port. According to cargo handled the berths are of different types i.e., General cargo berth, Dry bulk cargo berth, Liquid or powdered bulk berth, Containers berth, Passengers berth, Petroleum tankers berth, Fish port etc., It is necessary to have a closer look on the loads which are acting on the berthing structure for analysis and design.

The loading and unloading stack load mainly consists of general cargo of commodities like coal, iron ore, iron pellets, iron scrap, sodium sulphate, wood pellets, cocoa bean seeds, china clay, Sulphur, coking coal etc. The height of stack is generally restricted to a level dependent on type of cargo and their unit weights to satisfy the designed stack load on berthing structure. In other words, the stack height varied from material to material. For example, three materials like iron ore, coal and wood pellets having different permissible stack heights of 1m, 3.85m and 6.25m respectively corresponding to a design stack load of 5T/m^2. But the specified stack height may not be restricted since the

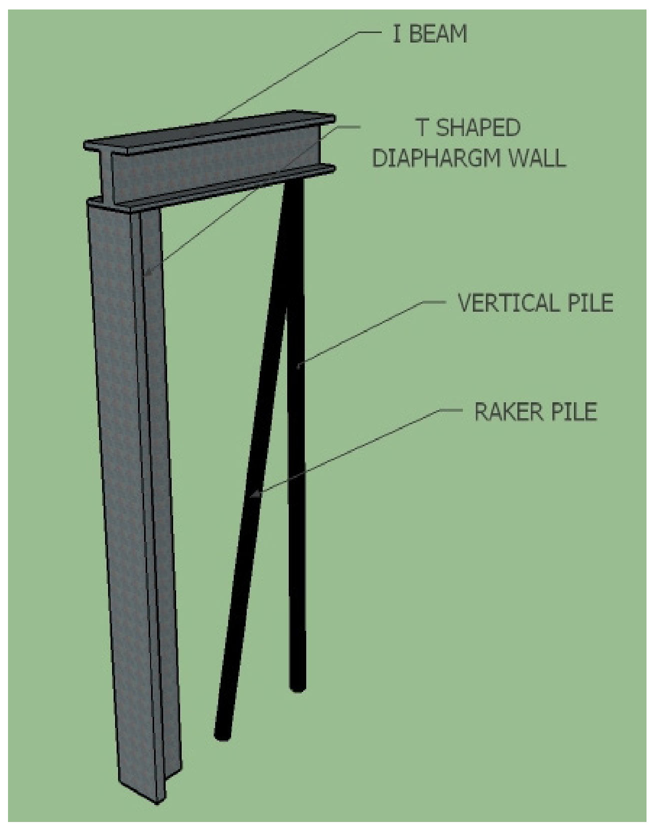
*Author for correspondence

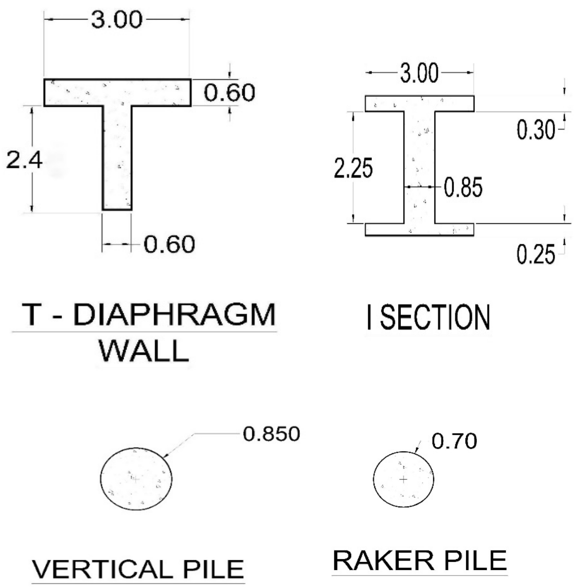
end user may not have awareness on the limitation of stack heights and unit weights of different materials.

In[1] studied that in practice, structures fail often due to causes not directly linked to the predicted nominal loading or strength, but instead, most often due to other factors such as human error, negligence, poor workmanship, or neglected loadings. In[2] investigated the fatigue design process in the welded joints were summarized. Fatigue damage expressions were formulated and the reliability format was employed to construct a design rule for low period structures. In[3] studied the consistency between field data and the model prediction verified the reliability of a probabilistic model, based on which further parametric analyses were carried out to investigate the effects of different design variables on the probability of steel corrosion. The Monte Carlo method was applied for this probabilistic analysis. The probabilistic approach is deemed useful for the service life design of reinforcement concrete structures in marine environments. In[4] studied the uncertainties in the random structural properties are modeledby considering the most significant parameters as random variables in Stochastic Free Vibration Analysis of RC buildings concluded the frequency responses using the metamodels are found to be fairly matching with the responses from the accurate ACS. In[5] conducted on a series of laboratory experimental setup designed with a single row of instrumented piles in a berthing structure reduced to a model scale. Experiments were carried out by applying both berthing and mooring forces. This study concluded that the Mooring force was much critical compared to the other lateral loads acting on the structure. Also in horizontal ground, for both berthing and mooring forces, front pile takes more loads compared to rear ones. In[6] studied behavior of diaphragm wall which was connected to two rows of large diameter vertical piles by a rigid deck system. The deck system being rigid and tie-rods flexible, the lateral loads were shared between the piles and the dead man diaphragm wall. The measured tie-rod forces compared very well within the analytical result and confirmed that a substantial portion of the lateral load was transferred to the piles. A diaphragm wall tied to a dead man diaphragm and a rigid deck supported by vertical piles, was carried out using Structural Analysis Program, assuming the dead man to be rigid and flexible to assess the sharing of lateral load between piles and the dead man.

2. Modelling

The entire berth of 255m length is divided into 5 units of 51m long. Each unit consists of T- Shaped Diaphragm walls (TDW) of 17 Nos, Raker piles (RP) of 700 mm (diameter) of 19 Nos and Vertical Piles (VP) of 850 mm (diameter) of 17 Nos. The T-shaped diaphragm wall was connected at the top through a cellular deck Main Cross Head Beam (MCHB) of 2.80 meters deep to series of vertical piles and raker piles on rear side (Refer Figure.1). All the substructure elements were socketed in hard rock. The structural members considered are assumed to be homogeneous and isotropic with same elastic modulus in compression and tension. A span of 3m has taken for the analysis which consists of T-shaped diaphragm wall, main cross head beam, vertical pile and raker pile. The berthing structure is considered as plane frame.The end supports of the retaining diaphragm wall and Anchor piles are taken at 28.00m below ground level. Analysis of berthing structure is done using STAAD Pro for obtaining Bending moment on the MCHB and TDW and Axial force on the VP and RP.





(a) (b)

Figure 1. (a) 3-D rendered view of berthing structure frame (b) Cross-sections of berthing structure components (in Meters).

2.1 Material Properties

- The materials M-30 grade of concrete and Fe415 grade of reinforced steel are used for the analysis.
- As per IS 456:2000, the stress- strain relationship is used.
- Characteristic strength of concrete, f_{ck}=30 N/mm^2.
- Ultimate strain in bending, ε_{cu} =0.0035.
- Yield stress for steel, f_y = 415 N/mm^2.
- Modulus of elasticity of steel, E_s = 21,0000 N/mm^2

2.2 Loads Considered On Deck and Substructure

Loads considered on Deck of Berthing structure.

- Dead Load
- Live loads on deck.
- Crane Load.
- Stack Load (Expressed as intensity of load per unit floor area on deck slab).
- BGML Load.
- IRC 70R Load.
- Concentrated Load
- Loads consider on Substructure.
- Earth pressure.
- lateral pressure due to surcharge.
- Mooring.
- Seismic load.

2.3 Load Combination Consider For Berthing Structure

Load combination taken for the design and analysis of the berthing Structure as per IS 4651 part 4 (1974).
Case 1: Without mooring condition.

- Dead Load + Live Loads+ Hydrostatic Force + Surcharge + Earth Pressure.

Case 2: With mooring condition.

- Dead Load+ Live Loads +Hydrostatic Force + Surcharge + Earth Pressure+ Mooring force..

3. Methodology

3.1 STAAD Pro Analysis

The STAAD Pro software was used to model the T-Shaped Diaphragm wall, Vertical pile, Raker pile and Main Cross Head Beam of the berthing structure (Refer Figure 2 for STAAD Pro wire frame model). A panel of 3m wide and 17.2m long was taken for analysis of the structure. The influence of variable stack and other loads on Main Cross Head Beam (MCHB), T-Shaped Diaphragm Wall (TDW), Vertical Pile (VP) and Raker Pile (RP) with and without mooring force conditions has been studied. The other loads Crane, IRC 70R, concentrated Load and BGML load were kept constant thorough out the analysis.

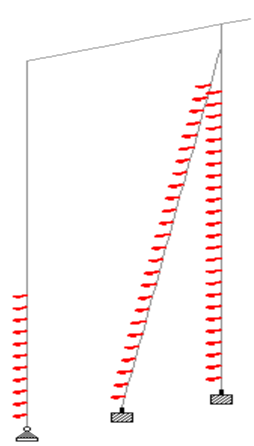


Figure 2. STAAD Pro wire frame model.

3.2 Monte Carlo Simulation

Monte Carlo simulation is a technique of simulation that relies on repeated random sampling and statistical analysis to compute the results. This method of simulation is very closely related to random experiments, experiments for which the specific result is not known in advance. This technique is used to study the distribution of random variables, to simulate the performance of or behavior of the system and to determine the reliability or probability of failure of system or a component. MATLAB Software is used for the generation of random numbers for each component, About 8 samples were generated for various Mean and SD for all the varying Stack load. For each component, the process is repeated similarlyvalues of mean(**μ**), standard deviation (**σ**) and Coefficient of Variation (COV) are obtained for each structural component.

4. Results and Discussions

The COV values obtained from random numbers generated from MATLAB software for each component i.e., MCHB, TDW, RP and VP for varying STACK load are plotted in graphs as shown in Figure 3 through respectively.

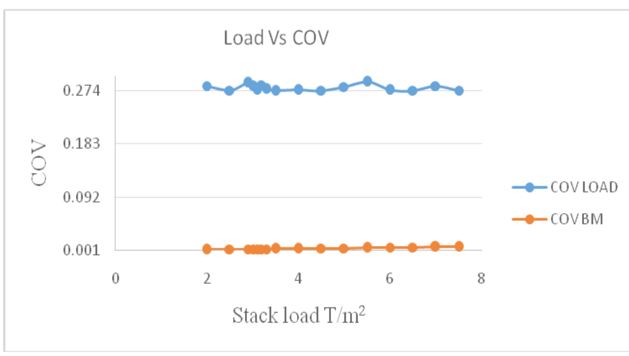


Figure 3. LOAD Vs COV in MCHB with mooring force.

4.1 Main Cross Head Beam

4.1.1 With Mooring Force

From Figure 3, it is observed that for a decrease in characteristic stack load of 50%, observed decrease in COV for load of 2.2% and COV for B.M of 50%. And for increase in characteristic stack load of 50%, observed decrease in COV for load of 2.11% and increase in COV for B.M of 48%.

4.1.2 Without Mooring Force

From Figure 4, it is observed that for a decrease in characteristic stack load of 50%, observed decrease in COV for load of 2.1% and COV for B.M of 50%. And for increase in characteristic stack load of 50%, observed decrease in COV for load of 2.9% and increase in COV for B.M of 43%.

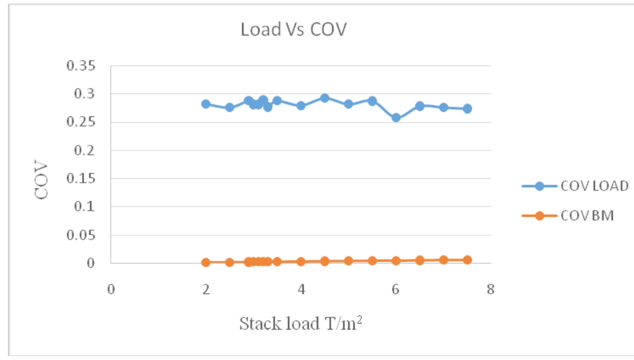


Figure 4. LOAD Vs SD in MCHB without mooring force.

4.2 T-Diaphragm Wall

4.2.1 With Mooring Force

From Figure5, it is observed that for a decrease in characteristic stack load of 50%, observed decrease in COV for load of 6.1% and COV for B.M of 52%. And for increase in characteristic stack load of 50%, observed decrease in COV for load of 4.80 % and increase in COV for B.M of 44%.

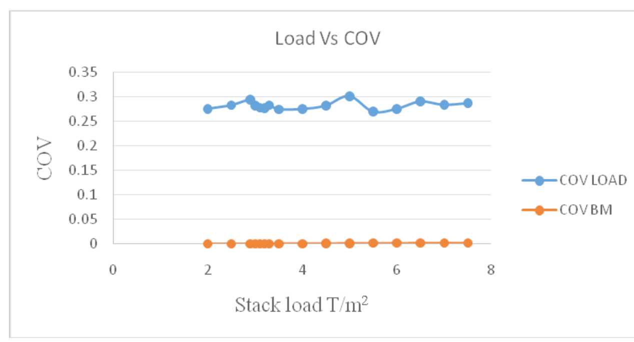


Figure 5. LOAD Vs COV in TDW with mooring force.

4.2.2 Without Mooring Force

From Figure 6, it is observed that for a decrease in characteristic stack load of 50%, observed increase in COV for load of 4.3% and decrease in COV for B.M of 47%. And for increase in characteristic stack load of 50%, observed increase in COV for load of 6.2 % and COV for B.M of 54%.

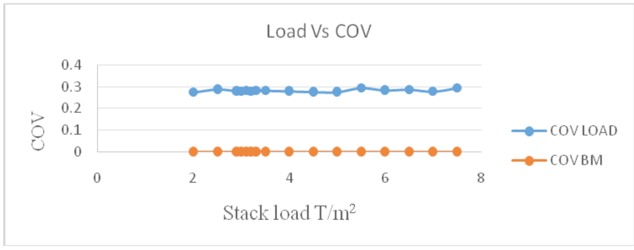


Figure 6. LOAD Vs COV in TDW without mooring force.

4.3 Vertical Pile

4.3.1 *With Mooring Force*

From Figure 7, it is observed that for a decrease in characteristic stack load of 50%, observed decrease in COV for load of 1.30 % and COV for A.F of 3.70%. And for increase in characteristic stack load of 50%, observed decrease in COV for load of 66 % and increase in COV for A.F of 158 %.

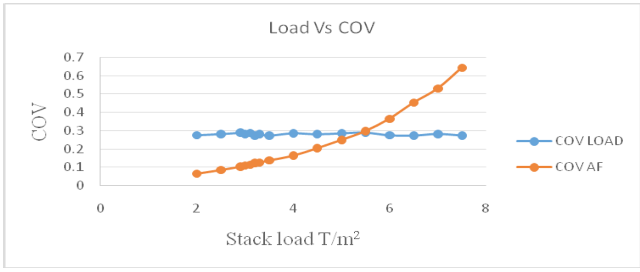


Figure 7. LOAD Vs COV in VP with mooring force.

4.3.2 *Without Mooring Force*

From Figure 8, it is observed that for a decrease in characteristic stack load of 50%, observed increase in COV for load of 15 % and decrease in COV for A.F of 17%. And for increase in characteristic stack load of 50%, observed increase in COV for load of 3 % and COV for A.F of 15.3 %.

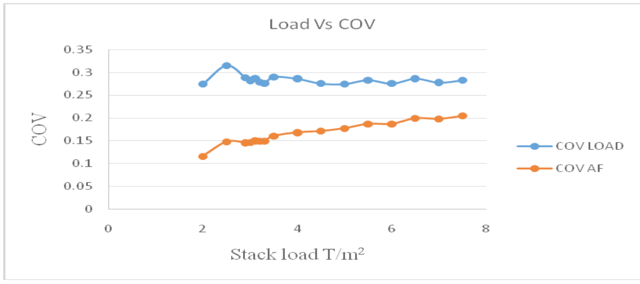


Figure 8. LOAD Vs COV in VP without mooring force.

4.4 Raker Pile

4.4.1 *With Mooring Force*

From Figure 9, it is observed that for a decrease in characteristic stack load of 50%, observed increase in COV for load of 4 % and COV for A.F of 8.50%. And for increase in characteristic stack load of 50%, observed decrease in COV for load of 46 % and increase in COV for A.F of 66 %.

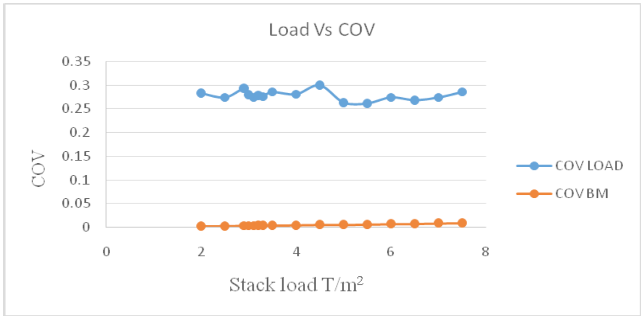


Figure 9. LOAD Vs COV in RP with mooring force.

4.4.2 *Without Mooring Force*

From Figure 10, it is observed that for a decrease in characteristic stack load of 50%, observed increase in COV for load of 0.5 % and decrease in COV for A.F of 49%. And for increase in characteristic stack load of 50%, observed decrease in COV for load of 5 % and increase in COV for A.F of 44 %.

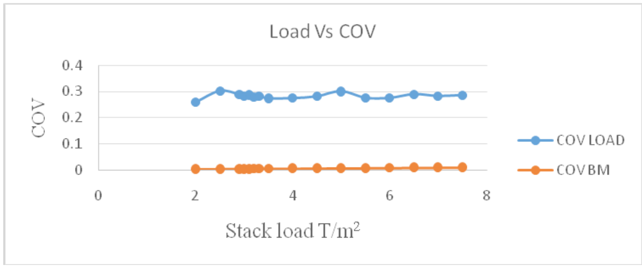


Figure 10. LOAD Vs COV in RP without mooring force.

5. Conclusions

From the Analysis, for variable stack load of 2.5 T/m^2 and 7.5T/m^2 when compared to service stack load of 5T/m^2 with and without mooring force condition, observed variation of results of load effects in Main Cross Head Beam (MCHB), T-shaped Diaphragm Wall (TDW) and Raker Piles (RP) and the following conclusions were drawn.

1. Main Cross Head Beam (MCHB): Stack load of 2.5T/m^2, the Coefficient of variation (COV) for Bending Moment was decreased by 50 % for both conditions of with and without mooring forces. For the Stack load of 7.5 T/m^2, the Coefficient of variation (COV) for Bending Moment was increased by 48% and 43% for conditions of with and without mooring forces respectively.
2. 'T'-Shaped Diaphragm Wall (TDW): For 2.5T/m^2 stack load, the COV for Bending Moment was decreased by 52 % & 47% for with and without mooring force conditions respectively. In case of Stack load of 7.5 T/m^2, the COV for Bending Moment was increased by 44% and 53% for conditions of with and without mooring forces respectively.
3. Vertical Pile (VP): For Stack load with 2.5T/m^2 intensity, the COV for Axial force was decreased by 66% and 17% for conditions of with and without mooring forces respectively. Stack load with 7.5 T/m^2 intensity, the COV for Axial force was increased by 158% and 15% for conditions of with and without mooring forces respectively.
4. Raker Pile (RP): In case of 2.5T/m^2 stack load, the COV for Axial force was decreased by 46% and 49% for conditions with and without mooring forces respectively. For 7.5 T/m^2 stack load, the COV for Axial force was increased by 66% and 44% for conditions with and without mooring force respectively.
5. From the study, it was concluded that the influence of variable Stack load has effect on the Bending Moment of MCHB & TDW and Axial Force of VP and RP of the berthing structure.
6. From the study, it is also concluded that due to variable stack load with and without mooring force conditions, the variation of results of load effects in case of Main Cross Head Beam (MCHB), T-shaped Diaphragm Wall (TDW) and Raker Piles (RP) were indicative, but found a significant variation of results of load effects in the case of Vertical Pile (VP).

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