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BASIC DESIGN REQUIREMENTS FOR STRUCTURES SUBJECTED TO DYNAMIC ACTION

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Abstract. The existence of industrial equipment such as crushers, grinders, compressors, sieve shaker and dryer, generate vibrations in structures. As a result, displacements, velocities and accelerations appear and cause discomfort during normal human activities, operational and / or operational problems in mechanical equipment. It is, therefore, a limit state, with the definition of permissible limits in the structure to displacement, velocity and acceleration. These values are recommended by equipment manufacturers and / or international standards. This work establishes the basic requirements that must be known in the design of concrete structures subjected to dynamic actions derived from industrial equipment. In this paper, a ball mill and a dryer are discussed as case studies. For the numerical modeling of the proposed problem, was used the Finite Element Method (FEM).

1 INTRODUCTION

Analysis and design of a structure should be made taking into account the technical and safety requirements and performance combined with the low final cost and economic use during their lifetime. Briefly, the structure must resist, with certain reservations, the most critical combinations of loads planned for his entire life. Therefore, it should be taken reference values of displacement, velocity and acceleration to assess whether the structure meets the Service Limit State.

A major challenge for engineers to analyze structures subjected to vibrations involves manipulating the dynamic properties of structural systems, varying the mass, stiffness and damping of the structure so that your design meets the legislated requirements. This often involves conflicting criteria of safety, functionality and comfort of users. The basic principle of a dynamic analysis is to remove the natural frequencies of the excitation frequency, thus avoiding the resonance phenomenon and ensuring that the amplitudes of vibration have allowable values. For evaluation of the structure is usually used Verein Deutscher Ingenieure (VDI) 2056.

Below are some pictures of equipment subject to dynamic action in mining.

Figure 1: Vibrating Screen (http://www.metso.com.br)

Figure 2: Crusher (http://www.metso.com.br)

Figure 3: Ball Mill (http://www.montcalm.com.br)

2 DYNAMIC ANALYSIS OF REINFORCED CONCRETE STRUCTURES

In general, investigation of vibrations of a reinforced concrete foundation block – both either directly settled or staked – is limited to the investigation of vibrations of the solid block resting on the ground or on stakes in a semi-infinite elastic environment. Therefore, a number of simplifications must be made in structural models in order to simplify the dynamic analysis model.

Connections between displacements and soil reactions (or stake) are determined through the definition of the elastic constants of the soil (or stake). It is important to assume that the inertial mass of the soil under the foundation are not part of the model being analyzed. In general soil mass active participation is in the order of 20% the total mass of the foundation block, modifying the natural frequency of the structure in the order of 10% below the value included in the model, excluding soil mass.

3 DESIGN VALUES FOR PERMISSIBLE VIBRATION RANGES

Reinforced concrete structures subject to dynamic forces from crushers and mills work comparatively within the range of vibrations considered as low-speed (300 to 400 rpm). In contrast, concrete blocks settled on soil (or stakes) have their lowest natural frequencies within 300 and 700 rpm, therefore analyzing them requires more care in terms of dynamics, as those are structures with high risk of resonance to occur.

The base reference value for the maximum permissible displacement limit varies from 0.20 to 0.25 mm. Cautious measures are necessary in these cases, in regard to other structures foundation near the base of the equipment subject to dynamic loads. Those measures must be taken in order to avoid structural pathologies in those nearby foundations. Distance may vary between 500 and 1,000 m.

For concrete structures intended to support equipment considered as high-speed (i.e. compressors, turbine generators, which operate at 1.500 rpm and above), the base reference value for permissible displacement limit is in the range of 0.04 to 0.06 mm. For such amplitude and rotation values, the threshold reference acceleration value is 0.2 g.

For equipment with rotation between 1,500 rpm and 3,000 rpm, interpolations between the following recommended limits are acceptable:

- For 3,000 rpm:
- Vertical vibrations: 0.02 to 0.03 mm
- Horizontal Vibrations: 0.04 to 0.05 mm
- For 1.500 rpm:
- Vertical vibrations: 0.04 to 0.06 mm
- Horizontal vibrations: 0.07 to 0.09 mm

For better detail of permissible velocities values in the design of steel and concrete structures, ranges can be adopted within the values below, recommended by VDI 2056, for the effective velocity, considering the equipment in operation:

- Turbine generators:
- Optimum range 0.7 to 2.5 mm/s
- Acceptable range: 2.5 to 7.0 mm/s
- Tolerable range: 7.0 to 18 mm/s
- Non tolerable range: > 18 mm/s.
- Heavy machinery (crushers, mills, vibrating screens):
- Optimum range 0.7 to 1.8 mm/s
- Acceptable Range: 1.8 to 4.5 mm/s
- Tolerable range: 4.5 to 11 mm/s
- Non tolerable range: > 11 mm/s.

4 DATA REQUIRED FOR DYNAMIC ANALYSIS

Equipment data shall be provided by the manufacturer including dynamic loads acting on structures and, where possible, with the permissible limits recommended in terms of displacement and/or velocities.

The details below must be obtained or provided:

- Operational speed of the equipment (in the start-up and in normal operation - to be used in the project).
- Characteristics, magnitude and points of application of dynamic loads produced by the equipment.
- Distribution of the equipment's static loads on foundations.
- Structural damping value to be used: in general, for concrete structures, values between 8 and 10% of critical damping can be adopted, and for steel structures, values between 3 and 5% can be adopted.
- Special care is required in cases of inertial mass oscillation having impact on structures. As this makes necessary that "full" and "empty" loading conditions are present, usually in structures with tanks and/or storage silos.

5 CASE STUDIES

For this article we analyzed two bases civilians subjected to dynamic action. The first is a base of a ball mill and the other is based on a dryer.

5.1 Ball Mill

Below is a sketch of the mill studied.

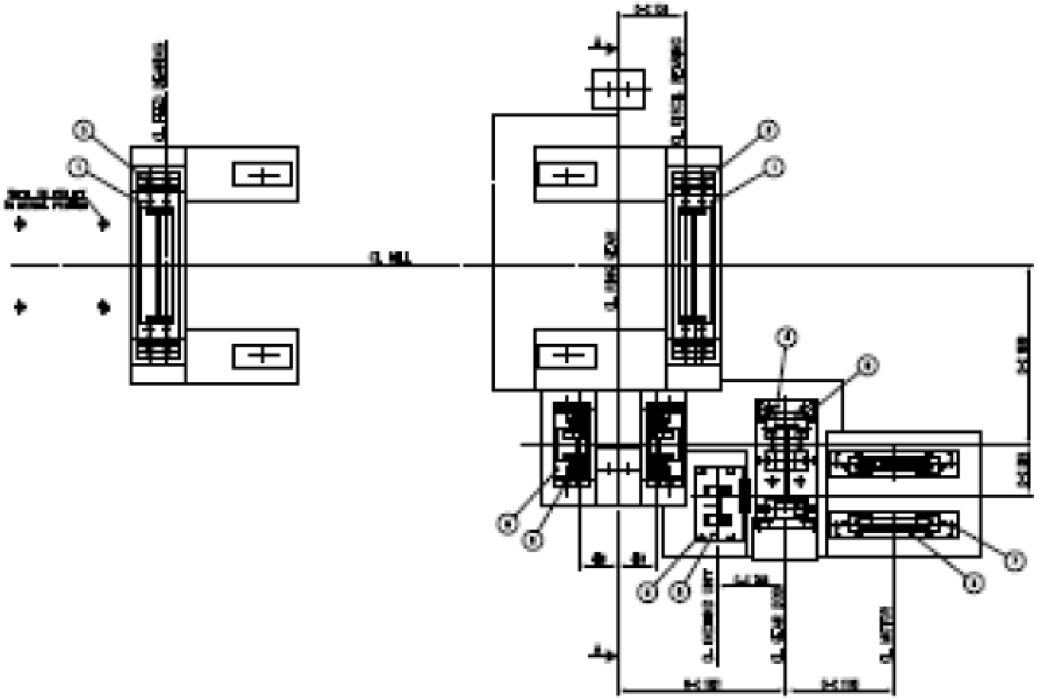

Figure 4: Plan View of the Ball Mill

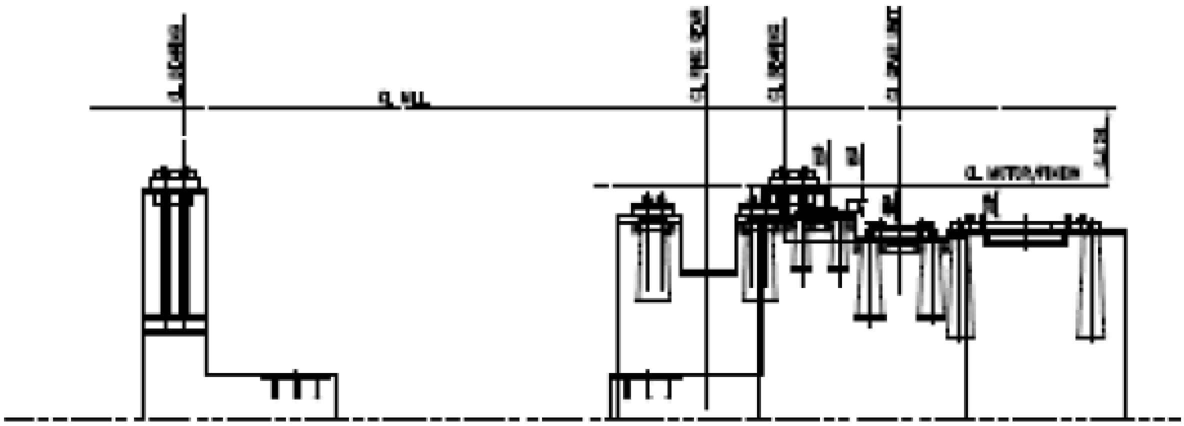

Figure 5: Side View of the Ball Mill

Below the three-dimensional model of the mill base in reinforced concrete.

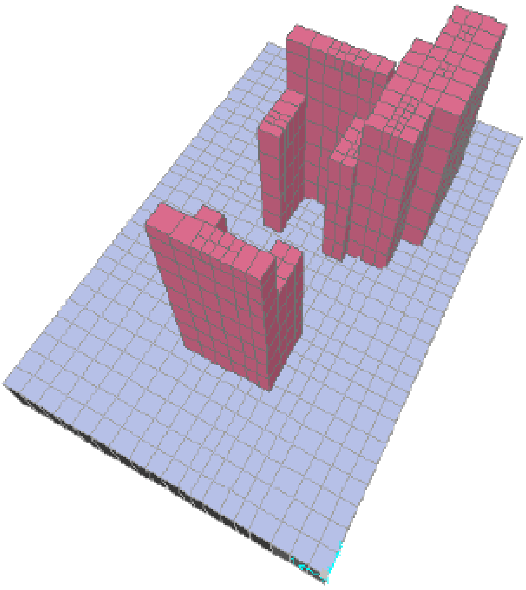

Figure 6: Three-Dimensional Numerical Model Base Mill

5.1.1 Loads and Numerical Model Considerations

	x	y	z
Ff		±0,1 tf	±0,2 tf
Fd	±0,2 tf	±0,02 tf	±0,9 tf
Fpf		±0,1 tf	±0,55 tf
Fpd	±0,2 tf	±0,02 tf	±0,5 tf

Table 1: Dynamic loads (continuous load during Max Power) - DINCASO1 and DINCASO2.

	x	y	z
Ff		-0,5 tf	+0,5 tf
Fd		-0,5 tf	+0,5 tf

Table 2: Dynamic loads (continuous load during max charge) - DINCASO3.

Excitation frequency of the mill = 19.8 rpm = 0,33Hz → T = 3,03 s.

5.1.2 Results

Results to DINCASO1 and DINCASO2:
Node 3143 (application point of Ff),
Node 3161 (application point of Fd),
Node 3189 (application point of Fpf) and
Node 3197 (application point of Fpd).
Ux=0,04 mm < 0,20 mm ok
Uy=0,04 mm < 0,20 mm ok
Vx=0,13 mm/s ok
Vy=0,11 mm/s ok < 0,7 mm/s → within the range considered optimal by VDI 2056.

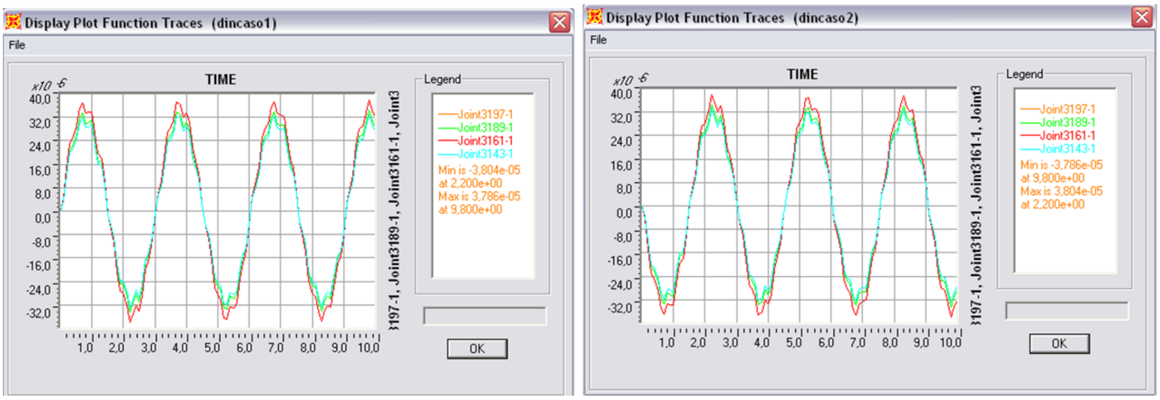

Figure 7: Displacement Analysis (m) Uxx

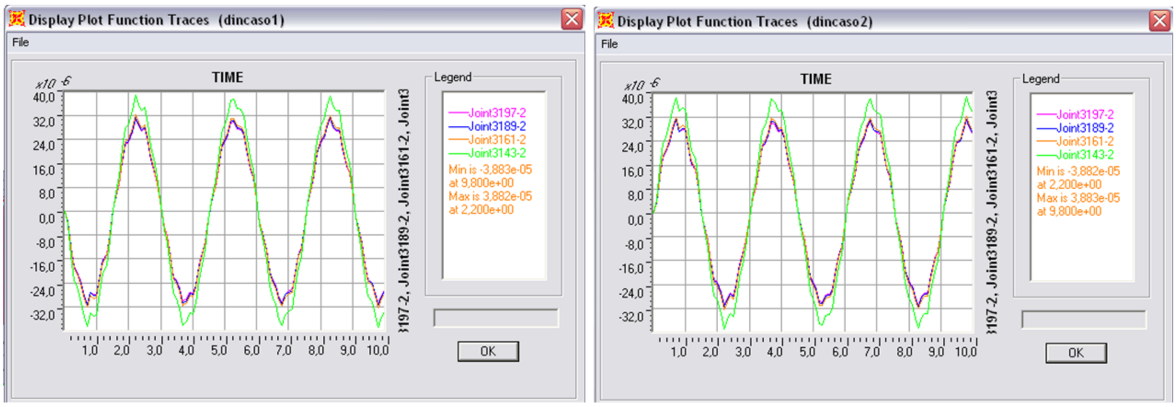

Figure 8: Displacement Analysis (m) Uyy

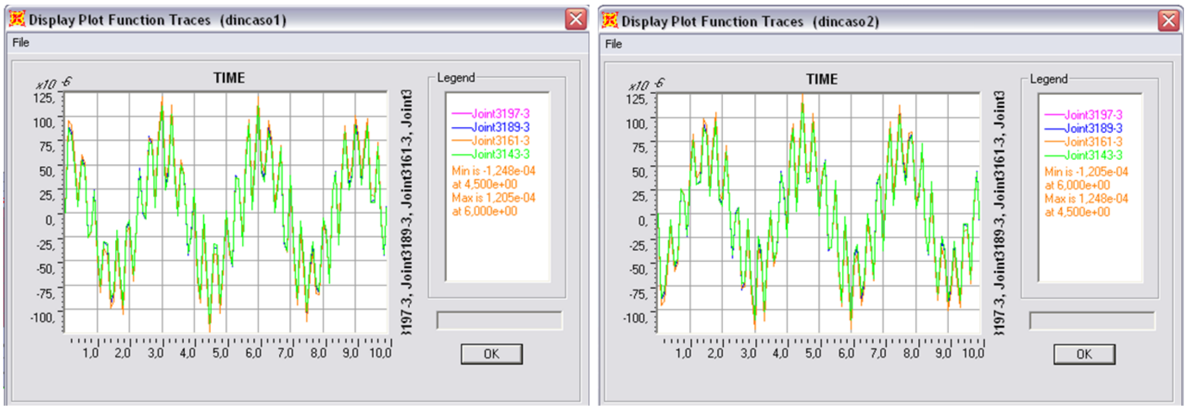

Figure 9: Speed Analysis (mm/s) Vxx

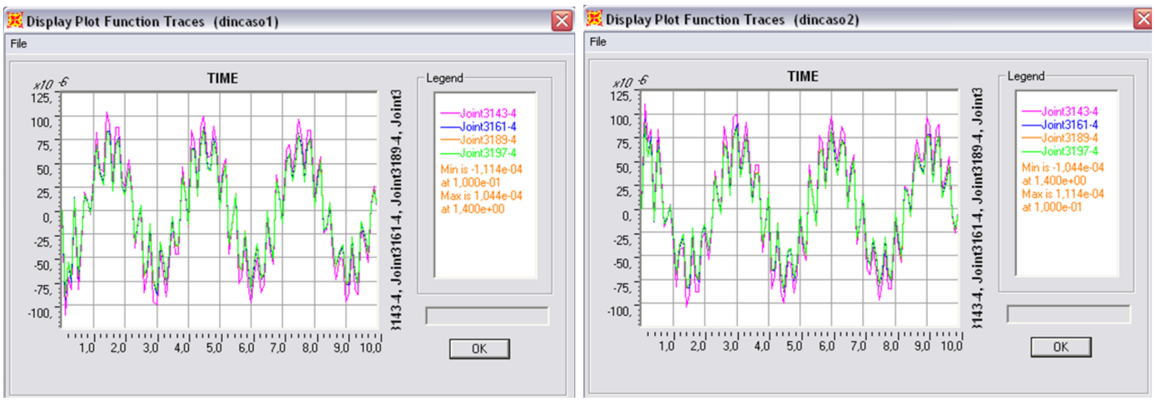

Figure 10: Speed Analysis (mm/s) Vyy

Results to DINCASO3:
Node 3143 (application point of Ff),
Node 3161 (application point of Fd),
Ux=0,005 mm < 0,20 mm ok
Uy=0,098 mm < 0,20 mm ok
Vx=0,05 mm/s ok
Vy=0,26 mm/s ok < 0,7 mm/s → within the range considered optimal by VDI 2056.

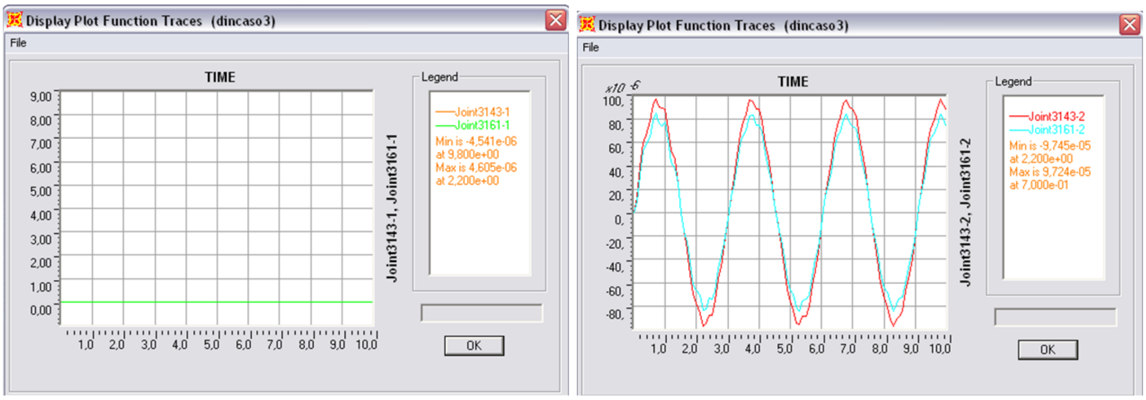

Figure 11: Displacement Analysis (m) Uxx e Uyy

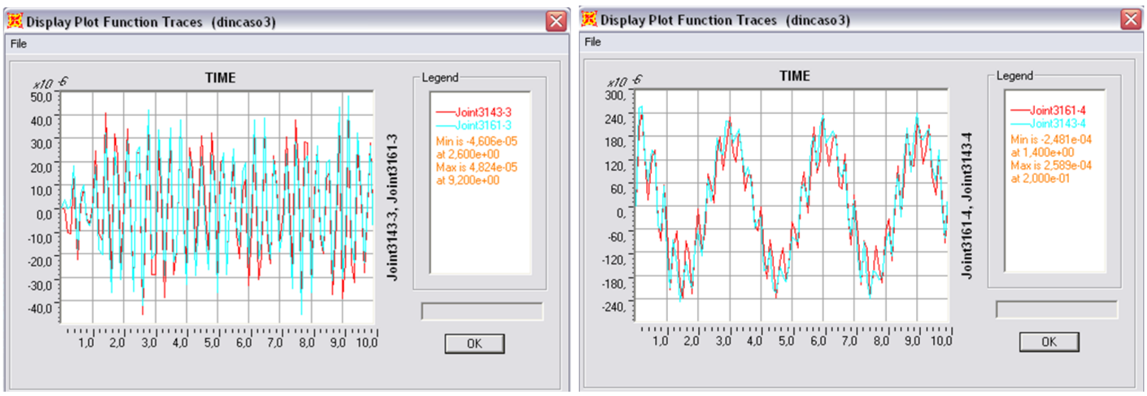

Figure 12: Speed Analysis (mm/s) Vxx e Vyy

5.1.2.1 Modal Analysis

Below are presented the results in modal analysis for the project under study.

OutputCase Text	StepType Text	StepNum Unitless	Period Sec	Frequency Cyc/sec	CircFreq rad/sec	Eigenvalue rad2/sec2
MODAL	Mode	1	0,338281	2,9561	18,574	344,99
MODAL	Mode	2	0,326223	3,0654	19,26	370,96
MODAL	Mode	3	0,291194	3,4341	21,577	465,58
MODAL	Mode	4	0,167021	5,9873	37,619	1415,2
MODAL	Mode	5	0,144135	6,9379	43,592	1900,3
MODAL	Mode	6	0,137822	7,2557	45,589	2078,4
MODAL	Mode	7	0,057132	17,503	109,98	12095
MODAL	Mode	8	0,047484	21,06	132,32	17509
MODAL	Mode	9	0,034232	29,212	183,55	33689
MODAL	Mode	10	0,029273	34,161	214,64	46069
MODAL	Mode	11	0,028177	35,49	222,99	49725
MODAL	Mode	12	0,022398	44,647	280,52	78693

Figure 13: Modes of Vibration and their Natural Frequencies

The values of the velocities and displacements present values below the limit values.

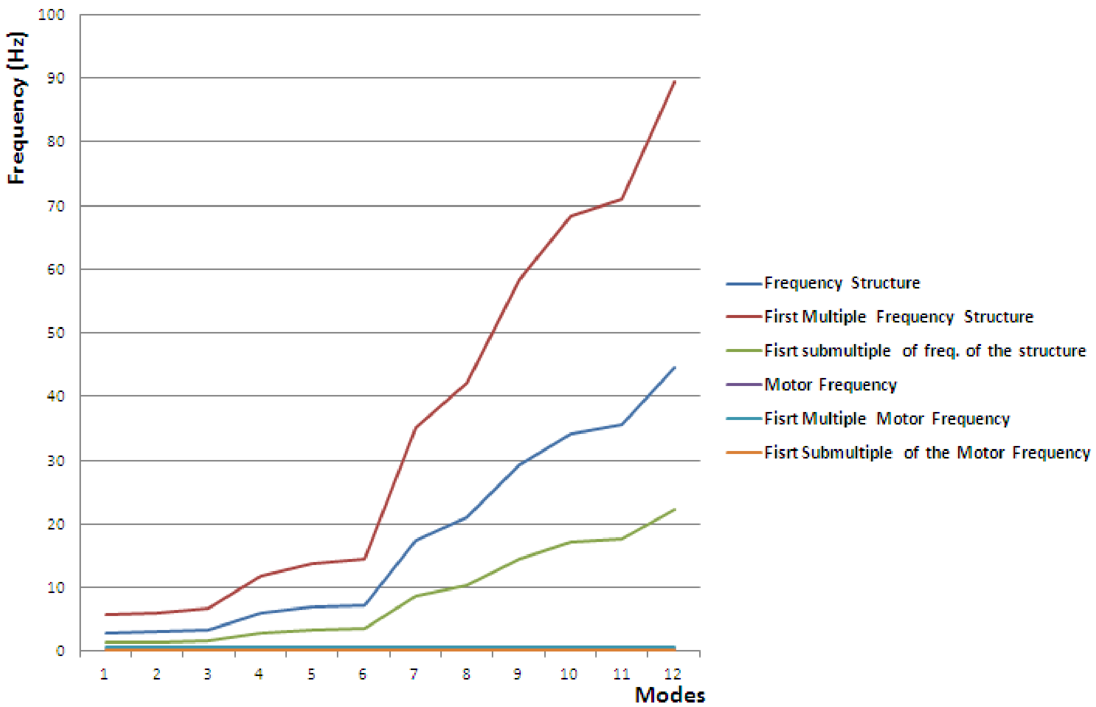

Figure 14: Analysis of Modal Response

As evidenced by the graph above, the natural frequencies of the base of the dryer are outside the limits of the frequencies of the motor. Was analyzed, in particular the possibility of coupling of these frequencies and its first multiples and submultiples, with no indication of resonance.

5.2 Dryer

Below is a sketch of the base of the dryer studied.

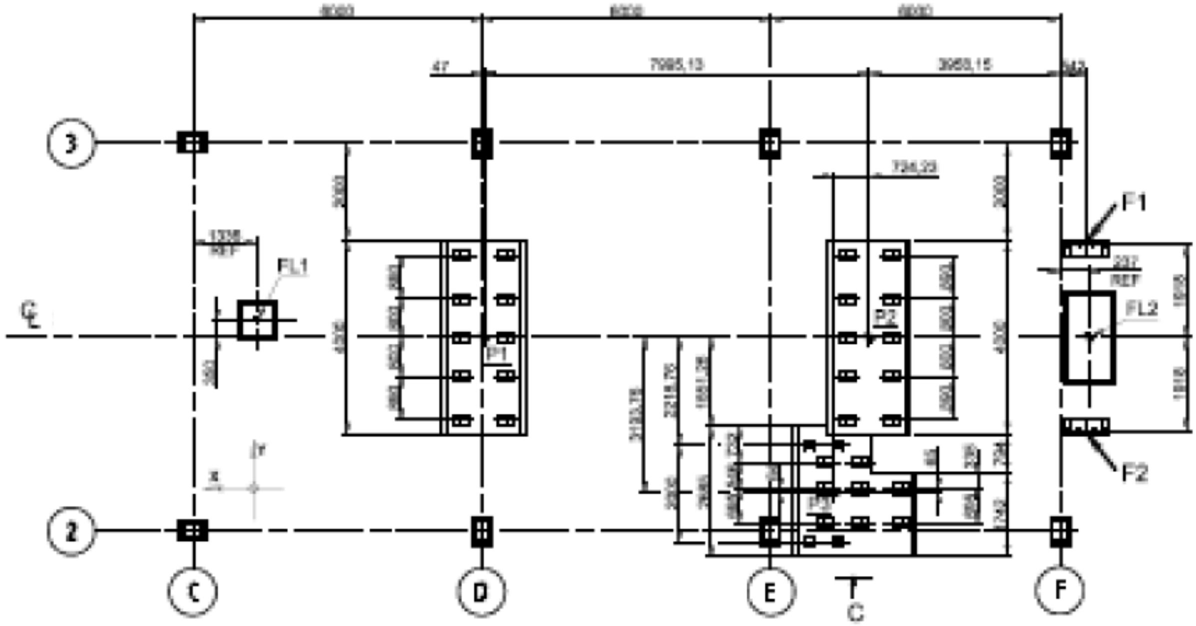

Figure 15: View of the Drier Plant

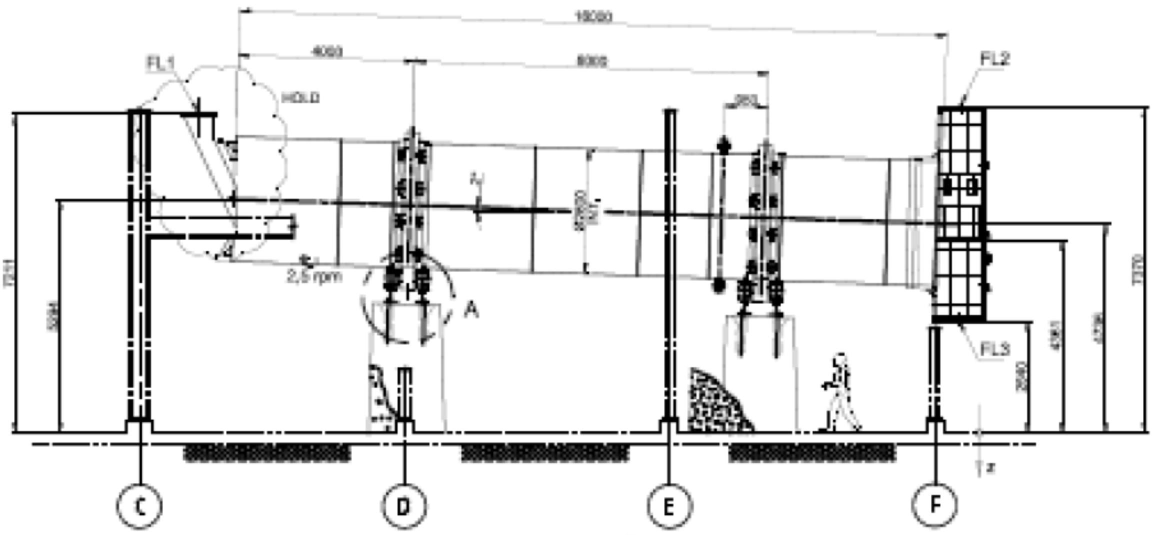

Figure 16: Side View of Drier

Below the three-dimensional model of the mill base in reinforced concrete.

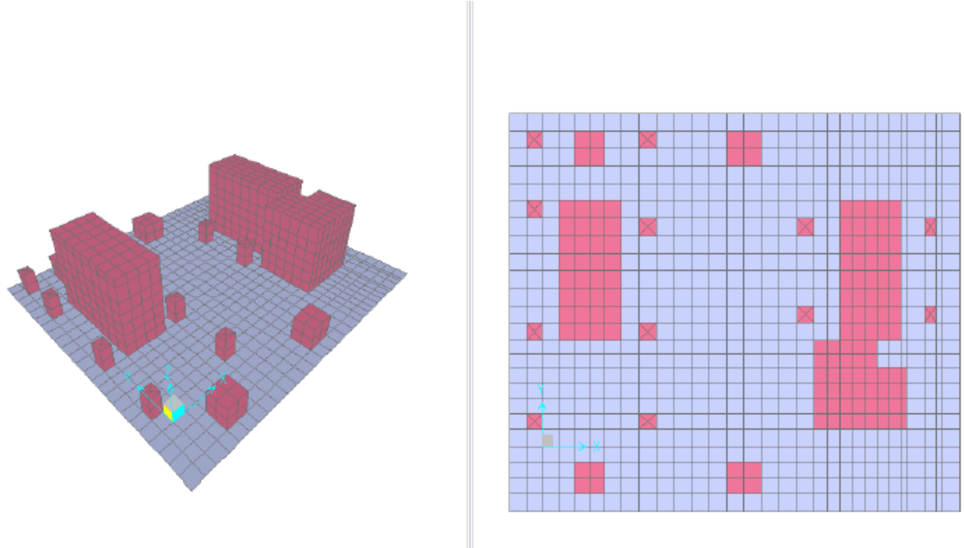

Figure 17: Three-Dimensional Numerical Model of Drier

5.2.1 Loads and Numerical Model Considerations

Below is the load used in this numerical modeling.

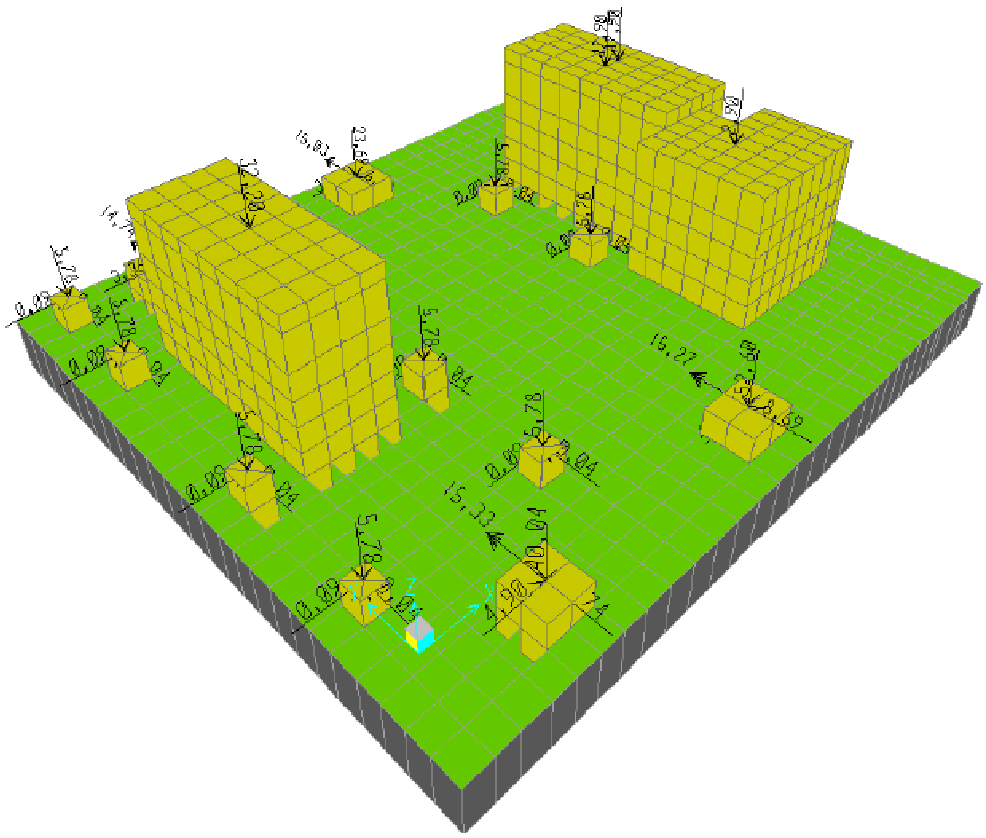

Figure 18: Applied Loads on the Model

Excitation frequency of the rotary dryer = 2.5 rpm = 0,04Hz → T = 24 s.

5.2.2 Results

Results to DINCASO1:
Ux=0,08 mm < 0,20 mm ok
Uy=0,02 mm < 0,20 mm ok
Uz=0,01 mm < 0,20 mm ok
Vx=0,03 mm/s ok
Vy=0,01 mm/s ok
Vy=0,01 mm/s ok < 0,7 mm/s → within the range considered optimal by VDI 2056.

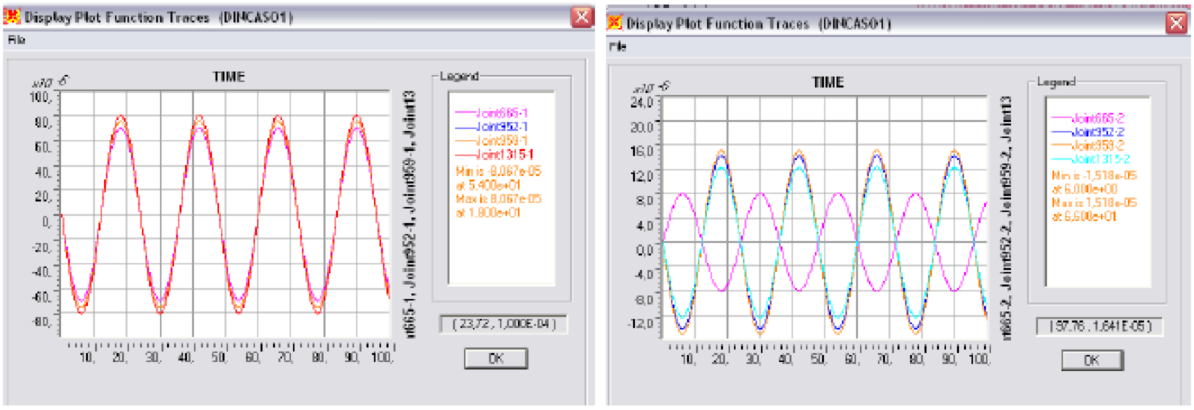

Figure 19: Displacement Analysis (m) Uxx e Uyy

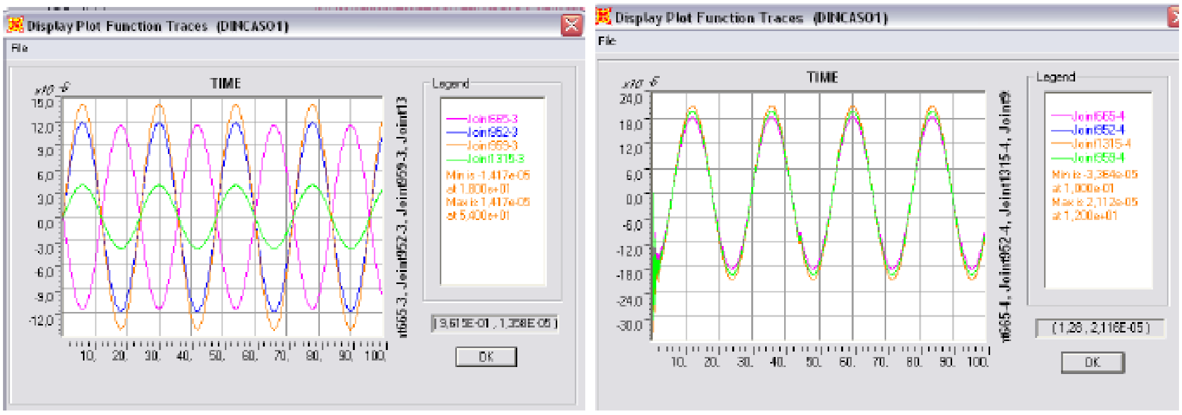

Figure 20: Displacement analysis Uzz(m) and speed Vxx (mm/s) respectively

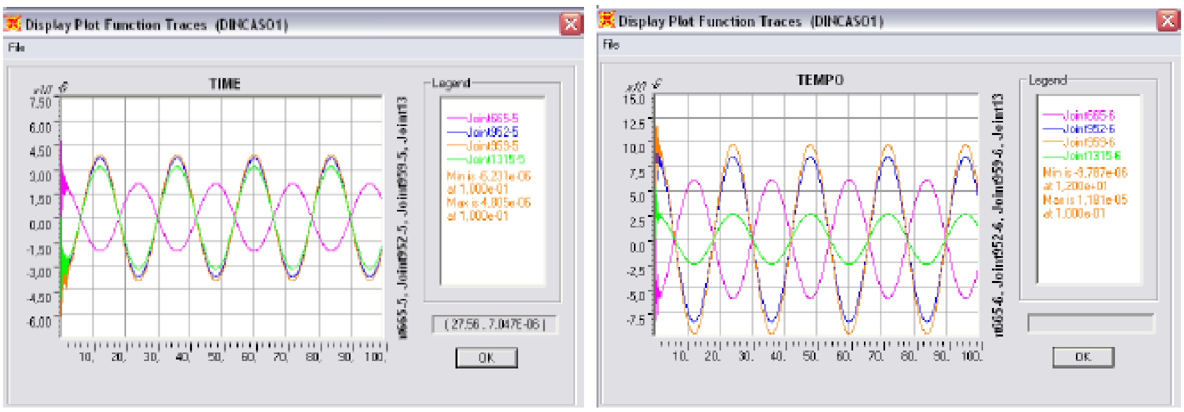

Figure 21: Speed analysis Vyy (mm/s) and Vzz respectively

The values of the velocities and displacements present values below the limit values.

5.2.2.1 Modal Analysis

OutputCase Text	StepType Text	StepNum Unitless	Period Sec	Frequency Cyc/sec	CircFreq rad/sec	Eigenvalue rad2/sec2
MODAL	Mode	1	0,250286	3,9954	25,104	630,21
MODAL	Mode	2	0,244703	4,0866	25,677	659,3
MODAL	Mode	3	0,234379	4,2666	26,808	718,66
MODAL	Mode	4	0,116913	8,5534	53,742	2888,2
MODAL	Mode	5	0,112446	8,8931	55,877	3122,3
MODAL	Mode	6	0,105758	9,4555	59,411	3529,6
MODAL	Mode	7	0,080142	12,478	78,401	6146,7
MODAL	Mode	8	0,073667	13,575	85,292	7274,7
MODAL	Mode	9	0,051473	19,428	122,07	14901
MODAL	Mode	10	0,043472	23,003	144,54	20890
MODAL	Mode	11	0,043237	23,128	145,32	21117
MODAL	Mode	12	0,042764	23,384	146,93	21587

Figure 22: Modes of vibration and their natural frequencies.

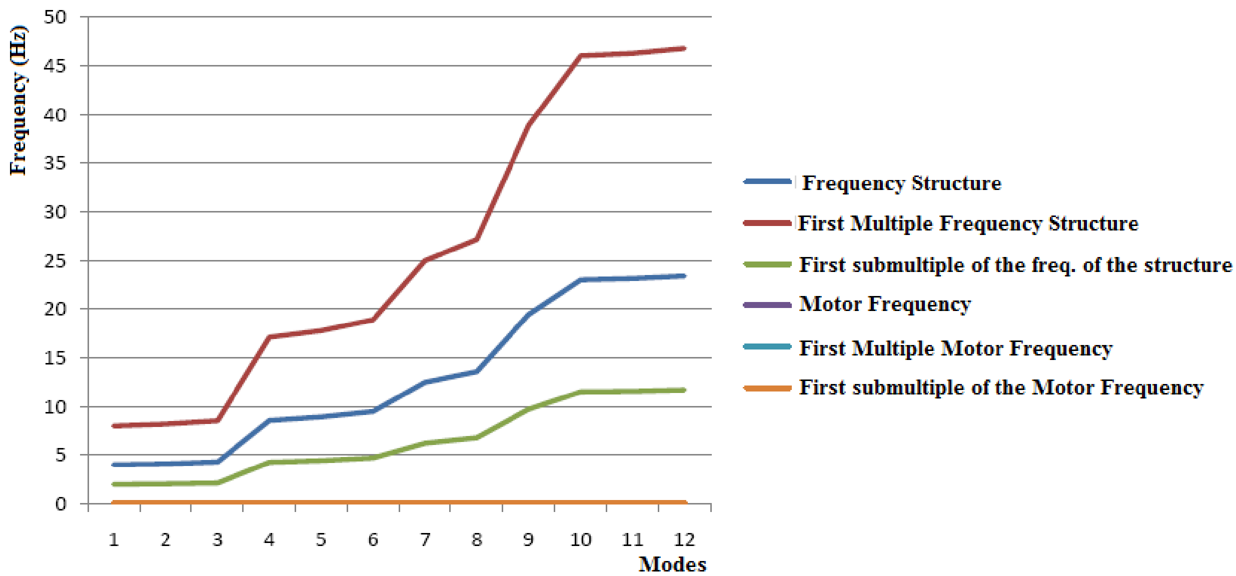

Figure 23: Analysis of Modal Response

The natural frequencies of the base of the dryer are outside the limits of the frequencies of the motor and there is no indication of resonance for this case neither.

6 CONCLUSION

This paper presented the basic requirements that must be met in the design of concrete structures subjected to dynamic action derived in general for industrial equipment.

Two case studies were discussed in this paper, a ball mill and a rotary dryer. Values of velocity and displacement of specific points of the bases of equipment were compared with reference values of VDI 2056. In two case studies analyzed the velocity and displacement values found were lower than the allowable.

Was also performed for the two models studied an analysis of the natural frequency of the base of equipment. It was found that these frequencies are outside the limits of the frequency of the motor and therefore no risk of resonance of the structure.

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