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DYNAMIC RESPONSE BEHAVIOUR OF MULTi -LEGGED ARTICULATED TOWER WITH & WITHOUT TMD

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ABSTRACT

Articulated tower platform is one of the compliant structures that are economically attractive especially as loading and mooring terminal to deep waters. These platforms are lighter when compared to the conventional fixed platforms. An articulated tower is a linear structure, flexibly connected to the sea bed through a universal joint and held vertically by the buoyancy force acting on it. The part of the tower emerging from the water supports the super structure designed to suit the particular application e.g. a tanker to be loaded etc. As the connection to the sea bed is through the articulation the structure is free to oscillate in any direction and does not transfer any bending moment to the base. Design methodologies of these towers ensures reduced motion characteristics with less deck acceleration while loads at the articulated joint are kept to minimum; this is required to establish sufficient stability under working conditions. In this paper the dynamic response characteristics like bending stress variations and the displacement of the Multi-Legged Articulated Tower(MLAT) are quantified through experimental investigations done by the author. A Tuned Mass Damper [TMD] is a small secondary mass-spring-damper system attached to the bottom of the deck plate. Its natural frequency is tuned near to the natural frequency of the MLAT vibration mode that is to be controlled. The TMD inertia forces produced by this motion are approximately anti-phase to the dynamic wind forces driving the MLAT. MLAT motion and hence the stresses are thus greatly reduced with the wave forces primarily driving the TMD instead of the MLAT. The energy of this motion is dissipated by the internal damping mechanism associated with the TMD. The MLAT itself is modelled as a single degree of freedom mass-spring-damper system. The mass of this system is selected to give the same kinetic energy (at the TMD attachment point) as the tower in the vibration mode under consideration. This mass, together with the natural frequency of the vibration mode, define the effective spring constant. The damping ratio for this system is assumed closer to 1% of the critical. The TMD mass is selected on the basis of maximum allowable TMD motion, maximum allowable MLAT deflection and off-tuned performance.

The equation of motion of MLAT has been formulated based on the model. The various dynamic responses of the structure have also been studied. The Bending Moment along the height of the model and the RAO are plotted from the results obtained from the experiment.

Key words: *Multi-Legged Articulated Tower, Tuned Mass Damper, Universal Joints,bending moment.*

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1. INTRODUCTION

The demand for oil and gas has brought the offshore drilling and production of hydrocarbon deposits to greater water depths. New concepts of structural systems have been developed which are suitable for deep water structures. Articulated towers belong to the class of compliant towers which have been found quite suitable for deep water applications. Similar to a reed which “bends but does not break” the articulated structures withstand with suppleness the combined effects of the waves, wind and currents.

There has been an increase in the use of mobile offshore systems for the storage and loading of oil into attendant tankers, particularly for fields that have a limited production capability, or are too remote from refining or terminal facilities to warrant the laying of a pipe line. A typical mobile loading and storage system is the articulated buoyant loading tower which may have either a single universal joint or a greater number of joints in the intermediate level which can be used at very deep water depths. The articulated tower with universal joints in the intermediate level is called a multi-hinged articulated tower.

The extension of the concept of the single-leg articulated tower led to the development of a new type of platform with several columns which are parallel to one another. The columns are connected by universal joints, both to the deck and to the foundation. The use of universal joint ensures that the columns always remain parallel to one another and the deck remains in horizontal position. There is no rotation about the vertical axis of the columns. This type of platform is called a multi-leg articulated tower which has three or more columns. The advantage of this system is that the pay loads and deck areas are comparable with the conventional production platforms in moderate water depths.

The single-leg articulated tower has been used successfully for single-point mooring, control tower and flare structure. This also can be used as a production platform for marginal fields, as an early production platform, or as a processing unit in deep waters.

As the connection to the seabed is through the articulation, the structure is free to oscillate in any direction and does not transfer bending moment to the base. Since the articulated tower is a compliant structure and it freely oscillates along with the waves, the wave force on the structure is much less than that of a fixed structure. The dynamic amplification factor is low compared to the other fixed structures since its natural frequency is much less than the frequency of the wave. Different types of articulated towers are shown in Fig. 1.

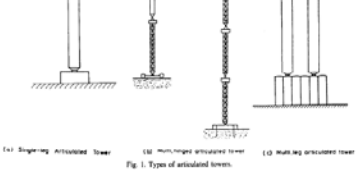


Fig. 1 Types of Articulated towers

A Tuned Mass Damper [TMD] is a small secondary mass-spring-damper system attached to the bottom of the deck plate. Its natural frequency is tuned near to the natural frequency of the MLAT vibration mode that is to be controlled. When the MLAT begins to oscillate, it excites the TMD into motion. The TMD inertia forces produced by this motion are approximately anti-phase to the dynamic wind forces driving the MLAT. MLAT motion and hence the stresses are thus greatly reduced with the wave forces primarily driving the TMD instead of the MLAT. The energy of this motion is dissipated by the internal damping mechanism associated with the TMD.

The MLAT itself is modelled as a single degree of freedom mass-spring-damper system. The mass of this system is selected to give the same kinetic energy (at the TMD attachment point) as the tower in the vibration mode under consideration. This mass, together with the natural frequency of the vibration mode, define the effective spring constant. The damping ratio for this system is assumed closer to 1% of the critical. The TMD mass is selected on the basis of maximum allowable TMD motion, maximum allowable MLAT deflection and off-tuned performance. Brief literature review is as follows:

2. LITERATURE REVIEW

Concepts of single legged articulated towers, well known in the literature [1-2] are extended to multi-legged articulated platforms; in the latter, more legs are connected parallel. Universal joints connecting shaft to foundation and deck necessitates legs of the tower to remain parallel and to keep the deck in a horizontal position under environmental loads. Buoyancy chamber, ballast, guy wires, axial piles and tendons, used as restoring forces reduce the structural stiffness that is required to constrain the structure's motion. Variation of the outer diameter of buoyancy chamber influences structure’s response more than that of its length and position [3]. Structural responses of single and double hinged articulated towers under combination of wind and waves showed more response under random wave condition in comparison to the regular one [4-5]; researchers simulated different wave and wind combinations using Monte Carlo simulation technique.

The Articulated tower studied under combined action of wind, waves and current also showed increased response in comparison to those under waves only [6]. A single leg inclined mooring (SLIM) tower is developed as a concept for an articulated structure to moor tankers with a single hawser in shallow water. Instability of an upright buoyant tower, addressing it as a special purpose single point mooring (SPM) is discussed [7]. Results showed that SLIM motions become near chaotic at higher wave heights. Analysis methodologies of slender articulated towers generally focus on their nonlinear response characteristics; these algorithms retain a relative motion quadratic drag component to model the wave-structure interaction [8]. Studies reported on single legged articulated towers under deterministic and random waves included nonlinear terms due to geometry and fluid-structure interaction, arising from large angle rotations and drag and inertia components, respectively [9]. It is shown that the tower response depends on wave frequency and amplitude; for most of the frequencies, tower exhibits quasi-periodic behavior and for certain frequencies it showed chaotic behavior. Nonlinear dynamic response of multi hinged articulated tower carried out using Lagrange equation approach showed satisfactory results when applied to towers at deep-waters. Analytical studies conducted on tanker-moored articulated tower showed that the tanker dominates the response of the system and does not respond to wave loads as rapidly when the tanker is fully loaded [10]; the study considered operation condition and environmental excitations as well. Dynamic responses of multi-legged articulated towers are dominated by drag forces and use of simplified Morison's equation approach that neglects diffraction effects is used in the current study. Experimental studies on articulated towers are limited to few researchers who demonstrated the influence of added mass on the tower response [11]; however, the study was limited to unidirectional regular waves.

Fujino and Abe [12] investigated the characteristics of a multiple tuned mass damper (MTMD) whose tuning frequency bandwidth was distributed around the natural frequency of the structure subjected to control. Wind tunnel model tests on Sydney Tower were performed by Vickery and Davenport [13], and on Citicorp Center, New York City by lsyumov *et al* [14]. Those are two notable earlier studies in which a model of a TMD was incorporated in the building model to study the effect of a TMD in reducing wind-induced responses. Tsai and Lin [15] numerically developed plots to obtain optimum damper parameters for harmonic excitations.

3. OBJECTIVE

- To have a detailed study on the experimental investigation being done on the dynamic response of MLAT with and without TMD
- To formulate the equation of motion of MLAT with and without TMD

4. EXPERIMENTAL MODEL

Materials for the model were selected such that the elastic limit of material was not exceeded. The four-legged articulated tower model was fabricated to a scale of 1:200 using Perspex tubes of 100mm diameter. Universal joints are used to connect the Perspex leg to the base which acts as a hinge at the base and oriented along the direction of propagation of wave.

4.1 Model details (ref. Fig (2, 3 and 4))

Model height = 1.2 m
Diameter of the tower = 0.1 m
Thickness of the tower = 0.05 m
Leg spacing = 0.3 m

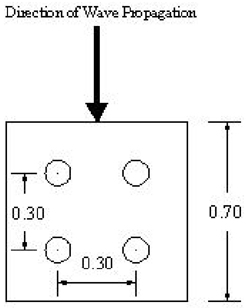
4.2 Parameters considered for the study

4.2.1 Regular Wave

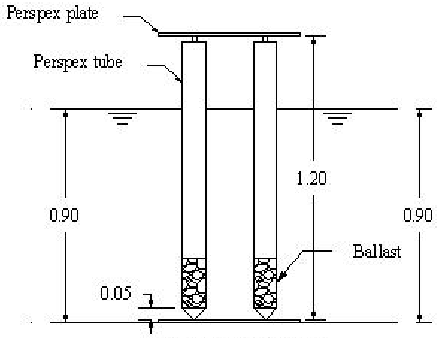
Wave Height : 0.06 m, 0.09 m, 0.12 m and 0.15 m
Wave period : 1.3 s, 1.5 s, 1.7 s and 1.9 s
Wave angle : 0^o

4.2.2. Mass distribution

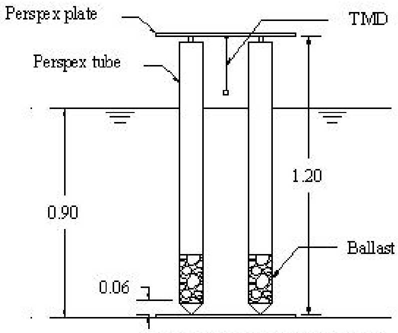
Sand ballast
Water ballast



Plan



Four Legged Articulated Tower



Four Legged Articulated Tower with TMD

Fig. 2 Articulated Tower

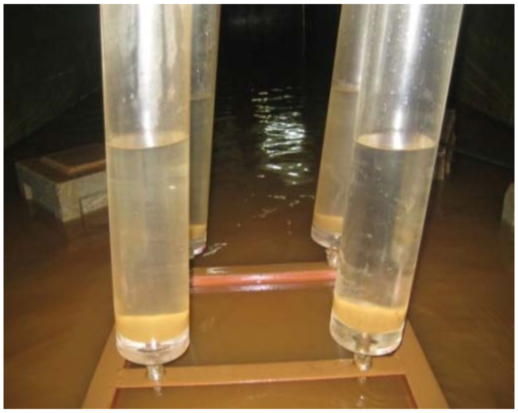


Fig 3(i) Mass distribution of the tower - water filled columns

Fig 3(ii) Mass distribution of the tower - sand filled columns

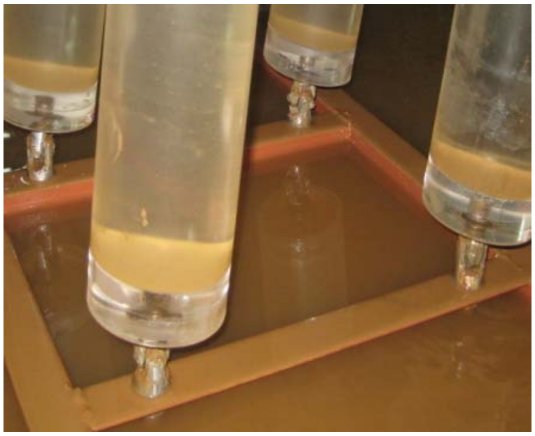


Fig 4(i) Model with instrumentation - universal joint

Fig 4(ii) Model with instrumentation - model fitted with accelerometers and strain gauges

4.3 RESULTS AND CONCLUSIONS.

The bending moment along the height of the model without TMD, is more when compared to the results obtained from the model with TMD. The model is tested with TMD's of mass 100gm, 150gm, 200gm and 250gm. The results showed that as the mass of the TMD's are increased the bending moment is decreased. However in certain cases the bending moment are higher for lower masses like 150gm.

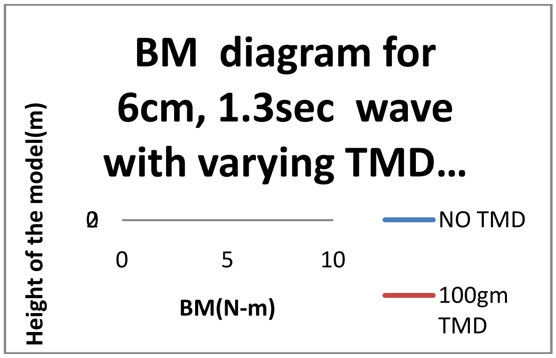


Fig 5.BM diagram

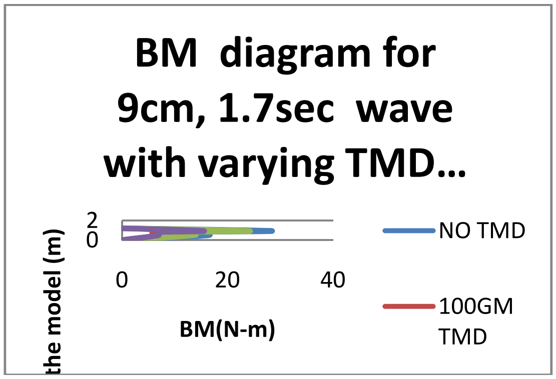
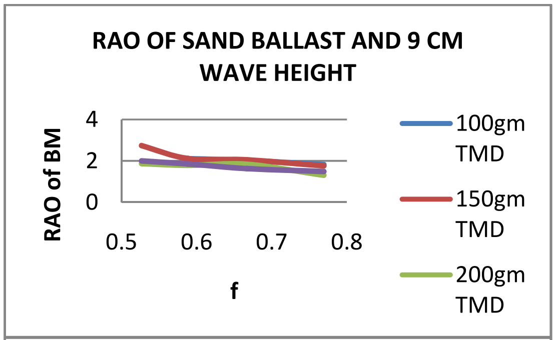
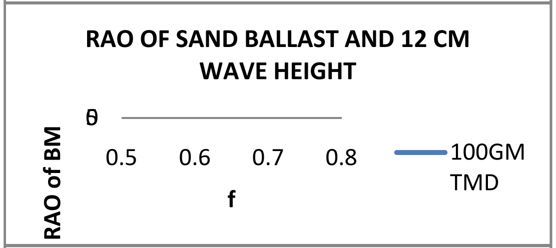
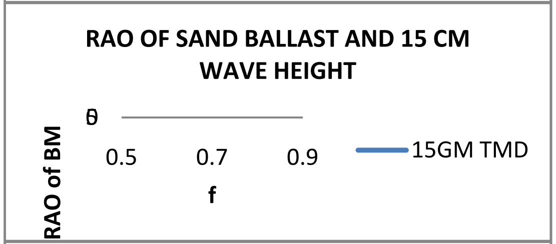


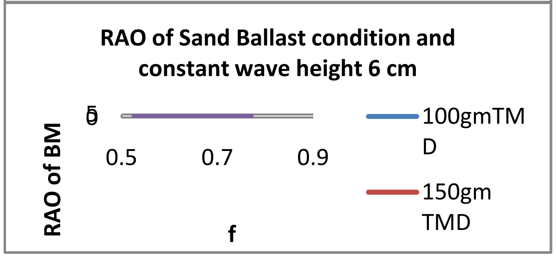
Fig 5.BM diagram

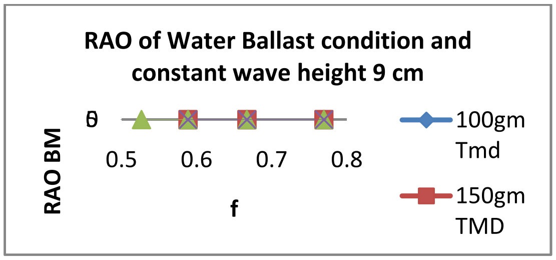
Inferences drawn from the study bring detailed insight to the dynamic response behavior of the multi-legged articulated towers under regular and random waves.

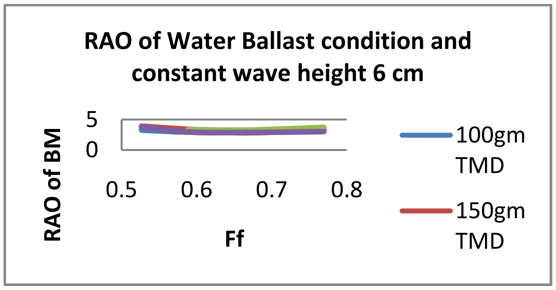

RAO OF SAND BALLAST AND 9 CM WAVE HEIGHT

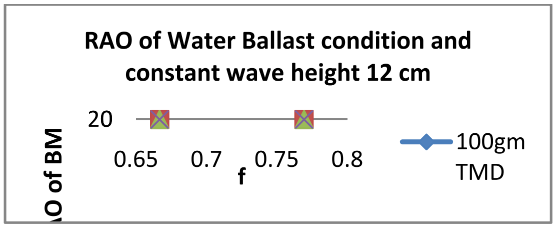

RAO OF SAND BALLAST AND 12 CM WAVE HEIGHT

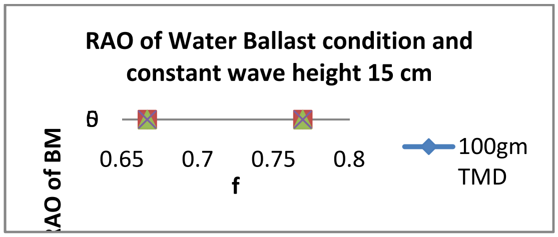

RAO OF SAND BALLAST AND 15 CM WAVE HEIGHT

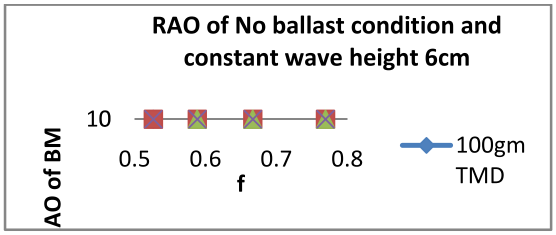

RAO of Sand Ballast condition and constant wave height 6 cm

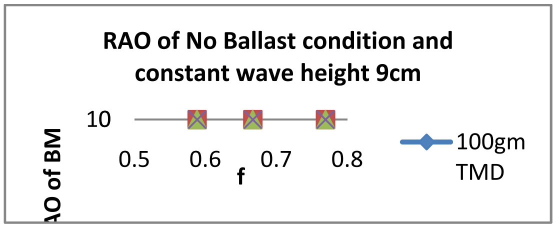

RAO of Water Ballast condition and constant wave height 9 cm

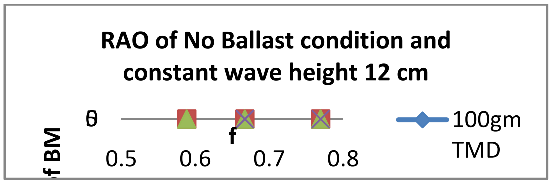

RAO of Water Ballast condition and constant wave height 6 cm


RAO of Water Ballast condition and constant wave height 12 cm


RAO of Water Ballast condition and constant wave height 15 cm


RAO of No ballast condition and constant wave height 6cm


RAO of No Ballast condition and constant wave height 9cm


RAO of No Ballast condition and constant wave height 12 cm

- The RAO graphs of the sand ballast conditions are almost similar; starting with a value 2.5 to 3 and decreasing to a value of 1.5 to 2. Along the frequency, 150 gm TMD is showing higher value than the other cases of TMD except in 15cm case. And the least value by 250 gm TMD.
- In the water ballast case for all wave height the graphs start from a value of 3 to 4 and end of in a RAO value of 2 to 2.5. The graphs are not having a shape similar to the sand ballast case as there is sloshing within the legs.
- Whereas in the no ballast condition it can be seen that the RAO is very high value compared to the sand and water ballast condition. We can also see that the RAO is least for the 250 gm TMD.

Based on the studies on experiments being conducted, following conclusions are drawn:

- Bending moment along the tower and deck acceleration increases with the wave height. By providing buoyancy chambers at the appropriate locations, this sensitivity to the increase in response can be controlled.
- Bending moment and the deck acceleration decreases with the increase in wave frequency.
- Bending moment of the structure decreases with increase in the mass of TMD. However in the case of 150gm TMD we see a fluctuation. This may be due to resonance.

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