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Effects of Asymmetry on Dynamically Loaded Foundations

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Abstract: Dynamically loaded foundations are subjected to long-term dynamic loads besides static loads. Dynamic loads require control of the vibration amplitudes to not to exceed the permissible limits as well as avoiding from resonance. Considering these circumstances, symmetric system designs are done. System symmetry is provided if the system's center of gravity and the support's center of rigidity are on the same vertical axis. However, this symmetry situation always cannot be maintained after the design. In this study, effects of machine placement and support rigidity change induced deviations from symmetry on vibrations of the dynamically loaded foundation systems are investigated.

***Index Terms*— Asymmetry, Dynamically loaded foundations.**

I. INTRODUCTION

DYNAMICALLY loaded foundations are under the influence of long-term dynamic loads besides to static loads. Therefore, vibrations of the system should be reviewed in the design, in addition to the strength. Control of vibrations can be achieved by avoiding from resonance and not to exceed the permissible vibration amplitude limits.

Machine foundations are the examples of dynamically loaded foundations. Machine foundation consists of machine foundation and supports. Machine and foundation's center of gravity (S) and the support's center of rigidity (O) are wanted to be on the same vertical axis. In this case, the symmetry of the system is satisfied and calculations are done easily.

System's symmetry, provided during the design, cannot be maintained in some cases. Incorrect placement of machine and its equipment, support component rigidity changes and irregularity in reinforcements are the main causes of deviation from symmetry. Deviations from symmetry resulting from incorrect placement of machine were investigated before [4-5]. In addition to this search subject, effects of support component rigidity changes caused deviations from symmetry on vibrations are investigated in this study.

II. SYSTEM AND ASSUMPTIONS

An asymmetrical machine-foundation-support system is shown in Fig. 1. Machine foundation is a rigid type block foundation. System is deviated from the symmetry in both horizontal axes perpendicular to each other. Distances between S and O along the x, y, z axes are δ_x, δ_y, δ_z, respectively. In symmetry situation, δ_x and δ_y eccentricities became 0. Dimensions of the foundation along the x, y, z axes are L_x, L_y, L_z, respectively. System's eccentricity ratio in x axis is η_x and can be calculated from (1).

$$\eta_x = \delta_x / L_x \tag{1}$$

The following assumptions were done in vibration calculations:

- Block foundation, compared with the ground lie on, can be considered as a rigid structure [6].
- Region between ±20-30% of the machine's operating frequency (ω) is called resonance zone [7]. Natural frequencies (λ) of the system should be keep out of this zone for avoiding resonance. Thus, the effect of damping on the vibration amplitudes can be neglected [8].
- A mass-spring model of the machine foundation will be composed for vibration calculation by neglecting the soil damping [9].

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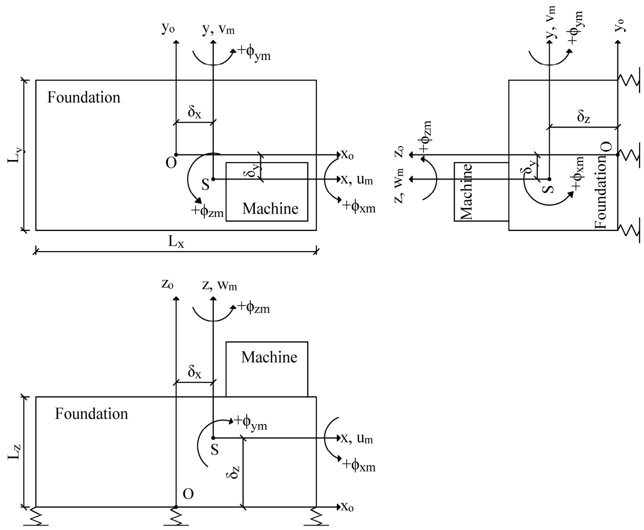

Fig. 1. An asymmetrical machine-foundation-support system.

Rigid structured block foundations have 6 degrees of freedom with 6 natural frequencies (λ) and 6 forced vibration amplitudes. Translation amplitudes along the x, y, z axes passing through the system's center of gravity are u_m, v_m, w_m and rotation amplitudes around these axes are ϕ_{xm}, ϕ_{ym}, ϕ_{zm}. Translation amplitudes along the x, y, z axes passing through the vertical projection of system's center of gravity on foundation floor level are $u_{m,tm}$, $v_{m,tm}$, $w_{m,tm}$. Limits of these amplitudes are given by the machine manufacturers. Harmful vibrations, that occur after exceeding these permissible vibration amplitude limits, will annoy surrounding people and damage near structures and machine foundation itself.

III. Numerical Applications

In various studies, effects of deviations from symmetry in one direction due to the placement of the machine (AX) on vibrations of two different machine foundations inducing vertical and horizontal dynamic loads were investigated [4-5]. In addition to this, effects of deviations from symmetry in one direction due to the support component rigidity changes (AX1) on vibrations of two different machine foundations inducing vertical and horizontal dynamic loads are investigated and results of both asymmetry situations are compered by themselves in this study.

A. Foundation for Machine Inducing Vertical Dynamic Loads

A vertical dynamic load creator four-cylinder diesel engine and its foundation system are shown in Fig. 2. Vibration variations for deviations from symmetry situations of this system will be examined.

The weight of machine and foundation block are 67 kN and 587 kN, respectively. Operating speed of the machine (ω) is 125.66 s^{-1} and amplitude of vertical dynamic load (F_z) is 15 kN. The permissible vibration amplitude on the foundation floor level is given as 0.04 mm. Foundation is supported from 8 points and the total rigidities of these supports in x, y, z axes are K_x=10152 kN/m, K_y=10152 kN/m, K_z=13882 kN/m, respectively. Rotation rigidities of these supports are negligible.

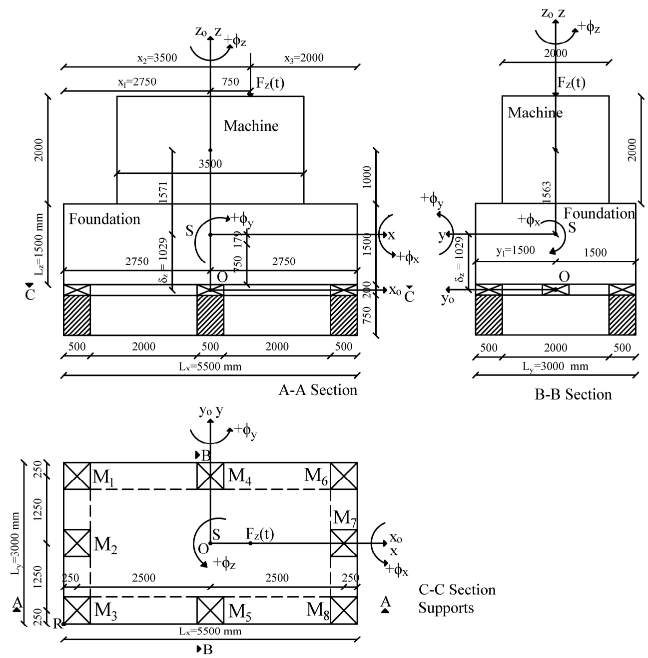

Fig. 2. A system for machine creating dynamic load in the vertical direction.

Deviation from symmetry situations of the vertical dynamic load creator system is shown in Fig. 3. In AX situation, deviation from symmetry resulting from incorrect placement of machine, machine is shifted 600 mm along the x axis. In AX1 situation, deviation from symmetry resulting from support component rigidity changes, M_1, M_2 and M_3 support components lost quarter of their own rigidities.

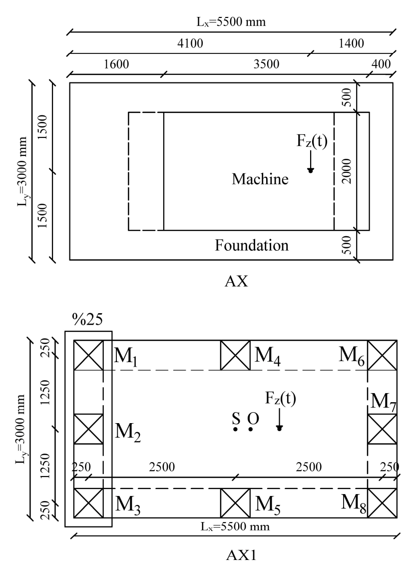

Fig. 3. Deviation from symmetry situations of the system that subjected to the vertical dynamic load.

In AX situation, variations of eccentricity ratios and natural frequencies are too small when compared with the AX1 situation. Thus, only variations of the natural frequencies by the eccentricity ratio in AX1 situation are shown in Fig. 4. In AX1 situation, all natural frequencies of the system are decreased while eccentricity ratios are increased.

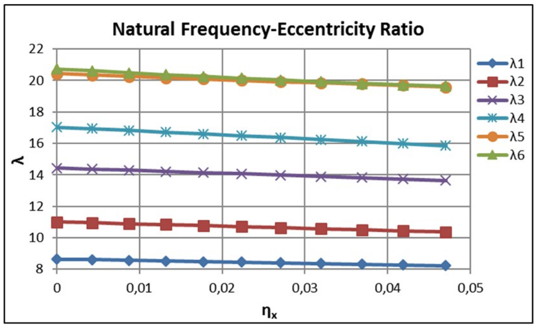

Fig. 4. Natural frequency variations of the vertical dynamic loaded foundation in AX1 situation.

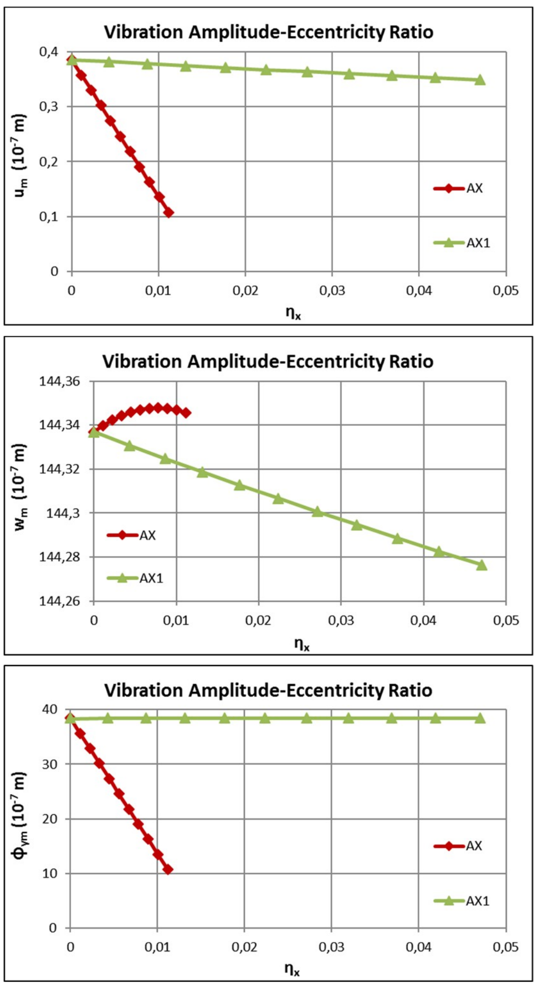

Fig. 5. Vibration amplitude variations of the vertical dynamic loaded foundation in asymmetry situations.

In Fig. 5, vibration amplitudes at the center of gravity of the vertical dynamic loaded foundation system that are generated for deviation from symmetry situations are given. Vibration amplitudes, that are 0 in symmetry situation, are not changed by the increase of eccentricity ratio. The highest changes of the vibration amplitudes along the horizontal axes (u_m and ϕ_{ym}) are observed in AX situation as a reduction because of impact point of the force changes by the position of the machine. For w_m amplitude highest change is occurred in AX1 situation but variations in both asymmetry situations are negligible.

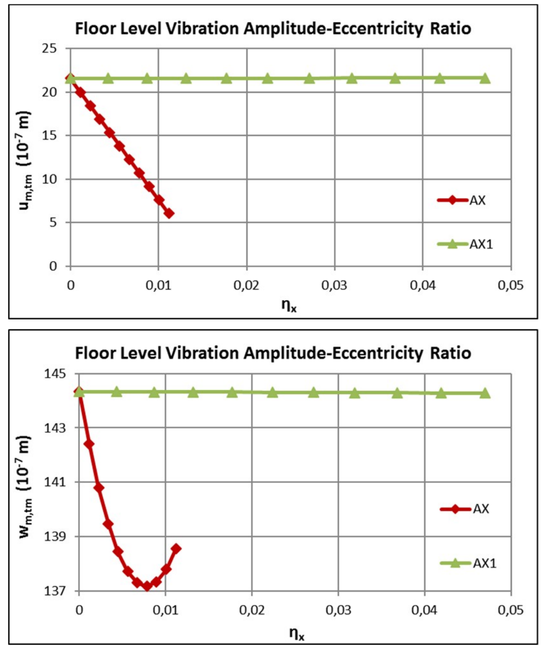

Fig. 6. Foundation floor level vibration amplitude variations of the vertical dynamic loaded foundation in asymmetry situations.

In Fig. 6, vibration amplitudes at the foundation floor level of the vertical dynamic loaded foundation system that are generated for deviation from symmetry situations are given. Both amplitudes are less than the limit value given by the machine manufacturer. In AX situation, $u_{m,tm}$ and $w_{m,tm}$ amplitudes are decreased with increment of eccentricity ratio while variation of these amplitudes are negligible in AX1 situation.

B. Foundation for Machine Inducing Horizontal Dynamic Loads

A horizontal dynamic load creator crusher and its foundation system are shown in Fig. 7. Vibration variations for deviations from symmetry situations of this system will be examined.

The weight of machine and foundation block are 500 kN and 2778.144 kN, respectively. Operating speed of the machine (ω) is 20.96 s^{-1} and amplitude of horizontal dynamic loads (F_x and F_y) are 36 kN. The permissible vibration amplitude on the foundation floor level is given as 0.6 mm. Foundation is supported from 12 points and the total rigidities of these supports in x, y, z axes are K_x=60000 kN/m, K_y=60000 kN/m, K_z=516000 kN/m, respectively. Rotation rigidities of these supports are negligible.

Deviation from symmetry situations of the horizontal dynamic load creator system is shown in Fig. 8. In AX situation, deviation from symmetry resulting from incorrect placement of machine, machine is shifted 790 mm along the x axis. In AX1 situation, deviation from symmetry resulting from support component rigidity changes, M_9, M_{10}, M_{11} and

M_{12} support components lost quarter of their own rigidities.

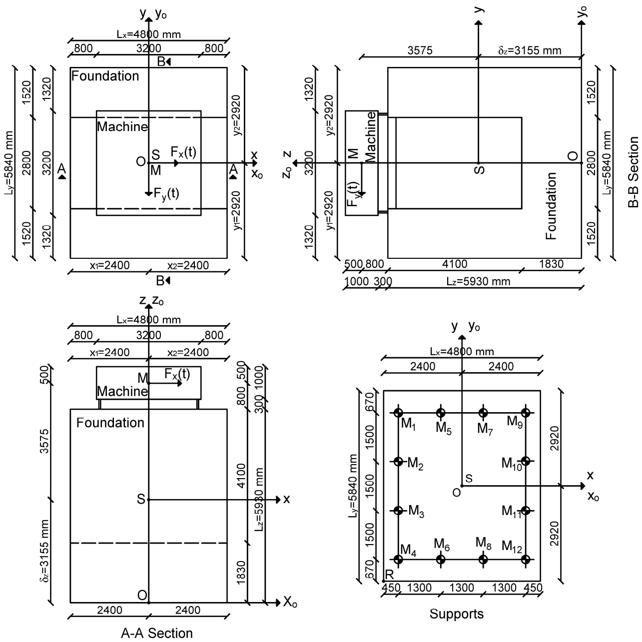

Fig. 7. A system for machine creating dynamic load in the horizontal direction.

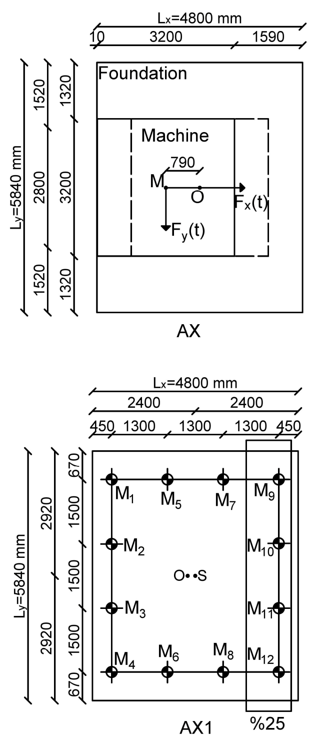

Fig. 8. Deviation from symmetry situations of the system that subjected to the horizontal dynamic load.

In AX situation, variations of eccentricity ratios and natural frequencies are too small when compared with the AX1 situation. Thus, only variations of the natural frequencies by the eccentricity ratio in AX1 situation are shown in Fig. 9. In AX1 situation, all natural frequencies of the system are decreased while eccentricity ratios are increased.

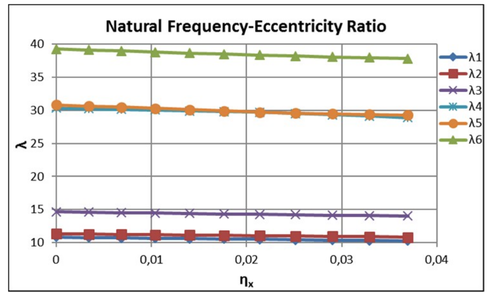

Fig. 9. Natural frequency variations of the horizontal dynamic loaded foundation in AX1 situation.

In Fig. 10, vibration amplitudes at the center of gravity of the horizontal dynamic loaded foundation system that are generated for deviation from symmetry situations are given. The highest vibration amplitude changes are observed in AX1. However, these amplitude changes are small in both asymmetry situations, except ϕ_{zm}. In ϕ_{zm}, highest change is observed in AX situation because of impact point of the force changes by the position of the machine.

Foundation floor level vibration amplitudes of the horizontal dynamic loaded foundation system for both asymmetry situations are given in Fig. 11. Both amplitudes are less than the limit value given by the machine manufacturer. In AX1 situation, $u_{m,tm}$ and $v_{m,tm}$ amplitudes are decreased with increment of eccentricity ratio while variation of $u_{m,tm}$ amplitude is negligible in AX situation. $w_{m,tm}$ amplitude is increased in both asymmetry situations but highest change is observed in AX situation.

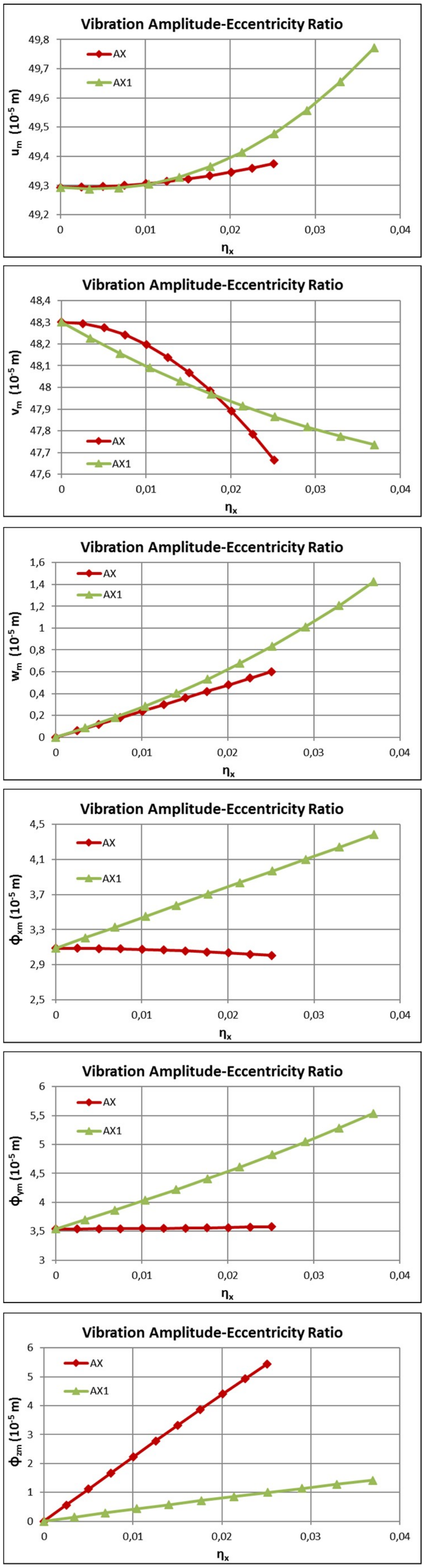

Fig. 10. Vibration amplitude variations of the horizontal dynamic loaded foundation in asymmetry situations.

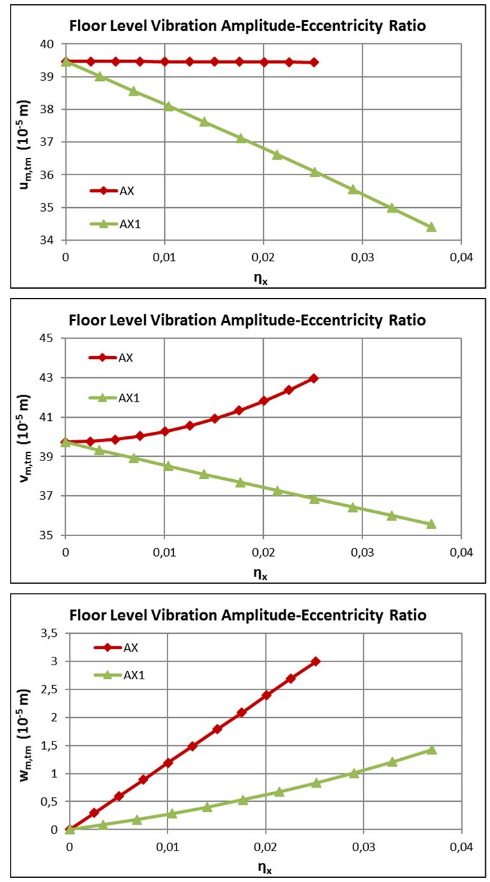

Fig. 11. Foundation floor level vibration amplitude variations of the horizontal dynamic loaded foundation in asymmetry situations.

IV. Conclusion

In this study that aimed to investigate the effects of deviation from symmetry situations on the vibrations of dynamic loaded foundations, the following results were obtained:

- Even improbable and high machine displacements are selected, variations of eccentricity ratios and natural frequencies are too small in AX situation.
- Despite this, variations of eccentricity ratios and natural frequencies are high in AX1 situation.
- Natural frequency changes are in the reduction form in AX1 situations. In the systems that have bigger natural frequencies (λ) than the operating speed of the machine (ω), high values of support component rigidity changes will cause resonance.
- In vertical dynamic loaded foundation system, highest changes of the vibration amplitudes at the horizontal axes are observed in AX situation because of impact point of the force changes by the position of the machine.
- In some cases, vibration amplitude reductions are observed due to deviation from symmetry situations.

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