International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 8 Issue 08, August-2019

Analysis and Design of Steel Frame Structure for Rotating Motors

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Abstract*: The term 'vibrations' when applied to floors refers to the oscillatory motion experienced by the building and its habitant during the course of normal day-to-day work. This motion is normally vertical (up and down), but horizontal vibrations are also possible. In another case, the effect of vibrations range from being a nuisance to the building users to causing damage to the loosenes s and fittings or even (in very extreme cases) to the building structure. Vibration is a mechanical phenomenon where oscillation of a mass occurs. There are two types of vibration: free vibration and forced vibration .Floor vibrations are generally caused by dynamic loads applied either directly to the floor by people or machinery.Machinery-induced vibrations are best dealt with at source through the provision of isolating mounts or motion arresting pads. Machines installed in factories tend to produce the most severe vibrations due to their size and the nature of their operation. However, floor vibration is rarely a problem in most factories, since it is accepted by the workforce as part of the industrial environment.Vibrations of mechanical equipment such as rotating machinery, should be strictly controlled according to the application and the criteria of existing technical standards and of those that are still being studied, and should be used as basis of the operating conditions of mechanical equipment, especially for predictive maintenance.At an early stage in the design process it is possible to locate both rhythmic activities and sensitive occupancy so as to minimize potential vibration problems and the costs required to avoid them. It is also a good idea at this stage to consider alternative structural solutions to prevent vibration problems. Such structural solutions may include design of the structure to control the accelerations in the building and special approaches, such as isolation of the activity floor from the rest of the building or the use of mitigating devices such as tuned mass dampers.

Keywords : Acceleration, Dynamic loads, Rotating Machinary, Vibrations etc.

I. INTRODUCTION

The competitive trends of the world market have long been forcing structural engineers to develop minimum weight and labour cost solutions. A direct consequences of this new design trend has been a considerable increase in problems related to undesired floor vibrations. For this reason, structural floor system's can become vulnerable to excessive vibrations that are produced by impacts due to mechanical equipment's. In the past, the demand for flexible use of commercial and administrative buildings was leading to a request for floors with long spans. These expectations have been met by the development of innovative construction techniques, e.g. composite floor systems as well as pre-stressed hollow core slabs. This trend has been supported further by the use of modern, high strength materials. Hence serviceability criteria, such as deflection limits and the vibration behaviour, define in the first instance the design of these new, slender constructions.While deflection limits are regulated in the relevant standards, the vibration comfort of slabs is not clearly defined.In addition, a generally accepted method for the reliable prediction of the action effects for vibrations, in general expressed in accelerations or velocities, are not available.

II. LITERATURE REVIEW

This section of the report provides an overview of how the vibration acceptance criteria has changed over the last 100 years. The acceptance criteria take on different forms such as graphs/scales and inequalities as research has been conducted to improve our understanding of vibration in structural systems.

1976 - Srinivasulu and Vaidyanathan: Handbook of Machine Foundations (1976) Another reference found in the technical literature on the theme available. Provides a simpler table of limit values of vibration amplitudes for different types of machine that will be used for the validation of the proposed models.

Rafael Marin Ferro [1] conducted a performance check of support frame structure to estimate the dynamic loads caused by rotating equipment on supports using computational models with strap software. The paper concluded that fully rigid structures is suitable for dynamic structure point of view.

1996 - Satish kumar et al. presented the results of experimental and analytical studies on the vibrational characteristics of a clamped-clamped plate which is partially filled and totally filled with an ERF. He has presented a semi-analytical conical shell finite element analysis used for the modeling of the rotor with the inclusion of the support bearing flexibility. A parametric study was also performed for looking into the frequency characteristics of the system. The study brings out the additional disk modes as well as the behaviour of the system at higher circumferential modes.

Jayarajan P. [2] studies revealed the dynamic analysis of turbo-generator machine foundations. This paper outlines the procedure for finite element modeling of foundation structure by considering both free vibration analysis & harmonic forced

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analysis. This paper concluded various challenges relater to modeling of structure, machine & soil for dynamic analysis.

III. METHODOLOGY

Betterment in vibration performance after construction are likely to be difficult to achieve and very costly. The valuation of vibrations should therefore be carried out as part of the serviceability checks on the floor during the design process. The vibration performance of the floor can be assessed using manual methods, a new simplified web-based appliances or finite element methods. Where a BIM model of the building is being created by the design team, the model should contain all the necessary cognition required to carry out the analysis.

In the numerical simulation of rotor dynamics, the formulation of a mathematical model that represents a rotating system requires prior knowledge of the project parameters such as dimensions and material data. The success of a rotating machine project consists mainly of:

Avoiding critical velocities, if possible;

- Minimizing the dynamic response in resonance peaks, if necessary;
- Passing through a critical speed; - Avoiding instability;
- Minimizing vibrations and loads transmitted to machine structure throughout the period of operation.

The critical speeds by which a machine can pass until reaching its operating speed become one of the major inconvenient in rotor dynamics. At these speeds, the machine shaft can reach higher amplitudes of vibration that can cause irreversible damage to the bearings and to other components of the rotor. In the case of a rotor shaft with conventional materials, the possible ways to reduce the amplitude of critical speeds is to balance the rotor, which means go to the source of the problem – however, it is very difficult to balance a rotor with perfection. We can also change machine speed rotation to avoid critical speeds, or change the speed by varying the rigidity of the bearings. If the machine must operate at a critical speed, the solution is to add external damping to the rotor. This property can be used in rotor dynamics, when it is necessary to reduce the amplitudes of vibration if the machine is at a critical speed. It is also necessary to have simplifying hypotheses that make the numerical model practical, without mischaracterizing its behavior.

IV. MODELLING OF THE ROTATING MACHINERY FRAME STRUCTURE

The structure of Steel frame rotating motor is modeled using the finite element software STADD PRO. The analytical models of the structure include all components that influence the mass, strength, stiffness and deformability of structures. The structural system consists of beams, columns, wall, braces, and foundation. Beams and columns are modeled as two noded beam elements with six DOF at each node. The main two cases are carried out using software STADD PRO. The model consists of 2 motor-pump sets (electric motor and hydraulic pump) on a platform (steel frame), Figures 1 and 2, one with its axis oriented transversely to the frame and the second with its axis oriented longitudinally. According to the STAAD program, we are considering the transverse displacements as X3, longitudinal displacements as X1 and vertical displacements as X2.

Information about the Electrical Motor:
Total Mass: MTm = 9,448 kg
Quality of the unbalancing: Q = 2.5 mm/s
Operation frequency: f = 60 Hz
Information about the Pump KSB RDLO 350 575:
Total Mass: MT b= 2,600 kg

The model can be analyzed by four means i.e. four different cases will be studied.

Case I : Single floor structure with diagonal bracings between side span columns.
Case II : Single floor structure without diagonal bracings
Case III : Double floor structure without diagonal bracings
Case IV : Double floor structure with diagonal bracings

One machine is placed in the openings of the upper level. The machine is not modeled and will only be represented by the dead load and the centrifugal forces they produce. The self-weight of the steel frame in the +Z-direction and an additional surface load of 0.48 Kn/m2 are defined. This Load Case will be imported as mass. Each of the machines has a self-weight of m = 62.16 slug. This dead load is acting as line loads on the adjacent members and is defined in load case 2.

The mass of the rotor (mR = 21.76 slug) rotates with 320 rpm at an eccentricity of e = 0.75 in. The centrifugal force Fr acts perpendicular to the rotational movement. To perform a time history analysis with the Direct Integration the eigenvalues and mode shapes are not required. The solution is done via a time step integration with the entire MDOF system. Important for the accuracy of the solution with the direct integration is the choice of the time step which is explained in more detail in the next section. Nevertheless, it is important to know the behavior of the structural system and to analyze the natural frequencies in order to understand possible cases of resonance. In the Natural Vibration Analysis, a diagonal mass matrix is considered and the masses are acting in the three translational directions X, Y and Z. The rotational degree of freedoms are also taken into account.

only the self-weight of the steel frame and the machine are of relevance. The load cases load case 1 and load case 2 are imported as masses into the module Stadd Pro. Two Mass Cases are defined with mass case 1.Mass case 2 is defined similarly with load case2.

The illustrated mode shape with a natural frequency of f = 5.36 Hz is very close to the excitation frequency of the machines fe = 5.33 Hz. When you perform a time history analysis, the use of the consistent mass matrix should be considered. The consistent matrix distributes the masses more equally over the members and this results in more local mode shapes to be identified. The consistent matrix has been checked for comparison reasons in this example, and a diagonal mass matrix was found to be sufficient.

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Model 1: Case 1:

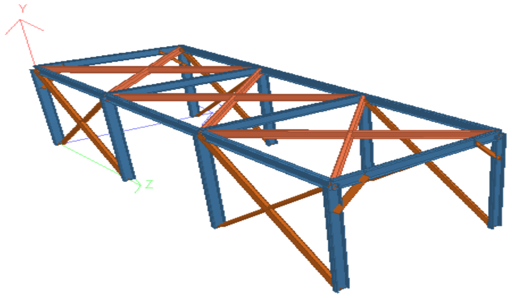


Figure 1. Case I : Single floor structure with diagonal bracings between side span columns

Model 2: Case 2:

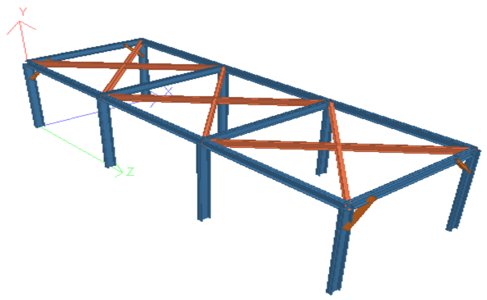


Figure 2. Case 2: Single floor structure without diagonal bracings

Model 3: Case 3:

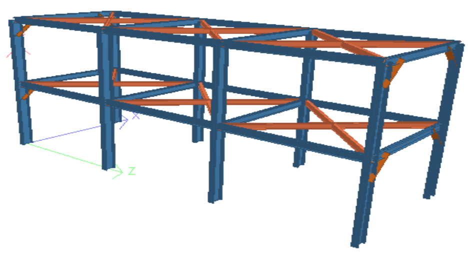


Figure 3. Case 3: Double floor structure without diagonal bracings

Model 4: Case 4:

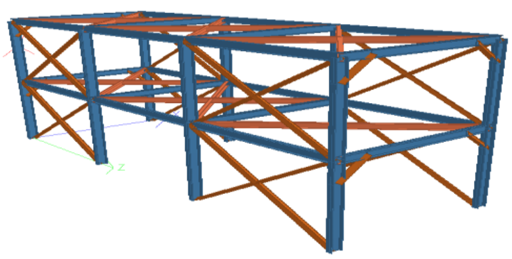
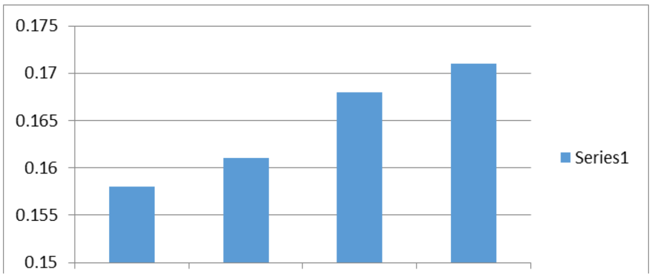


Figure 4. Case 4: Double floor structure with diagonal bracings

V. RESULTS AND DISCUSSION

Variation in displacements for rotating machinery for different models

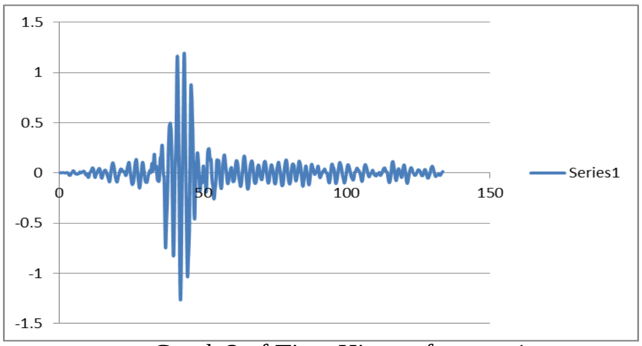


Graph 1 Displacement Variation for all cases

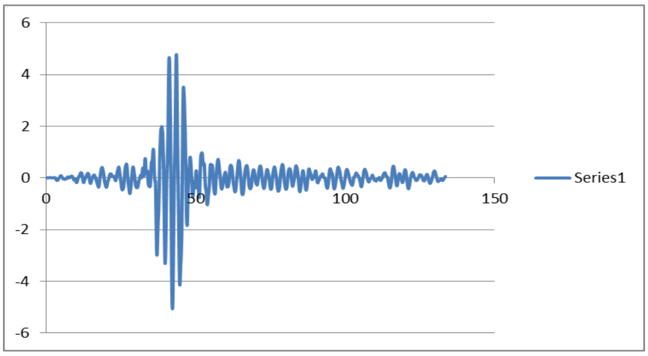
Table 1 Displacement Variation for all cases

MODEL	Case1	Case2	Case3	Case4
DISP	0.158	0.161	0.168	0.171

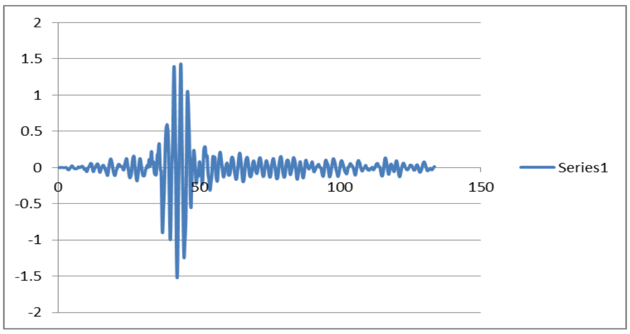
Results for acceleration for all cases of steel frame structures



Graph 2 of Time History for case 1



Graph 3 of Time History for case 2



Graph 4 of Time History for case 3

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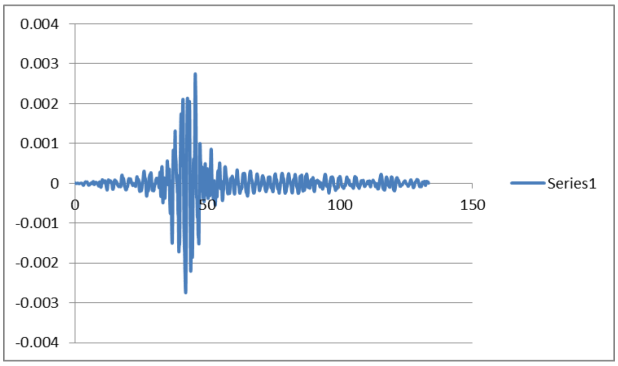


Graph 5 of Time History for case 4

From above two graphs we observed, the base shear value of case 3 and case 4 are 604KN and 725 KN respectively . Here we observed the story level are same in both case but due to provision of diagonal bracing in case 4 we are getting max Base shear which will helps in reducing lateral drift in structure.

Table 2 Max base shear for steel frame rotating machine structure

Different Cases	Maximum Base Shear(Bhuj Earthquake)
Case 1	504.1228
Case 2	504.1228
Case3	604.9474
Case 4	725.9369

When we compare case 1 with case 4 then here we observed, the base share value is directly proportional to the story level.

Response Spectra Analysis

Response Spectra diagram for Case 1

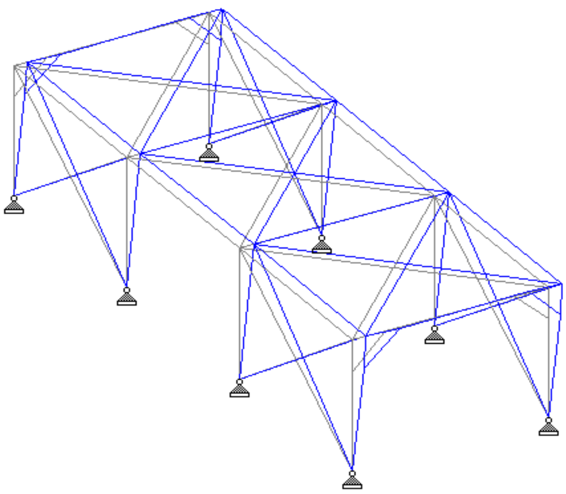
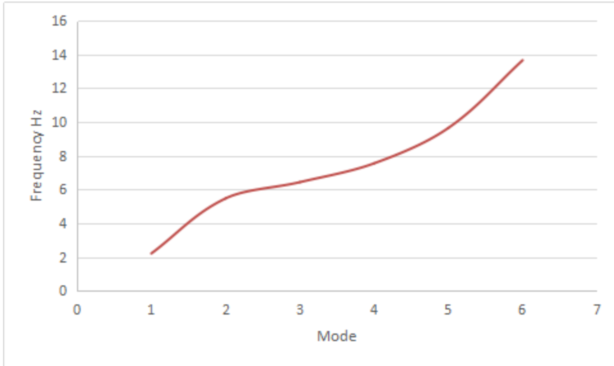


Figure 5 Case 1

Table 3 Responce Spectra for Case 1

Mode	Frequency Hz	Period seconds	Participation X %	Participation Y %	Participation Z %	Type
1	2.218	0.451	99.864	0	0	Elastic
2	5.476	0.183	0	0	8.673	Elastic
3	6.438	0.155	0.005	0	0.229	Elastic
4	7.552	0.132	0	0	5.652	Elastic
5	9.648	0.104	0	0	0.001	Elastic
6	13.654	0.073	0	0	0.147	Elastic



Graph 6 Mode shape vs Frequency for case1

Table 4 Response Spectra for Case 2

Mode	Frequency Hz	Period seconds	Participation X %	Participation Y %	Participation Z %	Type
1	0.719	1.391	0	0	99.99	Elastic
2	2.214	0.452	96.877	0	0	Elastic
3	2.55	0.392	2.988	0	0.002	Elastic
4	5.687	0.176	0	0	0.002	Elastic
5	7.759	0.129	0	0	0	Elastic
6	9.635	0.104	0	0	0	Elastic

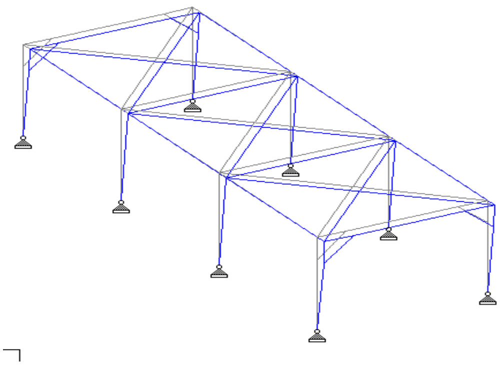
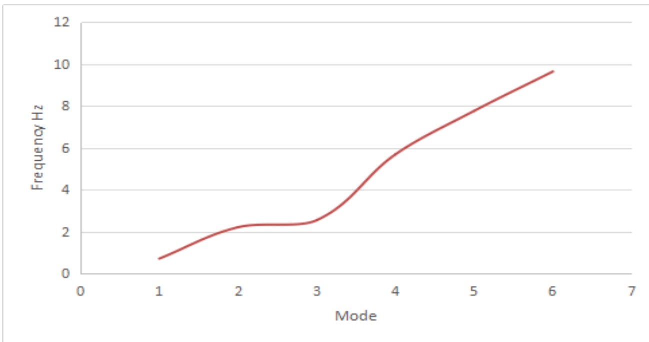


Figure 6 Case 2



Graph 7 Mode shape vs Frequency for case 2

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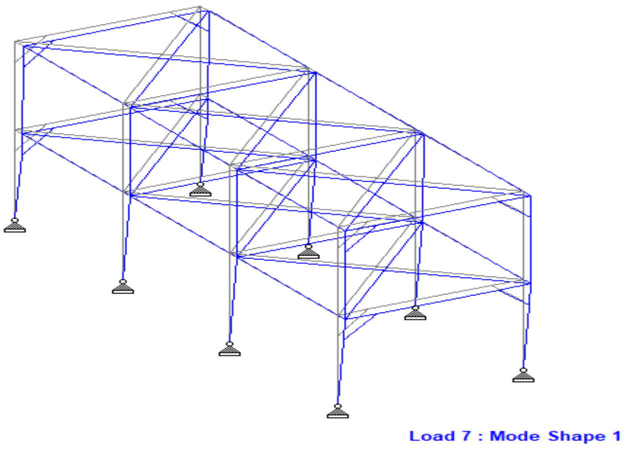
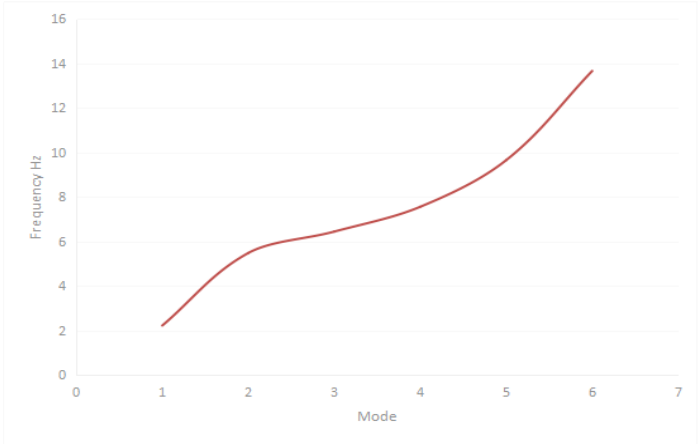


Figure 7 Case 3

Table 5 responce spectra for Case 3

Mode	Frequency Hz	Period seconds	Participation X %	Participation Y %	Participation Z %	Type
1	1.003	0.997	0	0	99.959	Elastic
2	2.821	0.354	95.955	0	0	Elastic
3	3.203	0.312	2.896	0	0.003	Elastic
4	5.717	0.175	0	0	0.004	Elastic
5	7.777	0.129	0	0	0	Elastic
6	9.121	0.11	0	0	0.025	Elastic



Graph 8 Mode shape vs Frequency for case 3

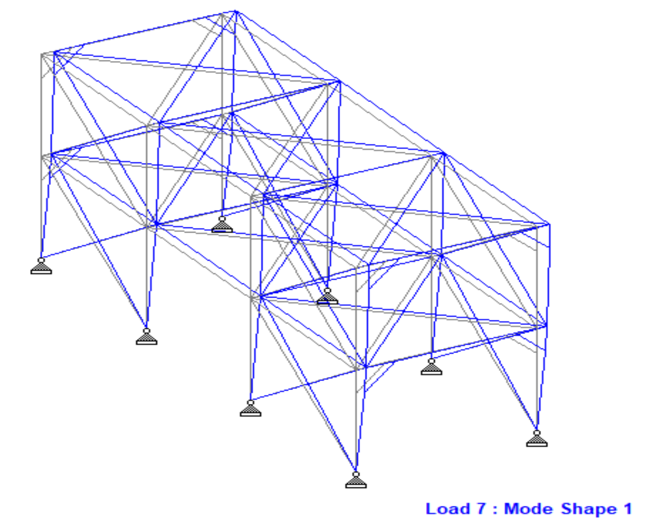
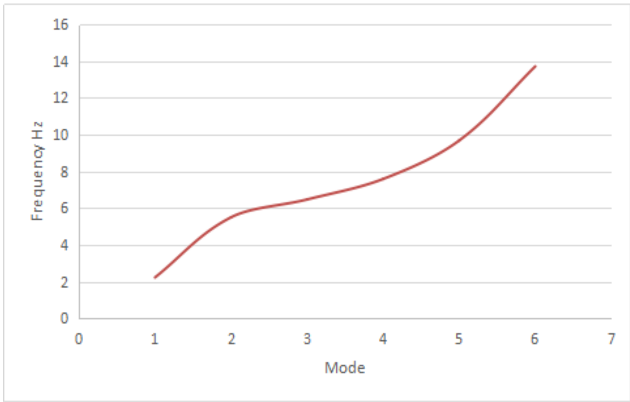


Figure 8 Case 4

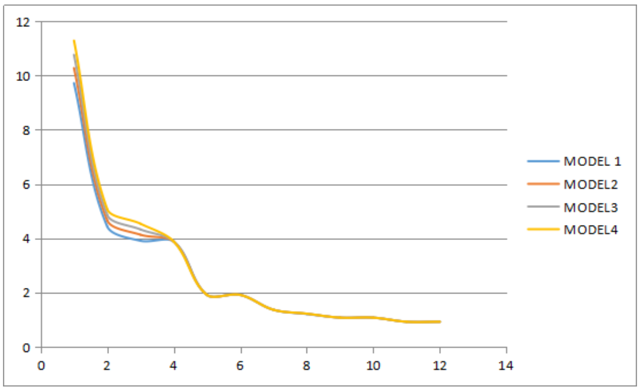
Table 6 Responce Spectra for Case 4

Mode	Frequency Hz	Period seconds	Participation X %	Participation Y %	Participation Z %	Type
1	2.233	0.448	99.531	0	0	Elastic
2	5.504	0.182	0	0	8.355	Elastic
3	6.475	0.154	0.003	0	0.246	Elastic
4	7.59	0.132	0	0	5.541	Elastic
5	9.683	0.103	0	0	0	Elastic
6	13.714	0.073	0	0	0.248	Elastic



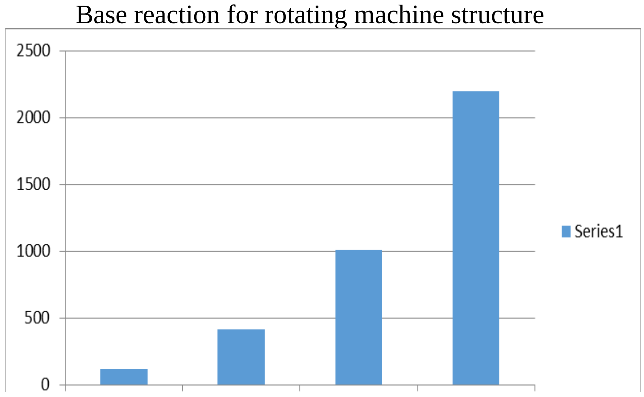
Graph 9 Mode shape vs Frequency for case 4

Comparison for variation in time period for all cases



Graph 10 Comparison for variation in time period for all cases

Base reaction for rotating machine structure



Graph 11 Base reactions for different cases

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VI. CONCLUSION

A. It was concluded that the platform displacements response spectra presented several energy transfer areas with several energy transfer peaks. This way, based on the displacements, velocities and peak acceleration values, obtained on the structural system steady-state response, it was possible to evaluate the structural model performance in terms of human comfort, the maximum tolerances of the mechanical equipment and the vibration serviceability limit states of the structure, based on the design code recommendations.

B. The results obtained throughout this investigation indicated that, for case 1 single floor structure with diagonal bracing we have maximum force is 91.1117 and maximum moment is 14.622, For case 2 Single floor structure without diagonal bracing there is maximum force 96.346 and maximum moment is 14.664. So, for these two cases as we know that for single story cases there is no change in forces and moment as we reinforced structure by extra bracing support.

C. For case 3 Double floor structure with diagonal bracing, Maximum force is 99.446 and moment is 18.356 and for case 4 double floor structure with diagonal bracings, force is 84.998 and moment is 16.833. So, form above case 3 and case 4 we conclude that there is chance for optimization for a structure by increasing the floor level and by addition of support bracings.

Here we observed, 16 to 20 % reduction in forces are occurs in case 4 due to provision of lateral and diagonal bracings. So, it is concluded, To minimized the lateral drift due to machine vibration we need to strengthen the structure by lateral and diagonal bracings.

D 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 re valuated, 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. Finally, the we would like to emphasize that further investigation will consider the study of vibration reducing techniques like base isolation or energy absorbing instrumentation at machine foundations, aiming to improve vibration performance of the investigated structural system.

APPENDIX

ACKNOWLEDGMENT

The author would like express special thanks to Dr. C. P. Pise, Prof. G. D. Lakade for his contribution in the preparation of his paper and helpful advice and for providing relevant references.

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