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Study Of Elastomeric Bearing Behaviour In Offshore Structural Systems

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Abstract: This study investigates the performance of elastomeric bearings in offshore structures under combined static and dynamic loading conditions. The research evaluates their deformation characteristics, load-carrying capacity, and effectiveness in enhancing structural stability in harsh marine environments. Experimental testing and numerical modeling were conducted to analyze the hyper-elastic and visco-elastic behavior of rubber materials, along with the influence of embedded steel shims.The results indicate that elastomeric bearings provide significant flexibility and damping, reducing stress concentrations and improving structural response under cyclic loading induced by waves and wind. However, environmental factors such as temperature variation and material degradation were found to influence stiffness and long-term performance. Comparative analysis shows that structures supported with elastomeric bearings perform better than fixed and pinned supports by offering an optimal balance between stiffness and flexibility. The study establishes improved performance criteria for stiffness and damping under operational and extreme conditions. These findings contribute to the optimization of design and material selection, enhancing the safety, durability, and reliability of offshore structural systems.

Keywords : Elastomeric Bearing, Offshore Structures, Load carrying capacity, Analysis, Safety, Marine Environment.

1. Introduction:

Bearings are critical mechanical components used in bridges and offshore structures to support loads, regulate relative motion, and minimize friction between structural elements. By replacing direct sliding contact with controlled movement, they reduce wear, vibration, and stress concentrations, thereby improving overall structural performance. Bearings are capable of carrying radial, axial, or combined loads and ensure that movement occurs only in the intended direction.

Elastomeric bearings are widely adopted due to their ability to accommodate deformation and absorb dynamic effects such as vibrations and cyclic loading. These bearings are typically manufactured using elastic materials, which enable them to resist applied loads while permitting controlled displacement. Their use enhances structural safety by mitigating the risk of damage or failure under sudden or repeated loading conditions. Additionally, elastomeric bearings are considered an economical solution and are designed in accordance with established standards such as IS codes, AASHTO, and EN 1337.

Based on their construction, elastomeric bearings are classified into reinforced and non-reinforced types. Reinforced bearings include laminated and PTFE sliding bearings, which are suitable for higher load and movement demands. Non-reinforced bearings, such as strip bearings and chloroprene rubber bearings, are generally used for lighter applications.

Structurally, an elastomeric bearing consists of a layered system comprising a bottom steel plate, an intermediate elastomeric layer, and a top steel plate. The elastomeric layer, often arranged in multiple thin layers, is responsible for accommodating deformation and reducing frictional effects.

The primary function of elastomeric bearings is to support heavy structural loads while allowing controlled horizontal movement relative to the foundation. This flexibility helps prevent cracking or structural failure due to imposed movements. Common materials used in their fabrication include natural rubber, synthetic rubber (such as neoprene), elastomers, and polytetrafluoroethylene (PTFE).

1.2. Offshore Structure:

Offshore structures are engineered systems installed in marine environments for purposes such as oil and gas extraction, marine transportation, and support of infrastructure like bridges and causeways. These structures are typically constructed using steel and concrete and consist of key components, including pile foundations, a jacket framework for support, and a topside deck to house operational equipment.

Designing offshore structures is highly complex due to exposure to severe environmental conditions such as waves, wind, and corrosion. Over the past few decades, their design and development have evolved significantly, primarily driven by the depletion of shallow-water resources and the increasing demand for energy. This has led to a shift toward deepwater exploration and the creation of more advanced structural systems.

Offshore engineering is considered a multidisciplinary field involving maritime, civil, mechanical, and environmental engineering due to the technical challenges involved. Offshore platforms play a vital role in global energy production, with their contribution increasing substantially over time as reliance on offshore oil and gas resources has grown.

1.2.1. Typres of Offshore Structures:

Fixed Offshore Structure

Structures Sub - Structures	Uses	Advantages	Disadvantages
Fixed Offshore Structures			
Jacket	Drilling Production	Very common, Well proven, Dry trees	No storage, WD1 < 100 m
Tower	Drilling Production	Very common, Well proven, Dry trees	No storage, WD 400 m
Jack - up	Drilling Production	Common, Well proven for production, Dry trees	No storage, water depth <100 m, foundation stability issues
Compliant Tower	Drilling Production	Dry trees, Large no. of wells, large payloads	No storage, current max 535 m up to 1000 m, large heavy structure in deep water
Gravity Structures	Drilling Production	Storage, Dry trees	WD 300 m
Monotower	Drilling Production	Unmanned, Proven, Dry trees	No storage, limited number of wells, WD < 100 m

Floating Offshore Structure

Structures Sub - Structures	Uses	Advantages	Disadvantages
Floating Offshore Structures			
Monohull	Production	Early production, storage, well proven, large variation in payload, large deck space, deep water	WD current maxm 1850 m up to 3000 m, wet trees, sensitive to motions
Semi - submersible	Drilling Production	Early production, low heave motion, well proven, dry trees	WD current maxm 2440 m up to 3000 m, no storage, wet trees
Tension Leg Platform	Drilling Production, Dry Trees	Dry trees, roll, pitch & heave negligible, several varieties	WD current maxm 1450 m up to 1500 m, no storage, sensitive to changes in payload
Spar	Drilling Production, Storage	Dry trees	WD current maxm 1700 m up to 3000 m, roll, pitch & heave significant

2. Method of Analysis:

Structural analysis is generally carried out using two main approaches: analytical and experimental methods. Analytical methods use mathematical and theoretical models to study structural behavior, including techniques such as the Finite Element Method, Boundary Element Method, and Bayesian approaches, which help predict system responses under varying conditions.

Experimental methods, in contrast, involve physical testing and observation to verify analytical results and evaluate actual performance. Common techniques include shear modulus testing, structural health monitoring, and scaled model testing, which are used to assess material characteristics, identify defects, and simulate real-life loading scenarios.

Together, these approaches provide a comprehensive and reliable framework for understanding and evaluating structural systems.

a. Analytical Method:

Analytical methods provide a preliminary and cost-effective approach for evaluating the behavior of elastomeric bearings in offshore structures. These methods use simplified mathematical models to estimate key parameters such as stiffness, deformation, and stability before conducting detailed simulations or experiments.

In offshore conditions, bearings are subjected to continuous, dynamic, and multi-directional loads from waves, wind, and vessel motion, requiring the inclusion of dynamic effects in the analysis. Techniques such as multi-body dynamic simulations use hydrodynamic inputs as boundary conditions, particularly for systems like FPSO units. To improve computational efficiency, complex bearing models may be simplified using equivalent spring representations, where stiffness is derived from detailed analyses.

Material behavior is often modeled as viscoelastic, accounting for temperature- and frequency-dependent properties using approaches like the Maxwell model or Prony series. Additionally, fatigue analysis is essential to predict long-term performance under cyclic loading, typically using stress-life relationships and cumulative damage models.

The Finite Element Method (FEM) is widely applied for detailed analysis, enabling accurate modeling of layered geometry, nonlinear material behavior, and large load conditions. It involves discretization, variational formulation, solution procedures, and post-processing, and may incorporate advanced techniques such as fluid-structure interaction for offshore applications.

A discretization strategy is understood to mean a clearly defined set of procedures that cover
(a) the mapping of reference elements onto the elements of the mesh.
(b) the creation of finite element meshes,
(c) the definition of basis function on reference elements (also called shape functions)
Finite element analysis employs various discretization strategies such as h-version, p-version, hp-version,

XFEM, and iso-geometric analysis, each offering distinct benefits depending on the problem type. The choice of discretization aims to achieve optimal accuracy and efficiency for a given class of models.
Numerical solution methods are broadly categorized into direct and iterative solvers, which are designed to efficiently handle sparse matrices arising from the chosen formulation and discretization.
Post-processing is used to extract meaningful results and evaluate solution accuracy. It includes error estimation techniques to verify results, and if inaccuracies exceed acceptable limits, the model is refined through adaptive methods or analyst intervention. Advanced post-processing techniques can also enhance solution accuracy through super convergence.

b. Experimental Method:

Experimental methods for analyzing elastomeric bearings in offshore structures focus on determining their mechanical properties under extreme environmental and loading conditions. Due to the large size and high load capacity of these bearings, testing often requires specialized, high-capacity equipment and may be combined with numerical simulation for a comprehensive analysis.

3. Design Criteria:

Design criteria for offshore platforms include operational requirements and environmental conditions that influence structural configuration and performance. Key operational factors include the platform's function—such as drilling, production, storage, or accommodation—which determines layout, equipment arrangement, and overall dimensions.
Site-specific conditions play a crucial role in design. The platform location must be defined in advance, as environmental parameters like wave characteristics, tides, and soil conditions vary geographically. Orientation is also important and is typically aligned with prevailing winds, waves, and currents to ensure stability and operational efficiency.
Accurate information on water depth and tidal variations is essential for determining structural elevations, including decks and access points. Additionally, deck elevation must be sufficiently high to avoid wave impact, with an appropriate air gap provided to accommodate extreme wave conditions and reduce the risk of structural damage.

Environmental Considerations:

Environmental considerations for offshore platforms involve evaluating meteorological and oceanographic conditions that influence design and performance. These conditions should be defined with the help of specialists, using measured or model-generated data that is statistically analyzed.
Environmental data are categorized into normal and extreme conditions. Normal conditions occur frequently and are important for construction and routine operation, while extreme conditions are rare but critical for determining design loads and ensuring structural safety.
All environmental data must be well-documented, including their sources, reliability, and the methods used for analysis, to ensure accurate and dependable design inputs.

4. Load Considerations:

Load considerations for offshore platforms involve defining design and operating environmental loading conditions. Design environmental loads correspond to extreme events that govern structural design, while operating loads represent less severe conditions under which normal operations continue.
The platform must be designed to withstand the most critical combination of loads. This includes the integration of environmental forces with dead loads and live loads to ensure safety and structural integrity under the most unfavorable conditions.

4.1 Load Types in Offshore Structures:

Offshore platforms are subjected to various types of loads that must be considered during design to ensure safety and performance.
Dead loads include the self-weight of the structure, permanent equipment, and hydrostatic forces such as buoyancy and external water pressure.
Live loads consist of variable loads during operation, including equipment, personnel facilities, stored materials, and forces generated from activities like drilling, crane operations, vessel mooring, and helicopter use.
Environmental loads arise from natural factors such as waves, wind, currents, earthquakes, and variations in water levels, and must be considered from all possible directions.
Wind loads act on exposed parts of the structure and require analysis of wind speed, direction, fluctuations, and duration for accurate assessment.
Gravitational loads include forces during fabrication, transportation, installation, and potential relocation of the platform.
Dynamic loads result from cyclic or impact actions caused by waves, wind, machinery, or vessel contact.
Wave loads, a major component of environmental loading, are dynamic in nature and may require advanced dynamic analysis,

LOAD ACTING ON STRUCTURE	MINIMUM	MAXIMUM
DEAD LOAD + LIVE LOAD	4000 kN	25000 kN
WAVE LOAD + WIND LOAD +CURRENT LOAD + INERTIA	500 kN	8000 kN

Table No. 1: Load Acting On Structure

5. Design Parameters:

The design parameters of the structure are based on the data available in IS codes and other certified documents like AASHTO LRFD, EN 1337 etc.
Evaluating the structural efficiency by comparing configurations with fixed and pinned supports

Physical Properties	Dimensions and Specifications
Height of Structure	20 m
Beam 1	450 mm X 200 mm
Beam 2	600 mm X 400 mm
Beam 3	1000 mm X 400 mm
Beam 4	1200 mm X 400 mm
Column Size (Dia)	400 mm
Support Type	Fixed, Pinned
Material Used	Steel

Table No. 2: Dimensions And Specifications Of Structure For Design

The structure is designed using STAAD Pro software. The design is based on the table above and the load applied is based on table no 1. Comparison of structure with 2 supports: fixed and pinned is done for knowing the reactions.

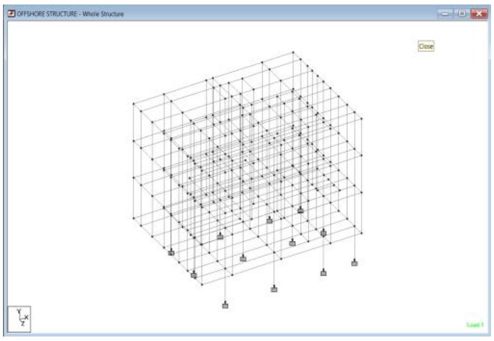


Fig 1: Design Of Offshore Structure

The structure is loaded with maximum load of 25000 kN and minimum load of 500 kN .

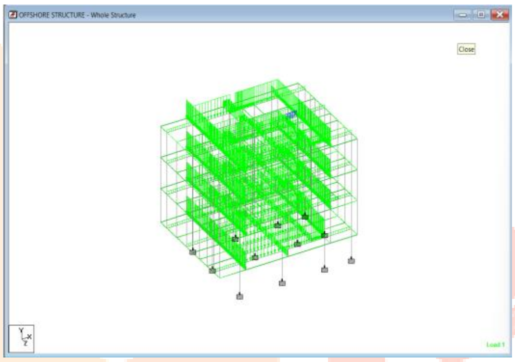


Fig 2: Load Applied On Structure

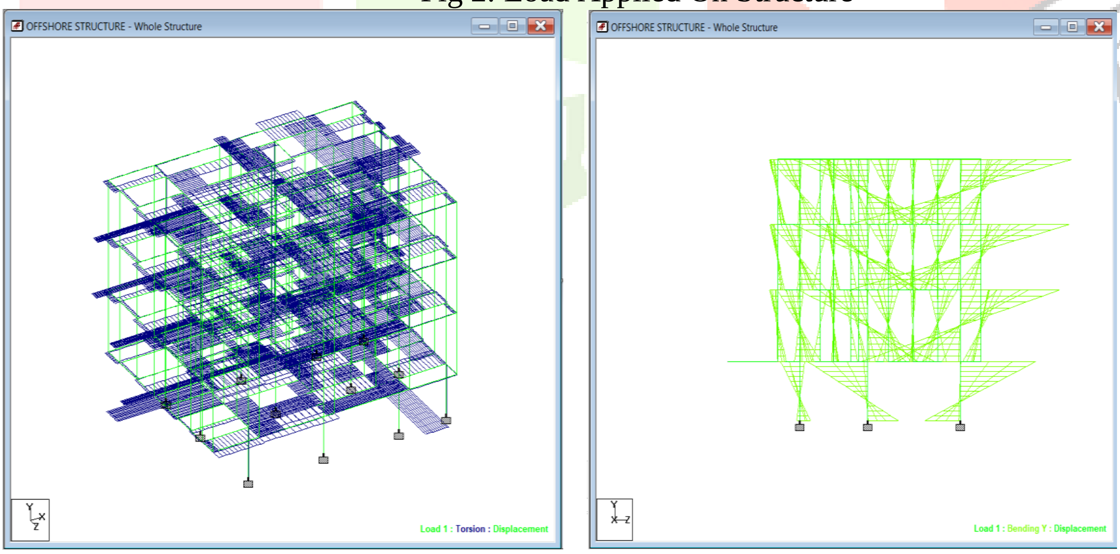


Fig 3: Reactions of Moment in X Direction And Deflection in Y Direction for Fixed Support

Fig 3 shows the reactions of load acting on the structure and having a moment in X direction. The second fig shows the structure having deflection in Y direction. This figures are supported with fixed supports.

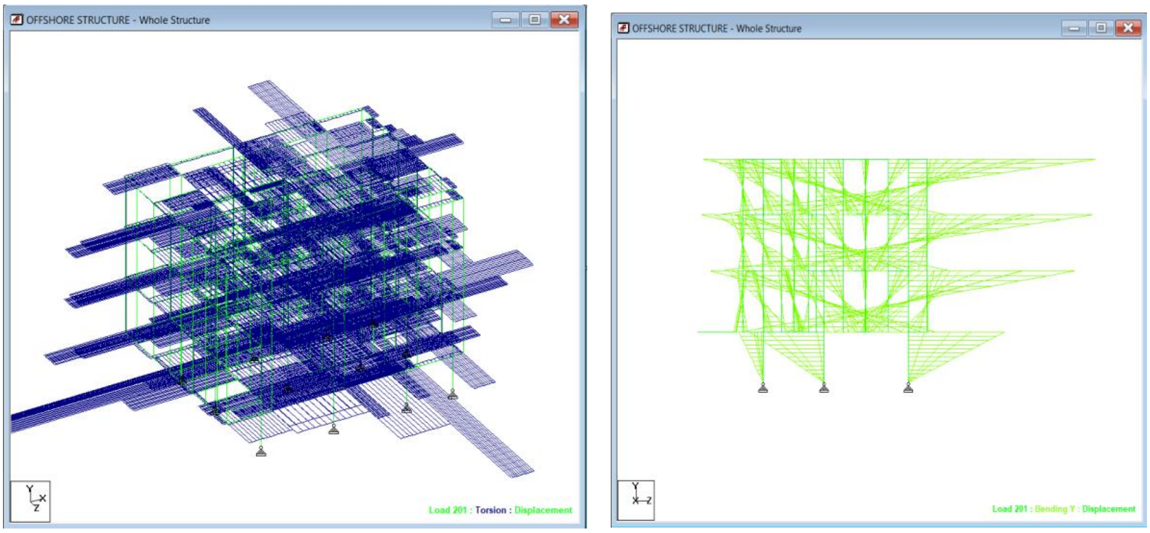


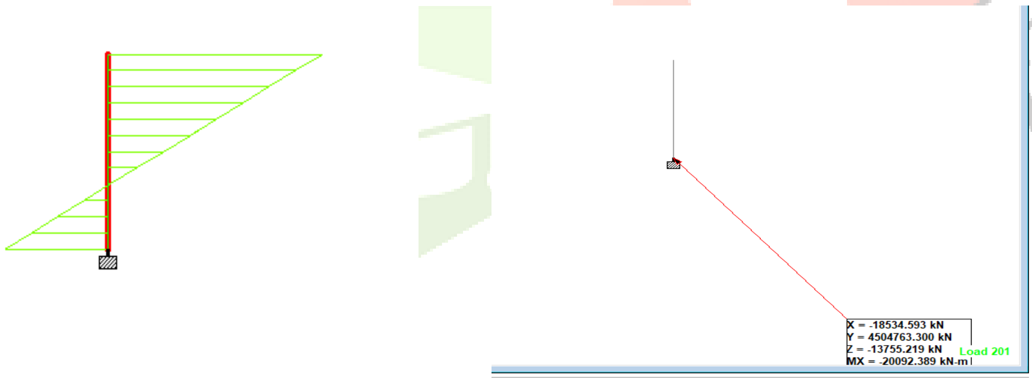
Fig 4 : Reactions of Moment in X Direction And Deflection in Y Direction for Pinned Support

Fig 4 shows the reactions of load acting on the structure and having a moment in X direction. The second fig shows the structure having deflection in Y direction. This figures are supported with pinned supports.

Comparison Of A Column Carrying The Maximum Load

FIXED SUPPORT STRUCTURE

The structure was analysed for a member carrying maximum load. Analysis states the base column no. 440 carries maximum load

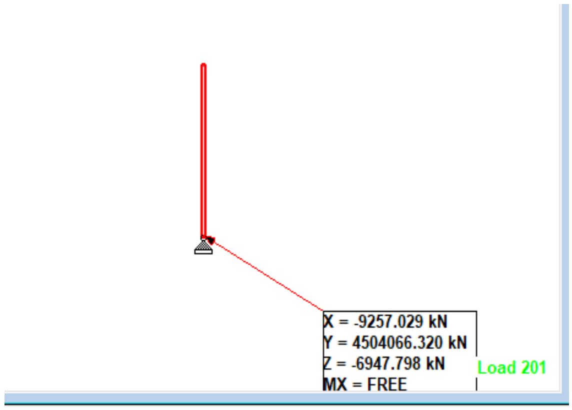


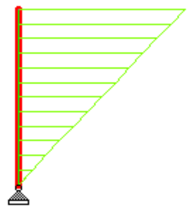
The reactions are accumulated in the table below:

REACTIONS ON COLUMN NO 440 WITH FIXED SUPPORT					
DIST	Mx	My	Displacement X	Displacement Y	Displacement Z
2.625	2310.667	-1158.39	24.141	-58.065	19.498
3	624.135	-3.382	18.123	-46.452	14.309
3.375	-1062.4	1151.626	11.757	-34.839	9.12
3.75	-2748.93	2306.635	5.984	-23.226	4.573
4.125	-4435.46	3461.646	1.752	-11.613	1.318
4.5	-6121.99	4616.655	0	0	0

PINNED SUPPORT STRUCTURE

The structure was analysed for a member carrying maximum load. Analysis states the base column no. 440 carries maximum load



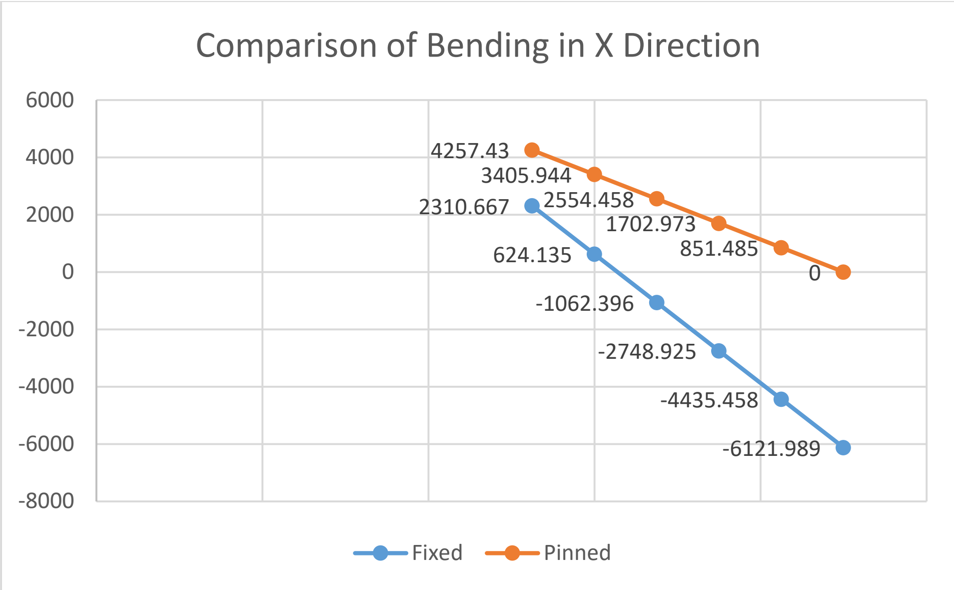


The reactions are accumulated in the table below:

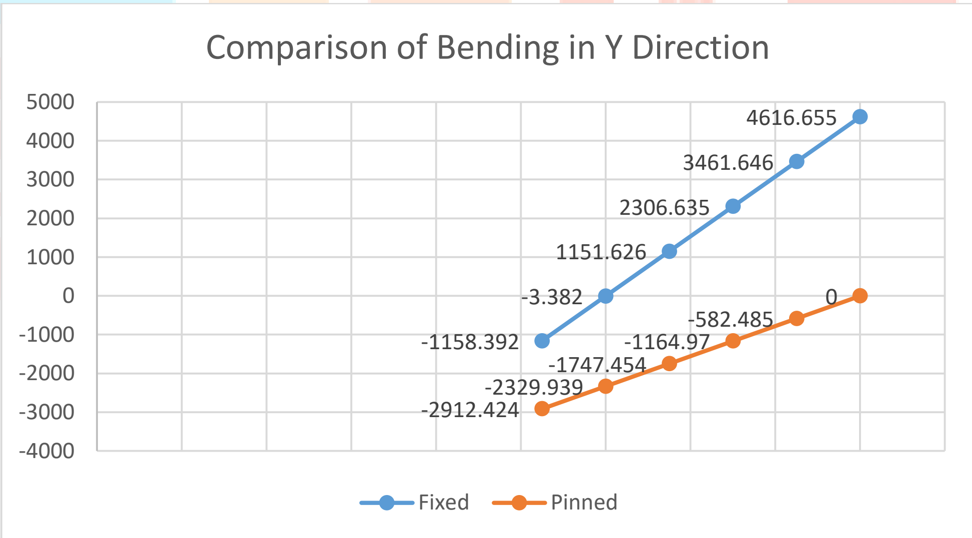
REACTIONS ON COLUMN NO 440 WITH PINNED SUPPORT					
DIST	Mx	My	Displacement X	Displacement Y	Displacement Z
2.625	4257.43	-2912.42	27.155	-58.05	32.717
3	3405.944	-2329.94	24.581	-46.44	28.13
3.375	2554.458	-1747.45	20.104	-34.83	22.239
3.75	1702.973	-1164.97	14.198	-23.22	15.37
4.125	851.485	-582.485	7.336	-11.61	7.849
4.5	0	0	0	0	0

6. RESULT:

After designing the structure on STAAD Pro software we found the reactions for bending and displacement of structure



Comparing the data for moment in X directionin both tables is compared. The analysis states fixed support is more steady and stable as compared to pinned supports.



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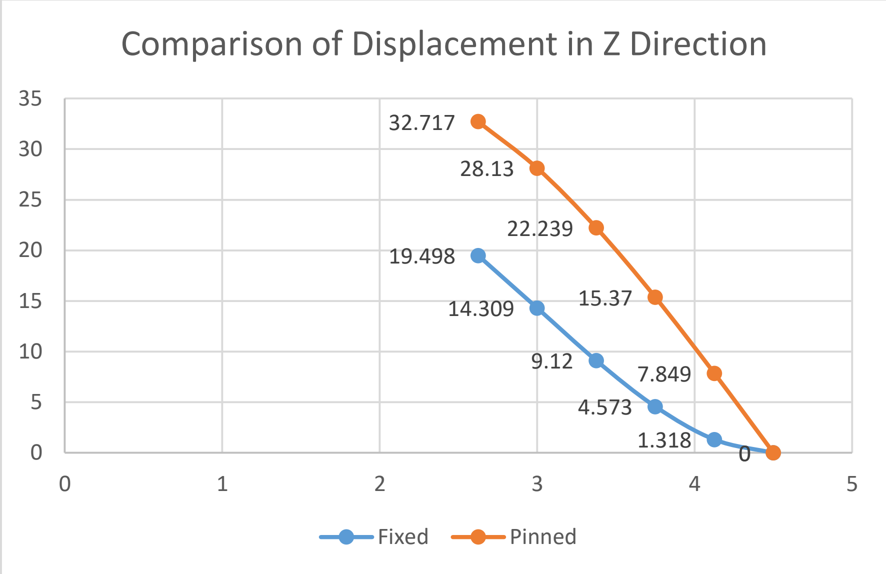

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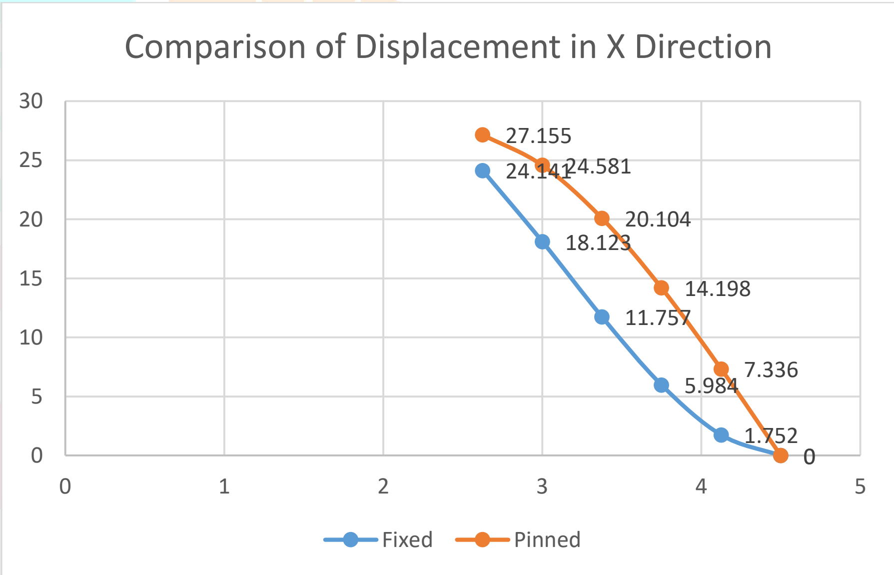

Comparing the data for moment in X directionin both tables is compared. The analysis states fixed support is more steady and stable as compared to pinned supports.

7. Conclusion:

After thoroughly studying the requirements and parameters of offshore structure the study shows:

- Providing fixed supports to the structure helps the structure to resist the loads acting with force.
- The structure is prominently efficient in providing strength to the structure.

Whereas,

- Structure with pinned supports are comparatively less efficient for the nature of activity.
- Structure with fixed support is found to be economical for use .

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