Response of Circular Foundation Subjected to Dynamic Forces in Sandy Soils

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ABSTRACT

In a machine-foundation soil system, the frequency and amplitude have to be controlled by suitable means such as by balancing of dynamic loads or using suitable foundation. The dynamic forces can be transmitted to the soil through the foundation by appropriate selection of foundation mass or by using damping. This paper is the outcome of a research study conducted recently to investigate dynamic response of circular foundation in sandy soils. The paper concentrates on dynamic behavior for circular foundation with cap-anchor made of reinforced cement concrete. The influence of increase of base diameter of cap-anchor foundation on resonant frequency and amplitude for various eccentricities ranging from 0^{o} to 42^{o} were studied. Significant increases in frequency with different eccentricities were observed with increase in base diameter of the cap-anchor foundation from 0% to 40%. On the other hand, reduction of amplitude at resonance was recorded with the increase of base diameter at various eccentricities. Increase in resonant frequency (η) was observed as 27% whereas percentage increase in amplitude reduction (Ψ) was recorded 64% with embedment ratio of 30% only. It was found that the increase of base diameter of the circular foundation with cap-anchor can control vibration and is capable of withstanding higher dynamic forces when compared to simple foundation or non-circular/vertical foundation with cap-anchor.

INTRODUCTION

When foundation and structures are subjected to forced vibration, the soil-foundation interactive properties and its behavior become different in various ways. Foundation engineers face various type of problems when foundation structures are subjected to forced vibrations due to dynamic loading. For the case of any foundation, firstly, it must comply the criterion for static loading, then it must be satisfactory for resisting dynamic loading. Two principle criteria are essential to consider while designing machine foundation; these are (i) vibration amplitude should be within the permissible limits and (ii) natural frequency of machine-foundation-soil system should be away from the operating frequency (i.e., avoidance of resonance condition). Resisting dynamic loading either from supported machinery or from external sources need special solutions governed by local sub-soil conditions, soil properties and other environmental criteria. One of the fundamental requirement in design of machine foundation is the prediction of resonance in order to ensure that the operational conditions lie well outside the critical state. Another factor is momentous to note that frequency of machine itself is not in tune to that of machine foundation soil system.

One of the way to eliminate all kinds of harmful effects of dynamic forces of machines when transferred to the soil through the foundation is by correct selection of the foundation mass or by the use of damping. Conventional method is to provide bigger foundations to control vibration of machine foundations which involved higher cost, material and time. It is necessary that foundation should be as light as possible in order to reduce the cost and to possess other advantages. In this paper an investigation was made to study the dynamic response of circular cap-base foundation in sand with increase in base diameter of cap-anchor by 0%, 10%, 20%, 30% and 40%. Trends of relationships among the paramount parameters such as resonant frequency and amplitude were established. It was probed that whether the cap-anchor foundation with increase diameter is capable of bearing higher dynamic forces subjected to vibrations as compared to simple foundation or vertical cap-anchor foundation.

Field Test

A sandy soil area was chosen for field test at Postagola area in the outskirt of Dhaka city. A pit having inner dimension of 2.5 m x 2.5 m x 3.0 m was made in the sandy soil. The depth of the bottom of the pit was 3m. The investigation was carried out in the pit. The pit was filled up layer by layer very carefully with sand up to the required level. The compaction was done in each layer in such a way that the density of compacted sand in each layer had one value (16.85 kN/m^3 with variation of $\pm$ 8%). The same sand with equal compacting effort was used for all the tests; i.e., the value was maintained constant for all the tests. The cap-anchor was then placed inside the pit and the filling was made inside and outside of the cap-anchor which was compacted to same density as the layers previously made under the cap-anchor. Figure 1 shows general view of cap base. The cap-anchor was of precast reinforced concrete with dowel bars protruding upward for connection with footing. The circular cap-anchor was of diameter 60 cm at bottom and 50 cm at top. The height of cap-base was 25 cm. The circular cap-anchor was connected to footing. Thus footing diameter was 50 cm. Vibratory unit was placed at the center of the footing to apply dynamic forces to the foundation system. Figure 2 shows the experimental set-up. Frequency and corresponding amplitude at various eccentricities were recorded with the help of vibration pick-up, speed control unit and vibration meter.

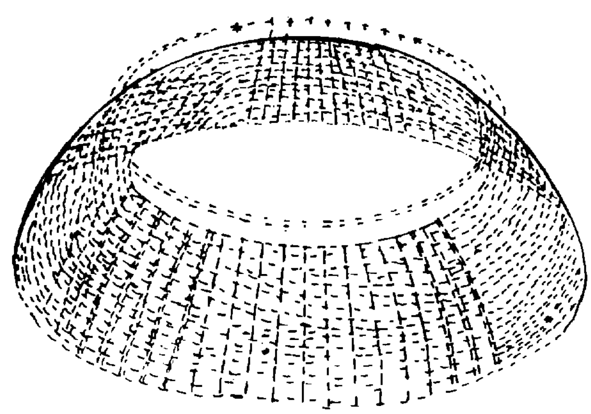

Fig. 1. Isometric view of the cap-anchor foundation

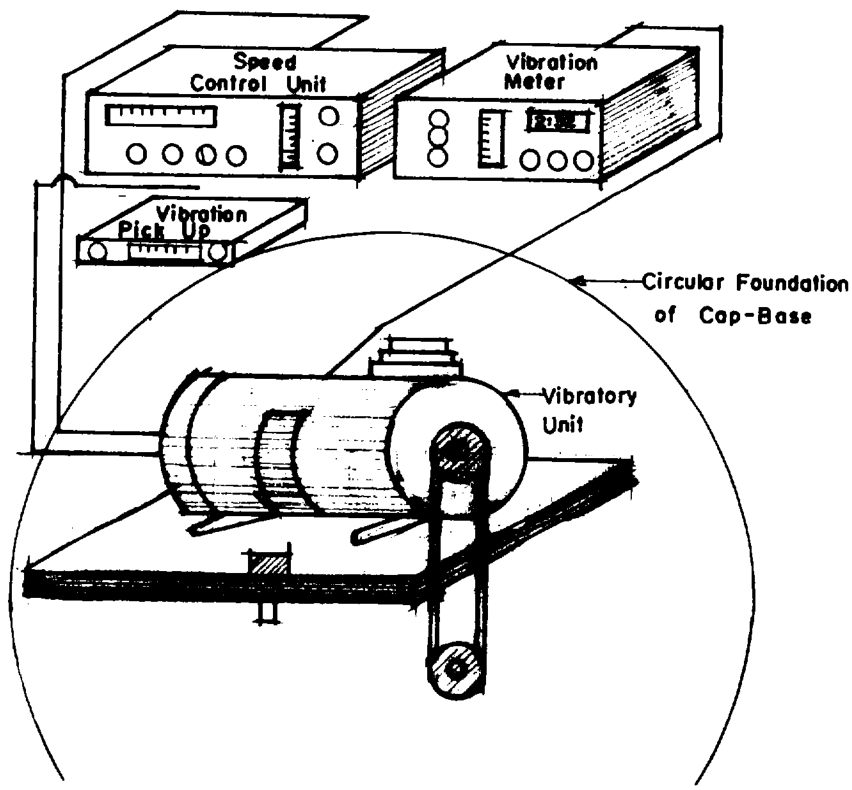

Fig. 2. Experimental set-up

The readings were recorded beyond the resonance condition, till the readings could be recorded. After completion of the test, the filled sand was removed and pit was emptied. For the next test, the pit was filled again following same procedure and under controlled conditions.

Following procedure as mentioned above with cap-base foundation of constant depth (25 cm), a number of tests were performed increasing base diameter of the cap-base foundation by 0%, 10%, 20% 30% and 40%. The testing procedure of all tests were same as mentioned above.

ANALYSIS AND RESULTS

Figure 3 shows the variation of resonant frequency with the increase of base diameter of cap-base. It shows that resonant frequency increases in a definite trend with the increase of base diameter of cap-base. Figure 4 shows increase in resonant frequency with the increase of base diameter of cap-base. Figure 5 shows the trend of variation of amplitude with the increase of base diameter of cap-anchor. The amplitude reduces gradually with the increase of base diameter of the cap-anchor. Figure 6 shows the variation increase of amplitude reduction versus increase in base diameter of cap-anchor. Figure 7 demonstrated the relationship between resonant frequency with area ratio. Similarly the reduction of amplitude with increase of area ratio of cap-anchor is shown in Figure 8. The results shows that by providing cap-anchor, the rigidity and confinement effect of soil increase. This way compressibility of the soil decreases. For the said reasons the spring constant value (k) increases which in turn increases resonant frequency.

CONCLUDING REMARKS

The cap-anchor increases overall stability of foundation. This is because when the cap-anchor is embedded, there is effect of surcharge of soil which restricts the movement in horizontal plane. Moreover, the soil inside the cap-anchor possesses frictional resistance which also restricts horizontal movement. Thereby an increase in stability of foundation occurs. By providing the cap-anchor foundation, the total area of soil foundation interface is increased and frictional force is mobilized at the surface of the footing and surrounding soils which increases dissipation of vibrational energy.

As compared to the plane foundation, the percentage increase in resonant frequency observed is 13.25 to 24.05, 20.14 to 22.11, 24.78 to 29.76, 26.62 to 33.58, 29.28 to 36.86 with increase of base diameter by 0%, 10%, 20%, 30% and 40% for electricity 0°, 7°, 14°, 21°, 28°, 35°, 42°. The pattern of wave propagation is different in the case of cap-anchor foundation. Waves are transmitted into the underlying supporting ground. These waves dissipate most of the impact energy vibrational energy is transmitted to the soil. This energy is carried away by outward and downward spreading waves. Hence the damping of waves is faster which results decrease of amplitude. The rate of amplitude reduction (in percentage) at resonance was observed to be 19.23 to 12.19, 41.27 to 27.82, 51.12 to 41.05, 61.11 to 53.97, 70.14 to 62.15 with increase in base diameter of cap-anchor as 0%, 10%, 20%, 30% and 40% for eccentricity 0° to 42°.

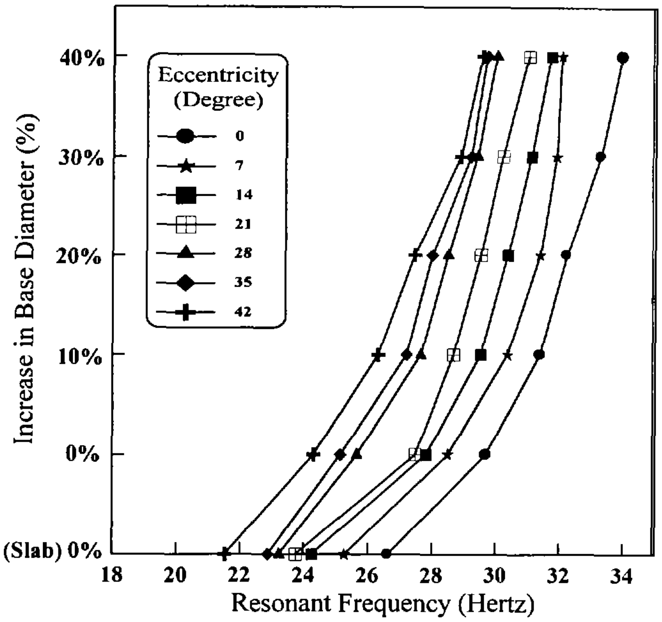

Fig. 3. Increase of resonant frequency due to enlargement of base diameter of cap-anchor foundation

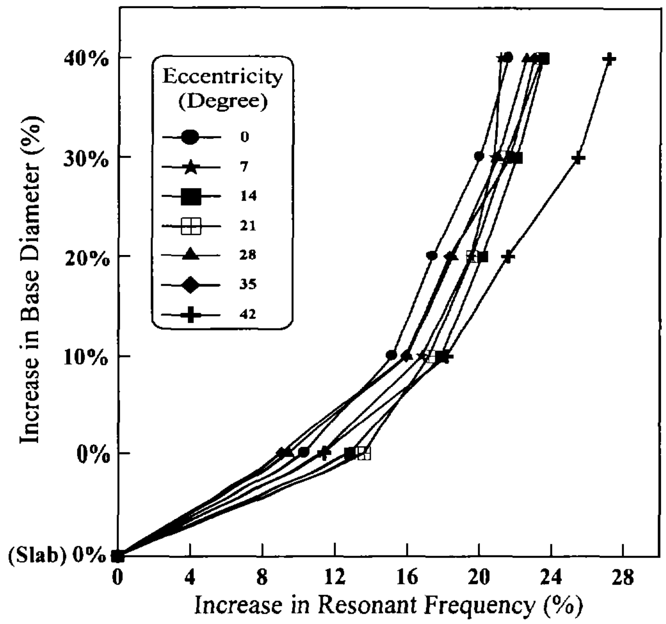

Fig. 4. Incremental rate of resonant frequency with increase of base diameter of cap-anchor foundation

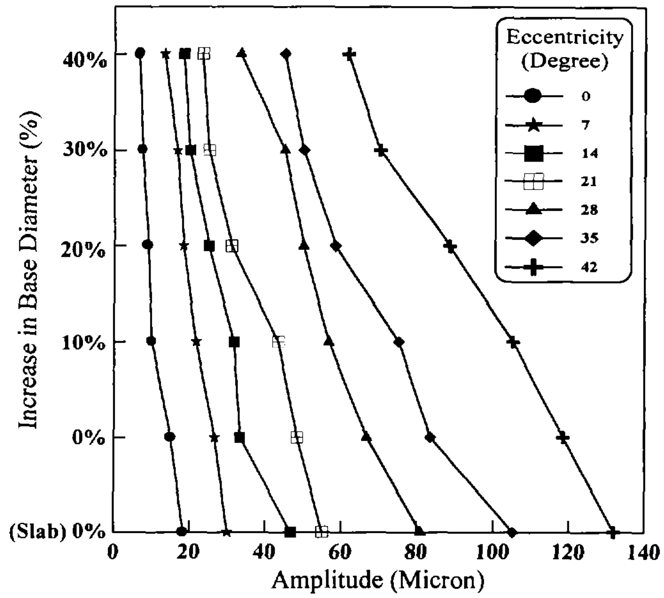

Fig. 5. Reduction of amplitude at various eccentricities due to increase of base diameter of cap-anchor foundation

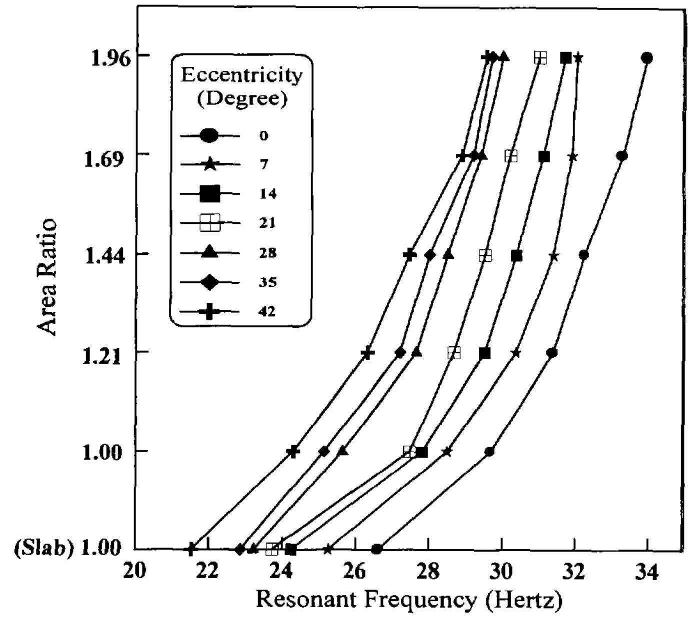

Fig. 7. Relationship showing resonant frequency with area ratio of cap-anchor foundation

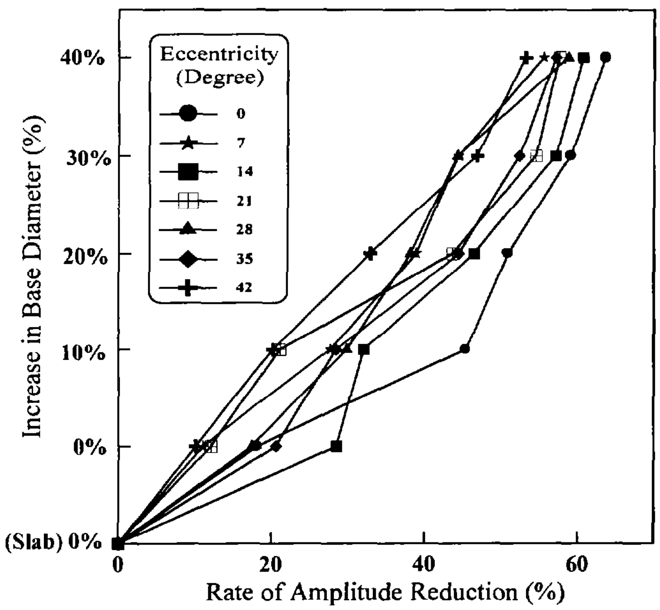

Fig. 6 Rate of amplitude reduction at various eccentricities due to enlargement of base diameter of cap-anchor

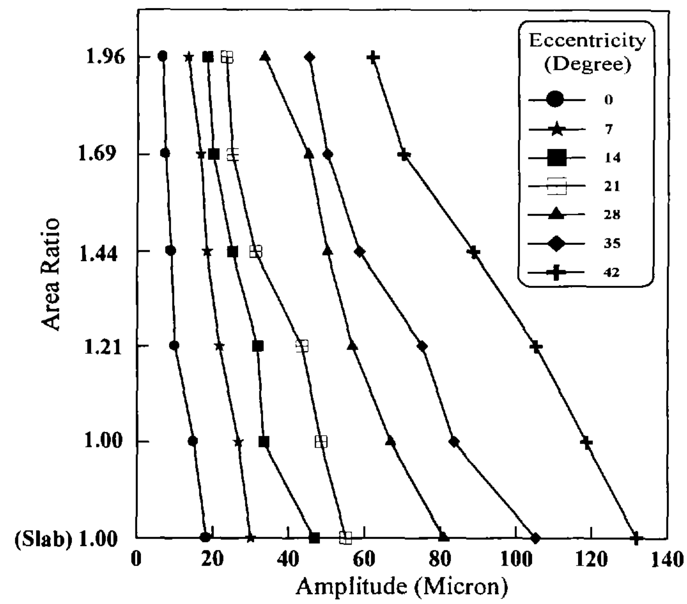

Fig. 8. Relationship between amplitude with area ratio of cap-anchor foundation

A regression equation using method of variance analysis was found to represent the dynamic response of circular RCC cap-anchor foundation.

Increase in resonant frequency

The relationship between increase in frequency ($\eta\%$) at resonance and percentage increase in diameter of base (D) with change of eccentricity from 0° to 42° is given by the following equation expressed by constant A.

$$A = \mathrm{Log}_e\left[\frac{\eta\%}{D}\right] ---------- (1)$$

The values of Constant A are given in Table 1.

Rate of amplitude reduction:

The relationship between the rate of amplitude reduction (ψ%) and increase of diameter of base (D) with change of eccentricity from 0° to 42° is given by the following equation expressed by constant B.

$$B = \text{Log}_e \left[\frac{\psi \%}{D} \right] ----------(2)$$

The values of Constant B are given in Table 1.

Table 1. Constant A and Constant B values

Eccentricity 'e'	Constant A *(Pertaining to Frequency Increase at Resonance)*	Constant B *(Pertaining to Amplitude Reductions)*
0°	3362×10^{-4}	8432×10^{-4}
7°	3421×10^{-4}	7012×10^{-4}
14°	3309×10^{-4}	6324×10^{-4}
21°	3112×10^{-4}	6021×10^{-4}
28°	2639×10^{-4}	5732×10^{-4}
35°	2321×10^{-4}	5629×10^{-4}
42°	2932×10^{-4}	6621×10^{-4}

Equation (1) & (2) provide relationships of the constant A and B with respect to percentage increase in frequency at resonance and percentage rate of amplitude reduction respectively with increase of base diameter of cap-anchor foundation varying eccentricity from 0° to 42°. In this investigation the percentage increase in resonant frequency was observed as 27% and percentage rate of amplitude reduction was recorded as 64% with increase in base diameter of cap-anchor foundation of 40% and embedded ratio of 0.30 only. By providing circular cap-anchor foundation. The construction cost was estimated and found lower than reinforced concrete block foundation of same depth (15cm) and one-third the diameter of circular cap-anchor foundation. Finally it can be concluded that circular cap-anchor foundation with increased based diameter is a better choice when foundation is subjected to dynamic forces & vibration in camparison with vertical cap-anchor foundation or simple embedded foundation.

REFERENCES

Ali H.N., and S. Scrhan,[1989]. Vertical vibration of machine foundations, Journal of Geotechnical Engineering, ASCE.

A Sridhran and R. Ramprased [1988]. Prediction of amplitude of vibration of machine foundation, Indian Geotdchnical Journal.

George G. and K.H. Stroke [1991]. Free vibration of embedded foundation theory versus experiment, Journal of Geotechnical Engineering, ASCE.

George Gazetas, R. Dobry and Tassaculas [1985]. Vertical response of ambitrarily shaped embedded foundation, Journal of the Ceotechnical Engineering, ASCE.