PERFORMANCE ANALYSIS OF OFFSHORE RISER SYSTEM IN ANNUALR ARRANGEMENT

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Abstract - *In Marine Structures, Risers are complex dynamic structures and the design of riser systems are primarily governed by loading from the environment and from the motions of the host platform. As the depth of oil exploration increasing day by day, the challenges to the risers are increasing. The dynamic effect from the host platform and the waves, are mitigated by the concept of SINGLE LINE OFFSET RISERS (SLOR). Since the SLOR has high individual displacement the SLOR are grouped together to reduce the displacement. The Grouped SLOR has great potential for large deep water developments, which typically have a complex and congested seabed layout immediately adjacent to the production vessel. As the riser spacing is greatly reduced compared to a conventional SLOR, the arrangement allows seabed real estate to be optimized without losing the many benefits of the freestanding riser concept. Typically grouping of SLOR is done linearly through a guide frame. In the present study, grouping of SLOR is done in annular pattern and its optimal configuration was explained. CFD analysis is carried out using ANSYS FLUENT and then displacements were calculated. It is found that the displacements in annular arrangement are lesser than that of the displacements in linear arrangement and downstream sections experience low drag compared to upstream sections whereas in series arrangement all the sections are exposed to flow and the sections toward the center of the guide frame attracts more drag than edge sections.*

Key Words: Marine Structures, Riser systems, SLOR, Annular arrangement, Computational Fluid Dynamics

1. INTRODUCTION

A riser is a pipe that connects an offshore floating production structure or a drilling rig to a sub-sea system either for production purposes or for drilling, completion and workover purposes. Risers are subjected to number of loads predominantly wave loads, current loads, loads due to movement of the vessel. Therefore, there is a requirement of the riser system which can be efficiently installed and used in the available space with longer life and lesser maintenance. Major disadvantage of Single Line Offshore Riser system is it requires high offset distances which otherwise leads to clashing of risers As a result, there a concept arrived is called Grouped SLOR. The Grouped SLOR is an "open bundle" riser solution that jointly developed by Subsea 7 and 2H Offshore Engineering Ltd. Nicholas Dale et al1 (2007) have done CFD analysis for Grouped SLOR in linear arrangement and found drag and lift coefficients. And in-place finite element analysis had done using the results form CFD analysis and found the top displacements. Mainly vortex induced vibration leads to great damage of offshore risers and it should be supressed (Yongtian Kang, 2020). In this work CFD analysis has been carried out for Grouped SLOR in annular arrangement and obtain drag and lift coefficients for different wave incident angle. The original SLOR arrangement consists of a rigid steel riser pipe extending from mudline to a buoyancy can that is typically situated at a depth of 100m-150m below the MWL. The buoyancy can provide the up thrust which applies tensile load to the riser pipe and generates an over pull at the mudline of 50Te to 150Te (Stephen A Hatton et al, 2005). The SLOR is generally situated 100 to 500 meters away from the vessel depending on the depth.

1.1 Grouped SLOR

Grouped SLOR is referred as open bundle hybrid riser system comprising number of individual SLOR arranged in close proximity without clashing and providing clear space for regular maintenance or replacement if required. Grouped SLOR consists of individual SLOR designed to meet it challenges as individual risers which are arranged in a pattern using a guide frame. Guide frame is tethered to the sea bed by tendons and the up thrust to the guide frame is provided by buoyancy tanks. The SLOR are held to the guide frame using a receptacle with gates bolted on to the front of the frame. These include a central opening which allows two arms to swing open to accommodate the riser guide stem, these are then swung closed using ROV and locked using pin. Generally Grouping of the SLOR is done linearly through a guide frame but in this grouping of SLOR is done in annular pattern and its advantages over the series arrangement were discussed. The main objective of the present work is to find the optimal range of the dimension that can be adopted to attract minimum drag on the buoyancy tank sections for adopted velocity of 0.1m/s. The optimum range of the dimension is decided based on the maximum drag on the buoyancy tank section. For his CFD analysis was performed in ANSYS.

1.2 Computational Fluid Dynamics (CFD)

Fluid flows are governed by partial differential equations which represent the conservation laws for mass, momentum, and energy. Computational Fluid Dynamics (CFD) is the art of replacing such PDE systems by a set of algebraic equations which can be solved using digital computers. The finite volume method is used and it is one of the numerical techniques applied in well-established commercial CFD codes to solve the governing equations of the fluid. Computational Fluid Dynamics provides a qualitative and qualitative prediction of fluid flows by means of mathematical modeling, numerical methods and software tools. In the present study Computational Fluid Dynamics (CFD) is using for evaluating the drag and lift coefficients and corresponding forces on individual cylinders due to the drag and lift.

1.3 Reynolds Averaged Navier Stokes Simulation (RANS)

In this approach, the variables in Navier Stokes equation are decomposed in to mean ($\emptyset'$) and fluctuating ($\emptyset''$) part. This is called as Reynolds decomposition. The Reynolds decomposition can be written as

$$\emptyset = \emptyset' + \emptyset''$$

By substituting the flow variables of governing equation in this form will result in Reynolds Averaged Navier Stokes equation. The tensorial form of the equation in Cartesian coordinate system can be written as

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\delta}{\delta xj}(\rho u_i u_j) = -\frac{\delta p}{\delta xi} + \frac{\delta}{\delta xj}\left[\mu\left(\frac{\delta ui}{\delta xj} + \frac{\delta uj}{\delta xi} - \frac{2}{3}\delta ij\frac{\delta ui}{\delta xi}\right)\right] + \frac{\delta}{\delta xj}(-\rho u'_i u'_j)$$

Where i, j are tensor indices and δij is Kronecker delta. This equation is similar to the general form of the Navier Stokes equation, but this decomposition of flow variables introduced a new term on the right-hand side of the equation, called Reynolds stress term, which is unknown. The main motivation of this approach is to model the Reynolds stresses. Boussinesq hypothesis relates the Reynolds stresses to the mean velocity gradients which is given as

$$-\rho u'_i u'_j = \mu_t\left(\frac{\delta ui}{\delta xj} + \frac{\delta uj}{\delta xi}\right) - \frac{2}{3}\left(\rho k + \mu_t\frac{\delta uk}{\delta xk}\right)\delta_{ij}$$

Where μt is the turbulent viscosity, k is the kinetic energy. This hypothesis is used in turbulence models such as Spalart-Allmaras model, k-ε models and the k-ω models

2. METHODOLOGY

The scope of the present work is finding drag, lift coefficients, forces due to drag and displacements caused due to those forces. For this the flow considered is unidirectional current with only velocity of 0.1m/s. The guide frame is chosen at a depth of 150m to 200m from the MSL and considered six risers of 12" diameter with water depth of 700m. Initially the diameter of the Buoyancy Cans is determined such that the net upward force is maintained to be in range of 100Te to 150Te. And then CFD analysis was performed using ANSYS FLUENT with different diameters of guide frame and with different angles of incidence. Drag and lift coefficients on cylinders was calculated and also Forces on individual cylinders due to the drag and lift were calculated. Using these forces top displacements due to above obtained forces were calculated using STAAD Pro V8i. Finally results obtained are compared with series arrangement of riser system.

2.1 CFD and In-place Analysis

To carry out the CFD analysis, ANSYS WORKBENCH consisting of different analysis systems is being used predominantly consisting of FLUID FLOW FLUENT. The commercial package is capable of handling various kinds of higher turbulence models and is well appreciated for its accuracy of results. It also provides contour plots at the end of analysis which aids in better understanding of flow variations and also make out key differences at the end of each analysis. For analysis of the structure to find out the displacements at various levels, STAAD Pro V8i is used.

2.2 Determination of Buoyancy Force

There should be upward force that retains risers in tension thereby providing extra stiffness for risers which results in reducing displacement. As per the reference, the net upward force is maintained to be in range of 100Te to 150Te. Therefore, maximum net upward force is targeted. To achieve the above condition, the following assumptions are made and are also used for further analysis like CFD analysis and for finding top displacement of the system.

Outer diameter of the buoyancy tank (D) is 4m
Length of the buoyancy tank is 23m
Density of water is 1025kg/m^3
Thickness of tank is 0.02m
Outer diameter of riser is 0.3048m
Inner diameter of riser is 0.254m
Net upward force = Buoyance force – (Weight of tank + Weight of riser)

2.3 CFD Analysis of Grouped SLOR in Series Arrangement

For CFD analysis AN SYS FLUENT is used. Six risers with buoyancy can diameter of 4m is taken and arranged in series pattern with different spacing. 2D modelling is done as shown in figure 1. Different spacing of 0.7D,1D,1.25D,1.5D,1.75D and 2D are used. Legrangian frame of reference is considered, Inlet velocity of 0.1m/s is employed and K-ω SST model is used for analysis. And it is essential that the characteristics of the flow and its parameters are to be carefully captured around the periphery of the cylinders as the flow changes from laminar, transition to turbulent. So it is necessary to provide fine meshing in that area (figure 2). So, here 15 number of inflation layers are provided with element face size of 0.02m with growth rate of 1.2 to meet the size of the triangular mesh that is provided for the fluid domain Maximum face size of the triangular mesh is 0.4m. The material given is fluid during meshing. Drag and lift coefficients obtained from ANSYS FLUENT through CFD analysis for the different models. Forces on individual buoyancy tanks due to drag and lift are calculated using the respective coefficients that are obtained from CFD analysis are shown in the table 1.

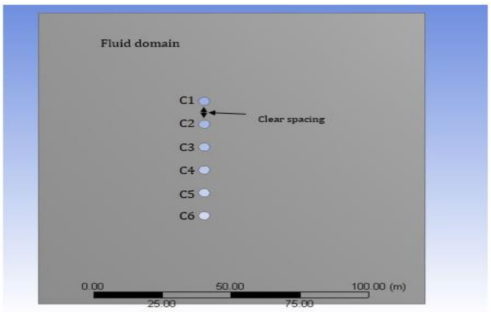


Fig-1: 2D model of the Buoyancy cans arranged in series pattern

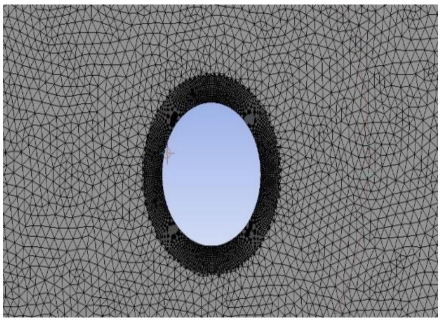


Fig- 2: Mesh around single buoyancy tank section

Table -1: Force(N/m) on each buoyancy tank at different spacing at currents velocity 0.1m/s

SPACING	C1	C2	C3	C4	C5	C6
0.75	73.08	58.60	56.16	56.08	58.46	73.24
1	53.04	43.40	41.74	41.87	43.24	53.08
1.25	41.20	35.29	34.28	34.24	35.28	41.29
1.5	34.75	30.63	29.89	30.02	30.61	34.82
1.75	30.46	27.30	26.78	26.97	27.16	30.34
2	27.13	24.76	24.64	24.49	25.04	27.25

2.3.1 Analysis to Find Displacements

By considering the forces that are obtained from the above calculations as external load and buoyancy as restoring force, finite element analysis is carried out in STAAD Pro V8 to find out the top displacements. The restoring force is given in the form of equivalent spring that obtained by taking into account the condition of equilibrium. The base of the risers is given fixed supports and top is restrained in global Y-direction. Top nodes of the model are free to displace in X-direction and given spring in Z-direction as mentioned in Table 2 for different upward thrust which is restoring force in form of buoyancy. Nodes at top and bottom of the buoyancy tanks are numbered and respective displacements in Z-direction are calculated in the analysis. Nodes at top of the buoyancy tanks are free to displace in X-direction and completely restrained in Y-direction and given spring in Z-direction with calculated spring stiffness in different cases. Forces due to drag and lift are given in positive Z-direction. Nodes at the bottom of the buoyancy tanks are completely free in all degrees of freedom.

Table-2: Spring stiffness (k) for different upward thrust (Te)

Up thrust(Te)	25	50	75	100	125	150
Restoring Force(N)	245250	490500	735750	981000	1226250	1471500
Spring K(kN/m)	3.50E-01	7.01E-01	1.05E+00	1.40E+00	1.75E+00	2.10E+00

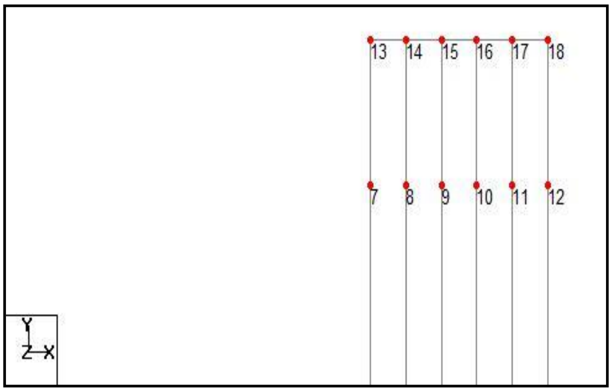


Fig-3: Nodes at the bottom of the risers with fixed supports

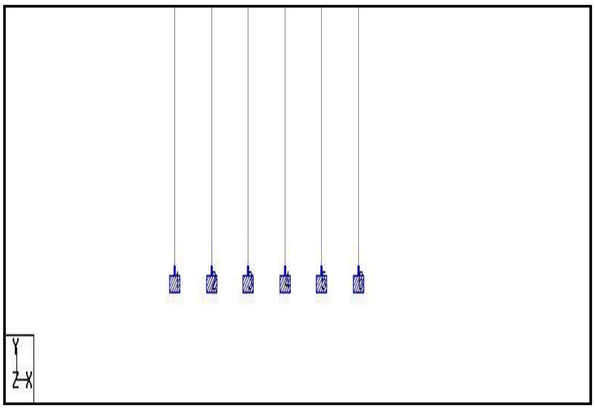


Fig-4: Nodes at top and bottom of buoyancy tanks

Displacements at top nodes are found from the analysis using STAAD Pro. The displacements are tabulated separately for different up thrust that can be customized depending on the installation, operational and site environmental conditions. Table 3 is showing the displacements for upward thrust of 25 Tonnes at different nodes with different spacing. Similarly, displacements are calculated and noted at different upward thrust of varying from 25 to 150 Tonnes. The maximum displacement for the current velocity of 0.1m/s is observed to be 4.08m for clear spacing of 0.75 times the diameter of the buoyancy tank that is beyond the range which is considered as critical and omitted. The displacement is approximately 0.6% of the water depth at current velocity of 0.1m/s. And the top displacements for the spacing of tanks in given range of 1D to 2D are ranging from 3m to 0.278m for different upward thrust provided by the buoyancy tanks.

Table-3: Displacements in mm of the model with upward thrust of 25 Tones in Z-direction

Node	0.75D	1D	1.25D	1.5D	1.75D	2D
7	4084.607	3006.392	2408.592	2071.65	1839.051	1660.797
12	4084.607	3006.392	2408.592	2071.65	1839.051	1660.797
8	4084.602	3006.389	2408.590	2071.648	1839.05	1660.797
11	4084.602	3006.389	2408.590	2071.648	1839.05	1660.797

9	4084.601	3006.389	2408.589	2071.648	1839.049	1660.797
10	4084.601	3006.389	2408.589	2071.648	1839.049	1660.797
15	4084.592	3006.382	2408.583	2071.643	1839.045	1660.792
18	4084.592	3006.382	2408.583	2071.643	1839.045	1660.792
16	4084.592	3006.382	2408.583	2071.643	1839.045	1660.792
14	4084.592	3006.382	2408.583	2071.643	1839.045	1660.792
13	4084.592	3006.382	2408.583	2071.643	1839.045	1660.792
17	4084.592	3006.382	2408.583	2071.643	1839.045	1660.792

2.4 CFD Analysis of Grouped SLOR in Annual Arrangement

For analysing the system as circular array, the arrangement is modelled as two models in which the flow direction changes with one at 0° and other at 30°. Model-1 is the arrangement with flow incident angle 0° as shown in figure 5. The buoyancy tanks are arranged in annular pattern along the guide frame which is circular in shape which has diameter varying for different models. The diameter of the guide frame is varied in terms of n times the diameter of the buoyancy tank. Different diameters of the guide frame are 3D,3.75D,4.5D,5.25D,6D are used. Similar to the meshing done for the model with linear arrangement, fine meshing is adopted around the walls of the buoyancy tanks. Here 25 number of inflation layers are provided with element face size of 0.03m with growth rate of 1.2 to meet the size of the triangular mesh that is provided for the fluid domain. The maximum face size of any element in the domain is 0.3m.

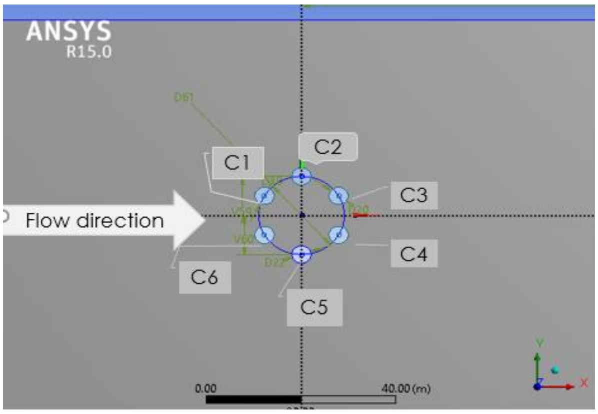


Fig-5: 2D Model-1 of the buoyancy tanks for CFD analysis

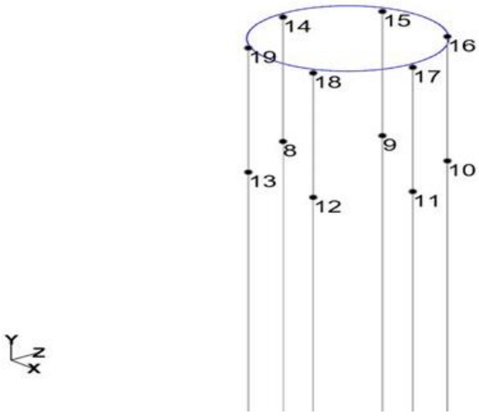


Fig-6: Nodes at top and bottom of buoyancy tanks in annular arrangement

The drag and lift coefficients for the model for different spacing are shown in Chart 1. Since the model is symmetric about horizontal axis that passes from middle of the model, the drags coefficients of cylinders 1,2,3 are equal to 4,5 and 6 respectively. From the above results it is evident that in this arrangement the drags of any cylinder is less than 2 for velocity of 0.1m/s Model-2 is the arrangement with flow incident angle 30°. CFD analysis is performed on model-2 using ANSYS FLUENT using K-ω SST model and the drag and lift forces are obtained. The drag on the tanks C2 and C3 are equal to C6 and C5 respectively due to symmetry. C1 experiences the maximum drag at any spacing as it completely exposed to the flow. The cylinders C2, C4 and C6 that are downstream experiences negative drag for diameter of guide frame <4.5D as shown in Chart 2.

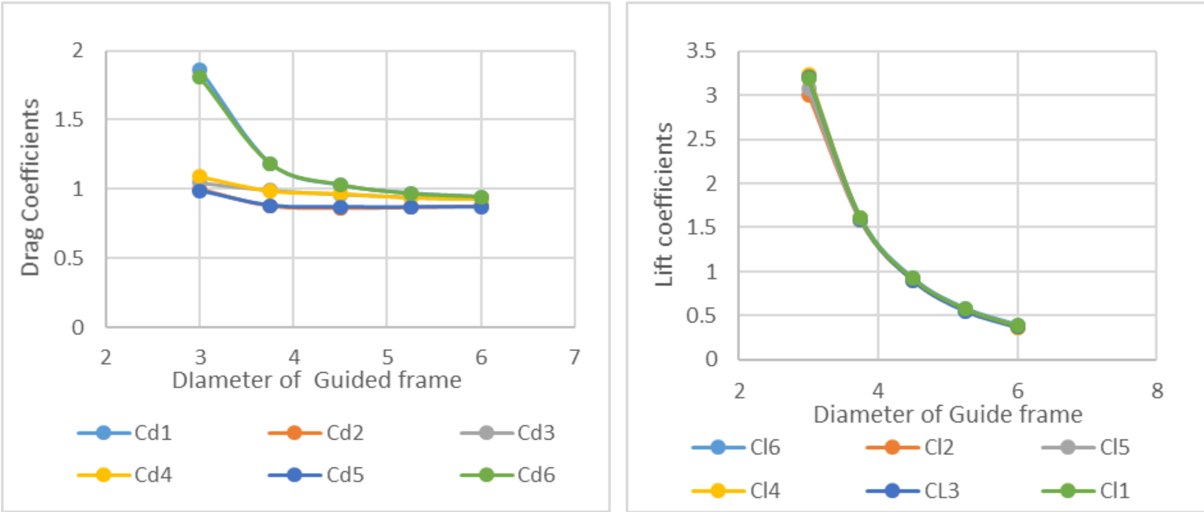


Chart-1: Drag and Lift Coefficients of the buoyancy tanks for model-1 with 0° incident angle

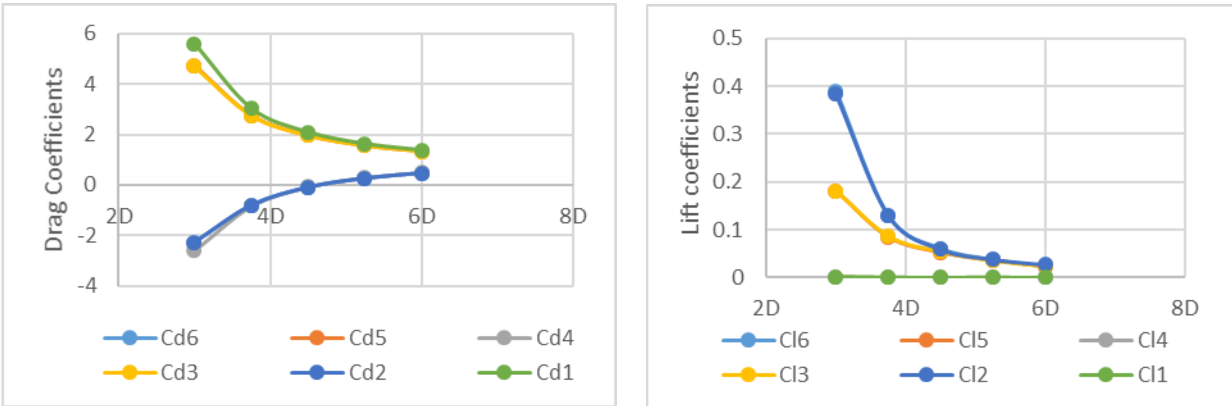


Chart-2: Drag and Lift Coefficients of the buoyancy tanks for model-2 with 30° incident angle

From the output data that is obtained from CFD analysis on both the models is used to find the forces on the buoyancy tanks. Drag and lift forces on each tank are calculated separately from the drag coefficients and lift coefficients that are obtained from the CFD analysis. The forces on the different buoyancy tank sections reduces with increase in the diameter of the guide frame as shown in chart 3. Forces on the sections becomes equal in both the models when the diameter of the guide frame is increased beyond 6D as the drag on the all the sections will be equal to that of the independent section. The negative force on cylinders C2, C4 and C6 are due to the negative drag. As the diameter of the guide frame increases the drag on the cylinders C2, C4 and C6 shifts to positive drag and the drag on the remaining sections also decreases.

2.4.1 Analysis to Find Displacements

To find out the displacement at the top of the system i.e. at the guide frame where we observe the maximum displacement due to the drag force, the forces calculated from the drag coefficients obtained from CFD analysis using direct weighing method are used as input. The analysis is carried out in structural analysis package STAAD Pro V8i and the Grouped SLOR system in annular arrangement is modelled as shown in figure 6. In this model total structure consists of 18 nodes from 2 to 19. First six nodes are at the bottom of the risers which are the supports that are considered fixed. Nodes from 8 to 13 are the nodes that are present at the starting of buoyancy tank i.e. bottom of buoyancy tank and nodes from 14 to 19 are top nodes where the displacement is considered to be maximum and is considered for results and comparison. The guide frame will be designed such a way that it doesn't deform under the forces that are transferred from the risers and acts as rigid member that transfers the forces. Since the design of the guide frame is not in the scope of the project the members are taken as rigid with lesser cross-section area and higher moment of inertia in the analysis so that it contributes negligible weight to the structure and has higher strength. Table 4 shows the horizontal displacements at different nodes in model-2 and model-1 at restoring forces of 150 Tonne with varying diameter of the guide frame from 3D to 6D. Similarly, horizontal displacements at different restoring forces are calculated and noted.

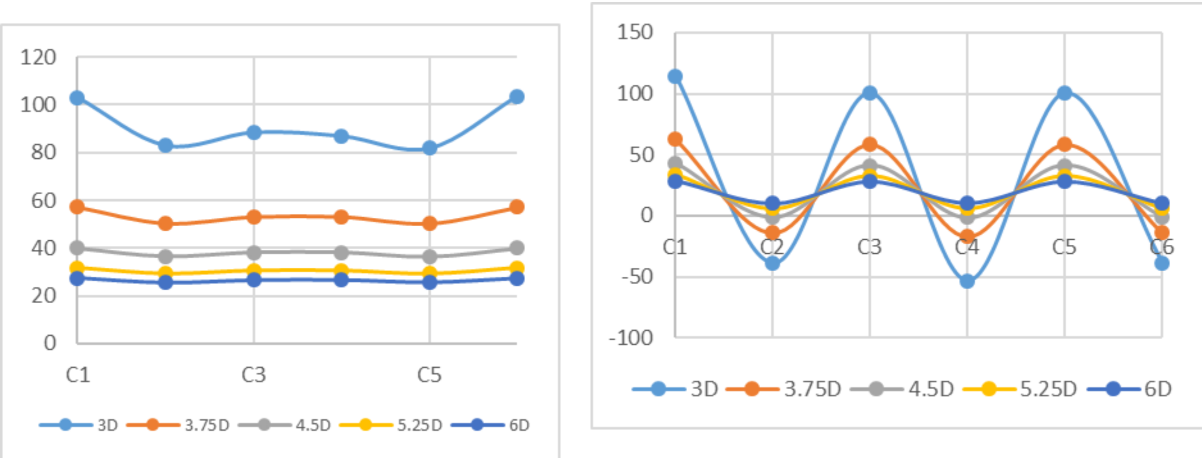


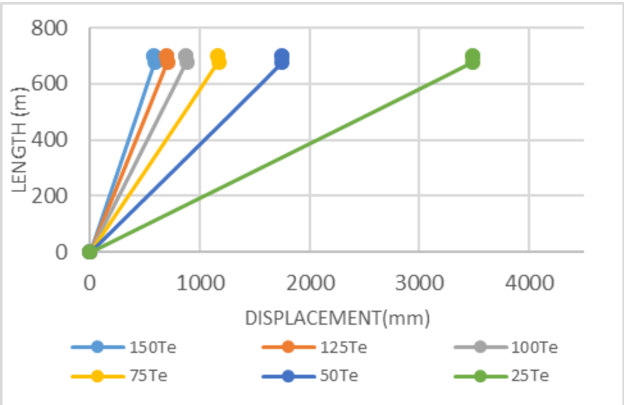
Chart-3: Variation in forces due to increase in spacing in model-1 and model-2

Table -4: Horizontal Displacements of the model-2 and model-1 in mm with upward thrust of 150 Tone at nodes

Model -2						Model -1					
Node	3D	3.75D	4.5D	5.25D	6D	Node	3D	3.75D	4.5D	5.25D	6D
8	339.51	247.01	225.65	214.02	209.27	8	998.56	588.07	419.73	336.76	291.51
9	339.45	242.14	222.84	212.3	208.08	9	998.57	588.25	419.86	336.84	291.57
10	339.50	246.77	225.54	214.04	209.22	10	998.56	588.25	419.86	336.84	291.57
11	339.44	241.94	222.80	212.35	208.10	11	998.55	588.06	419.73	336.76	291.52
12	339.50	246.78	225.54	214.12	209.22	12	998.56	588.50	419.97	336.91	291.62
13	339.45	242.14	222.84	212.34	208.08	13	998.56	588.51	419.98	336.91	291.63
14	339.47	243.21	223.03	212.08	207.56	14	998.53	585.13	417.61	335.04	290.01
15	339.46	243.13	222.98	212.05	207.54	15	998.53	585.13	417.61	335.04	290.01
16	339.47	243.20	223.02	212.08	207.56	16	998.53	585.13	417.61	335.04	290.01
17	339.46	243.12	222.98	212.05	207.54	17	998.53	585.13	417.61	335.04	290.01
18	339.47	243.20	223.02	212.08	207.56	18	998.53	585.14	417.61	335.04	290.01
19	339.46	243.13	222.98	212.05	207.54	19	998.53	585.14	417.61	335.04	290.01

3. RESULTS AND DISCUSSIONS

For the comparison of two different arrangements the dimension of the guide frame which is in maximum exposure to the flow is considered. Chart 4 shows the comparison of the displacements of the system with minimum dimension of the guide frame and for different restoring forces. In case of linear arrangement, the dimension is the length of the guide frame and in case of annular arrangement the dimension is diameter of the guide frame assuming guide frame is circular. Minimum dimension is taken as 3.75 times the diameter of the buoyancy tank since beyond that length the drag is exceeding 2 in both the arrangements. The displacements in annular arrangement with guide frame diameter of 3.75D with maximum top displacement of 3490mm (with upward thrust of 25Te) and minimum top displacement of 588mm (with upward thrust of 150Te) are lesser than that of the displacements in linear arrangement with guide frame length of 3.75D. with maximum top displacement of 4084mm (with upward thrust of 25Te) and minimum top displacement of 685mm (with upward thrust of 150Te). The dimension range of 6D to 6.25D is considered in comparison, since in annular arrangement the maximum diameter in optimal range is 6D wherein the drag on each section is equal to that on the independent section. In series arrangement the maximum dimension in optimal range is 10D for the present adopted model as the clear spacing is 2D between sections. Annular arrangement has advantage over series as there will be less twisting and turning at the top near guide frame as the maximum exposed dimension is more in series arrangement compared to annular arrangement. Downstream sections experience low drag compared to upstream sections whereas in series arrangement all the sections are exposed to flow and the sections toward the center of the guide frame attracts more drag than edge sections.



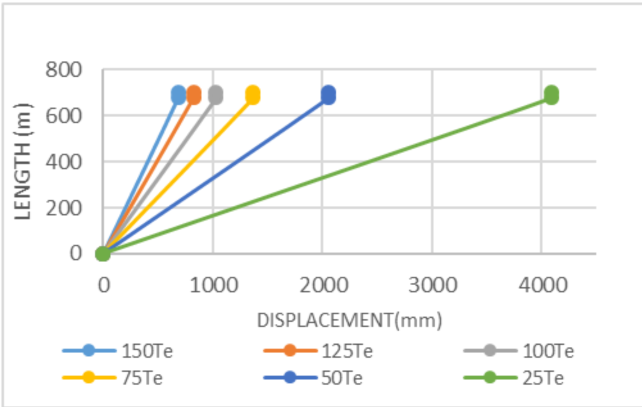


Chart-4: Comparison of the displacements of the system with minimum dimension of the guide frame and different restoring forces.

4. CONCLUSIONS

Grouping of SLOR in annular arrangement reduces the space occupancy since for the same dimension of the guide frame the drag on the sections is more on the series arrangement compared to annular arrangement. In both the arrangements the number of risers of same purpose to be considered should be even in number to take the advantage of symmetry. There will be less twisting motion in annular arrangement that series arrangement due to lesser exposed length to the flow. The downstream sections experience less drag in annular arrangement due to shielding effect of the upstream sections those reduces the velocity of the flow. The shielding effect in linear arrangement is present when the angle of incidence of the flow is 0° i.e. along the line of arrangement. When the incident angle is 30° in annular arrangement the upstream member attracts the more drag while the downstream sections have negative drag when the flow between the sections is turbulent due to less space when the diameter of the guide frame is less than 4.5D. Though the section C1 attracts more drag, the force on that member is counteracted by the negative forces due to negative drag on the sections C2, C4 and C6 thereby reducing the top displacements. The maximum drag on any section is more when the flow incident angle is 30° than that of 0°, but the net force is maximum when the flow is at 0°. Therefore, the model-1 with flow incident angle of 0° is used in the comparison with series arrangement. For linear arrangement the minimum clear spacing required between the sections is 1D and the maximum is 2D which gives the length of the guide frame 5D and 10D respectively. For annular arrangement the minimum diameter of the guide frame that can be adopted is 3.75D and maximum is 6D.

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BIOGRAPHIES

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