THE DYNAMIC ANALYSIS OF MILL FOUNDATION

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Introduction

This paper deals with the dynamic analysis of mill foundation in Cement Factory, Beocin ("BFC Lafarge"). The aim of this analysis was to calculate the dynamic properties of foundation system i.e. to estimate the displacements of foundation subjected to defined spectra of dynamic load.

Description of mill fundament

Foundation of mill is presented in Figure 1. It consists of massive concrete block with main dimension 7.5m×9.4m and thickness is 3.8m. This concrete block is placed over 26 concrete piles Φ406, which are 11.5m long. Position of these piles is also given in Figure 1.

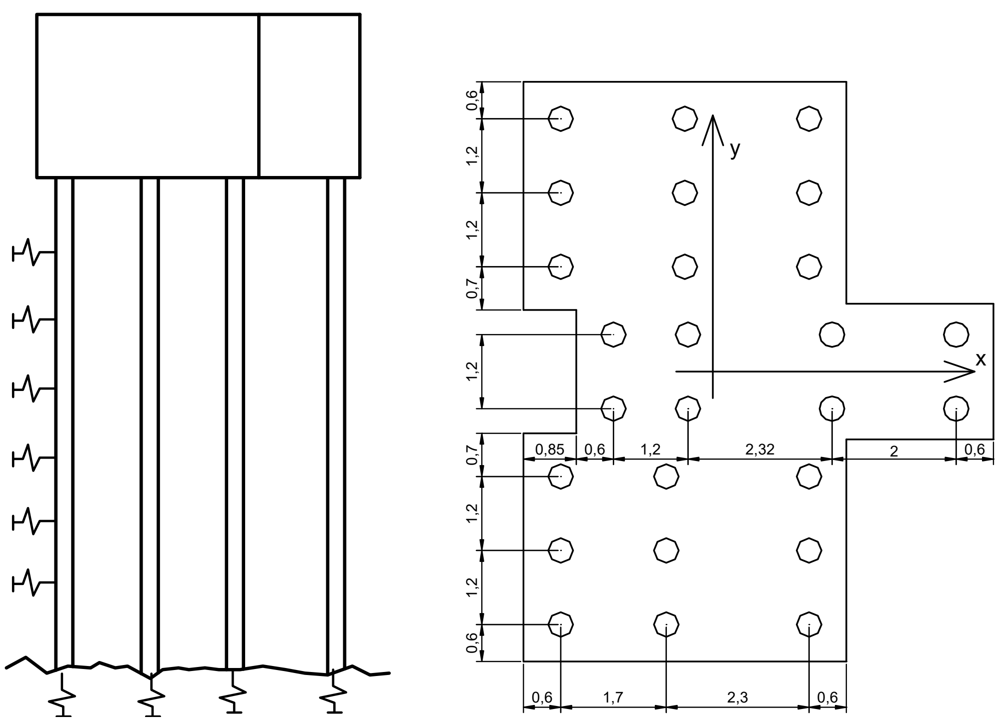

Figure 1. Massive foundation block and piles positions

Over the massive concrete block, there is mill with the mass of 178500kg. The mill produces dynamic force P_{din} = 865 kN in frequencies range of 1.0 – 1.5 Hz. The mass of the mill and the foundation is all together is 669000kg. In the dynamic analysis, the mill and concrete block were assumed to be rigid, i.e. they were considered as rigid body. This assumption results in reduction of degrees of freedoms for dynamic analysis to

six. Position of mass center of this rigid body (concrete block and the mill) is shown in Figure 2, where CB is mass center of concrete block, CM is mass center of mill and CS is mass center of the rigid body.
The rigid body has mass moments reduced to center of mass of Ix_C =7663831 kg m^2, Iy_C = 5901624 kg m^2 and Iz_C = 4954115 kg m^2.

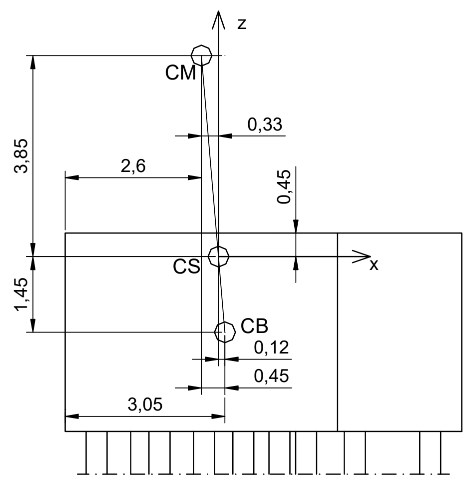

Figure 2. Locations of the center's of masses

Dynamic analysis

Dynamic analysis was performed taking into account soil-structure interaction. Influence of the soil to the behavior of mill foundation system was modeled using elastic supports with appropriate dynamic characteristic. These characteristics of soil were calculated, based on coefficients of elastic deformations for horizontal and vertical dynamic load. The properties are based on soil type and depth of soil and load level.

The distribution of forces to piles, deformability of system and dynamic properties of system were obtained from analysis of elastic system, using Finite Element Method. The graphical presentation of model is presented in Figure 3. The concrete block were modeled using thick plate finite elements (depth of plate is 3.8m), leading to almost rigid body (relative deformation of this plate in compare with deformations of other parts of system was negligible) . Using this elements we also obtain the correct values for moments of mass of this concrete block. Un deformability of piles inside the plate was modeled using very stiff supporting frame. The material for frame elements in supporting frame had small value of volume mass and large value for modulus or elasticity. The same frame element properties were used in "upper part frame", over the plate. The "upper part frame" connects the point of "Center of Mass of Mill" – CM in fig. 2 and the point of "center of mass of rigid system"-CS in fig.2 , with plate. In the node at the point of "Center of Mass of Mill", the mass characteristic of mill is assigned.
The piles were modeled using the frame elements with circular cross section and material properties of concrete.

The characteristics of springs at pile base are calculated from elasticity coefficients "C" for soil's of corresponding type and depth. The rigidity of vertical springs at pile base is:

$$K_z = \frac{A \cdot C}{n} = \frac{49 \cdot 109000}{26} = 205423 kN/m \qquad (1)$$

K_z – rigidity of spring at pile base in z direction,
A – loaded area, e.i. area of soil loaded with pile basis
C – elasticity coefficient for soil
n – number of piles

The properties of horizontal springs were obtained from elasticity coefficients for horizontal load. Since these coefficients are functions of depth, the coefficients for depth at the middle of piles were applied. The surrounding soil is loaded thru side face of pile group area volume. This pile group area volume is the volume occupied by piles and soil just around piles. In this case, the pile group area volume is equal to volume with base of area loaded with pile basis (A) and height of piles 11.5m. The contact area of pile group area volume in x direction is 9.4×11 m giving the coefficient of elasticity in x direction of $C_x = 53100 kN/m^3$. This leads to rigidity of springs (if they are equally distributed throw all piles and placed on every meter in vertical dimension) of:

$$K_x = \frac{b_y \cdot C_x}{n} = \frac{9.4 \cdot 53100}{26} = 19201 kN/m \quad (2)$$

The contact area of pile group area volume in y direction is 5×11 m giving the coefficient of elasticity in y direction of $C_y = 60200 kN/m^3$. This leads to rigidity of springs (if they are equally distributed throw all piles and placed on every meter in vertical dimension) of

$$K_y = \frac{b_x \cdot C_y}{n} = \frac{5 \cdot 60200}{26} = 11585\ kN/m \quad (3)$$

The one half of mass of the soil in pile group area volume, is attached to piles throw the nodes (distributed equally-spaced at every meter) giving additional mass of 1600kg per node on piles.

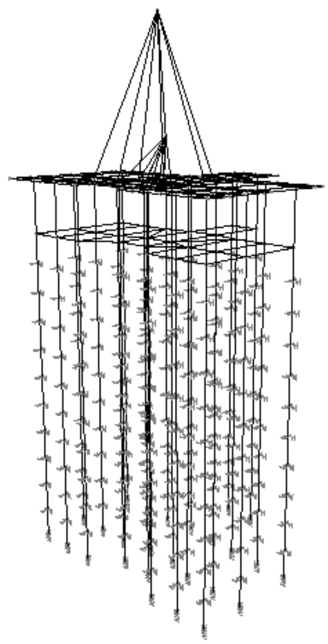

Figure 3 Finite element model of fundation system :
plate, piles and springs that represents the interaction of piles and soil

Using this finite element structural model, the lowest six natural frequencies were calculated and presented in Table 1.

	T_i (s)	ν_i (Hz)
1	0.3166	3.1586
2	0.3122	3.2031
3	0.2038	4.9068
4	0.1132	8.8339
5	0.1097	9.1158
6	0.1060	9.4340

Table 1.

Displacement of node at location at mass center of mill (CM – in fig. 2) exposed to static load is is shown in Table 2.

direction	Static displacement (mm)
X	$-9.188 \cdot 10^{-2}$
Y	0
Z	-0.2578

Table 2.

As it is known, displacement caused by dynamic load is equal to the displacement caused by static load and multiplied with dynamic coefficient (amplification).

$$y_{dyn} = y_{stat} * N_P \tag{4}$$

Amplification can be calculated from equation (5):

$$N_P = \frac{1}{\sqrt{\left(1-\left(\frac{\nu_p}{\nu}\right)^2\right)^2 + 4\zeta^2\left(\frac{\nu_p}{\nu}\right)^2}} \tag{5}$$

where: ζ - is damping (in relation with critical damping),
ν - is natural frequency,
ν_p - is frequency of dynamic load.

Diagrams of amplification for first six modes, as a function of frequencies, are drawn in Figure 4 and 5. Damping in Figure 4 is ζ=0.1, and in Figure 5 is ζ=0.2 and ζ=0.5.

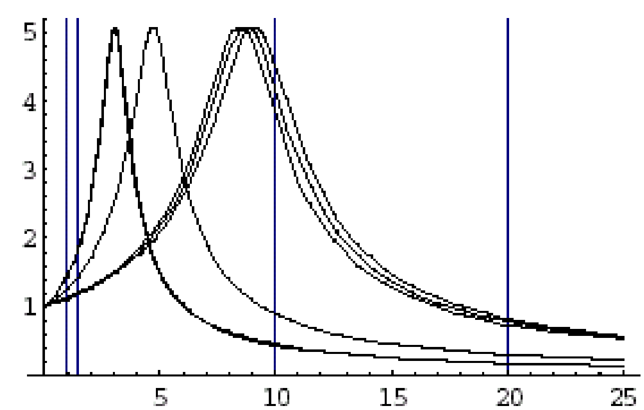

Figure 4. Amplification as a function of frequencies (for first six modes) for assumed damping of 0.1

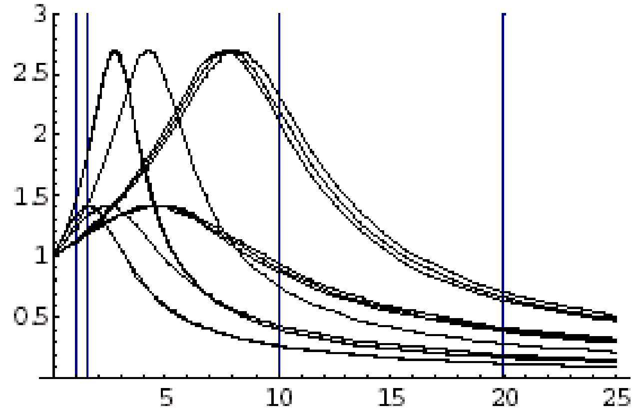

Figure 5. Amplification as a function of frequencies (for first six modes) for assumed damping of 0.2 and 0.5

Since the dynamic force is expected in frequencies area of 1 – 1.5 Hz, it is interesting to consider amplifications of system in frequencies between 1 – 1.5 Hz.

Relative vertical displacement of the point CN, (center of mass of mill (CM in figure 2)), the point where dynamic force is applied, in eigenvectors is given in Table 3. Displacements were calculated for first six modes.

Mode	Vertical displacement	Relative ratio
1	0.00128	3.9%
2	0.00000	0.0%
3	0.00000	0.0%
4	0.00000	0.0%
5	0.03121	95.4%
6	0.00020	0.6%

Table 3.

It is clear, from Table 3., that there is no vertical displacement in second, third and fourth mode. Displacement in first and sixth mode also can be neglected. It means that only fifth mode produces vertical displacement in the point where dynamic force is acting.
Diagram of amplification for fifth mode, as a function of frequencies and damping, is given in Figure 6. Damping was chosen as: 0.1; 0.2; 0.4; 0.5 and 0.7.

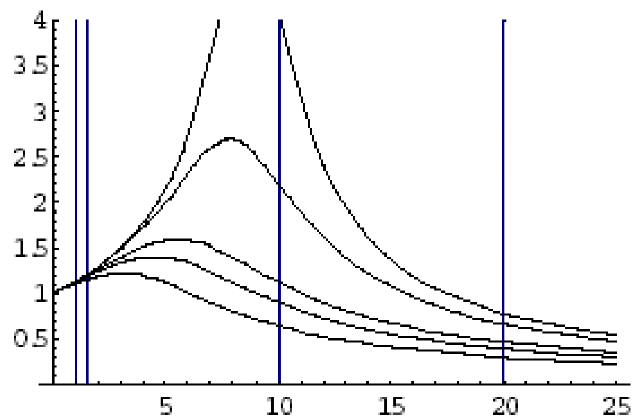

Figure 6. Amplification as a function of frequencies for the fifth mode, for damping of 0.1,0.2,0.4,0.5 and 0.7

It can be concluded, from Figure 6., that damping has a small influence to the values of amplification, when the frequencies are in area: 1 – 1.5 Hz. These amplifications are between 1.1 – 1.2 (10% - 20%).

According to presented dynamic analysis, maximum value of displacement is:

$$y_{dyn} = y_{stat} * N_P = 0.257 * 1.2 = 0.3mm \quad (6)$$

Permissible value of displacement for this kind of mill foundation is 0.4mm.

CONCLUSION

The results of dynamic analysis of structures are determined by mechanical properties of materials exposed to dynamic load. The mechanical properties of soils (i.e. modulus of elasticity, damping, etc.) are parameters that can not be considered as exact values. Variation of underground water level, or changing of stress state can significantly change these parameters. Never the less, in engineering practice we have to assume some values for these parameters and make some rough calculation in order to proves the safety behavior of structure exposed to dynamic load. The procedure presented in this paper may seems primitive and rough, but it can be successfully applied for solving this types of problems in civil engineering practice.

References:

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