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Analysis of submarine outfalls subjected to wave load

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Professional paper

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Analysis of submarine outfalls subjected to wave load

Significant improvements have been made in recent years in the field of submarine outfall construction technology. Such an advancement resulted in structural improvements of submarine outfalls, especially with regard to diffuser pipes, risers, and ports. The paper focuses on the modelling of one part of submarine outfall, namely the diffuser pipes made of various materials, and on the effects of their surroundings (internal and external flows). The fluid structure interaction technique is applied in the analyses. The analyses conducted in the paper show that the highest stress values are obtained in the pipe-riser connections. Highest displacements are observed when wave load is axially applied on the structure.

Key words:
diffuser pipes, fluid and structure domains, material properties, numerical analyses

Stručni rad

Engin Gücüyen

Analiza valnog opterećenja podmorskih ispusta

Posljednjih se godina bilježi značajan napredak u području tehnologije izvođenja podmorskih ispusta. Takav napredak doveo je do konstrukcijskih poboljšanja podmorskih ispusta, posebice difuzorskih i vertikalnih cijevi te sapnica. Rad se bavi modeliranjem jednog dijela podmorskog ispusta, točnije difuzora, izrađenih od raznih materijala te utjecajima njihovog okruženja (unutarnji i vanjski tokovi). U analizama primijenjena je tehnika interakcije fluida i konstrukcije. Provedene analize pokazuju da su naprezanja najviša na spojevima između glavne i vertikalne cijevi. Najviši se pomaci ostvaruju pri osnom nanošenju valnog opterećenja na konstrukciju.

Ključne riječi:
difuzori ispusta, domene fluida i konstrukcije, svojstva materijala, numeričke analize

Fachbericht

Engin Gücüyen

Analyse zur Wellenbelastung für Unterwasserausläufe

In den letzten Jahren werden bedeutende Fortschritte bei der Ausführung von Unterwasserausläufen verzeichnet. Diese Fortschritte haben zu Verbesserungen der Konstruktionsqualität von Unterwasserausläufen geführt, insbesondere bei Diffusor- und Vertikalrohren, sowie Düsen. Diese Arbeit befasst sich mit der Modellierung eines Teils von Unterwasserausläufen, bzw. Diffusoren aus verschiedenen Materialen, unter Berücksichtigung von Umgebungseinflüssen (Innen- und Außenströme). Bei den Analysen wurde die Interaktion von Fluid und Konstruktion in Betracht gezogen. Die durchgeführten Analysen zeigen, dass an Verbindungen zwischen Haupt- und Vertikalrohren die größten Spannungen auftreten. Größere Verschiebungen werden erzielt, wenn die Wellenbelastung in Achsenrichtung aufgetragen wird.

Schlüsselwörter:
Auslaufdiffusoren, Fluid- und Konstruktionsdomäne, Materialeigenschaften, numerische Analysen

1. Introduction

The most nonaggressive method to disposal of wastewater is deep offshore discharge by multiport diffusers. The definition of discharging waste covers a broad range of including hot salty water (brine), urban liquid wastes, concentrated waste water remaining from sea-water desalination plants and industrial wastewater. Dilution of these waste transported to receiving environment is supplied by ports on the risers located at the end of submarine outfalls. Submarine outfalls are composed of onshore headwork, the feeder pipe and the diffuser pipe, where a set of riser and ports are located [1-5].
Installation, operation and maintenance [6] of submarine outfalls are highly costly and a high-tech process that should provide structural and environmental requirements. According to environmental impact assessment maximum dilution and minimum environmental hazards should be satisfied during its service life. From the point of structure safety, wave-current loads, ship anchors impact loads, fishing trawlers and internal-external corrosion should be considered in design procedure [7]. Parts of the submarine outfalls, except risers and ports can be protected from external influences by burying the structure. Since the riser and ports are operated in aggressive media they are made of more flexible materials such as HDPE and elastomeric although having some disadvantages [8-10]. While the riser diameters are constant, the ports ones can also be constant (bell mouthed) or variable (duckbill). In this study three diffuser models under consideration are seen in Figure 1. In the first model (Model 1) all diffuser parts are manufactured by steel material. The second model (Model 2) is resulted by combining a steel diffuser pipe and elastomeric (rubber made) riser-ports. And the last one (Model 3) is elastomeric diffuser. Moreover, three different diffuser models are located in two fluid domains where wave directions are lateral (Ambient 1) and axial (Ambient 2) for each one. Thus, by obtaining six Cases, wave direction effects on structural behaviour can be investigated in addition to material effects.
Domain dimensions are symbolized in Figure 1. The dimensions of the fluid domains are 8.50 m in the direction of diffuser (L), 3 m perpendicular to diffuser direction (b) and 25 m in vertical direction (d). Solid models are composed of a main pipe whose diameter is 0.55 m (D) with four risers on it. Vertical risers having 1 m length (L_r) with four ports are placed at 2 m intervals (L_p) between each of them. The structural behaviour of a submarine outfall and controlling it during its service life is a complex problem and time taking process that should be compatible with the extreme offshore environmental conditions. Offshore structures have the added complication over that of onshore structures of being constructed in aggressive ocean environment where hydrodynamic interaction effects and dynamic response become major considerations in their design [11]. Numerical methods are widely drawn on to investigate the behaviour of offshore structures under ambient effects. The analyses are performed in two ways. In the first way, hydrodynamic forces are effected to the system by modelling the structure without fluid domain [12, 13]. In the second one, direct FSI methods can be utilized in analyses of offshore structures. Fluid-Lagragian [14, 15],

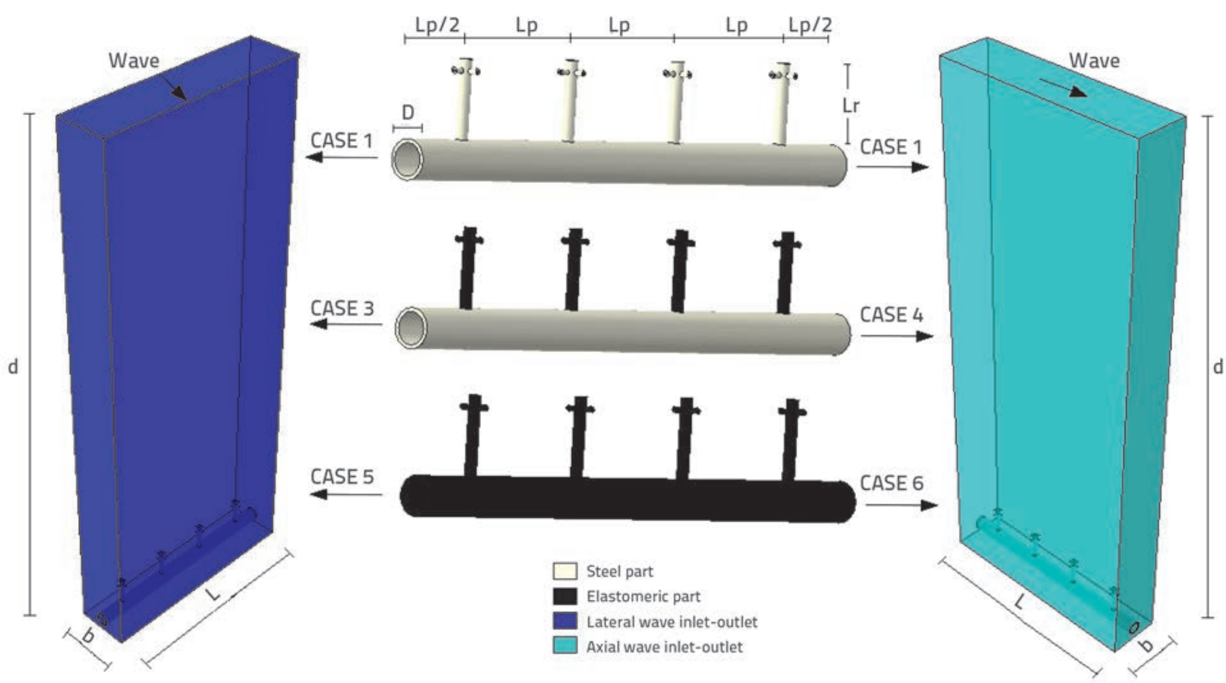

Figure 1. Case configurations for diffuser models

Table 1. Case situations

Domains \ Cases	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Fluid domains	Ambient 1	Ambient 2	Ambient 1	Ambient 2	Ambient 1	Ambient 2
Solid domains	Model 1	Model 1	Model 2	Model 2	Model 3	Model 3

Lagrangian-Eulerian (ALE) [16-18] and Eulerian-Eulerian [19] methods can be given as examples of direct FSI. In this paper, among these methods Fluid-Lagragian one is adopted to model structural analysis of submarine outfall diffusers.
This paper specifies riser-port materials and internal-external flow effects on structural behaviour of brine discharging submarine outfalls in computational manner via FSI. FSI calculations of diffuser generated with different materials and internal-external flows are performed by using ABAQUS Finite Elements Analysis program [20]. Computational Fluid Dynamics (CFD) technique is adopted in performing fluid domains. Fluid domains are composed off internal and external ones. While internal flow is steady, the external flow is unsteady for which Airy wave theory is employed. Wave direction is set to two different directions as axial and lateral to detect effects on structural behaviour of models. Six analyses are performed by matching three solid models with different materials and two fluid models with different flow directions. As a result of this study, variation of discharge velocities, displacements of ports and diffuser pipes, stress values and distributions are determined for each situation described above.

2. Numerical computations

In order to implement the structural behaviour of the described models, ABAQUS finite element analysis program which is widely used by researchers is adopted. The nonlinear analysis of the submarine outfall located in offshore environment is carried out using an incremental procedure following Abaqus/CFD-Abaqus/Explicit. The systems analysed in this paper are coupled physical ones where two physical systems interact. One example of a coupled system is fluid-structure interaction (FSI), where a fluid and a structure are the systems. The structure can be movable and/or deformable and the fluid flow can be internal and/or external. Forces due to a moving fluid are applied as pressure on the structure, which then will be deformed. The diffuser internal and external surfaces interact with the surrounding fluid. Thus, it is exerted to define the co-simulation interaction with the Abaqus/Explicit model and it is likewise for CFD model as well. Mentioned methods evaluating to compute the analyses are described for fluid and solid domains in the following sections.

2.1. Fluid domains

Three diffuser models are located on two different fluid domains of which composed of 3D fluid geometry with axial and lateral wave directions. Fluid domains comprise of internal and external ones. The internal fluid domain represents steady flow discharging salty water. Finite elements method (FEM) based CFD [20] technique is adopted to perform internal and external flows surrounding the solid diffuser models. The physical features of finite elements supported CFD technique extracts the equations of motion reduce to incompressible Navier-Stokes equations given by Eqns (1-3).

$$\rho\left(\frac{\partial U}{\partial t}+U\frac{\partial U}{\partial x}+V\frac{\partial U}{\partial y}+W\frac{\partial U}{\partial z}\right)=-\frac{\partial P}{\partial x}+\rho g_x+\mu\left(\frac{\partial^2 U}{\partial x^2}+\frac{\partial^2 U}{\partial y^2}+\frac{\partial^2 U}{\partial z^2}\right) \quad (1)$$

$$\rho\left(\frac{\partial V}{\partial t}+U\frac{\partial V}{\partial x}+V\frac{\partial V}{\partial y}+W\frac{\partial V}{\partial z}\right)=-\frac{\partial P}{\partial y}+\rho g_y+\mu\left(\frac{\partial^2 V}{\partial x^2}+\frac{\partial^2 V}{\partial y^2}+\frac{\partial^2 V}{\partial z^2}\right) \quad (2)$$

$$\rho\left(\frac{\partial W}{\partial t}+U\frac{\partial W}{\partial x}+V\frac{\partial W}{\partial y}+W\frac{\partial W}{\partial z}\right)=-\frac{\partial P}{\partial z}+\rho g_z+\mu\left(\frac{\partial^2 W}{\partial x^2}+\frac{\partial^2 W}{\partial y^2}+\frac{\partial^2 W}{\partial z^2}\right) \quad (3)$$

where U, V and W are the velocity, g_x, g_y and g_z are gravitational components at the x, y and z directions respectively. ρ, μ and P stand for the density, the dynamic viscosity and the pressure. The fluid properties are chosen to represent salty water for both internal and external flows at temperature of 20 °C with density (ρ) of = 1025 kg/m³ and dynamic viscosity (μ) of = 0.0015 Ns/m². The fluid is modelled as EOS material with velocity of sound in salty water, co=1560 m/s and the constants (k, Γ_0) are equal to zero. Where k is slope of the U_s–U_p curve and Γ_0 is Grüneisen ratio.
For flow around the constant diffuser, the following boundary conditions are applied to the fluid domain to compute the Eqns (1-3). Application zones of boundary conditions are seen in Figure 2. In this figure; two velocity inlets are applied to fluid geometry. While first one is for internal flow, the other one is for external flow. An outlet boundary condition is specified with fluid pressure that is set to zero at external flow. Bottom of external flow is set to wall where all velocity components are zero. Finally, the far field velocity is assumed to be equal to inlet velocity at external flow.
As it is seen in Figure 2 internal and external flows are modelled in the same geometry. The blue arrows show direction of the external flow and the red ones show internal flow. Two fluid domains are created and the only difference is the wave directions between models. The material, mesh and geometrical properties do not differ between models. Geometrical properties are determined according to diffuser geometries and the conditions given by [3, 21, 22].

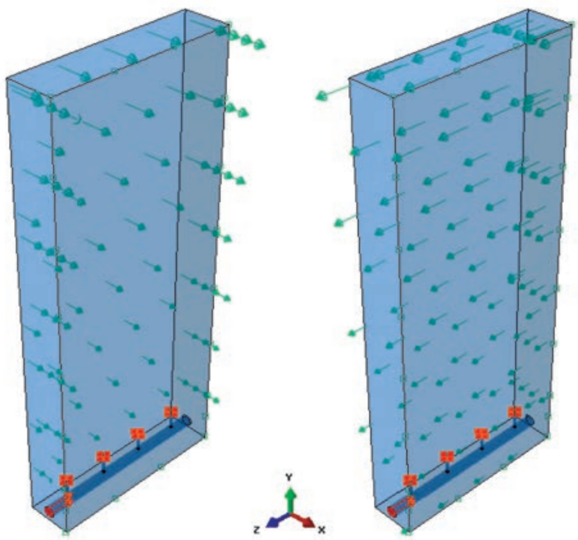

Figure 2. Fluid domains and boundary conditions

Average velocity value of 1.00 m/s has been performed as normal uniform velocity inlet boundary condition for internal flow. Fluid passing through the diffuser is sea water which is used for cooling operation. Simultaneously, Airy (Linear) Wave Theory velocity equations given above are assigned to model external wavy environment.

$$U = \frac{H}{2}\frac{gT}{L_W}\frac{\cosh[2\pi(y+d)/L_W]}{\cosh(2\pi d/L_W)}\cos(\frac{2\pi}{L_W}x - \frac{2\pi}{T}t)$$
$$V = \frac{H}{2}\frac{gT}{L_W}\frac{\sinh(2\pi(y+d)/L_W)}{\cosh(2\pi d/L_W)}\sin(\frac{2\pi}{L_W}x - \frac{2\pi}{T}t) \quad (4)$$

$$W = \frac{H}{2}\frac{gT}{L_W}\frac{\cosh[2\pi(y+d)/L_W]}{\cosh(2\pi d/L_W)}\cos(\frac{2\pi}{L_W}z - \frac{2\pi}{T}t)$$
$$V = \frac{H}{2}\frac{gT}{L_W}\frac{\sinh(2\pi(y+d)/L_W)}{\cosh(2\pi d/L_W)}\sin(\frac{2\pi}{L_W}z - \frac{2\pi}{T}t) \quad (5)$$

Finite elements analysis program [20] invokes time and location varying velocity equations to calculate hydrodynamic wave forces acting on the diffusers where d is water depth (the structure deployment), H is wave height and T is wave period [23, 24]. In this paper, employed parameters taken into account are d = 25 m, T = 8 sec, H = 2.50 m. Wavelength (L_w = 95.72 m) is calculated according these parameters. When the relative depth d/L_w is between 0.05 and 0.5, the wave is classified as intermediate water depth as mentioned in this study. If the wave acts laterally to the structure, Eqn (4) stands for wave inlet boundary and if the wave direction is axial to the structure, Eqn (5) is used. Mesh design of the boundary conditions of the fluid domains should be made. FC3D4 (4-node modified tetrahedron) typed members which are proper for FSI problems are consulted in the analyses. By selecting the node distances 0.01 m, the same value of wall thickness, at internal flow and 0.50 m at the rest of geometry, 36641 nodes and 172364 elements constitute the domains. The same mesh structure is evaluated for both flow models including lateral and axial wave directions. According the results obtained from CFD analyses, changes in discharges velocities for different models are determined. Also, changes in structural behavior of models are obtained from solid modelling of diffusers.

2.2. Solid domains

Three diffuser models with different material properties are fixed supported, one spanned and having 8 m length at the end of discharge system. Diameter of the main pipe is 0.55 m. Vertical risers having 1 m lengths with four ports are placed at 2 m intervals between each of them. While the diameter of the risers is 0.18 m, the value of the diameter is reduced to 0.06 m on each port. Bell mouthed ports are implemented in this study. Pipe thicknesses of the models are 0.01 m. The diffuser flow conditions according to geometric properties are verified by [25]. Risers are numbered from 1 to 4 starting from end of the diffuser.

The unmeshed and meshed geometry of the diffuser can be seen in Figure 3 with supports having 0.30 m length and riser numbers on it. 1982 nodes are assigned to constitute the supports in the beginning and at the end of the diffuser models.

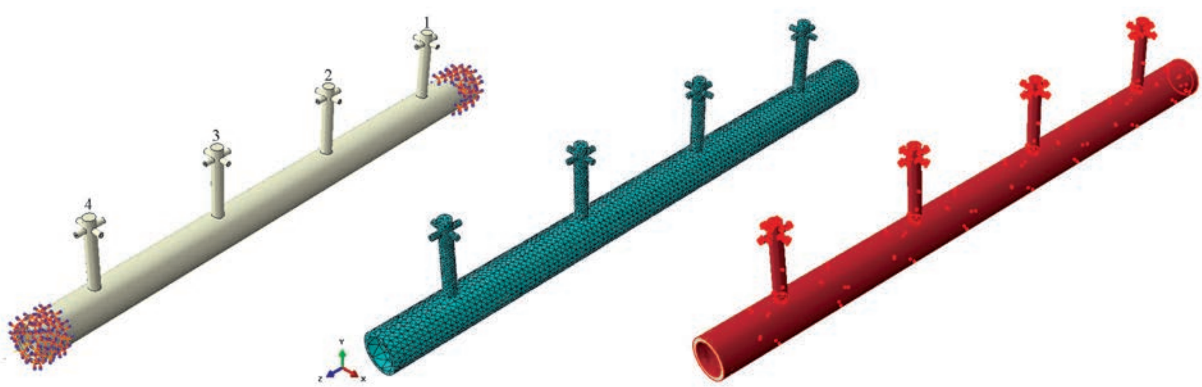

Figure 3. Support conditions, mesh structure and interaction surfaces of solid geometries

The red geometry represents fluid-structure interaction surfaces that should be determined in analyses procedure. Finite elements program [20] allows users to construct two or more materials on the same geometry by creating instances on the part. Hereby the ports and risers can be modelled with different material except main pipe. A density of 1200 kg/m^3, Young's modulus of 2.5 x10^7 N/m^2, and Poisson ratio of 0.45 are defined for the elastomeric material. On the other hand, density of steel material is 7850 kg/m^3, Young modulus is 2.1x10^{11} N/m^2 and Poisson ratio is 0.30 [26, 27].

The models are divided into small pieces in finite elements analysis to perform complex solutions. The structural models in Abaqus/Explict are comprised of 10-node modified tetrahedron elements (C3D10M), which are compatible with contact problems. Distances between meshes are taken as 0.01 m on ports and riser, which is the same value of wall thickness, and 0.05 m on diffuser pipe. Duration and volume problems occur when smaller values are defined. As a result, ultimate mesh structure is achieved by creating 57738 total numbers of nodes and 29135 modified tetrahedron elements of type C3D10M as seen in Figure 3.

The equation of motion for structures that Finite Elements program utilizes under hydrodynamic forces (P) can be written as follows. The forces are obtained from CFD analysis and penetrate through the structure on the interaction surfaces that are identified on both fluid and structure.

$$m^{NJ}\ddot{u}_s^N|_t = \left(P^J - I^J\right)|_t \tag{6}$$

Where, m^{NJ} is mass matrix, P^J external applied load vector obtained from CFD, I^J is internal force vector that is created by stresses in the elements, $\ddot{u}_s$ is acceleration and t represents time. In this study, explicit integration rule is performed via [20] to obtain displacements that will be transferred from structure to fluid. The explicit dynamics analysis procedure is based upon the implementation of an explicit integration rule together with the use of diagonal element mass matrices. The equations of motion for the body are integrated by using following equations.

$$\dot{u}^N_{s(i+\frac{1}{2})} = \dot{u}^N_{s(i-\frac{1}{2})} + \frac{\Delta t_{(i+1)} + \Delta t_{(i)}}{2}\ddot{u}^N_{s(i)} \tag{7}$$

$$u^N_{s(i+1)} = u^N_{s(i)} + \Delta t_{(i+1)}\dot{u}^N_{s(i+\frac{1}{2})} \tag{8}$$

In the Eqns (7-8), u_s^N and $\dot{u}_s^N$ are degree of freedom (N) of displacement and velocity components. The nodal accelerations can be obtained by the equation given below.

$$\ddot{u}^N_{s(i)} = (m^{NJ})^{-1}(P_i^J - I_i^J) \tag{9}$$

The internal force vector is assembled from contributions of the individual elements such that a global stiffness matrix is not necessary to be formed. No iterations are required in the mentioned method to update the displacements, velocities and accelerations. The explanations of Eqns (7-9) are cited from [20].

As well as displacement values, the values of Von-Mises Stresses of solid models, caused by applied forces are derived from analyses. The analysis program [20] evaluates the well-known Von Mises (σ_{VM}) equation which is given below.

$$\sigma_{VM} = \sqrt{\frac{1}{2}\left[(\sigma_{xx}-\sigma_{yy})^2 + (\sigma_{yy}-\sigma_{zz})^2 + (\sigma_{zz}-\sigma_{xx})^2 + 6({\sigma^2}_{xy} + {\sigma^2}_{yz} + {\sigma^2}_{zx})\right]} \tag{10}$$

Where σ is stress of the material and x, y, z are the related directions.

2.3. Fluid-structure interaction (FSI) analyses

Flow around diffuser is determined by two separate models in FSI technique including solid and fluid ones. The analyses under consideration have high complexity with strong physics coupling. Just as the fluid domain composed of internal and external flows, the diffuser models constitute the solid domains. Interacting between domains is satisfied by FSI. Instead of no slip, no penetration boundary conditions on interacting surfaces of fluid models, the boundary conditions are dictated by [20] determining the fluid structure interaction surfaces. Boundary condition about mesh displacements is satisfied on contact surfaces by modelling FSI coupling. By determining the contact surfaces, where the forces transfer from fluid to structure and deformations transfer from structure to fluid, is also identified. Two analysis jobs have been created in the solutions. While the first one represents the Abaqus/Explicit structural model, the other one represents the Abaqus/CFD model. The analyses are carried out with the time increment of 4e^{-6} sec for 8 sec analysis time.

Table 2. Discharge velocities

Riser number	Average discharge velocities on ports [m/s]					
	Case 1	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**
1	10,68	10,57	10,80	10,69	10,97	10,85
2	10,70	10,58	10,81	10,70	10,99	10,86
3	10,71	10,60	10,83	10,72	11,01	10,89
4	10,72	10,61	10,84	10,73	11,02	10,90

3. Analysis results

In order to perform the submarine outfall analysis, the Abaqus/Explicit and Abaqus/CFD jobs need to execute together. Two functions such as Abaqus/Explicit structural model and Abaqus/CFD model have been utilized in the analyses. When the co-execution completes, the results of the Abaqus/Explicit and Abaqus/CFD portions of the analysis are saved in separate output database files.

Since discharge velocity is the main parameter providing the efficient discharge operation, average discharge velocity values according to rise numbers are presented in Table 2. As one riser has four ports, average velocity values are given in following table. Maximum discharge velocity value of 11.02 m/s is achieved on the fourth riser of Case 5 and minimum one is 10.57 m/s on the first riser of Case 2. First of all, it can be said that there is no significant difference between these values. The velocity profiles of Cases 5-6 are shown in Figures 4-5. View-cut tool of the analysis program is operated to obtain following Figures.

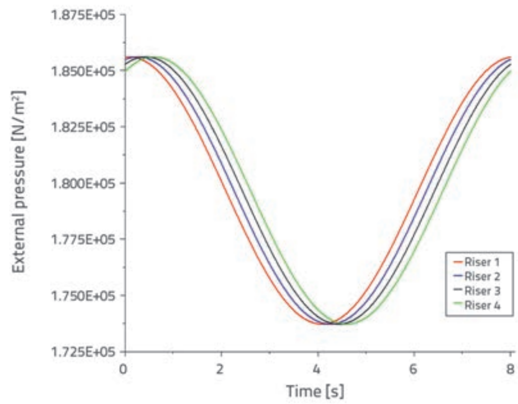

Figure 6. Hydrodynamic wave pressure on risers

Lateral sectional views of velocity profiles of Case 5 and Case 6 are shown in Figure 4 from top to bottom respectively. All units are m/s between Figure 4 and Figure 5.

In Figure 5, cross-sectional views of velocity profiles of Case 5 and Case 6 are presented from left to right respectively.

Hydrodynamic external pressure values on risers obtained from CFD analyses are presented in Figure 6. These values occur when the wave effects axially. In the case, when the wave direction changes to lateral, the same value between 1.851×10^5 N/m^2 and 1.837×10^5 N/m^2 is determined for all risers. The hydrostatic internal pressure is 1.973×10^5 N/m^2.

Hydrodynamic pressure values obtained from analysis program according to riser numbers as determined in Figure 3, are obtained on the peak points of risers. Both fluid and structure results can be obtained from FSI analyses. Maximum displacement values of risers, caused by fluid flow, are given in Table 3. While maximum displacement has increased from 1.50×10^{-3} m to 2.70×10^{-3} m between Case 2 and Case 1, it changes between 3.3×10^{-3} m and 3.5×10^{-3} m for Case 3 and Case 4. Visual charts of the values given in Table 3 are shown between Figures 7-9 for deformed and non-deformed shapes of solid models. The units are meters in Figures 7-9.

After obtaining displacement values of models Von-Mises stresses are obtained. These values are numerically given in Table 4 and visually performed in Figures 10-12. The units are N/m^2 in Figures 10-12.

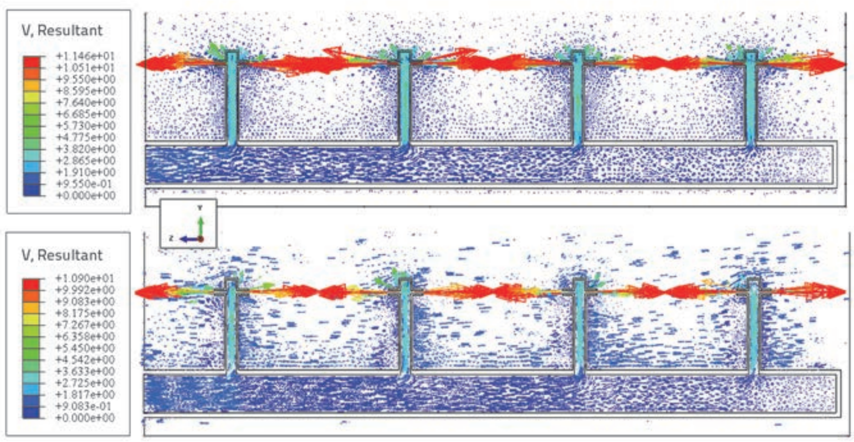

Figure 4. Lateral sectional views of velocity profiles

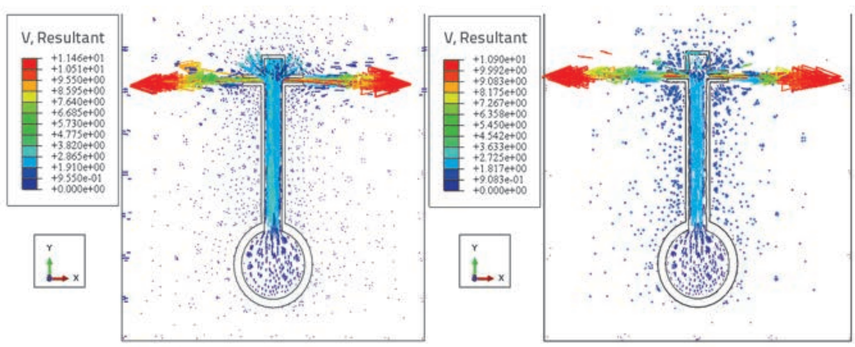

Figure 5. Cross-sectional views of velocity profiles

Table 3. Maximum displacements of risers [$\times 10^{-3}$ m]

Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
1,5	2,7	3,3	3,5	5,6	6,1

Table 4. Maximum Von-Mises Stresses [$\times 10^6$ N/m^2] of diffuser models

Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
1,961	2,569	1,754	2,423	1,262	1,427

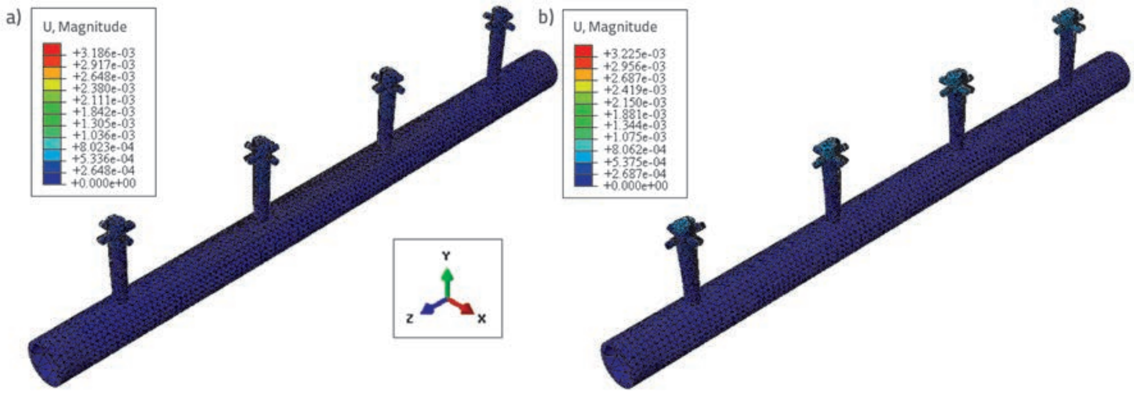

Figure 7. Displacement values of: a) Case 1; b) Case 2

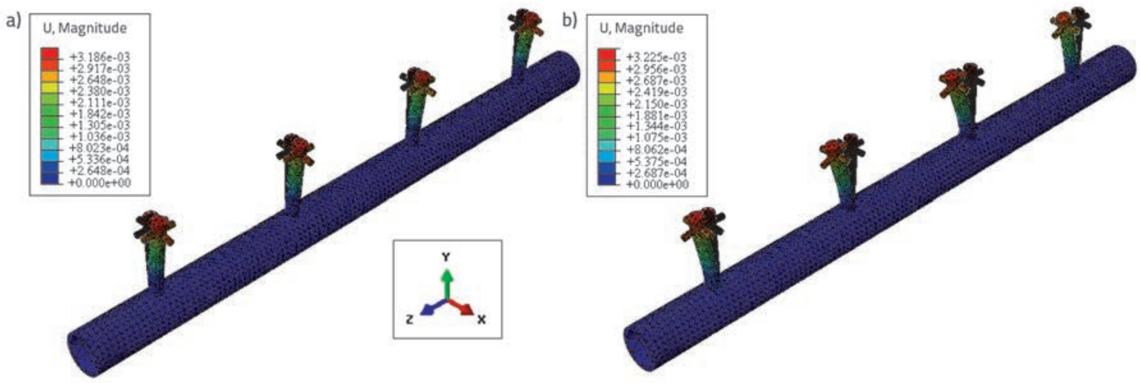

Figure 8. Displacement values of: a) Case 3; b) Case 4

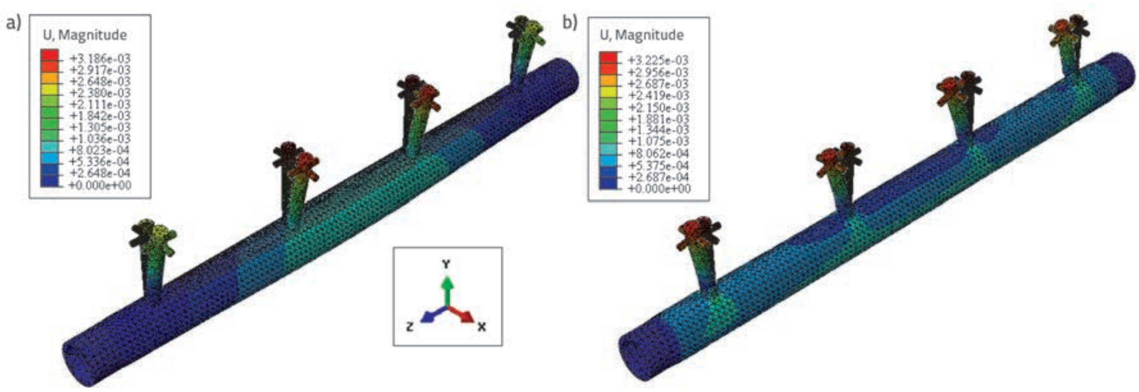

Figure 9. Displacement values of: a) Case 5; b) Case 6

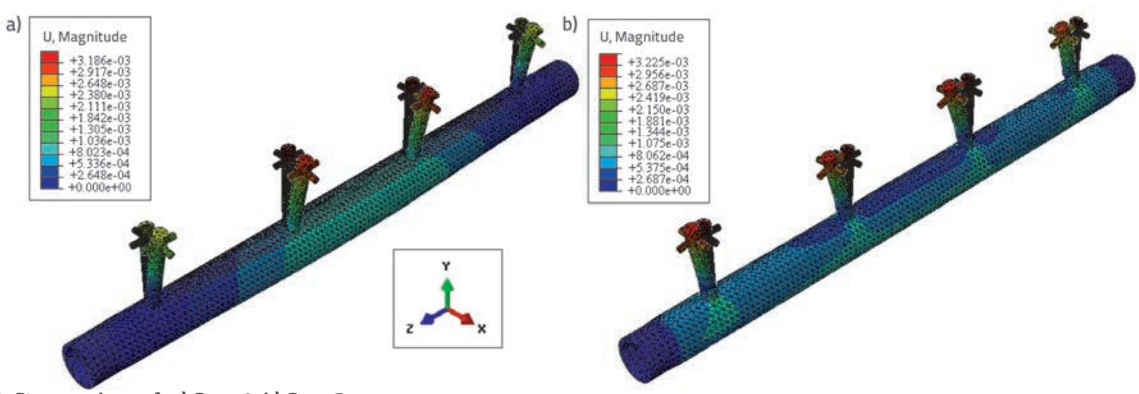

Figure 10. Stress values of: a) Case 1; b) Case 2

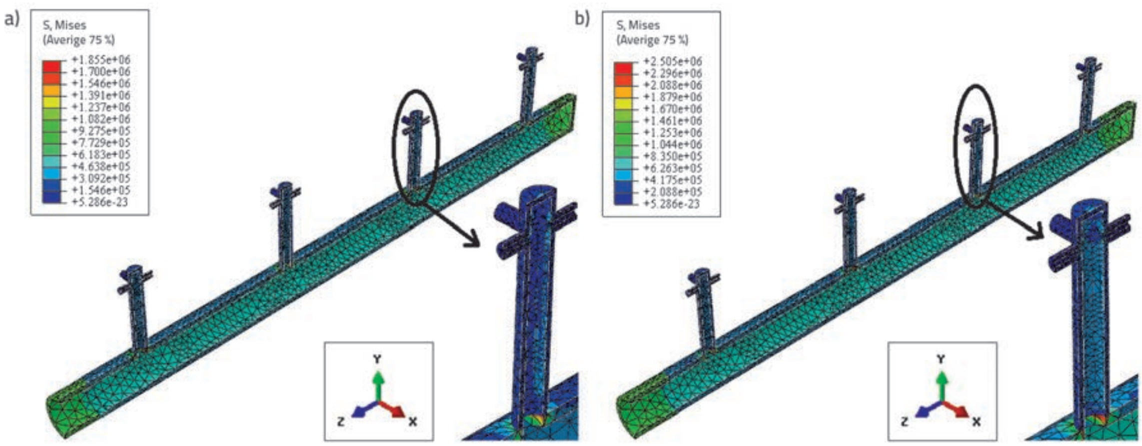

Figure 11. Stress values of: a) Case 3; b) Case 4

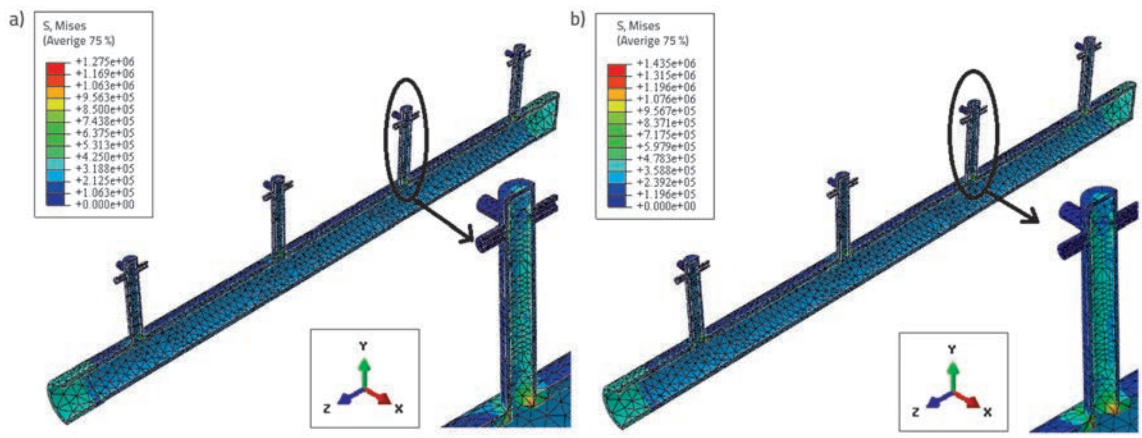

Figure 12. Stress values of: a) Case 5; b) Case 6

4. Conclusions

The study is conducted to determine both material and wave direction effects on the discharge velocities and the structural behaviour of submarine outfalls in numerical manner. Numerical analyses are performed by the FEM Program (ABAQUS) via coupled CFD and Explicit techniques. Six Cases are created by matching two different wave directions with three diffusers with different materials. In addition to structural characteristics of diffusers, ambient flow characteristics should be confirmed in order to ensure the effective discharge. The structural effects on discharge are determined by port geometries (duckbill valves and bell mouthed) and material properties of the structure. From the aspects of ambient flow, the diffuser is located perpendicular and parallel to flow direction to determine the effects of ambient flow direction on the settlement of diffusers. As referred in the references, the minor velocity difference between risers for the same Case is acceptable due to loss in flow rate. In this study the diffusers are exposed separately to both lateral and axial wave loads. Lateral wave loads are approximately 1% less effective on discharge velocities than axial one. Another investigated parameter is the material. The difference between Model 1 and Model 2 is approximately 1.1% both having the same material on main pipe. This difference increases to 2.76 % between Model 1 and Model 3 having different material properties.

According to discharge velocities it can be said that material properties are more effective than wave direction. Incidence wave direction effects are reduced by adopting four ports on a riser. The most important result is that the discharge system provides efficiently discharge condition by avoiding water intrusion to ports by providing the condition Froude number (Fr) is bigger than 1 (Fr > 1) in all Cases. After the efficient discharge is confirmed by velocity values, the structural behaviour of models according to displacement and stress values are examined related to results given in Figures 7-12 and Tables 3-4.

When the diffusers are investigated according to maximum displacement values, the biggest results are obtained from Case 6. In this Case, main pipe and risers are produced from elastomeric material and wave load is axially effected. Increase in rigidity due to material type is the main reason of the displacement changes between all cases. Although maximum displacement value is 6.1 x 10^{-3} m for Case 6, it is decreased to 5.6 x 10^{-3} m for Case 5 in which the same diffuser is under the effect of lateral wave load. Axial wave has increased the displacement values by 7.20 % in comparison with lateral wave in elastomeric diffuser.

While Case 3 and Case 5 are effected by lateral loads, Case 4 and Case 6 are effected by axial wave loads. By this way, more critical displacement results are obtained from axial wave loads rather than lateral loads. In addition, almost same displacement values are determined for all risers of same model while wave load is axially effected to structure. On the other hand, lower displacements occur when lateral loads are effected the structure. However, similar displacement values are obtained under lateral wave loading for Case 3 whose main pipe is steel and risers are rubber.

When diffusers are investigated according to Von-Mises stresses, the stress results reach the highest values in the pipe-riser connections for all Cases. These values are given in Table 4. The biggest stress value is determined for Case 2 in which main pipe and risers are produced from steel material. In Cases 3-4 stress in pipe-riser connections can not pass from main pipe to riser due to different material property. Thus, stresses are accumulated in the main pipe. The lowest stress value is observed for Case 5. Stress values are bigger under axial wave loading than lateral loading as well as displacements. More critical results are determined by both displacement and stress values under axial loading condition. The main reason for this situation is the distance which wave passes on structure is bigger for axial loading than lateral one.

In this paper, diffuser model having 8 m span length is modeled in the analysis program. Effect of axial wave loading can be observed better when diffuser length is taken just as the wavelength. As a result, Case 5 becomes prominent as the most proper design in terms of flexible risers under the effect of ship anchor crushing, wave and current loads and suitability of lateral loading due to structural phase. To avoid possible damages because of external loads, embedding to soil method can be applied when external loads are effective.

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