











Figure 8 Effect of  $L/d$  on  $M_{n,max}$  for  $h_1/L=0.5$  and  $h_3/L=3$

## VII. DISCUSSION

1. Referring to Fig. 3, the normalized maximum bending moment ( $M_{n,max}$ ) of pile along its length is evaluated at different frequency ratios ( $\omega/\omega_1$ ). It is found that the  $M_{n,max}$  is greatest at frequency ratio,  $\omega/\omega_1=1$ . This signifies the greater contribution of first natural mode of vibration to pile bending moment. This trend is found for all the eight cases shown in Table 1. Secondly, bending moment is largest for case-8 of table-1 for  $\omega/\omega_1=1$ , and least for case-1. This show strong influence of other parameters on the bending moment. Influence of excitation frequency on bending moment is also evaluated at different frequencies of excitations (1, 0.5, and 2) and result shown in Fig.-4, which again shows the significant effect of first natural mode of vibration ( $\omega/\omega_1=1$ ).
2. Referring to Fig.-5. The effect of various soil pile parameters on the  $M_{n,max}$  is shown in Fig.-5, and 6. These soil pile parameters are  $E_p/E_{s1}$ ,  $V_2/V_1$ ,  $L/d$ , and  $h_1/L$ .  $h_3/L=1$  in all the cases.
3. As  $E_p/E_{s1}$  increases for constant value of  $V_2/V_1$ , the  $M_{n,max}$  increases. This is because the stiffness of pile increases with respect to the top soil layer stiffness.
4. The ratio of the shear wave velocity ( $V_2/V_1$ ) of the soils considered in the study, affects  $M_{n,max}$  in similar fashion as discussed in para-3 above. As the top soil layer becomes less stiff compared to bottom soil layer, the  $M_{n,max}$  increases.
5. Effect of  $L/d$ : As the  $L/d$  ratio increases, the  $M_{n,max}$  increases. However, for low values of  $E_p/E_{s1}$ , or  $V_2/V_1$ ,

the rate of increase in  $M_{n,max}$  with  $L/d$  is not very pronounced.

6. Effect of  $h_1/L$ : increase in the thickness of the upper softer soil layer compared to the length of pile significantly increases the  $M_{n,max}$ . This conclusion is based on comparing the  $M_{n,max}$  in Fig. 5 and Fig. 6.
7. Referring to Fig. 7 and Fig. 8. The effect of all the parameters as described in para-3 above is studied for  $h_3/L=3$ . It is seen that the  $M_{n,max}$  increases with  $h_3/L$ . This is expected as the free field motion increases as the  $h_3$  increases.

## REFERENCES

- [1] Mizuno, H. (1987). "Pile damage during earthquakes in Japan. Dynamic Response of Pile Foundations" American Society of Civil Engineers, New York: (ed. T. Nogami), pp. 53-78.
- [2] Ahmad, M.H. El Nagggar, and A.N. Khan, "Artificial neural network application to estimate kinematic soil pile interaction response parameters", Journal of Soil dynamics and Earthquake Engineering, 27, 2007, 892-905
- [3] Ahmad, M.H. El Nagggar, and A.N. Khan, "Maximum kinematic pile bending moment in layered soil profile: artificial neural network approach", Geo-Denver, New Peaks in Geotechnics, Denver, Co, February 18-21, 2007.
- [4] Nikolauo A., Mylonakis G., Gazetas G. (1995). "Kinematic Bending Moments in Seismically Stressed Piles", NCEER Technical Report, Buffalo, NY.
- [5] Gazetas G, Fan K, Tazoh T, Shimizu K, Kavvadas M, Makris N. "Seismic pile-group—structure interaction", Piles under dynamic loads, Geotechnical special publication no. 34, 1992. p. 56–93.
- [6] Kaynia, A. (1997), "Earthquake-induced forces in piles in layered media, Geotechnical Special Publication, 70, ASCE, 75-95.
- [7] Kavvadas M. and G. Gazetas (1993), "Kinematic seismic response and bending of free-head piles in layered soil" Geotechnique, 43, No.2, 207-222.
- [8] Gazetas, G. & Dobry, R. (1984a). "Horizontal response of piles in layered soils" J. Geotech. Engng Div. Am. Soc. Civ. Engrs. 110, No.1,20-40.
- [9] Gazetas, G. & Dobry, R. (1984b). "Simple radiation damping model for piles and footings. Horizontal response of piles in layered soils". J. Geotech. Engng Div. Am. Soc. Civ. Engrs., 110, No.6, 937-956.