

수치해석을 이용한 얇은 기초의 강성효과 산정

Numerical Analysis for Evaluating Rigidity Effect on Settlement of Shallow Foundations

엔흐틀 어드게렐¹⁾, Odgerel Enkhtur, 김성렬²⁾, Sung-Ryul Kim, 정성교³⁾, Sung-Gyo Chung

¹⁾ 동아대학교 토목공학과 석사과정, Graduate student, Dept. of Civil Engineering, Dong-A University

²⁾ 동아대학교 토목공학과 조교수, Assistant Professor, Dept. of Civil Engineering, Dong-A University

³⁾ 동아대학교 토목공학과 교수, Professor, Dept. of Civil Engineering, Dong-A University

개요 : 얇은기초의 침하량은 기초강성에 따라 크게 좌우되지만 기준의 이론적인 연구결과는 실무에 적용하기에 불충분하였다. 그러므로, 본 연구에서는 3차원 수치해석법을 이용하여 직사각형 기초의 길이비에 따른 강성 보정계수를 산정하고자 하였다. 우선, Mayne & Poulos(1999)가 정사각형 기초에 대하여 제안한 강성 보정계수와 비교하여 본 수치해석 기법의 적용성을 검증하였다. 그리고, 검증된 수치해석 기법을 적용하여 직사각형 기초의 길이비를 $L/B=1, 2, 5$ 로 달리하여 해석을 수행하였다. 그 결과, 동일한 기초강성에서 기초의 길이비(L/B)가 증가함에 따라 강성 보정계수 값이 점차 증가하는 결과를 보여주었다. 그러나 $L/B=5$ 인 경우에는 강성계수가 10이상 되더라도 기초는 완전강성 거동을 보이지 않았다.

주요어 : 기초 강성 보정계수, 기초 강성, 얇은 기초, 탄성침하

1. Introduction

Generally, the rigidity of shallow foundations significantly affects the settlement. However, conventional methods for predicting settlement assume the foundations to be perfectly flexible or perfectly rigid, because the practical and reliable methods for the rigidity correction of footing have not been proposed.

Several researches have been performed for evaluating the effects of the footing rigidity. Brown (1969) proposed the correction factor of a circular footing resting on a semi-infinite elastic medium by numerical analyses. Mayne and Poulos (1999) proposed a practical chart for evaluating the factor based on the Brown's result. Fraser and Wardle (1976) suggested the correction factor for rectangular footings with different aspect ratios and various stiffness factors. As seen above, the chart developed by Mayne and Poulos has been widely used for practical applications, which is available only for circular footings. In addition, the Fraser and Wardle's method used the stiffness matrix that combines the Boussinesq theory with plate bending finite elements for FEM analysis.

The purpose of this paper is to provide a practical chart for taking account of the rigidity correction factor of footings, which can be applied for various aspect ratio of rectangular footings and the location on the footings. To achieve this, the commercial software FLAC 3D were used. The numerical modelling was verified by comparing with the chart of Mayne and Poulos, and then the verified model was applied to evaluate the rigidity correction factor for the rectangular footing.

2. Review of Previous Researches

Mayne and Poulos (1999) proposed an equation for the settlement calculation of shallow footings as

$$\rho_e = \Delta\sigma B \frac{1-\nu^2}{E_s} I_G I_F I_E \quad (1)$$

where, $\Delta\sigma$ = applied stress on footing

B = diameter of circular footing or the equivalent diameter of rectangular footing

ν = Poisson's ratio

E_s = Young's modulus of founded soil

I_G = factor for considering the variation of E_s with depth

I_F = rigidity correction factor

I_E = embedment correction factor

The footing flexibility K_F and the rigidity correction factor I_F are defined by Equations (2) and (3), respectively.

$$K_F = (E_{fdn} / E_{sAV})(t/d)^3 \quad (2)$$

$$I_F \approx \frac{\pi}{4} + \frac{1}{(4.6 + 10 \cdot K_F)} \quad (3)$$

where, d = diameter of circular footing or the equivalent diameter of rectangular footing

t = footing thickness

E_f = Young's modulus of footing

The limiting values of the rigidity correction factor are $I_F=1$ for the perfectly flexible footing and $I_F=\pi/4$ for perfectly rigid footing. The rigidity correction factor curve proposed by Mayne and Poulos (1999) are shown in Fig. 1, which was originally proposed by Brown (1969). The following categories for flexibility was made: (i) perfectly rigid with $K_F > 10$; (ii) intermediate flexibility with $0.01 < K_F < 10$; and (iii) perfectly flexible with $K_F < 0.01$.

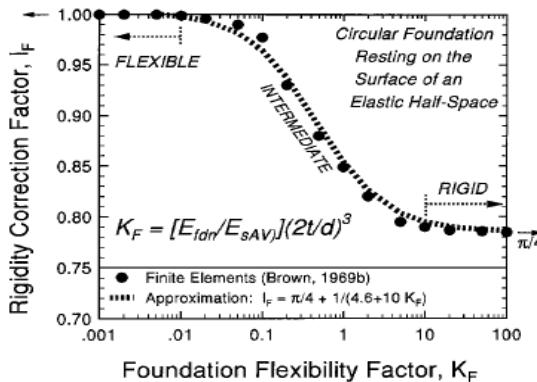


Fig. 1. Footing rigidity correction factor (Mayne and Poulos, 1999)

In addition, Mayne and Poulos (1999) suggested the settlement ratio at the edge and at the corner of the circular and square footings as

$$\frac{\rho_{edge}}{\rho_{center}} \approx 1 - \frac{1.533}{(4.6 + 10 \cdot K_f)} \quad (4)$$

$$\frac{\rho_{corner}}{\rho_{center}} \approx 1 - \frac{2.3}{(4.6 + 10 \cdot K_f)} \quad (5)$$

where, ρ_{center} , ρ_{edge} , ρ_{corner} = settlements at the center and edge of circular footing, and the corner of square footing, respectively.

However, the chart proposed by Mayne and Poulos can be applied only for the circular or square footings, although they insisted that the equations can be used for the other geometries by using the equivalent area concept.

Fraser and Wardle (1976) proposed the rigidity correction factor for the rectangular foundation by performing FEM analysis, in which the stiffness matrix used was combined the Boussinesq theory with plate bending finite elements.

Fig. 2 shows the comparison of the rigidity correction factors between the Mayne & Poulos and Fraser & Wardle methods. It shows that for a circular footing, the flexibility correction factor at $L/B=1$ on the Fraser & Wardle curve is much lower than that of the Mayne & Poulos curve. It is probable that the difference in the factors is due to the assumption adopted for the ground in the Fraser & Wardle analysis.

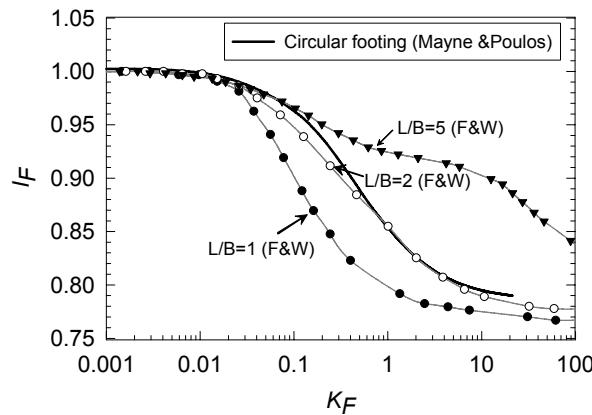


Fig. 2. Comparison of rigidity correction factors between existing methods
(L , B = length and width of footing, respectively)

3. Analysis Method

3D finite difference analyses were performed by using FLAC 3D program for this study. Linear elastic materials were used for the footings and founded soils, which have a constant value of Young's modulus with depth. Table 1 shows the used input parameters. A proper mesh which insignificantly affect the calculated settlement was found, and then applied for the analysis. Fig. 3 shows an example of the used meshes for the circular and rectangular footings. The footings with smooth bases are subjected to a uniform load.

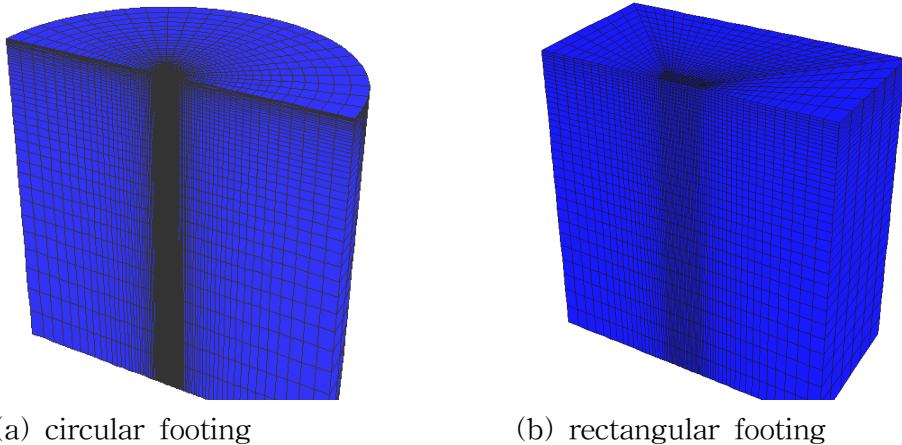
First of all, it was verified that the numerical analysis performed using the given modelling agrees well with the results provided by Mayne and Poulos. Then, such modelling was applied for a

number of cases of that account for the shape, location on the footing and rigidity of footing.

Table 1. Input parameters for analyses

Parameters	Unit	Values
q	kPa	100
E_f	kPa	2.5×10^7
E_s	kPa	1.0×10^5
v_f	-	0.20
v_s	-	0.25
a	m	10
t	m	0 ~ 2

Note: E_f and v_f = Young's modulus and Poisson's ratio of footing



(a) circular footing

(b) rectangular footing

Fig. 3. Three dimensional meshes used for circular and rectangular footings

4. Analysis Results

For the verification of this analysis, the rigidity correction factors obtained by Mayne & Poulos and this study were compared as shown in Fig. 4. It shows that this study results relatively agree with those of Mayne & Poulos.

Using the similar modelling to the above, the rigidity correction factors for various aspect ratios of rectangular footings were evaluated and the results were compared with those by Fraser and Wardle, as shown in Figs. 5 and 6. It shows that both results have a similar trend with a small difference, exceptionally indicating a big difference at $L/B=1$. Meanwhile, Mayne and Poulos suggested that the rigidity correction factors of square footing are extended to the rectangular footing that has the same area. However, it can be seen that the rigidity correction factors vary with the aspect ratio. In addition, at the same K_F value, the I_F value increases with increasing the L/B ratio. Mayne and Poulos suggested that for $K_F > 10$, the footing should be considered as a perfectly rigid footing. However, for the large aspect ratio ($L/B=5$), the I_F value decreases continuously with the increase of K_F .

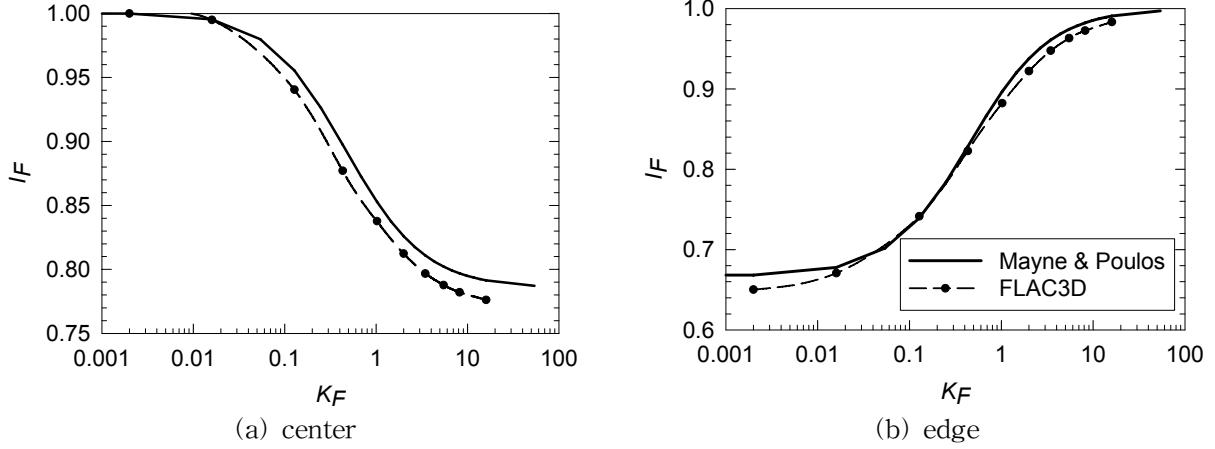


Fig. 4. Comparison of footing rigidity factors of Mayne & Poulos and present study

Fig. 6 shows the correction factors at the center, side and corner of the footing. The present results shows a similar trend to those of Fraser and Wardle, while the I_F value at $L/B=1$ (Fig. 6. a.) is different from the value at the $K_F > 0.01$. It is probable that the difference occurred due to the unreliable assumption for the ground modelling in the Fraser & Wardle analysis.

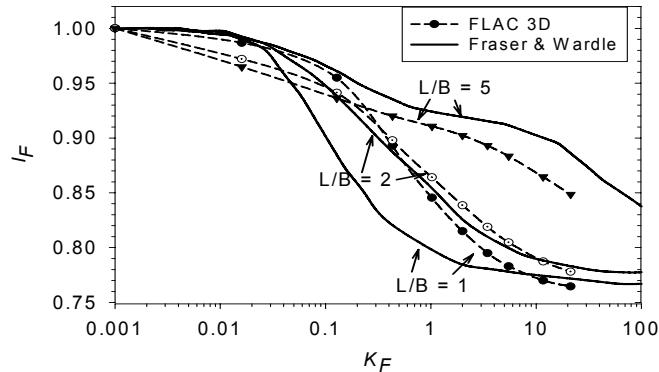


Fig. 5. Comparison of footing rigidity factors for various aspect ratios of rectangular footings

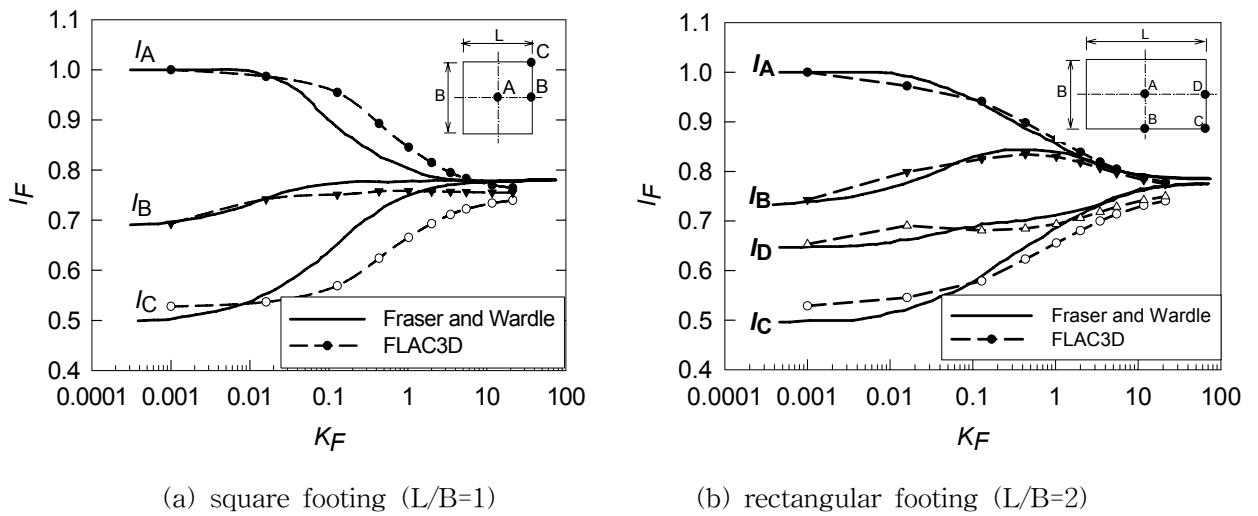


Fig. 6. Footing rigidity factors with location

5. Conclusions

The following conclusions were drawn from this study.

- (1) The rigidity correction factor of footing varies depending on the aspect ratio of the rectangular footing, so that the curve proposed by Mayne and Poulos is inappropriate to use for the rectangular footing with large aspect ratios.
- (2) For the large aspect ratios ($L/B > 5$), the I_F value decreases continuously with the increase of K_F , although Mayne and Poulos suggested that for $K_F > 10$, the footing was considered as a perfectly rigid footing.
- (3) Comparing with the present study, the rigidity correction factors proposed by Fraser and Wardle gave a different I_F value at the center of square footing, and thus they may underestimate the settlement

Acknowledgement

This work was supported by the Korea Science and Engineering Foundation (KOSEF) NRL Program grant funded by the Korea government (MEST) (No. R0A-2008-000-20076-0), and by Dong-A University, Busan Korea.

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