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Effect of Mooring Lines Pattern in a Semi-submersible Platform at Surge and Sway Movements

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Abstract Exposure to environmental conditions at sea for floating structures is inevitable. Environmental conditions that waves are most important of them will enter forces on structure of semi-submersible platforms. Therefore such structures should be deployed in the operational capability of their own, that one of these methods is mooring them. In this condition, structure shows different behavior compared with unmoored structure. Wave force cause motions of structure and subsequently produce tension force on mooring lines. Hence, investigation of structure movements and selection an appropriate mooring system to minimizing the structure motions must have been discussed. semi-submersible platforms mooring systems results restoring force in horizontal plane, and thus control degree of freedom on Surge, Sway and Yaw movements. This study estimated Surge and Sway movements of a semi-submersible platform when that it has been exposed to 0, 45 and 90 degrees of sea wave direction with the environmental conditions of the Caspian Sea using Flow-3d (version10.0.1) software. Also the seven symmetric mooring systems in the form of 4 and 8 numbers of mooring lines' systems have been used to investigate the best modes.

Keywords: *semi-submersible platform, mooring lines, Surge, Sway*

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1. Introduction

Today with the increasing human demand on energy resources, especially deep water oil resources, using many kinds of offshore platforms in coastal states to exploit the resources of the continental shelf more and more attention has been. On the other hand, since the search for oil and gas in the deep waters (over 600 meters) is advanced. therefore, it is impossible to use a fixed platform in such depths.

Fixed platforms due to heavy construction and installation costs are commonly used up to limited depths of 360 meters to 450 meters.

Hence the idea of using floating platforms that has ability to use in deep waters over the past was considered. Those Semi-submersible platforms are one of them.

In fact, for controlling of vertical responses in floating structure, the decisive factor is the size and shape of the floating platform and to reduce response must be paid to the optimization platform [1].

According to aim of this study, the horizontal responses of a Semi-Submersible platform for discussion and analysis have been studied.

Investigation on the motion performance of semi-submersible platform will help make better designs, reduce operating cost, and improve survival capability and operating efficiency.

In the past, some research has been done on the semi-submersible platforms and mooring lines, such as the research cited by: Morch and Moan compared the calculated and measured the wave-induced motion of a moored semi-submersible platform [2]. Fylling & Lie studied on design of mooring systems, riser systems and anchors in floating platforms both individually and together, and have provided a calculation method for layout optimization of Anchors [3]. Ferrari & Morooka found an optimum design method for mooring of semi-submersible platforms [4]. Soylemez tested the motion of a twin hulled semi- submersible platform [5]. Wu simulated the motion response of semi-submersible platform and mooring forces in regular waves by numerical method [6]. Chen calculated the motion response and mooring line forces of a moored semi-submersible under wave action [7].

As the semi-submersible platform has been widely used in recent years, the studies in this field are increasing: Maffra et al investigate feasibility of optimizing mooring for a semi-submersible platform with using Genetic Algorithm, and finally found it possible and useful [8]. Jordan & Beltran made possible estimation of physical parameters of a cable line in viscous environment with introducing an adaptive algorithm that is sensitive to the depth, by inputs of this algorithm that are forces and positions that determined by equipment on the vessel itself [9].

Garrett by studying a moored semi-submersible platform in the Gulf of Mexico at depth of 1800m was performed concurrent dynamic analysis using both time domain and frequency domain [10]. Davies et al investigated the effect of fiber stiffness on the response of mooring lines in deep water [11]. Stansberg studied Current effects alone and in combination with the effects of waves on a moored floating structure in different sea conditions [12]. Huilong et al studied effect of mooring nonlinear stiffness in the hydrodynamic response of floating structures and was provided a new formula to the nonlinear stiffness matrix for chain mooring system [13]. Waals investigated the effect of wave direction on the low-frequency wave motions of floating structures and the tension forces in mooring lines [14]. Ma et al analyzed mooring system of drilling ship that was designed for the South China Sea in depth of 1500 meters [15]. Lassen et al studied the behavior of chain mooring components in both laboratory and numerical models under the pretension and outside of the plate stress condition [16]. Su-xia et al are examined slack Problems due to the tension reduction mooring lines [17]. Zhu & Ou studied the hydrodynamic behavior of a semi-submersible platform with sea waves and wind forces [18].

Also engineers and scientists in Iran also did lots of researches on semi-submersible platform: Daghigh et al introduced an optimum design for mooring pattern and Floating bridge sizes of Urmia Lake and sizes using disjoint elements in parametric solutions and optimization of anchor's weight in mooring issue has been be discussed [19]. Mazaheri & Mesbahi obtained to maximum displacement of the structural that is very essential to arrangement of mooring lines with design of a network model of artificial intelligence, for a period of N years, Comparison of artificial intelligence network results shows that this network can well be used to predict the structural response due to arbitrary loads [20]. Mazaheri & Incesik used reply axis method for predicting the mooring tension force [21]. Rezvani & Shafieefar investigate the optimization of floating platform mooring system with aim of reducing horizontal platform responses by using package SESAM that has considered the Mimosa software [22].

2. Mooring Lines

A floating structure has 6 degrees of freedom that mooring line system is only able to control and reduce the horizontal responses of a semi-submersible platform and it does not have a major impact on the vertical responses.

Among the parameters in the modeling and analysis of a semi-submersible platform, mooring system has a special importance. There are several parameters for the design of mooring systems. Therefore to define the appropriate mooring system, which leads to minimum displacements of structure, several aspects must be considered.

This study concentrated on a model of mooring system which minimize Surge and Sway movements. The static equilibrium equations of the mooring lines are in Equation 1 and 2:

$$T = (T - dT)\cos d\theta + Pd\sin\theta \quad (1)$$

$$(T - dT)\sin d\theta = Pds\cos\theta \quad (2)$$

Where T is the force at the top end of the segment, P the combined force of the gravity and buoyancy per unit length of mooring line, θ the top slope of the segment of mooring line, ds the length of the segment, dT and dθ the increments of force and slope in the segment.

And parameters of equations for a segment of the mooring line are shown in Figure 1.

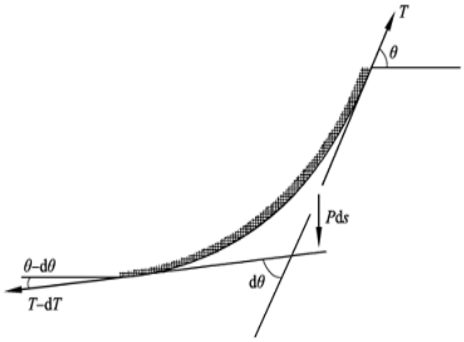

Figure 1. A segment of mooring line

In the Semi-submersible Platform, for proper operation and preventing damage on systems and equipment of excavation units it required that horizontal motion of structures be limited to less than 1% of water depth [23], that is defined in Table 1.

Table 1. Limits of semi-submersible platform movement

Operation	Duration (%)	Max surge/sway amplitude (% of water depth)
Drilling	43.4	5
Running easting	12.5	3
Cementing and well testing	11	-
Blow out preventer and riser handling	9.9	1

3. Modeling

Intended in simulate, a case study modeled with Flow3D (hydrodynamic software) that gives time domain analysis for investigation of the structure movements.

In this simulation used a platform with specifications of GVA 4000 platform like Iran ALBORZ platform. Table 2 defined the characteristics of this platform.

Table 2. characteristics of Iran ALBORZ platform

Overall length.	98.6 m	Columns diameter	12.9 m
Overall Width	78.8 m	The distance between the columns in the longitudinal direction	73.4 m
Pontoon length from outside to outside	73.4 m	The distance between the columns in the transverse direction	54.7 m
Length of Pontoons	80.5 m	Tonnage moved in the transportation draft (7.2 m)	20665 ton
Width of Pontoons	18.5 m	Tonnage moved in the survival draft (16.2 m)	26525 ton
height of Pontoons	7.5 m	Tonnage moved in the operational draft (19.5 m)	28621 ton

At this research, modeling is done by taking a survival situation, hence, conditions that draught is 16.2 meters.

In this modeling, total weight on the floated body plus body weight is equal to weight of the water displaced by the floating structure. And total weight is applied at the semi-submersible platform body's center of mass.

Table 3 shows details of semi-submersible platform weight, center of gravity and center of buoyancy.

Table 3. Iran ALBORZ semi-submersible platform weight, center of gravity and center of buoyancy

parameter	weight (ton)	Z(m)
center of gravity	26525	24.52
center of buoyancy	26525	5.2

Geometry of the flume created for semi-submersible platform in a water depth of 500 m and also meshing of model has been selected as integrated single block. The dimensions of these cells should be considered that the FAVOR[1] conditions can be satisfied.

In Figure 2 meshed view of semi-submersible platform in flume of the fluid is shown.

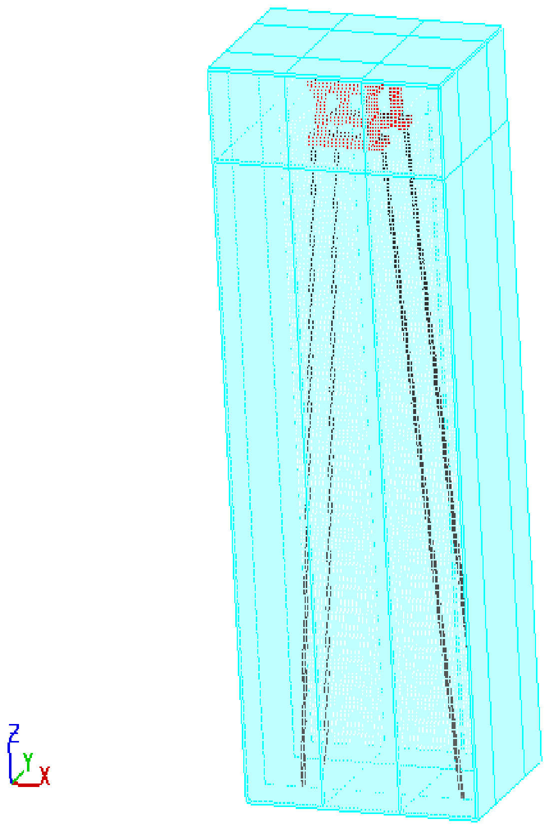

Figure 2. Meshing of semi submersible platform with 4 mooring lines

Validation for grid cell size done with 4 meshing networks with 1000000, 1200000, 1500000 and 2000000 cells was in kind 6 of mooring systems.

And more converged results for the grid cells with 1200000 are valid.

Of course, we used fine mesh in the near range of semi-submersible platform to enhance network quality, and coarse mesh far filed.

In flow3d software both to Cartesian coordinates and cylindrical coordinates there are 6 surfaces to define the boundary conditions.

1 Fractional Area Volume Obstacle Representation

Boundary conditions are defined in Figure 3 with 6 surfaces.

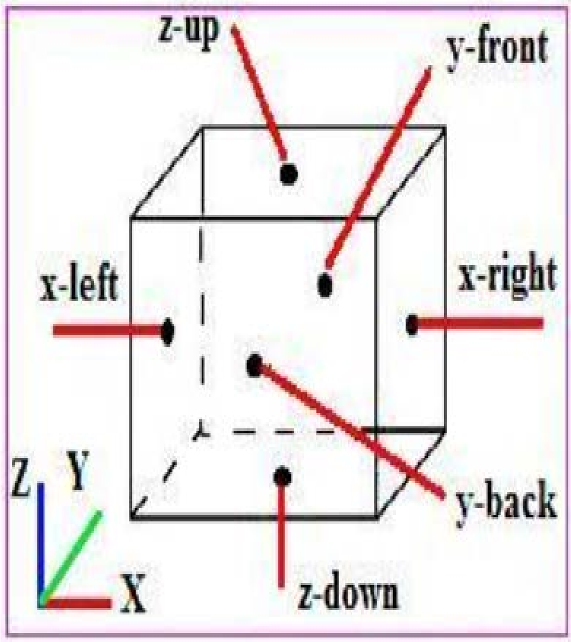

Figure 3. Boundary conditions with 6 surfaces

Boundary conditions changes respect to wave direction selection for each of the 0, 45, or 90 for bounds X and Y.

Also, for analyze the variable patterns of mooring lines geometric arrangement from 7 types of layout that those are, 3 kinds with 4 lines in the geometrical arrangement (Figure 4) that in kind 1 mooring lines are perpendicular to the wave direction, in kind 2 mooring lines are parallel to the wave direction and kind 3 that mooring lines are in cross formation (angle of 135 degree between mooring line and structure), and also 4 kinds with 8 lines in the geometrical arrangement that are shown in Figure 5 (Angles of 30, 45, 60 and 90 degree between adjacent mooring lines) and by applying of wave forces direction in angle of 0, 45 and 90 degree, has been studied.

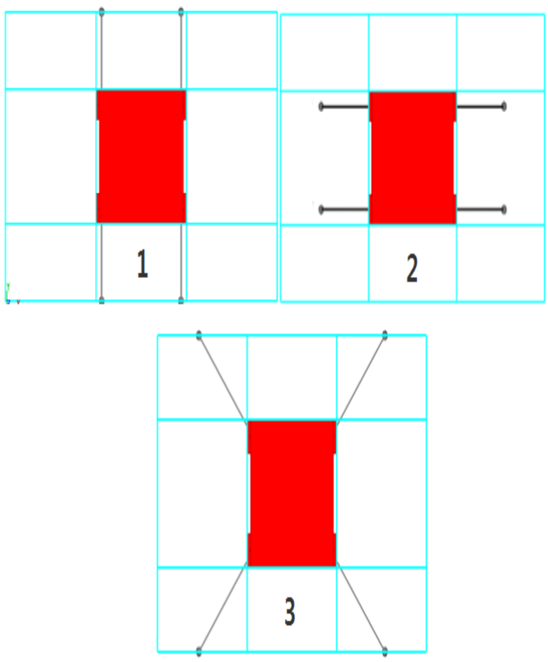

Figure 4. 3 kind of mooring system arrangement with 4 mooring lines

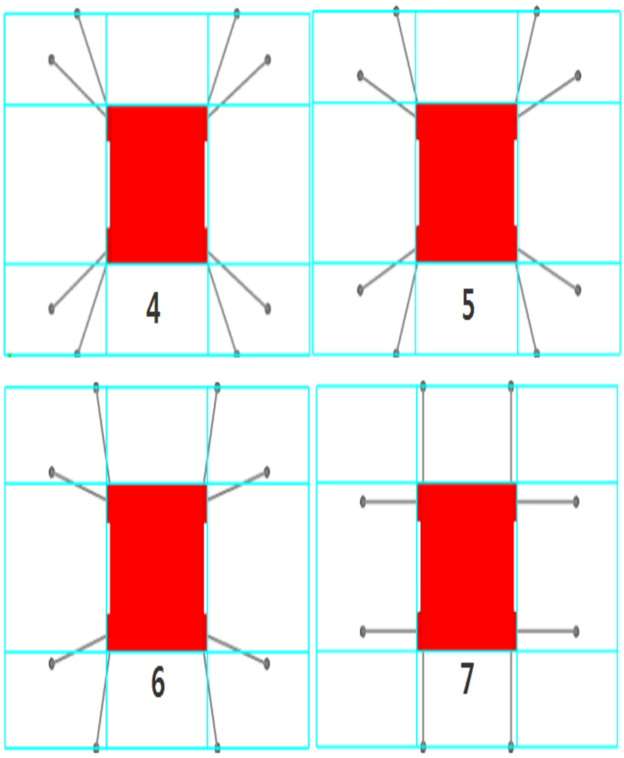

Figure 5. 4 kind of mooring system arrangement with 8 mooring lines

To evaluate the impact of environmental conditions on the structural motions, also we use the Caspian Sea environmental information with water depth under 1000 Meters that SADRA Company Published. And apply the final threshold conditions in order to assess maximum possible displacement structures are used. These data are presented in (Table 4).

Table 4. Caspian Sea environmental threshold conditions data

Environmental conditions	1 Year- wave	100 Year- wave
H_s	5.6 (m)	9.5 (m)
T_p	10.3 (s)	12.8 (s)

Also to apply the environmental wave forces on the semi-submersible structure for large members used from Diffraction theory (Equation 3) and for thin members used of Morrison equation (Equation 2) that these equations are as following:

$$F = -\rho C_I \frac{\pi}{4} D^2 \omega^2 + \frac{H}{2} \frac{\text{Cos h}(ky)}{\text{Cos}(kh)} \sin(\omega t - \varepsilon) \quad (3)$$

$$F = C_m \rho \frac{\pi}{4} D^2 \dot{u} + C_d \frac{1}{2} \rho D u |u| \quad (4)$$

Where In equation 3, ρ is fluid density, CI is inertia coefficient, D is pile diameter, ω is angular velocity of fluid particle, H is wave height, k is wave number, y is depth from sea base, h is wave height adjacent pile and ε is angle of arrears.

And In equation 4, Cm is inertia coefficient, ρ is fluid density, D is pile diameter, $\dot{u}$ is horizontal accelerate of fluid particle in pile axis line, Cd is drag coefficient and u is horizontal velocity of fluid particle in pile axis line.

Surge movements analysis of semi-submersible platform specified in Figure 6 for 7 kind mooring systems and 3 incoming wave with angles of 30, 45 and 90 degree.

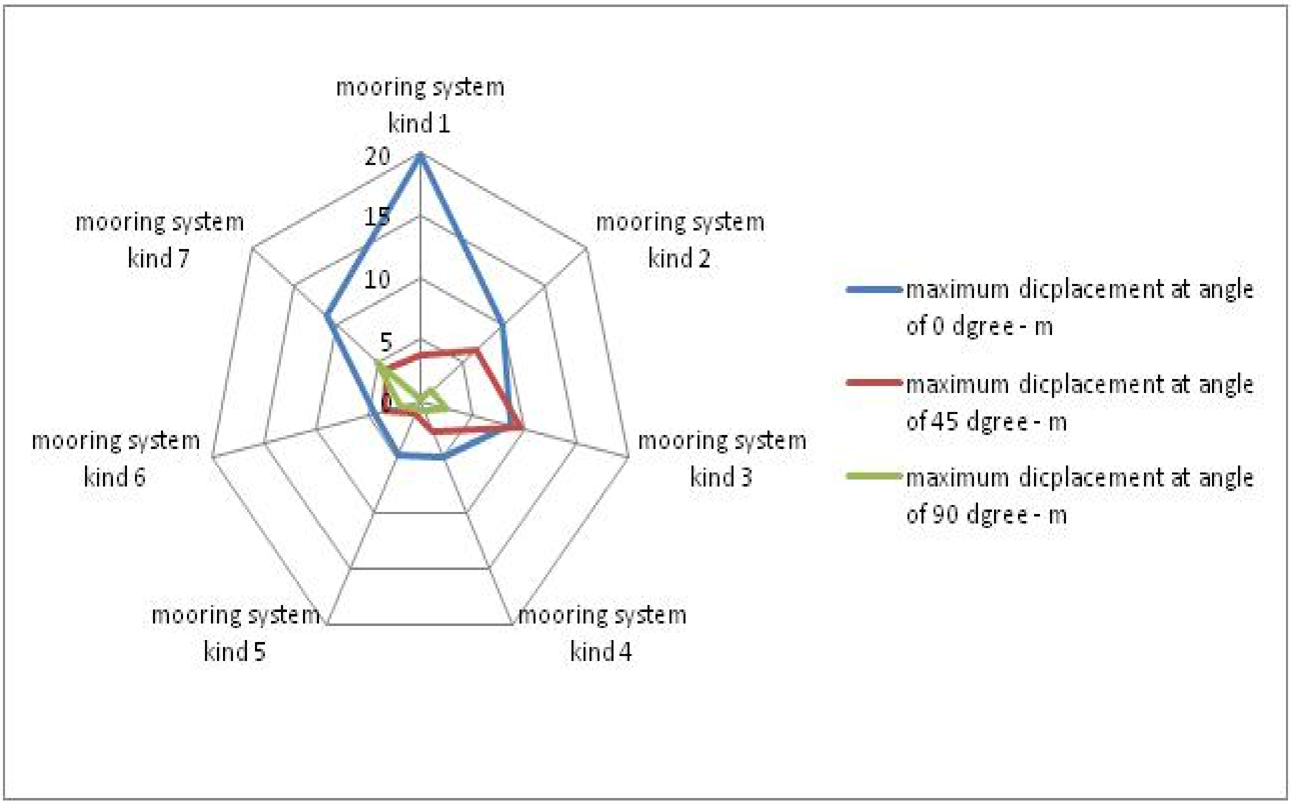

Figure 6. Semi-submersible platform Surge movement

Also Sway movements under different angles of the incident wave are defined in Figure 7 for 7 kind mooring systems and 3 incoming wave with angles of 30, 45 and 90 degree.

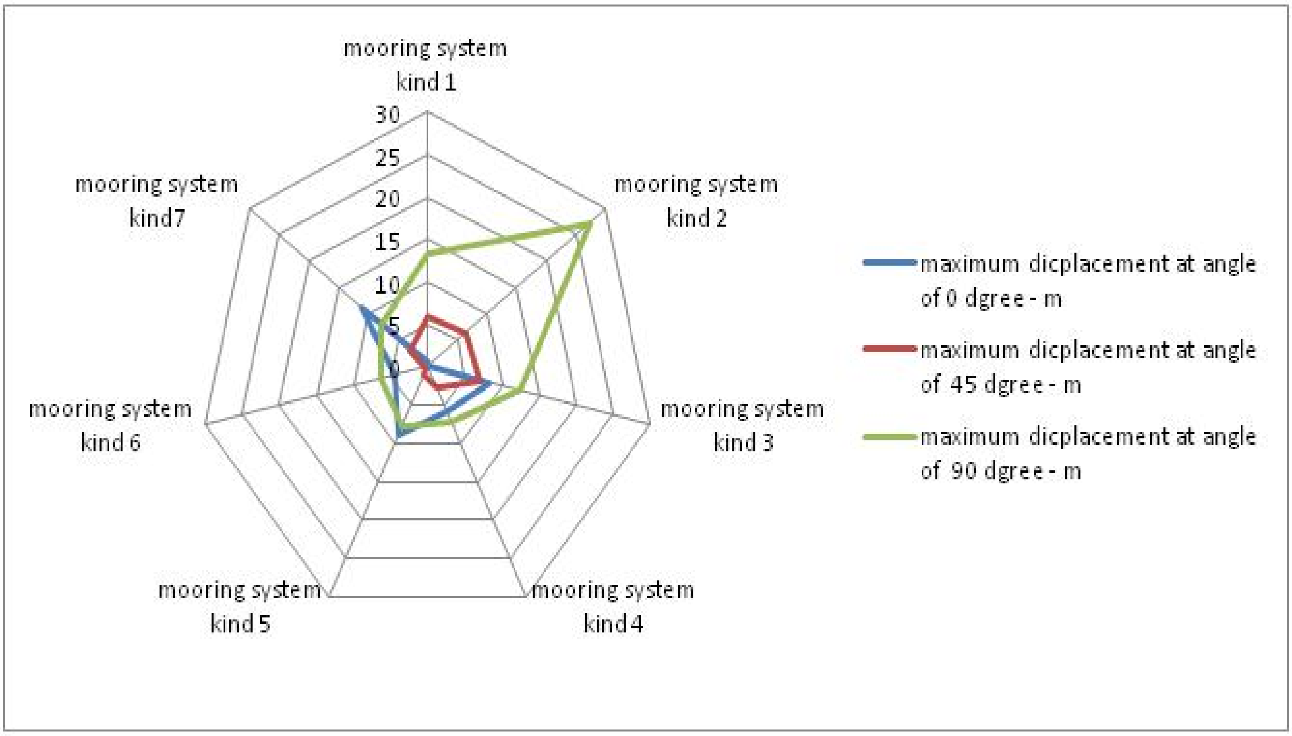

Figure 7. Semi-submersible platform Sway movement

4. Conclusions

We applied the Flow3d software to analyze the 7 various mooring system types of a semi-submersible platform. According to our numerical results following conclusions can be drawn:

1) Semi-submersible structure when that moored with 4 mooring lines has relatively large displacements. That is more than allowable amount of horizontal movement of a semi-submersible platform in regulations (equivalent to 1% of the water depth to avoid hitting the riser system and its proper functioning). Hence using this type of mooring system is not recommended.

2) Also in 8 lines mooring systems from analysis of the Surge and Sway movement it clearly has be seen that the structural displacements obviously reduced.

3) According to the results of analysis, most appropriate mooring system is Pattern Type 6 (60 degree angle between the two adjacent mooring lines) that causes the lowest range of horizontal structure motions.

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