Anodic Protection Response to Pile Driving for Fix Steel Jackets

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١. Introduction

Offshore structures work in sever harsh environmental conditions which lead to high corrosion rates. To protect such these structures, various methods have been used. For example, for atmospheric and splash zones, proper covering protection systems have been employed. In Sub Sea zone due to environmental characteristics which is a solution of various salts, anodic protection system is practiced. The anodic protection system consists of a pipe or a tubular which is covered by a sacrificial substance. The sacrificial element due to difference between its natural galvanic potentials and main structure corrodes; therefore, it protects the main structure of corrosion and the sea water is the electrolyte. The tubular is the structural element which bears loads and connects the anode, structurally and electrically to the main structure. In normal conditions, the tubular only bears the sacrificial substance weight which when the offshore structure is in service a portion of the weight is neutralized by buoyancy. But in pile driving stage, the hammer impacts induce a series of impulses which applies a great amount of acceleration (force).
In general practices the common way to design anodic system and predict its behavior under such this condition, is using relative codes and standards and the equations and assumptions which are brought in them. In this study a typical anodic system which was used in South pars gas field development phases ۶, ٧&٨ is considered. The anode responses to pile driving impulses are modeled through proposed methods in codes and standards along with making an analytic model and FEA analysis, which the effect of sea water compensation is considered (Fig ١a, ١b and ٢).

٢. Pile driving:

According to South pars gas field development phases ۶, ٧&٨ Jacket pile analysis report document, it is found that the anodic protection members which are mounted on the jackets legs are subjected to ٢۵g acceleration during pile driving stage.

٢-١. Standard based calculation method:

According to reference ۵:

$$a = ٢۵g \rightarrow \ddot{y} = ae^{-k.t} Cos\,\omega.t$$

$$\omega.t \rightarrow \infty \Rightarrow \begin{cases} \ddot{y} \rightarrow ٠ \\ y = ٠ \end{cases}$$

Where t is time, g is gravity acceleration, y the anode fluctuation position and $\ddot{y}$ is anode acceleration. It is assumed that:

$$\omega.t = ١٠\pi \rightarrow \ddot{y} = ٠.١g \Rightarrow \begin{cases} \omega.t = ١٠\pi \\ \omega = \dfrac{٢\pi}{T} \end{cases} \Rightarrow t = ۵.T$$

$$۰.۱g = ۲۵g.e^{-k.t}Cos۱۰\pi = ۲۵g.e^{-۵k.T} \rightarrow e^{-۵k.T} = ۰.۰۰۴ \rightarrow k.T = ۱.۱۰۴ \rightarrow \ddot{y} = ۲۵g.e^{-۱.۱۰۴t/T}Cos\omega.t$$

$$\Rightarrow \ddot{y} = ۲۴۵.۲۵e^{-۶.۹۳۷.t/\omega}Cos\omega.t$$

The initial conditions to solve the obtained differential equation are: $\begin{cases}\dot{y} = ۰\\ y = ۰\end{cases}$ which leads to Figure ۳. In this case, the anode damping ratio considered to be constant and under critical value.

۳. Analytic method:

۳-۱. FEA analysis:

An FEA analysis was conducted in order to find the static and transient response of anode to induced impulse along with modal analysis to determine the dominant natural mode shape which governs the response mode shape and frequency (Fig ۴a and ۴b). In fact, as it was anticipated, the mode shape similar to static deformation is the dominant mode shape, thus the anode vibrates with its frequency due to induced impacts which will be used in analytic anode response calculation. It was found that the third natural mode shape is the dominating mode.

۳-۲. Compensation calculation:

As the anode fluctuates in sea water, this fluid has viscous damping effect on the anode surfaces. The anode surfaces are flat, therefore the flow regimes and their effects should be considered for flat surfaces. The flow regimes are functions of Reynolds number which is calculated by:

$$\mathrm{Re}_x = \frac{\rho.V.x}{\mu}$$

For flat surfaces, for $\mathrm{Re}_x < ۵۰۰۰۰۰$ the flow is considered to be laminar and for $\mathrm{Re}_x > ۵۰۰۰۰۰$ turbulent. For every type of regimes, the drag coefficient is calculates by:

$$Laminar \quad Flow: \quad C_D = \frac{۱.۳۲۸}{\sqrt{\mathrm{Re}_x}}$$

$$Turbulent \quad Flow: \quad C_D = \frac{۰.۰۷۴}{\sqrt[۵]{\mathrm{Re}_x}}$$

The drag force is $F_D = \frac{۱}{۲}\rho.V^{۲}.C_D.A$. As the C_D is direct function of Re_x and changes over distance from the edge of surface, thus, the drag force is calculated by integrating the $dF_D = \frac{۱}{۲}\rho.V^{۲}.C_D.dA$ and $dA = b.dx$, which b is anode circumferential here. Therefore:

$$F_D = \int_{۰}^{l} \frac{۱}{۲}\rho.V^{۲}.C_D.b.dx \qquad (Compensation) \quad C = \frac{F_D}{V} \quad \Rightarrow \quad \begin{matrix} Laminar \quad Compensation \quad Flow: C_L = \dfrac{۱.۳۲۸\rho.V^{۲}.b.l^{\frac{۱}{۲}}.V^{\frac{۱}{۲}}}{۱۰۰۰} \\ Turbulent \quad Compensation \quad Flow: C_T = \dfrac{۰.۰۹۲۵\rho.V^{۰.۸}.b.l^{۰.۸}}{۳۱.۶۹۸} \end{matrix}$$

Where the ρ is sea water density, l is the flow regime length and V is the flow velocity. The $x_L = \frac{۰.۵}{V}$ shows the point where the laminar flow regime changes into turbulent. Thus the upper binds of integration for laminar and turbulent flows are $l = x_L$ and $l = L - x_L$ respectively which L is surface length. The total compensation is considered as summation of C_T, C_L and structural damping which is commonly assumed as $\zeta = ۰.۰۵$.

۳-۳. Anode response calculation:

The impact effect on the anode structure is considered as inducing an initial velocity, and then the structure starts to damped free vibration. Therefore the initial conditions for damped free vibrations are: $\begin{cases} \dot{y} = \frac{\hat{F}}{m} \\ y = ۰ \end{cases}$ (Fig ۵). The damping is a function of anode vibration velocity in sea water (Fig. ۶).

۴. Summary and conclusion:

Transient analysis in FEA showed that the natural mode shape which is similar to the static response of anode structure is the dominating mode shape which determines the response of structure. Therefore in analytic method it was used as vibrating frequency.
As it was seen, in standard method, the damping ratio was considered as a constant value, but in the introduced analytic approach the sea water compensation is considered as anode vibration velocity function.
The effect of sea water compensation on the anode structure is completely obvious. In comparison to standard method, the fluctuations are damped more rapidly. Due to damping changes in respect to anode vibration velocity, the anode vibration amplitude graph is not smooth like constant damping ratio case.

۵. References:

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٥. South pars gas field phases ۶, ۷&۸, "Anode Attachment Design Calculation" SP۶/۷/۸-۱-۰۳۰۰-OS-CN-۰۰۶-D۲.
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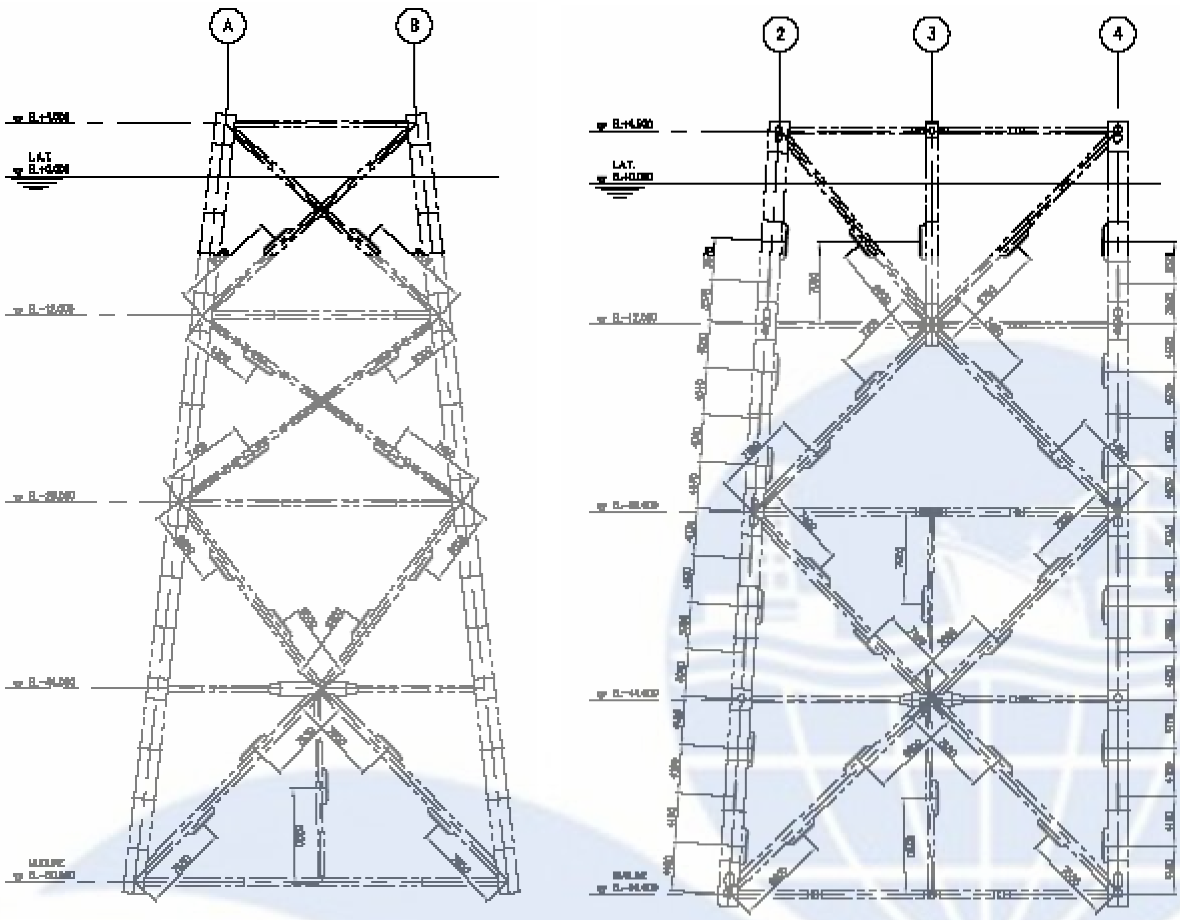
٧. DNV Notes ۳۰,۵ (Environmental conditions/Loads).



(a) b)

Fig. ۱: a) SPD۶ jacket, front view. b) SPD۶ jacket side view.

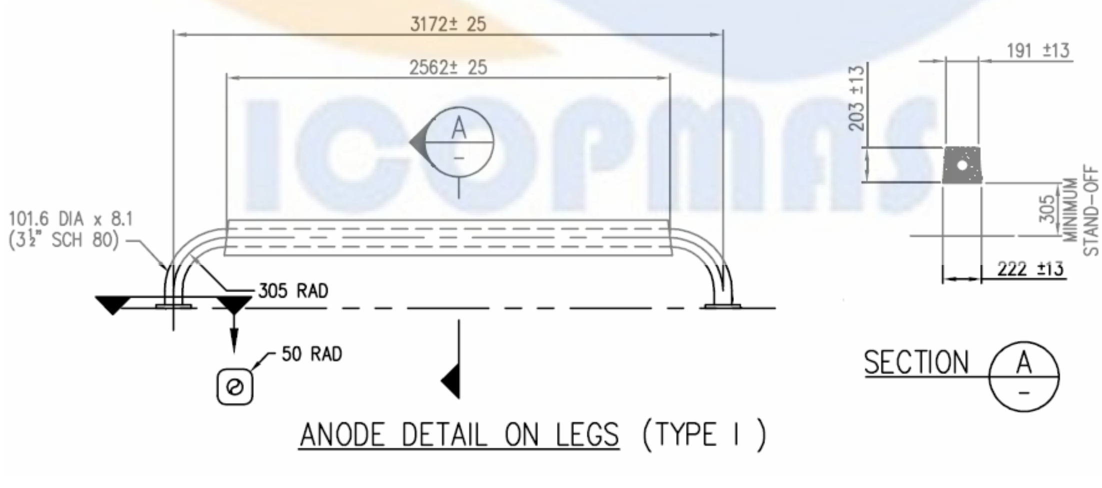


Fig. ۲: The typical used anode geometric features.

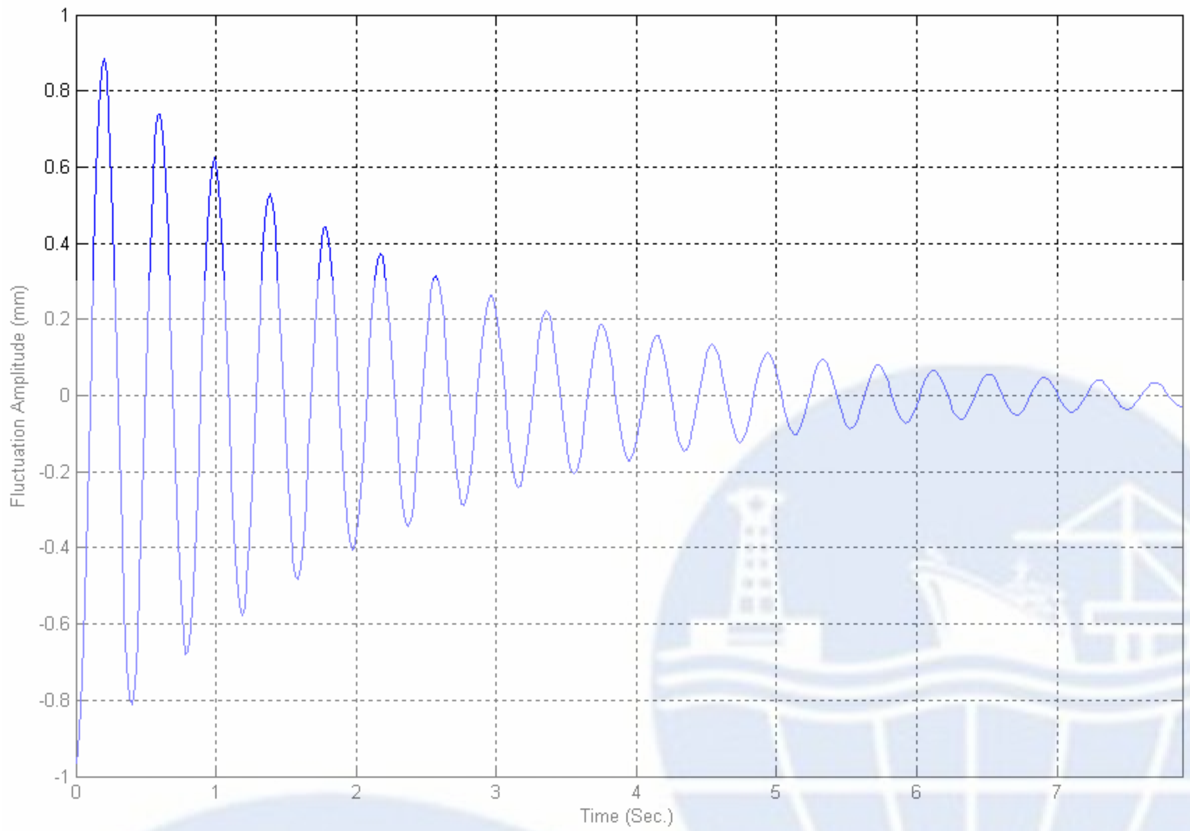


Fig. ۳: Anode response to the pile driving impacts by standard method.

(۴a)

(۴b)

Fig ۴: a) Static anode deformation result to pile driving impact (FEA). b) Modal analysis result of dominating natural frequency mode in transient analysis, $f_n = ۲.۵۳۴ \ Hz$ (FEA).

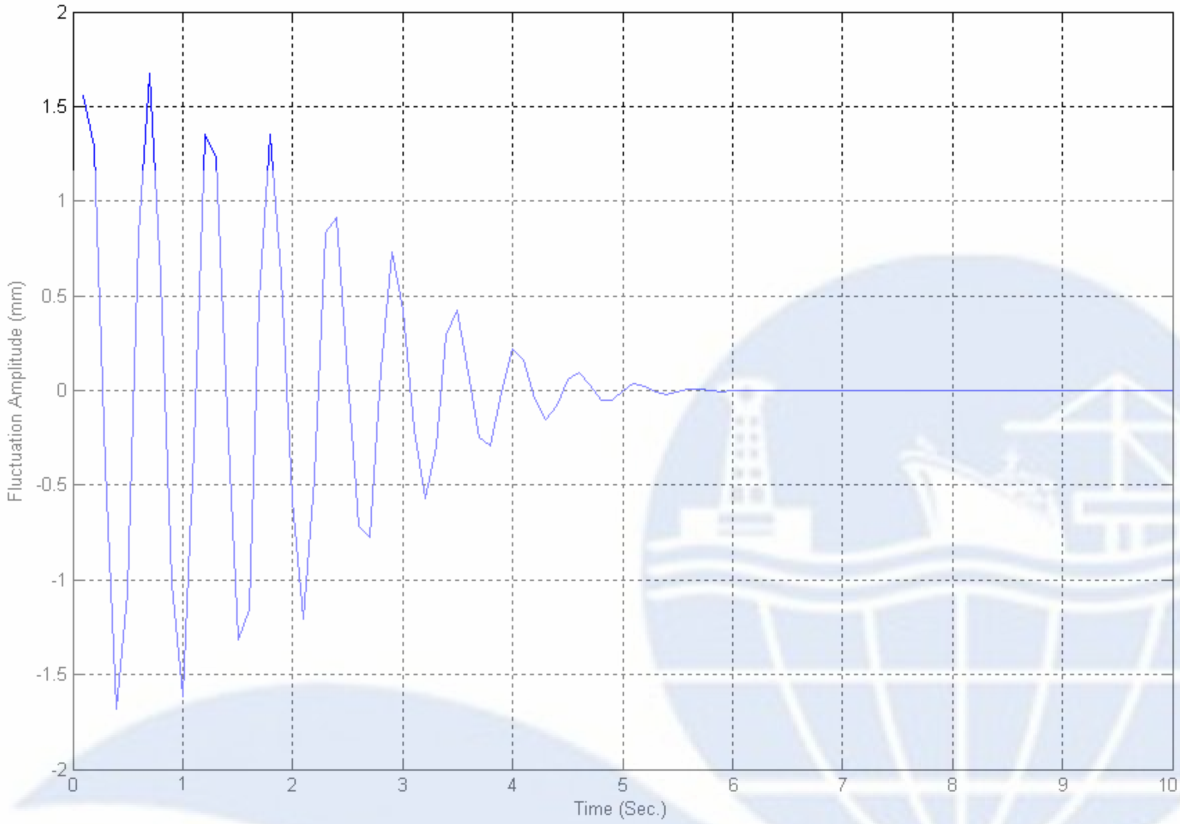


Fig. ۵: Anode response to the pile driving impacts by analytic method.

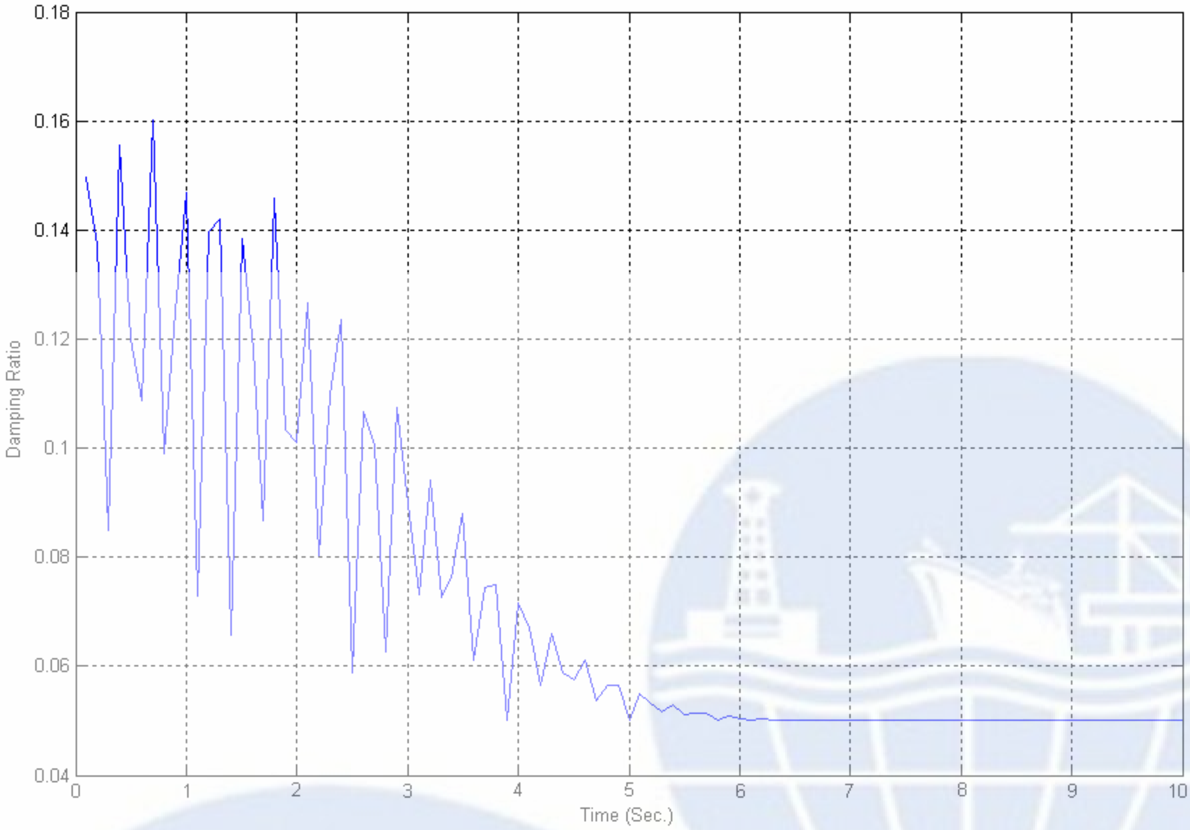


Fig. ۶: Total damping ratio in analytic method.