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VIBRATION ANALYSIS OF AN OIL PRODUCTION PLATFORM

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Abstract. The present paper investigated the dynamic behaviour of an oil production platform made of steel and located in Santos basin (Merluza field), São Paulo, Brazil. The structural model consists of two steel decks with a total area of 1915 m^2 (upper deck: 445 m^2 and lower deck: 1470 m^2), supported by piles. Mechanical equipments were located on the steel decks of the structural model, related to electrical generators and compressors. The proposed computational model, developed for the steel platform dynamic analysis, adopted the usual mesh refinement techniques present in finite element method simulations implemented in the GTSTRUDL program. In the computational model, floor steel girders and columns were represented by three-dimensional beam elements, where flexural and torsion effects are considered. The steel decks were represented by shell finite elements. The representation of the soil was based on the Winkler's Theory. A numerical analysis was made, in order to assess the dynamic behaviour of the deck structure when subjected to actions coming from the electrical generators and compressors. Based on the peak acceleration values, obtained on the structure steady-state response, it was possible to evaluate the structural model performance in terms of human comfort, maximum tolerances of the mechanical equipment and vibration serviceability limit states of the structural system, based on the design code recommendations.

1 INTRODUCTION

Structural engineers have long been trying to develop solutions using the full potential of its composing materials. At this point there is no doubt that the structural solution progress is directly related to an increase in materials science knowledge.

On the other hand, the competitive trends of the world market have long been forcing structural engineers to develop minimum weight and labour cost solutions. A direct consequence of this new design trend is a considerable increase in problems related to unwanted floor vibrations. For this reason, the structural floors systems can become vulnerable to excessive vibrations, for example, produced by impacts such as mechanical equipments (rotating machinery) (Rimola, 2010).

This way, the present paper investigated the dynamic behaviour of a production platform made of steel and located in Santos basin (Merluza field), São Paulo, Brazil. The structural model consists of two steel decks with a total area of 1915 m^2 (upper deck: 445 m^2 and lower deck: 1470 m^2), supported by piles. Mechanical equipments were located on the steel decks of the structural model, related to electrical generators and compressors (Rimola, 2010).

The representation of the soil was based on the Winkler's Theory (Winkler, 1867). This theory simulates the soil behaviour as a group of independent springs, governed by the linear-elastic model. In the Winkler's model, the soil stiffness was considered as the necessary pressure to produce a unitary displacement (Winkler, 1867).

The proposed computational model, developed for the steel platform dynamic analysis, adopted the usual mesh refinement techniques present in finite element method simulations implemented in the GTSTRUDL program (GTSTRUDL, 2008). In this computational model, floor steel girders and columns were represented by three-dimensional beam elements, where flexural and torsion effects are considered. The steel decks were represented by shell finite elements. In this investigation, it was considered that the steel has an elastic behaviour.

The structural model dynamic response was determined through an analysis of its natural frequencies and peak accelerations. The results of the dynamic analysis were obtained from an extensive numeric study, based on the finite element method utilising the GTSTRUDL program (GTSTRUDL, 2008). In this investigation, dynamic loadings coming from the rotating machinery (electrical generators and compressors) were applied on the steel decks of the structural system (production platform).

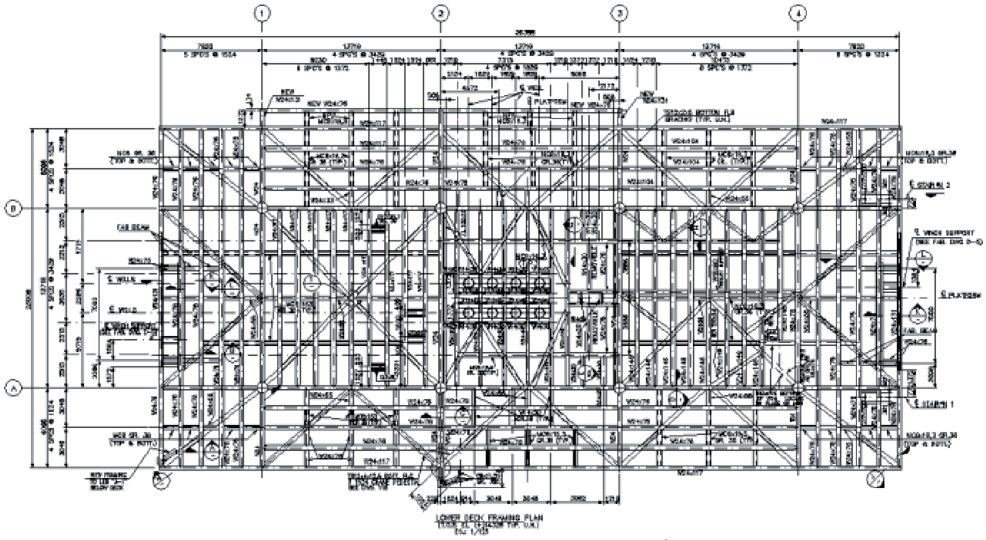
A numerical analysis was made, in order to assess the dynamic impacts on the deck structure coming from the electrical generators and compressors. Based on the peak acceleration values, obtained on the structure steady-state response, it was possible to evaluate the structural model performance in terms of human comfort, maximum tolerances of the mechanical equipment and vibration serviceability limit states of the structural system, based on the design code recommendations (CEB 209/91, 1991; ISO 1940-1, 2003; ISO 2631-1, 1997; ISO 2631-2, 1989; Murray et al., 2003).

2 STRUCTURAL MODEL

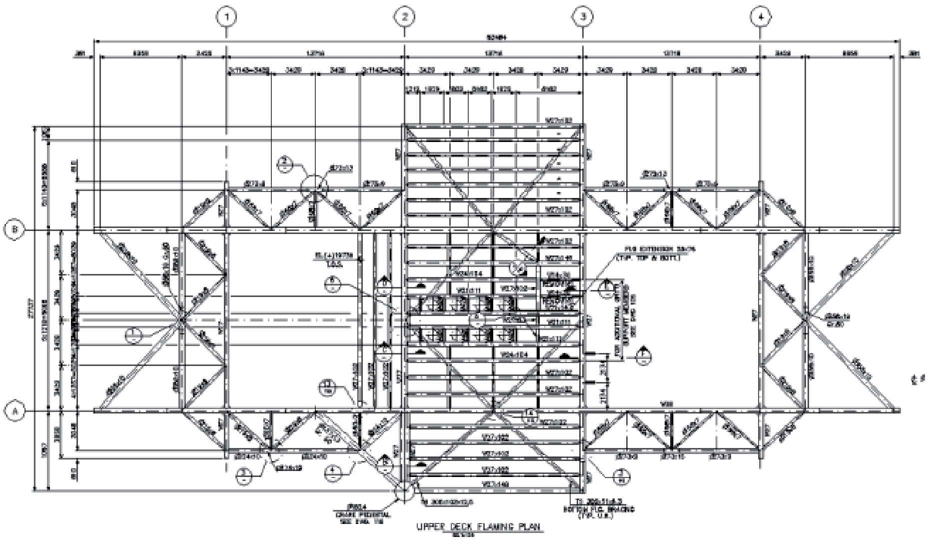
The structural system investigated in this paper is related to a production platform made of steel and located in Santos basin (Merluza field), São Paulo, Brazil. The structural model is supported by steel piles and consists of two steel decks with a total area of 1915 m^2.

The structural model is constituted of steel beams and steel deck plates (upper deck: 445 m^2 and lower deck: 1470 m^2), as presented in Figure 1. A 2.05×10^5MPa Young's modulus was adopted for the steel beams and decks. The structural system is constituted by a lot of elements with very different geometrical characteristics, see Rimola (2010).

a) Investigated structural model



b) Lower deck: 1470 m^2



c) Upper deck: 445 m^2

Figure 1: Investigated structural model.

3 COMPUTATIONAL MODELLING

The proposed computational model, developed for the composite floors dynamic analysis, adopted the usual mesh refinement techniques present in finite element method simulations implemented in the GTSTRUDL program (GTSTRUDL, 2008).

In this computational model, floor steel girders were represented by a three-dimensional beam element with tension, compression, torsion, and bending capabilities. The element has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z axes. On the other hand, the steel deck plates were represented by shell finite elements (GTSTRUDL, 2008).

In this investigation, it was considered that both structural elements (steel beams and steel deck plates) presented total interaction and has an elastic behaviour. The finite element model is illustrated in Figures 2 and 3 and a typical steel deck cross section is shown in Figure 4. The finite element model has 1824 nodes, 3079 three-dimensional beam elements, 509 shell elements and 10872 degrees of freedom.

Figure 2: Finite element model: production platform with steel jackets and piles.

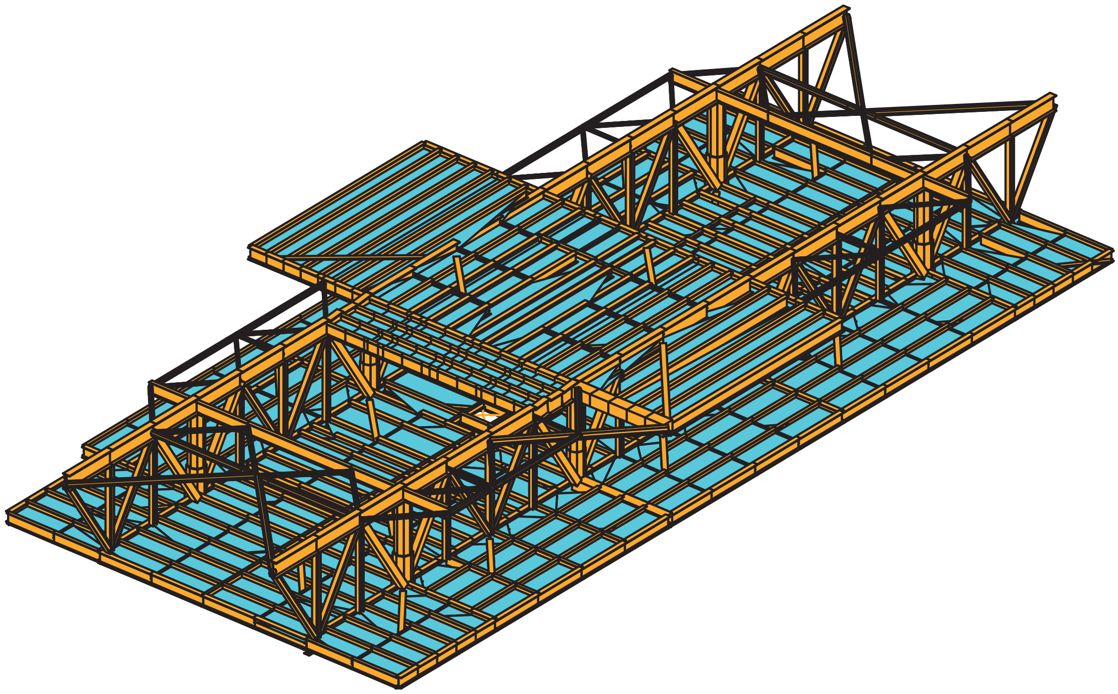


Figure 3: Finite element model: upper and lower steel deck.

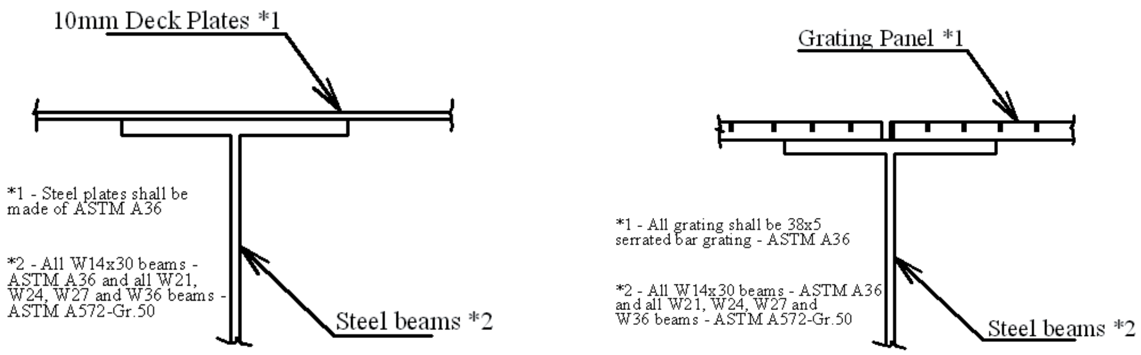


Figure 4: Typical steel deck cross section,

4 DYNAMIC ANALYSIS

For practical purposes, a linear time-domain analysis was performed throughout this study. This section presents the evaluation of the investigated structural model vibration levels when submitted to dynamic excitations produced by mechanical equipments (rotating machinery) acting on the upper and lower steel decks.

The production platform dynamic response was determined through an analysis of its natural frequencies and peak accelerations. The results of the dynamic analysis were obtained from an extensive parametric analysis, based on the finite element method using the GTSTRUDL program (GTSTRUDL, 2008).

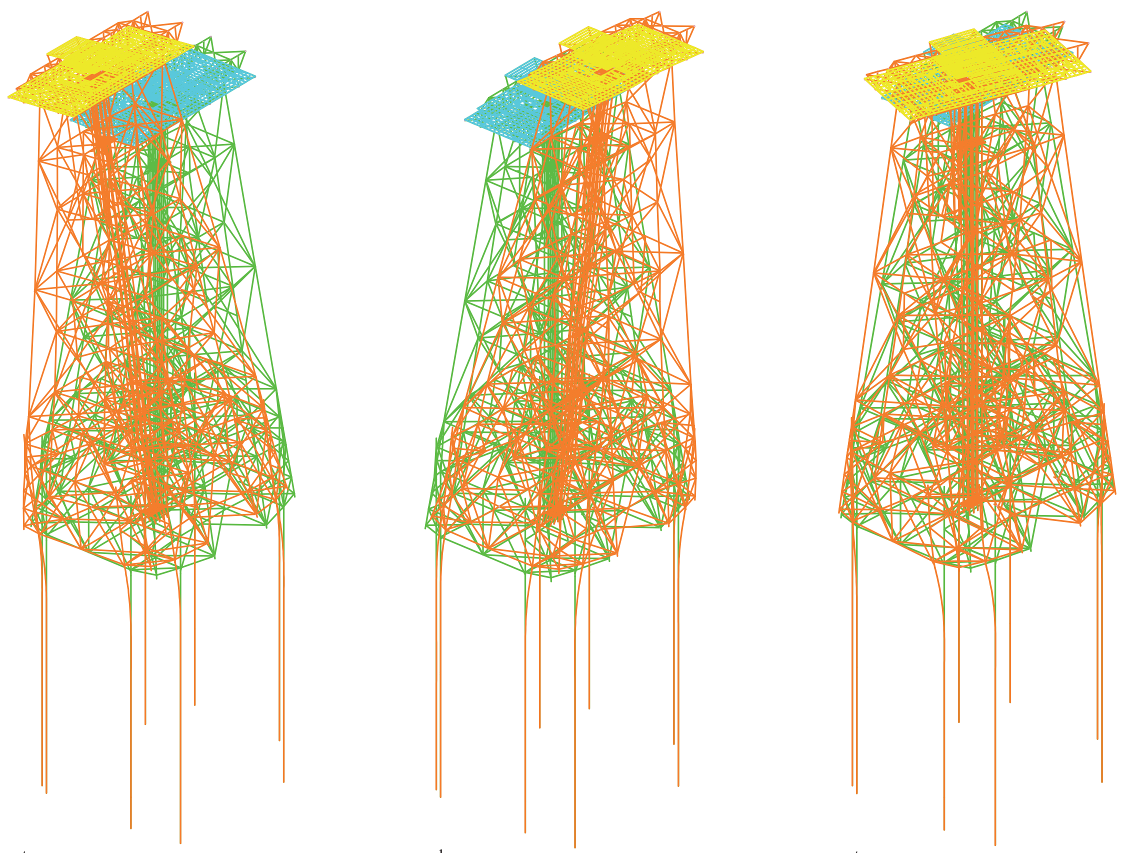
In order to quantitative and qualitatively evaluate the obtained results according to the proposed methodology, the structural model peak accelerations were calculated and compared to design recommendations limiting values (CEB 209/91, 1991; ISO 1940-1, 2003; ISO 2631-1, 1997; ISO 2631-2, 1989; Murray et al., 2003.). This comparison was made to access a possible occurrence of unacceptable excessive vibration levels and human discomfort.

4.1 Natural frequencies and vibration modes

The production platform natural frequencies were determined with the aid of the numerical simulations, see Table 1, while the corresponding vibration modes are shown in Figure 5. Each natural frequency has an associated mode shape and it was observed that the first vibration modes presented predominance of the steel jacket system. However, flexural effects were predominant in the steel deck plate (upper and lower), starting from the eighth vibration mode (f_{08} = 1.99 Hz - Vibration Mode 8), see Table 1. It is important to emphasize that torsional effects were present starting from higher mode shapes, see Table 1. Figures 5 and 6 illustrated the mode shapes corresponding to six natural frequencies of the investigated structural system.

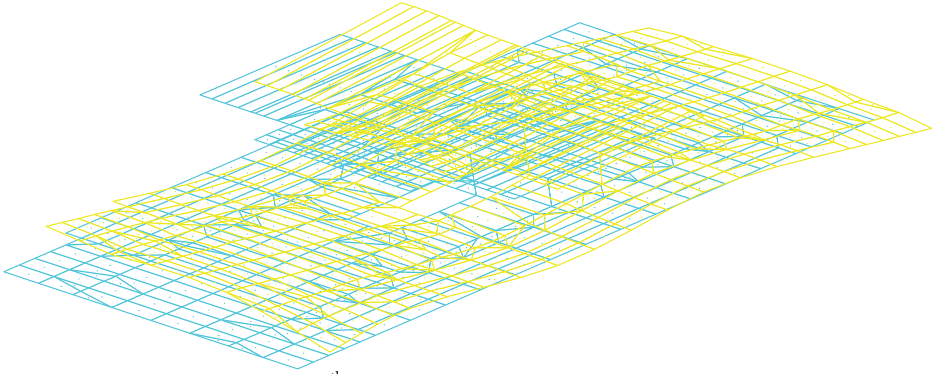
Natural Frequencies (Hz)		Vibration Modes	
f_{01}	0.67	Mode 1	Vibration modes with predominance of the steel jacket system (vibration modes 1 and 2: flexural effects and vibration mode 3: torsional effects).
f_{02}	0.71	Mode 2	
f_{03}	1.20	Mode 3	
f_{08}	1.99	Mode 8	Vibration modes with predominance of the steel deck displacements (vibration modes 8, 17 and 49: flexural effects).
f_{17}	2.61	Mode 17	
f_{49}	4.14	Mode 49	

Table 1: Production platform natural frequencies.

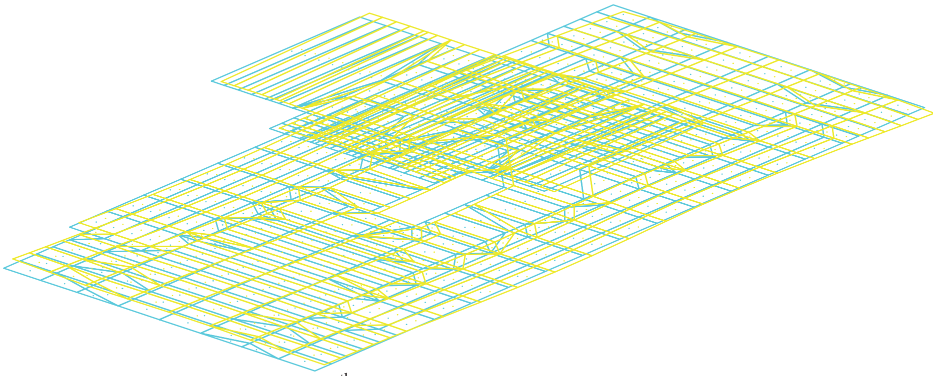


a) 1st vibration mode f_{01}=0.67 Hz b) 2nd vibration mode f_{02}=0.71 Hz c) 21st vibration mode f_{03}=1.20 Hz

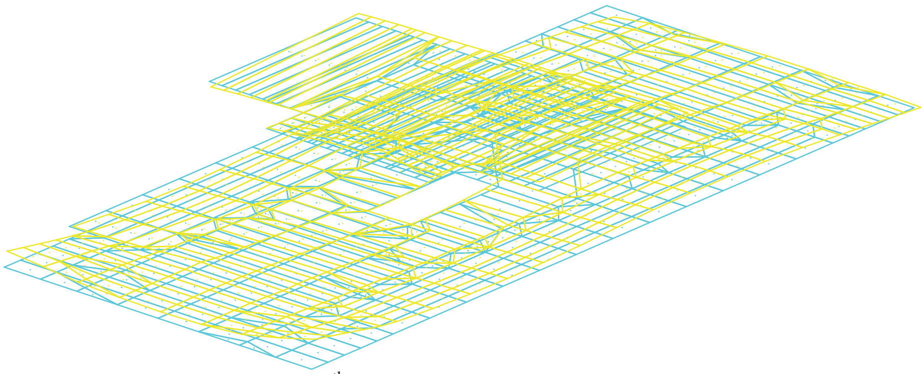
Figure 5: Vibration modes with predominance of the steel jacket system.



a) 8th vibration mode f_{08}=1.99 Hz



b) 17th vibration mode f_{17}=2.61 Hz



c) 49th vibration mode f_{49}=4.14 Hz

Figure 6: Vibration modes with predominance of the steel deck system.

4.2 Structural system dynamic response

The present analysis proceeds with the evaluation of the steel platform's performance in terms of vibration serviceability effects, considering the impacts produced by mechanical equipments (rotating machinery), due to the fact that unbalanced rotors generate vibrations which may damage their components and supports and produce dynamic actions that could induce the steel deck plate system to reach unacceptable vibration levels, leading to a violation of the current human comfort criteria for these specific structures.

The first step of this procedure concerns in the determination of the structural system displacements, velocities and peak accelerations. It was considered the mechanical equipment data according to Table 2. Figure 7 shows the equipment supported by a steel beam ("I" section) and Figure 8 presented the mechanical equipment location on the structural model. In this analysis, a damping ratio of 0.5% (ξ=0.005) was considered for the structural system (Murray et al., 2003).

Equipment data	
Protective cover	1.2 kN
Coupling	5.3 kN
Gear unit	37.5 kN
Motor swing	15 kN
Rotor weight	10.8 kN
Input frequency	30 Hz
Output frequency	0.94 Hz

Table 2: Equipment data.

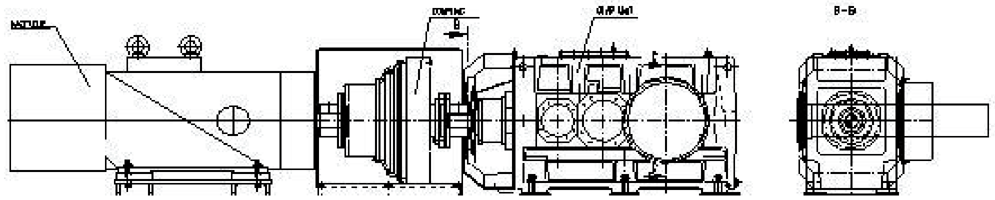


Figure 7: Driving unit (motor, coupling and gear) supported by a steel beam (Rimola, 2010).

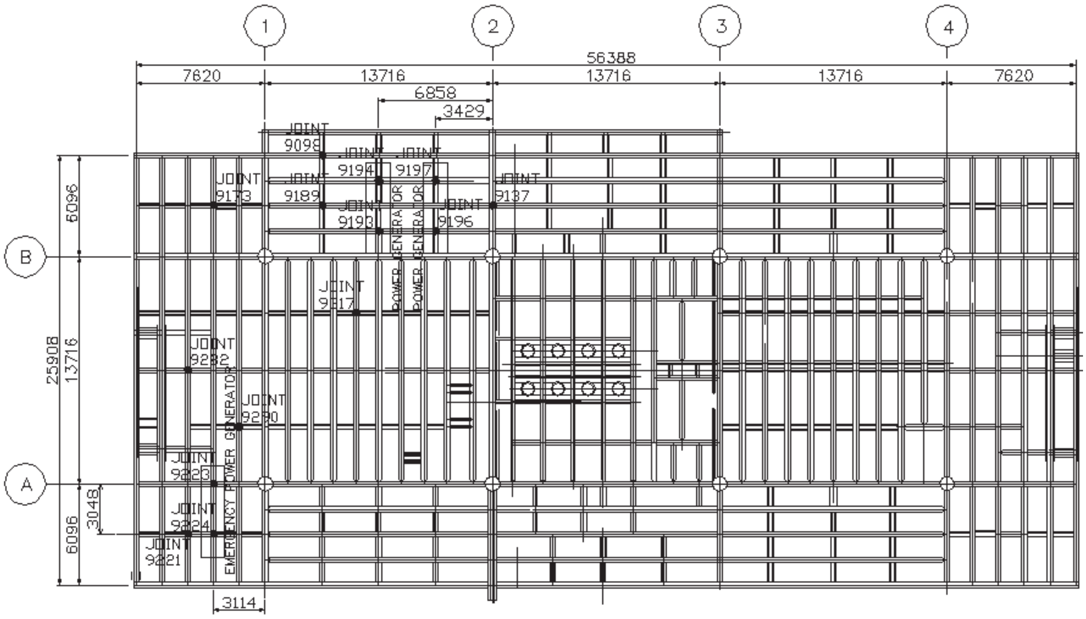


Figure 8: Location of the mechanical equipment on the deck (dimensions in mm).

The imperfect unbalance of the rotor creates a dynamic loading which depends of the mass and angular velocity of the equipment and the eccentricity located between the centre of gravity of the equipment and the rotation axis (Rimola, 2010), see Eq. (1). In sequence, Table 3 illustrates the dynamic loading data used in the modelling of the dynamic action applied on the platform steel deck plate system, see Figure 8.

These dynamic actions were properly combined in order to better represent the dynamic excitation induced by the equipment on the investigated structure. The modelling of the dynamic loading presents two components related to the vertical and horizontal directions, as illustrated in Figures 9 and 10.

$$P_0 = m\ R\ \omega^2 = P_0 = m\ (R\omega)\ \omega \tag{1}$$

Where:
P_0: amplitude of the dynamic load (kN);
m: total mass in rotation (kg);
ω: equipment frequency (rd/s);
Rω: balance quality grade (ISO 1940-1, 2003): Rω = 0.0025m/s).

Equipment	Weight (kN)	Frequency (rd/s)	Rω (m/s)	P_0 (kN)
Rotor	10.80	188.49	0.0025	0.51
Gear	18.75	6.03	0.0025	0.028

Table 3: Dynamic actions related to the equipment (Rimola, 2010).

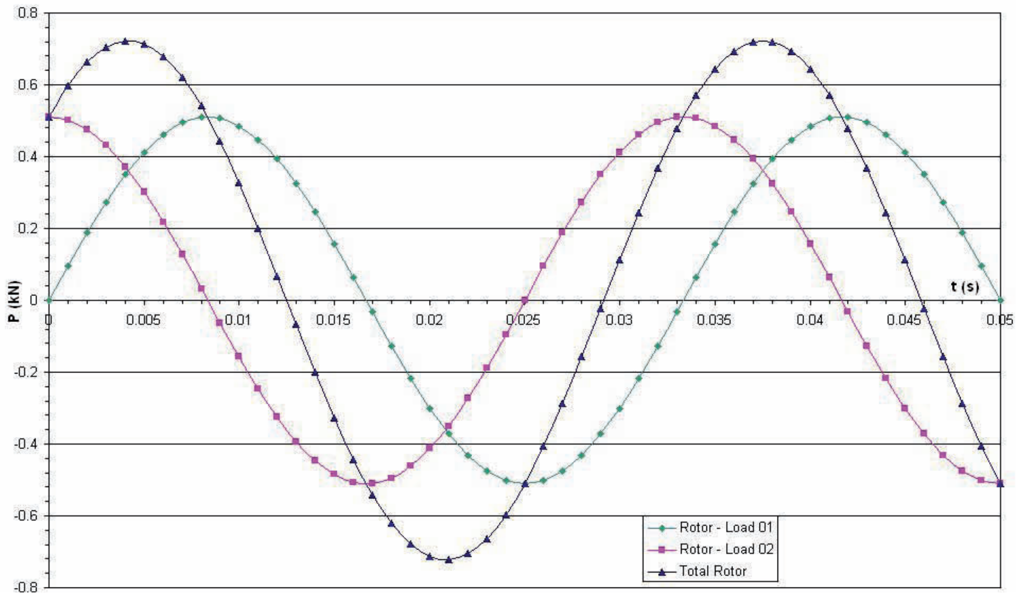


Figure 9: Rotor dynamic load: 0.51 sen (188.49t) + 0.51 sen (188.49t + π/2).

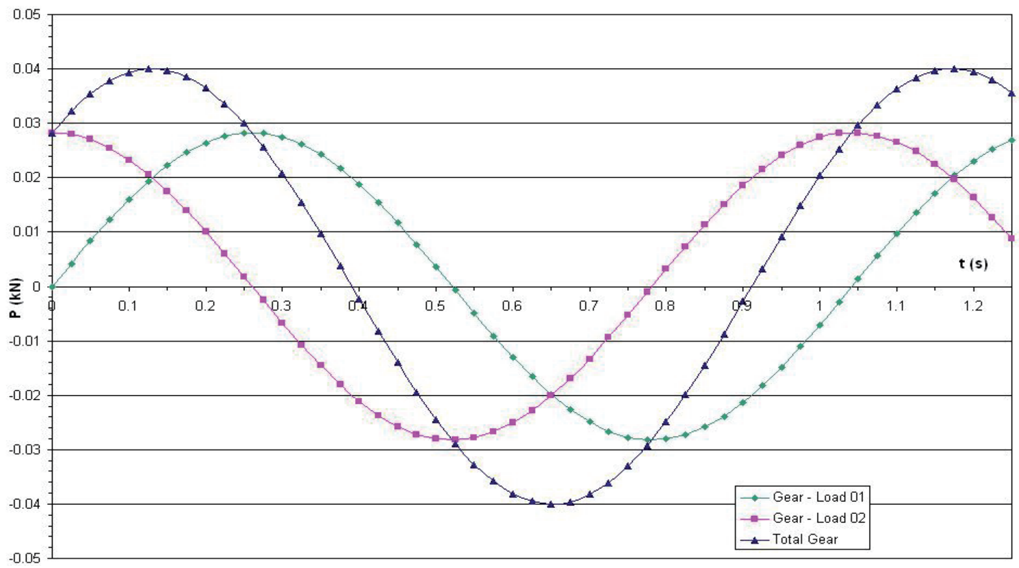


Figure 10: Gear dynamic load: 0.0283 sen (6.03t) + 0.0283 sen (6.03 + π/2).

In sequence of the analysis, Tables 4 to 6 present the vertical translational displacements, velocities and accelerations, related to specific locations on the steel deck, near of the mechanical equipment, see Figure 8, calculated when the combined dynamic loadings were considered, see Eq. (1) and Figures 9 and 10.

These values, obtained numerically with the aid of the proposed computational model, were then compared with the limiting values proposed by design code recommendations (CEB 209/91, 1991; ISO 1940-1, 2003; ISO 2631-1, 1997; ISO 2631-2, 1989; Murray et al., 2003). It must be emphasized that only the steady state response was considered in this investigation.

Rotor Support (Node 9194) (μm)	Rotor Support (Node 9197) (μm)	Rotor Support (Node 9224) (μm)	Steel Deck (Node 9290) (μm)	Amplitudes Limit Value (μm)
54	**446**	7	331	40 to 60*
Gear Support (Node 9193) (μm)	Gear Support (Node: 9196) (μm)	Gear Support (Node 9223) (μm)	Steel Deck (Node 9317) (μm)	
77	432	38	17	
*For vertical vibration for height speed machines (>1500 rpm) (ISO 1940-1, 2003).				

Table 4: Vertical displacements related to the combined dynamic loading (driving).

The allowable amplitudes are generally specified by manufactures of machinery. When manufacture's data doesn't indicate allowable amplitudes, reference (ISO 1940-1, 2003) recommends these limiting values for machinery performance, see Table 4. The maximum amplitude value at the base of the driving support (Node 9197: see Figure 8), on the platform steel deck was equal to 446 μm (or 0.446 mm or 0.0446 cm), see Table 4, indicating that the recommended limit value was violated and the machinery performance can be inadequate (0.446 mm > 0.06 mm) (ISO 1940-1, 2003).

Rotor Support (Node 9194) (mm/s)	Rotor Support (Node 9197) (mm/s)	Rotor Support (Node 9224) (mm/s)	Steel Deck (Node 9290) (mm/s)	Velocities Limit Value (mm/s)
10.18	**84.12**	1.38	62.52	0.70 to 2.8*
Gear Support (Node 9193) (μm)	Gear Support (Node: 9196) (μm)	Gear Support (Node 9223) (μm)	Steel Deck (Node 9317) (μm)	
14.49	81.46	1.32	3.23	
*Tolerable velocity for electrical motors according (ISO 1940-1, 2003).				

Table 5: Velocities related to the combined dynamic loading (driving).

The maximum velocity value calculated at the base of the driving support (Node 9197: see Figure 8), on the platform steel deck was equal to 84.12 mm/s, see Table 5. The allowable velocity for a perfect condition to machinery performance is located in the range of 0.7mm/s to 2.8 mm/s, see ISO 1940-1 (2003), as presented in Table 5. This velocity value is not in agreement with those proposed by the design codes (84.12 mm/s > 2.8 mm/s) (ISO 1940-1, 2003), violating the recommended limits.

Rotor Support (Node 9194) (m/s^2)	Rotor Support (Node 9197) (m/s^2)	Rotor Support (Node 9224) (m/s^2)	Steel Deck (Node 9290) (m/s^2)	Accelerations Limit Value a_{lim} (m/s^2)
1.92	**15.86**	0.26	11.77	0.315 to 1.0*
Gear Support (Node 9193) (m/s^2)	Gear Support (Node: 9196) (m/s^2)	Gear Support (Node 9223) (m/s^2)	Steel Deck (Node 9317) (m/s^2)	
2.73	15.35	1.37	0.61	
*Acceptable values of human comfort in accordance with (ISO 2631-1, 1997).				

Table 6: Accelerations related to the combined dynamic loading (driving)

People working temporarily near to driving could be affected in various degrees (human discomfort). The allowable acceleration value when the human comfort is considered (ISO 2631-1, 1997) is located in the range of 0.315 m/s^2 to 1.0 m/s^2, as illustrated in Table 6. The peak acceleration value calculated at the base of the rotor support (Node 9197: see Figure 8), on the platform steel deck was equal to 15.86 m/s^2, see Table 6. This maximum acceleration value violated the recommended limits proposed by the design codes (15.86 m/s^2 > 1.0 m/s^2) (ISO 2631-1, 1997), causing human discomfort.

5 CONCLUSIONS

This paper investigated the dynamic behaviour of a production platform made of steel and located in Santos basin (Merluza field), São Paulo, Brazil, when subjected to impacts produced by mechanical equipments (rotating machinery). The main objective of the paper was to assess the dynamic impacts on the steel deck structure coming from the electrical generators and compressors.

Based on the peak acceleration values and maximum displacements and velocities, obtained on the structure steady-state response, it was possible to evaluate the structural model performance in terms of human comfort, maximum tolerances of the mechanical equipment and vibration serviceability limit states of the structural system, based on the design code recommendations.

The results obtained throughout this investigation indicated that the platform steel deck analyzed in this work violated the human comfort criteria, as well as its vibration serviceability limit states, inducing that individuals working temporarily near the machinery could be affected by human discomfort.

On the other hand, considering the machinery performance, it was also concluded that the platform steel deck design, should be revaluated, due to the fact that the displacements and velocities values related to the machinery supports were very high and violated the recommended limits proposed by design codes.

6 ACKNOWLEDGEMENTS

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