Soils and Foundations 2013;53(2):349–356

The Japanese Geotechnical Society

Soils and Foundations

www.sciencedirect.com
journal homepage: www.elsevier.com/locate/sandf

Influence of model footing diameter and embedded depth on particle size effect in centrifugal bearing capacity tests

Y. Toyosawa[a], K. Itoh[a], N. Kikkawa[a], J.-J. Yang[b,*], F. Liu[c]

[a]Construction Safety Research Group, National Institute of Industrial Safety and Health, 1-4-6, Kiyose, Tokyo 204-0024, Japan
[b]Key Laboratory of Marine Environment and Ecology, Ocean University of China, Ministry of Education, Qingdao 266100, PR China
[c]Beijing Municipal Engineering Research Institute, Beijing 100037, PR China

Received 5 July 2010; received in revised form 12 October 2012; accepted 8 November 2012
Available online 11 March 2013

Abstract

The influence of the model footing diameter and embedded depth on the bearing capacity of circular shallow footings was studied by centrifugal model testing in order to determine a model footing size and embedded depth against particle size in a model ground. In the series of 37 tests, the ground was made by river sand whose particle size was adjusted by sieving to a mean particle size of 0.6 mm. The diameter of the model footing and the embedded depth were considered as influential parameters in this study. The diameter of the model footings varied from 5 to 40 mm and the ratio of the footing diameter to the mean particle size was calculated as 8.3–66.7. The ratio of the embedded depth to the footing diameter was 0, 0.5 and 1.0. As a result, the bearing capacity in the same equivalent diameter of footing was not dependent on the diameter of model footing when the ratio of footing diameter to particle size is more than 50 with any ratio of embedded depth to footing diameter. Our results that the proposed relationship between the ratio of footing diameter to the particle size and the ratio of the embedded depth to the footing diameter can be used to choose a reasonable model footing diameter, embedded depth and the particle size of ground material for centrifugal model tests.

Keywords: Centrifugal model test; Particle size effect; Bearing capacity; Footing diameter; Embedded depth; IGC: E-3/E-14

1. Introduction

In centrifugal model tests, the footing and soil particles should be modeled in size by a factor of N under N–g centrifugal acceleration. However, if the size of soil particles are reduced by a factor of N, the model soil will have very different stress–strain characteristics compared with the prototype soil. Therefore, often the same soil as in prototype is used, and only the model footings are made smaller by a factor of N (Kusakabe, 1993; Okamura et al., 2004). In such cases, the particle size of soil used will be significant compared with the dimensions of the model footing. That is, the effect of particle size in centrifugal bearing capacity tests raises doubts as to the reliability of such tests. Therefore, it is necessary to investigate how particle size affects the bearing capacity of the centrifugal model tests in terms of various model footing diameter, D_m, and different embedded depth of footing, d_m.

The effect of particle size on bearing capacity is due to the shear band thickness (Okamura et al., 2004; Tatsuoka et al., 1992, 1991, 1997; Siddiquee et al., 1992), since the shear band thickness is proportional to the particle size, D_{50}. When the particle size is sufficiently small compared with the model

*Corresponding author. Tel./fax: +86 0532 667 81773.
E-mail addresses: toyosawa@s.jniosh.go.jp (Y. Toyosawa), k-ito@s.jniosh.go.jp (K. Itoh), kikkawa@s.jniosh.go.jp (N. Kikkawa), jjyang@ouc.edu.cn (J.-J. Yang), liufeidada2012@163.com (F. Liu).
Peer review under responsibility of The Japanese Geotechnical Society.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.sandf.2012.11.027

footing size, the bearing capacity in a centrifugal model ground should be the same as that in the prototype ground. However, when the particle size is not so small in comparison with the model footing size, the bearing capacity in a centrifugal model ground can be affected by the shear band formation. This is called the "particle size effect". In addition, if the model ground is loose, the shear band cannot be observed clearly. The footing shape, i.e. whether it is rectangular or circular, also affects the bearing capacity since rectangular footings are usually used in plane-strain problems, with the effect that the movement of soil particles is constrained in 2 dimensional directions and the shear band formation is more affected than when circular footings are used. The embedded depth is also an important factor for the bearing capacity of shallow footing, since the shear bands do not generate large confining pressure. Thus, the particle size effect is less obvious with increasing embedded depth. Generally, the particle size effects are obvious under conditions in which a shear band can easily be generated in the ground (Tatsuoka et al., 1997) and the ratio of the footing size to particle size is small (Okamura et al., 2004). Therefore, the ratio of the footing size to particle size, the embedded depth of footing, the density of sandy model ground and the footing shape are considered to be factors that influence the bearing capacity of the model ground in the centrifugal model tests.

Gemperline (1988) and Okamura et al. (2004) reported that the particle size effects became less obvious as the density of sand decreased. Okamura et al. (1993) showed that particle size has a smaller effect on circular footings than on strip footings. However, previous research only qualitatively described this phenomenon and did not quantitatively study the relationship between the influenceable factors and the particle size effects. In the research reported in the literature on circular footings, by Ovesen (1975, 1979) and Xu and Zhang (1996), the particle size effect was evaluated by merely comparing the load-settlement curves from a few experimental cases under conditions of no embedment. In this research, the particle size effect has been investigated using quantitative indicators for 37 cases of various diameters and depth of embedment.

Gemperline and Hon (1988), Kimura et al. (1985), Pu and Hao (1988), Pu and Ko (1988), and Yamaguchi et al. (1976) researched the influence of embedment on bearing capacity by centrifugal model tests. Liu et al. (2007) carried out bearing capacity tests using a centrifuge for several densities of sand, footing shapes and embedment while the particle size effects on bearing capacity were studied. However, few studies have been done on the influence of embedment on the bearing capacity with the particle size effect.

Yang et al. (2007) studied the particle size effects in the case of no embedment and introduced the index which was used to quantify the particle size effects for rectangular footing.

In this paper, a series of 37 bearing capacity tests with circular footing was conducted on dense sand by centrifuge and the effects of model footing diameter and embedded depth of footing on the bearing capacity are discussed in detail using quantitative indexes (such as Δq_u, D_m/D_{50}, d_m/D_m, etc.). The relationship of both ratios well expressed the extent and degree in the bearing capacity.

Fig. 1. Test container (diameter: 500 mm and depth: 300 mm).

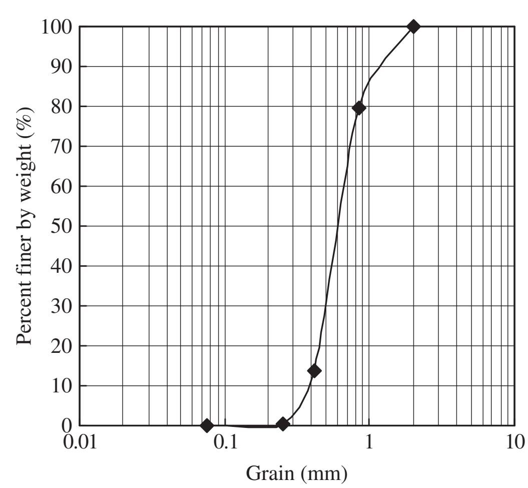

Fig. 2. Curve of grain size distribution of river sand after sieving.

Table 1
Properties of the river sand after sieving.

Soil particle density, ρ_s (g/cm^3)	Maximum dry density, $\rho_{d\max}$ (g/cm^3)	Minimum dry density, $\rho_{d\min}$ (g/cm^3)	Water content, w (%)	Mean particle size, D_{50} (mm)
2.692	1.585	1.296	0.13	0.6

Table 2
Properties of sandy ground in the gravity field.

Relative density, D_r (%)	Dry density, ρ_d (g/cm^3)	Void ratio, e
98–99	1.578–1.582	0.702–0.706