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EFFECT OF SOIL TREATMENT ON THE DYNAMIC RESPONSE OF PILES

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ABSTRACT

Clay deposits of low strength and high compressibility are the foundation soils for many structures. These structures are often supported by Piles and in many situations are exposed to dynamic loads. To alleviate some of the problems associated with these soils, an innovative technique using electrokinetics is now being investigated to improve the soil properties around the piles. The present paper represents a theoretical study on the potential influence of different parameters of this technique on the dynamic response of piles. The soil reactions are computed considering radial inhomogeneity. These reactions are then used to calculate the response of single piles to harmonic loading. The results showed a great influence of this strengthening technique on the pile response to dynamic loads. The response was improved by 25% to 50% in all vibration modes and improvement parameters considered in this study. It is expected that this technique would be cost efficient for the construction of new offshore structures and the rehabilitation of existing ones.

RÉSUMÉ

Les dépôts d'argile de faible resistance et de haute compressibilité constituent les sols de foundations de plusieurs ouvrages. Ces ouvrages reposent le plus souvent sur des pieux et, dans plusieurs cas, sont soumis à des charges dynamiques. Pour pallier certains problèmes associés à ces sols, une technique innovatrice utilisant l'électrocinétique est étudiée afin d'améliorer les propriétés du sol autour des pieux. Cet article présente une étude théorique de l'influence des différents paramètres de cette technique sur la réponse dynamique des pieux. Les réactions du sol sont déterminées en considérant une hétérogénéité radiale. Ces reactions sont ensuite utilisées pour calculer la réponse des pieux isolés aux charges harmoniques. Les résultats ont montré que cette technique a une grande influence sur la réponse du pieu. La réponse a été améliorée par 25% à 50% dans tous les modes de vibration et les paramètres considérés dans cette étude. Cette technique pourrait être rentable pour la construction et la réhabilitation des ouvrages en mer.

INTRODUCTION

Improvement of foundation soils using existing treatment techniques such as chemical grouting, dynamic compaction and jet grouting can significantly enhance the general load bearing capacity of foundations. However, these techniques may not be suitable to piled foundations in offshore environment. The research on electrokinetic strengthening of soft natural clays for engineering applications was initiated by Inculet and Lo (1988). They found that application of a strong non-uniform electric field improved the properties of natural clays significantly. Further development of the theory of dielectrophoresis and its application in geotechnical engineering was investigated by Lo et al. (1994). Recently, Shang and Dunlop (1996) found that the electrokinetic treatment resulted in an increase of the shear strength of a marine sediment by up to 267% and an increase of the pull out resistance of steel plates, embedded in that marine sediment by up to 88%. In this technique, improvement in the clay properties occurs due to a nonuniform electric field, i.e., the electric field intensity varies within the clay layer. A laboratory experimental program is currently underway by the authors to investigate the potential effect of this technique on the capacity and dynamic response of piles installed in clayey soils. The objective of this research is to theoretically examine the potential influence of different parameters of the technique on the dynamic response of piles installed in electrokinetically strengthened clayey soils. The methodology involves performing a parametric study to investigate the effect of increasing the soil shear modulus and the width of the improved zone on the pile response, considering the soil properties within the improved zone to vary nonlinearly. The soil reactions to the pile motion are computed considering radial inhomogeneity due to the soil improvement. These soil reactions are then used to calculate the response of single piles to harmonic loads.

ELECTROKINETIC PROCESS

To investigate the effect of the electrokinetic process, a case of four piles and five electrodes are presented. Improvement in the soil properties is basically due to the action of dielectrophoresis, which exists in nonuniform electric fields only, therefor a high voltage electric field must be applied to the clayey soil through electrically insulated electrodes. Cylindrical symmetry is commonly used for electrode design, the arrangement considered here includes a central electrode located coaxially within four outer cylindrical electrodes. The central and outer electrodes are copper rods of radius R_a with an insulation layer of radius R_b. The radial distance between the central and outer electrodes is R_c. An electrical potential U_o is applied to the outer electrodes which are arranged close to the piles to get the maximum effect around each pile. The electric field intensity E (V/m) in an ideal cylindrical field can be expressed as (Shang 1993)

$$E = \begin{cases} \dfrac{U_o v_o}{K_b \lambda r} & (R_a \le r < R_b) \\ \dfrac{U_o v_o}{K_m \lambda r} & (R_b \le r < R_c) \end{cases} \qquad [1]$$

and zero elsewhere. In Eq. 1. λ, is a constant related to configuration of the field and given by

$$\lambda = \frac{1}{K_b} . \ln\frac{R_b}{R_a} + \frac{1}{K_m} . \ln\frac{R_c}{R_b} \qquad [2]$$

K_b is the permittivity of the insulation layer, r is the radial distance to the centre of the cylinder, and v_o is the unit radial vector, K_m is the relative permittivity of the soil. U_o is the potential difference between the central electrode and the outer electrodes. The electric field intensity, givin by Eq. 1, is inversely proportional to the radial distance, r. The distribution of electric field intensity for a case of five electrodes is illustrated by the equi-intensity lines in Fig. 1a.

SOIL REACTIONS MODEL

Soil reactions to pile motion are conveniently defined by impedance functions (dynamic complex stiffness).These are established as forces necessary to produce a harmonic oscillation of a layer of unit thickness with a unit amplitude. To account approximately for the effect of change of soil properties adjacent to the foundation, Novak and Sheta (1980) introduced a massless narrow annular boundary zone of modified shear modulus and material damping. Veltsos and Dotson (1986) proposed a solution that accounts for the mass of the boundary zone. However, Novak and Han (1990) found that a homogenous boundary zone with nonzero mass overpredicts the resonant frequency and yields undulating impedances due to the wave reflections from he interface between the two media. Dotson and Veletsos (1990) proposed a boundary zone for which the shear modulus is considered to increase exponentially. El Naggar (1997) developed a frequency domain solution that accounts for radial variation of the complex shear modulus of the soil layer for different vibration modes.

SINGLE PILE ANALYSIS

The computation of single pile stiffness and damping is based on the approach given by Novak and Sheta (1980) whose application is facilitated by an efficient computer program DYNA4 (Novak et al. 1993). The program accounts approximately for the mass of the of the disturbed zone through the use of mass participation factor, mp, that represents the fraction of the disturbed zone mass to be added to the pile mass at each layer. It is assumed that the pile is cylindrical of radius r_o is surrounded by a linear viscoelastic medium composed of two concentric regions as shown in Fig. 1b. An outer semi infinite undisturbed region with a shear modulus G_o and material damping D_o and an inner annular zone of disturbed material with shear modulus G_m, width t_m and material damping D_m. The dynamic response of a vertical pile installed in improved clayey soil is evaluated for different treatment configurations. The thickness of the improved zone varies according to the applied electric field intensity and electrode arrangement. The effect of the thickness ratio, t_m/r_o, and the shear modulus ratio, $GR = G_m/G_o$, on the pile response is investigated. The pile is a steel pipe with constant cross section, embedded in a layered soil medium comprising two layers. The pile, soil and improved zone properties are shown in Fig. 1c.

RESULTS

Figure 2. shows the vertical response of a pile embedded in an improved soil with different configurations, subjected to harmonic load with a quadratic amplitude (varies with ω^2, where ω is

the excitation frequency). It may be noticed from the figure that as GR increases the response decreases. The reduction for $t_m/r_o = 1$ in the vertical response.is about 20% for GR = 2 and about 40% for GR = 4. It may be also noticed that increasing t_m/r_o from 1 to 2 has a negligible effect on the vertical response. Figure 3. represents the lateral response of the pile. It may be observed that the response is decreased by 25% for $t_m/r_o = 1$ and GR = 2 and almost halved for GR = 4. Similar to the vertical vibration case, increasing the width of the improved zone has insignificant effect on the response. In Fig. 4, the rotation of the pile head about Y axis is demonstrated. Similar observation can be made regarding the effect of GR and width of the improvement zone.

CONCLUSION

Theoretical evaluation for the effect of the electrokinetic treatment on the dynamic response of piles installed in soft clay is presented in this paper. It was found that the response is improved in all vibration modes considered in this study due to the electrokinetic treatment. It was also found that the effect of the increase in GR is more significant than the increase in the width of the improved zone for the range of parameters considered in this study. With the information and insight into the pile response that have been provided in the present study, it is expected that the electrokinetic treatment technique would be cost efficient for the construction of new offshore structures and the rehabilitation of existing ones.

ACKNOWLEDGMENT

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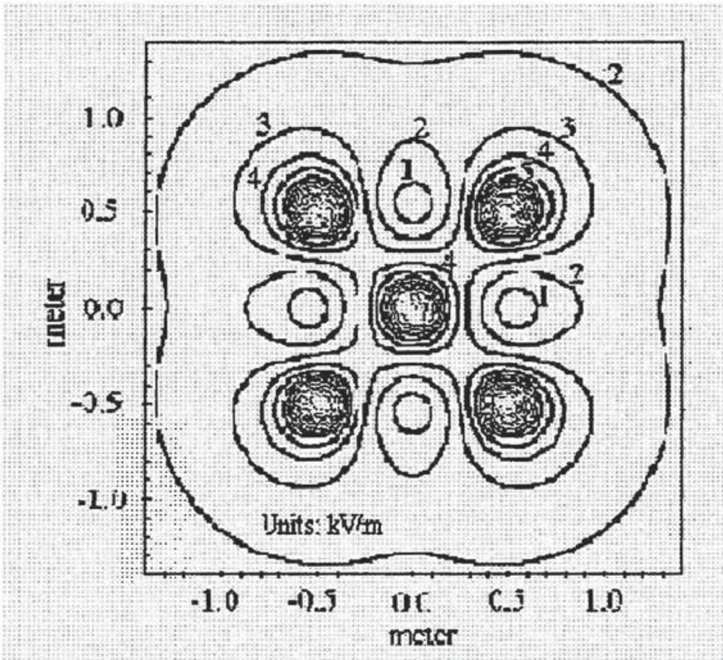
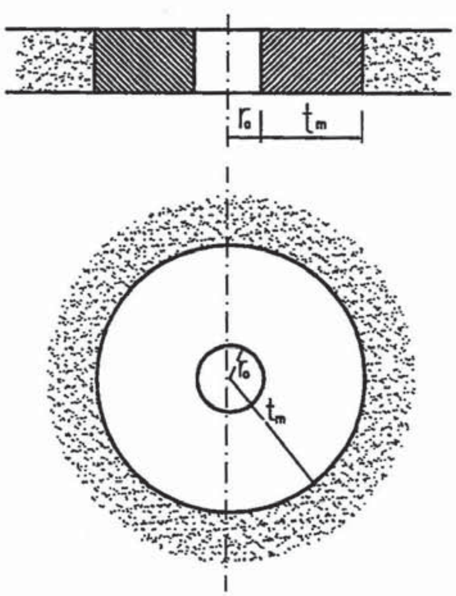


a) Electric Field Intensity Distribution



b) Soil Reactions Model

Soil Layer				Improved zone				
No.	TH. m.	Vs m/s	Density KN/m^3	GR	Pois. ratio	D	$\frac{t_m}{r_o}$	mp
1	3.00	45	15.6	Varies from 1.0 to 4.0	0.40	0.10	Varies from 2.0 to 0.25	1.00
2	6.00	60	18.0		0.40	0.10		

Vs = 60 m/s D = 0.10
Pois. ratio = 0.40 Density = 18 KN/m^3

c) Pile and Soil Properties

FIGURE 1. a) Electric Field Intensity Distribution b) Soil Reactions Model c) Pile and Soil Properties

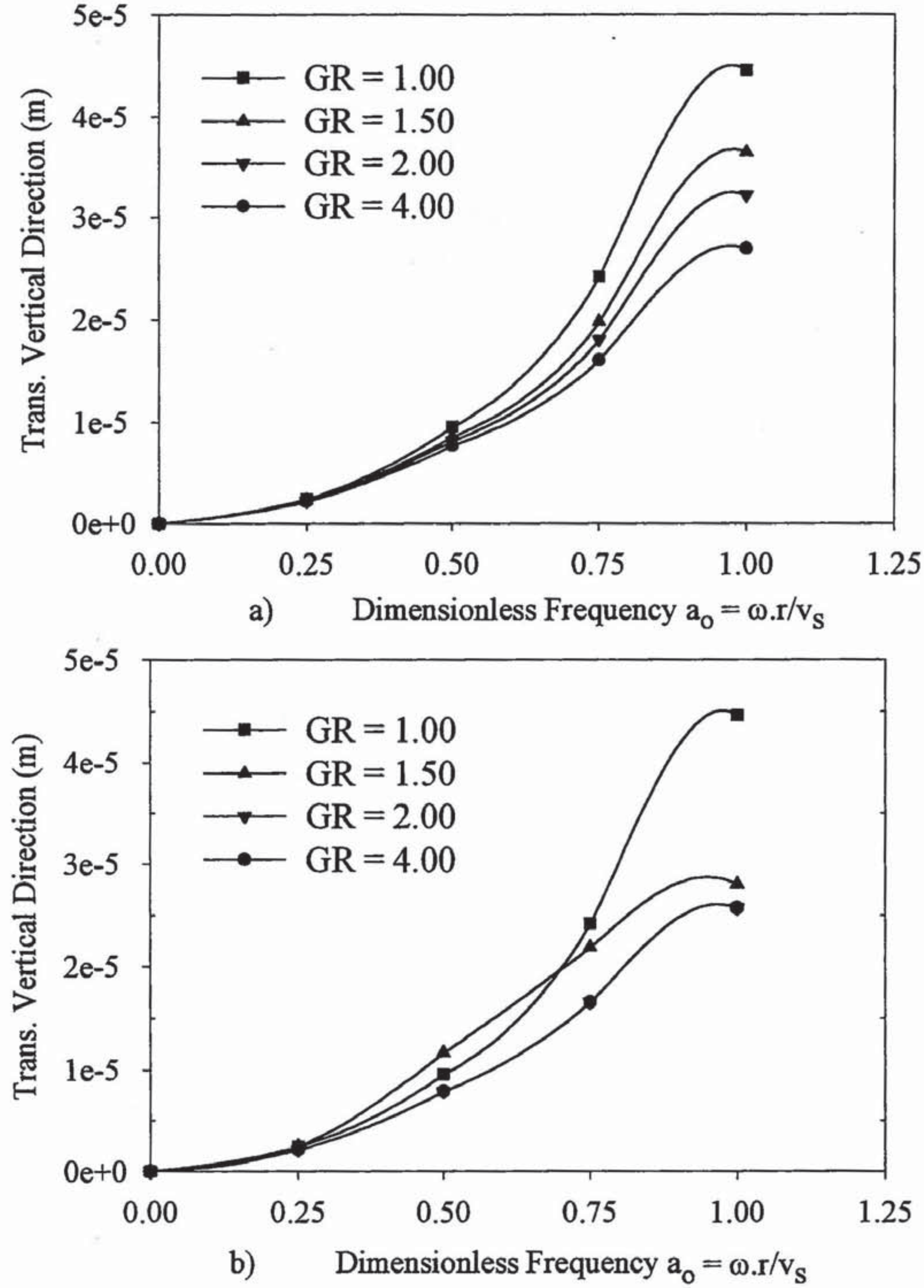


FIGURE 2. Vertical Response to Quadratic Load
a) $t_m / r_o = 1$ b) $t_m / r_o = 2$

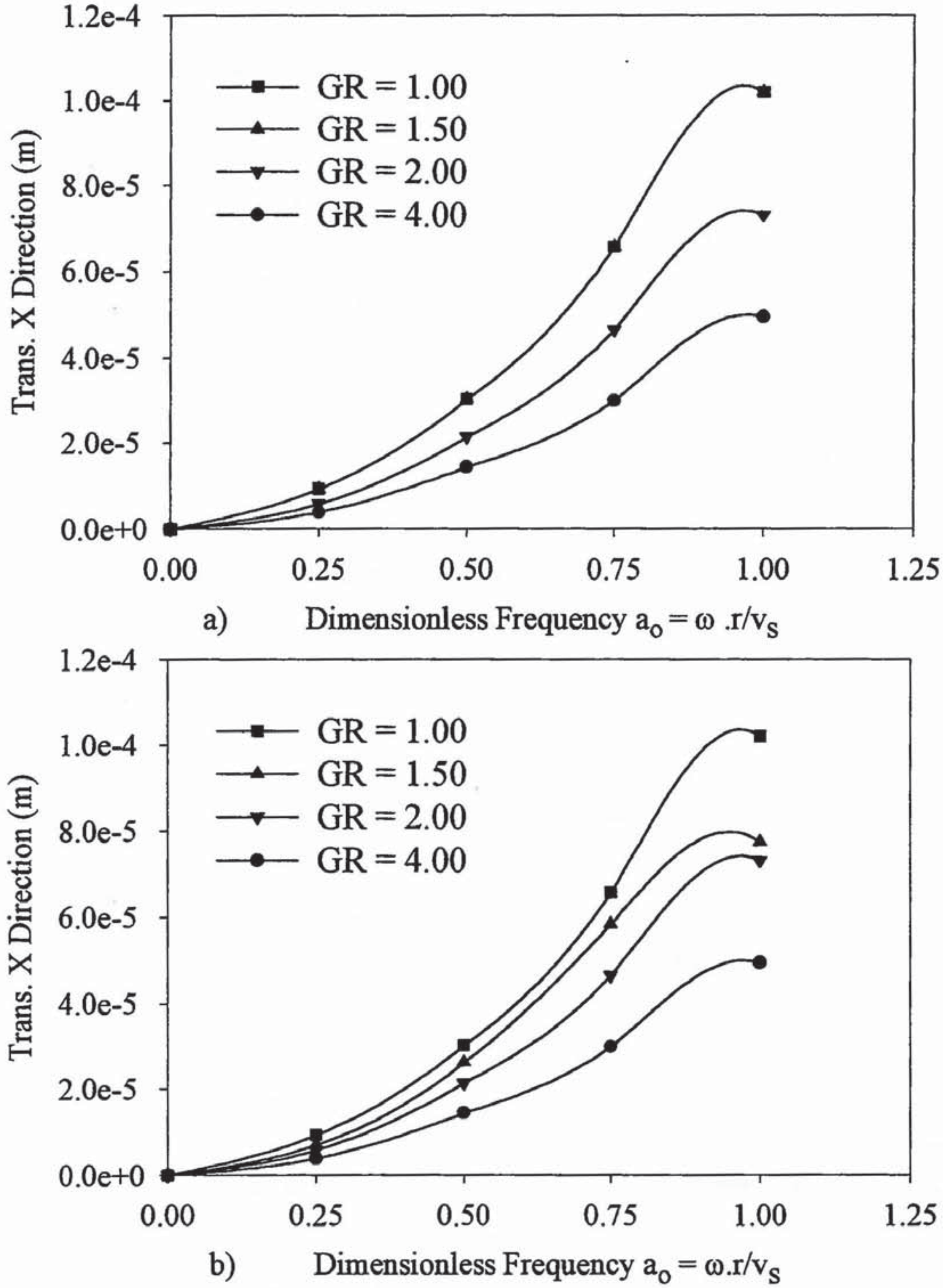
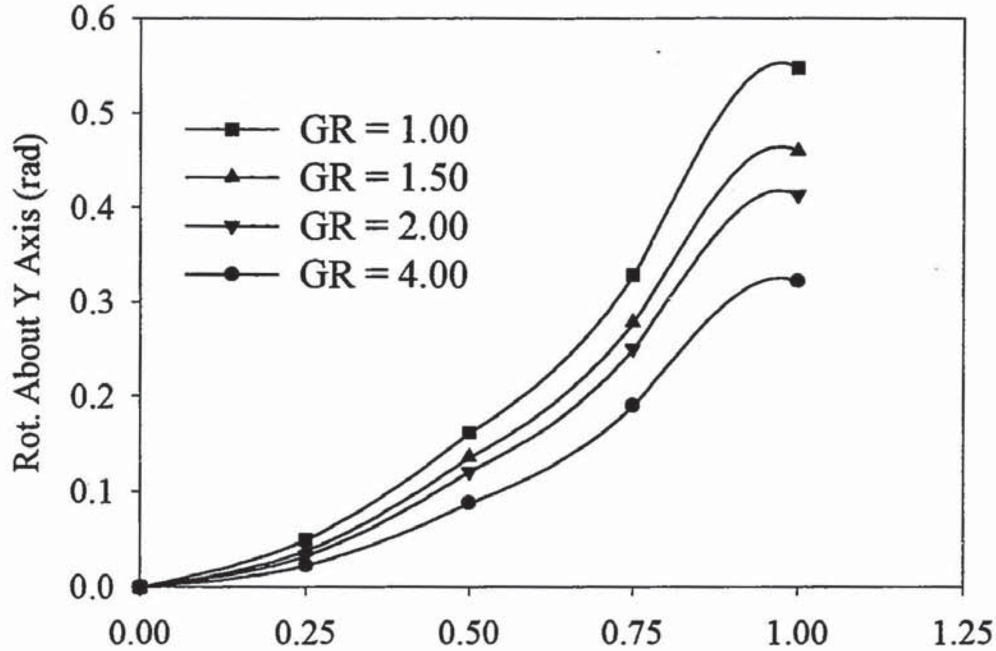
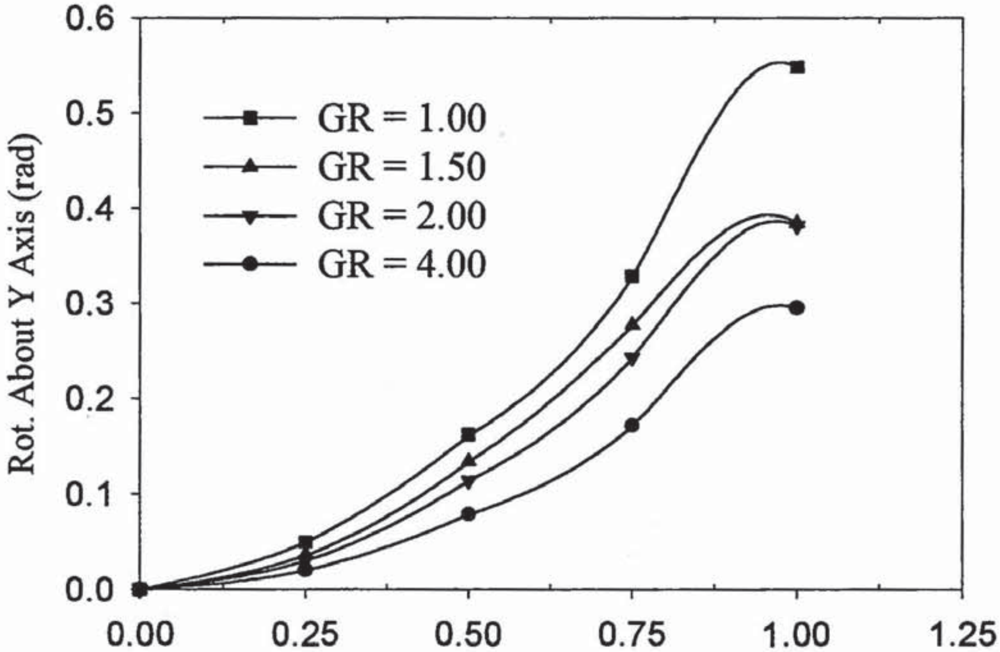


FIGURE 3. Lateral Response to Quadratic Load
a) $t_m / r_o = 1$ b) $t_m / r_o = 2$



a) Dimensionless Frequency $a_o = \omega.r/v_S$



b) Dimensionless Frequency $a_o = \omega.r/v_S$

FIGURE 4. Rotational Response to Quadratic Load
a) $t_m / r_o = 1$ b) $t_m / r_o = 2$