FOUNDATION-STRUCTURE INTERACTION OF A GROUP OF BUILDINGS WITH PILE FOUNDATION ON EXPANSIVE SOIL

INTERACTION FONDATION-STRUCTURE DANS UN GROUPE DE BÂTIMENTS AVEC FONDATIONS PAR PIEUX SUR UN SOL EXPANSIF

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A groupe of 176 residential houses, on a soil probably expansive, has suffered damade in brick walls and partitions. A three-dimensional finite element method has been applied to the set soil-piles-foundation beams to find out the relationship between swelling and stresses in several structural elements.

Un groupe de 176 maisons individuelles, construites sur un sol probablement gonflant, a subi des dégâts dans les murs de brique et les cloisons. Une méthode de calcul tridimensionnelle par éléments finis a été appliquée à l'ensemble sol-pieux-poutres de fondation pour déterminer la relation entre le gonflement du sol et les tensions dans les divers éléments des structures.

INTRODUCTION, STRUCTURE AND FOUNDATION

A group of 176 residential houses, in Seville, has suffered damage in - brick walls and partitions.

The houses, two storeys high, have a frame structure and brick cladding. There are expansion joints each three to four houses.

The foundation soil was supposed to be expansive and a pile foundation was chosen (fig. 1). The ground structural floor, 30 cm above the soil, is supported by beams, 60 cm deep, embedded in the ground and supported by the piles. The pile caps are braced in a direction perpendicular to these beams by crossbeams, 40 cm deep, also embedded in the ground. There is one single pile for each cap, except under expansion joints, where there are two piles under each cap. The pile diameter is 45 cm, except at the end of each row of houses and at the expansion joints, where the diameter is 35 cm. The depth of the piles is 10.5 m, and the - depth of the reinforcement 8 m.

Cracks appeared already at the end of construction and have increased with time. There are cracks up to 15 mm wide.

Levellings and the general scheme of cracks correspond to a rising of the axis of symmetry of each group of 3-4 joined houses respect to the

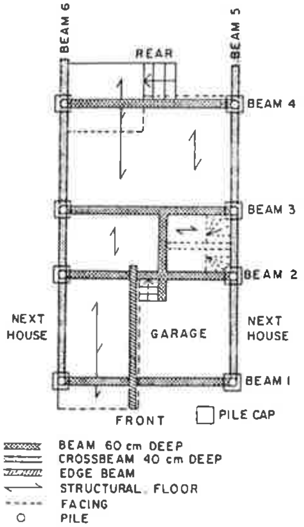

Fig. 1. Foundation and ground floor structure of one house

expansion joints or end of row. This rising may reach up to 55 mm, and the measured angular distorsions in the direction of the façadds range from 1/100 to 1/300.

SOIL PROPERTIES

Table I collects some average properties of the soil layers and the values used in calculations. The water table appears at a depth around 6.5 m. Poisson's ratio used in the calculations is 0.3.

Swell tests have been carried out on samples taken after the damage was established. These samples give little or no swelling, but this may be due to an increase in its water content respect to its state before construction. On the other hand, shrinkage is very important, and swelling after shrinkage is important in many cases.

Table I
Soil properties

Layer	Soil type	Depth m	w_L	q_u kPa	N_B blows/20 cm	Modulus of Elasticity MPa	
						I	II
1	Brown clay	1.0	58	50	12	10	5
2	Red clay	5.5-6.5	46	210	29	16	10
3	Silty clay	8.5	31		108	80	22.5
4	Sandy gravel	12.5			R	80	160

FINITE ELEMENT METHOD

The analysis of the soil-structure interaction has been carried out with the finite element method develop by Justo et al. (1983, 84, 85) for the study of foundations on expansive soil.

Delgado (1986) has shown in his Ph.D. thesis that if the input data are correct, the difference between the displacements calculated by this method and measured is less than 25%.

The fundamentals of the method have been presented by Justo et al. (1983, 84) and Delgado (1986). As a summary we may say that the soil is modelled as an elastic, isotropic, non-linear and heterogeneous solid, subject - to gravity loads and volume changes, and an equivalent, simplified stress-path is followed.

CALCULATIONS

Table II gives a description of the different cases studied.

Table II
Parameters of the different cases studied

Case		Discretization Type	Discretization Depth m	Modulus of Elasticity (table I)	Depth of expansive soil (m)
Complete foundation		I	8.50	I	5.5
Partial foundation	A	II	8.50	"	"
	B	III	"	"	"
	C	II	12.50	"	"
	D	"	"	II	"
	E	"	"	"	6.5
	F	IV	"	"	5.5
	G	II	"	I	"

The soil is in contact with the lower side of the beam in all cases, except in case G, in which the beam is free, and case E in which the beam is completely embedded.

Discretization (fig. 2)

Type I corresponds to the complete foundation of one house, including elements of the foundation (piles) and structure (beams that support the structural ground floor and crossbeams). As the stresses in beams 1 to 4 are quite similar, in types II to IV only the part of the foundation around beam 3 indicated in figure 2 (where stresses were slightly larger) has been considered.

In type I, a plane of symmetry along beam 6 has been assumed (as if the row had only two houses). In types II to IV a plane of symmetry along - beam 3 has been added.

Type II is the basic type of discretization corresponding to the partial foundation. Types III and IV have a more dense discretization. In type IV the thickness of the soil elements surrounding the piles is 10 cm instead of 50 cm in type II.

Swelling of soil

Owing to the reasons indicated under "Soil properties" above, the true expansivity of the soil is unknown and probably small.

For this reason different constant, small swellings of the free soil profile (under self weight) have been considered (v. Delgado, 1986).

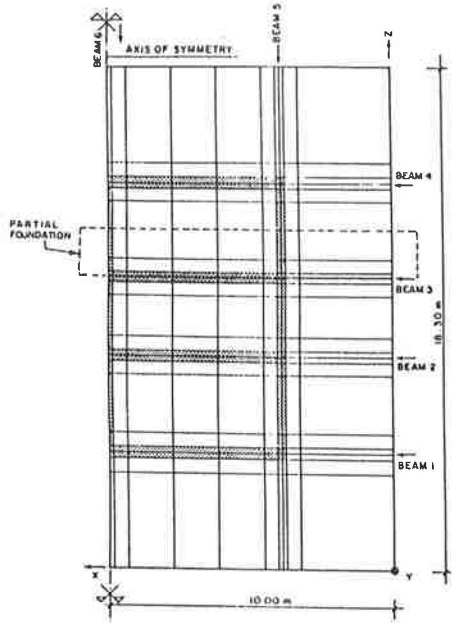

Fig. 2. Plan of discretization of the complete foundation and partial foundation

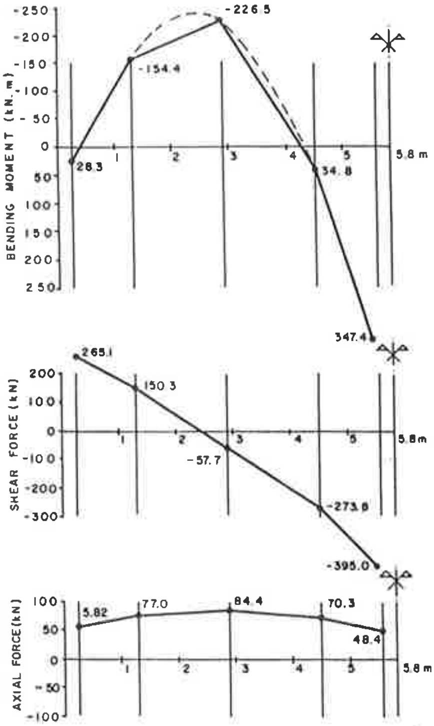

Fig. 3. Bending moments, shear and axial forces in beam 3 of complete foundation (v. fig. 2). Swelling 0.6.

Cases A and B have been calculated under swellings of 0, 0.6 and 1%. Interpolation has allowed to find the swelling that produces the rupture of the beam as 0.37%. This swelling has been applied to cases A and C to G.

RESULTS

From the calculated stresses at the centre of each element, the bending moment, shear and axial forces have been calculated in the different elements of piles and foundation beams (v. fig. 3).

Table III shows the maximum tensile forces in the reinforced and unreinforced zones of the pile.

An increase in the density of discretization produces a small increase in the shear stresses in beams and tensile forces in piles (case D to F in table III).

In the cases of the complete foundation, and partial foundation, A and B, the pile is assumed fixed in the upper part of layer 4 (table I). In the remaining cases, this layer has been discretized and the real length of the pile considered. We see in table III that the passage from case A to C produces only a small decrease in stresses: we see that the

Table III

Maximum tensile forces (kN) in the piles with a swelling of - 0.37%

Case	Reinforced	Unreinforced
A	606	210
C	571	206
D	255	105
E	368	216
F	394	219
G	208	68

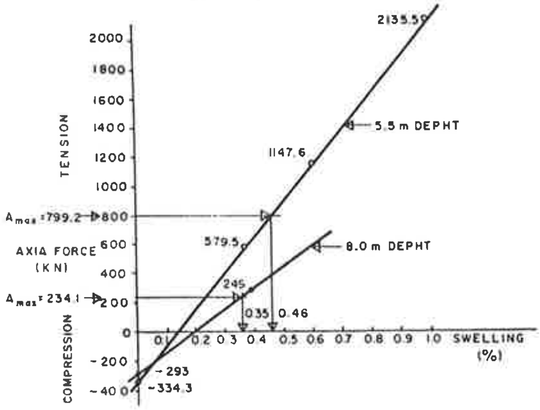

Fig. 4. Maximum tensile forces in 45 cm piles as a function of swelling (case A)

embedment produced by the gravel layer is important. The vertical displacement of the piles is of the order of 1 mm.

As expected, the relationship between bending moment or axial forces and swelling is linear (fig. 4). - From these relationships, and knowing the strength of the materials, it is possible to find the swelling that produces rupture in different elements (table IV).

The decrease of the modulus of Elasticity o: expansive layers produces an important decrease in the stresses in soil and concrete (v. table III). So, for rupture, we - need a larger swelling in - case D than in cases A to C (v. table IV).

The embedment of the beams produces an important increase in stresses (table III, cases D and E), larger in piles than in beams.

If the beam is free from - contact with the soil, the stresses decrease (table III, cases C to G). The tensions in the pile would be around tree times smaller (fig. 5). So the problem with the piles in this building is due mainly to not having freed the beams from the soil.

Table IV

Section	Swelling (%)	
	Cases A & B	Case D
35 cm pile, unreinforced zone	0.29	0.43
45 cm pile, " "	0.35	0.56
35 cm pile, reinforced zone	0.36	0.66
Loading beam, end	0.37	0.65
" " , centre	0.44	0.76
45 cm pile, reinforced zone	0.46	0.95
Crossbeam, end	0.58-0.66	0.95

CONCLUSIONS

1. The finite element method is a valuable method to resolve problems

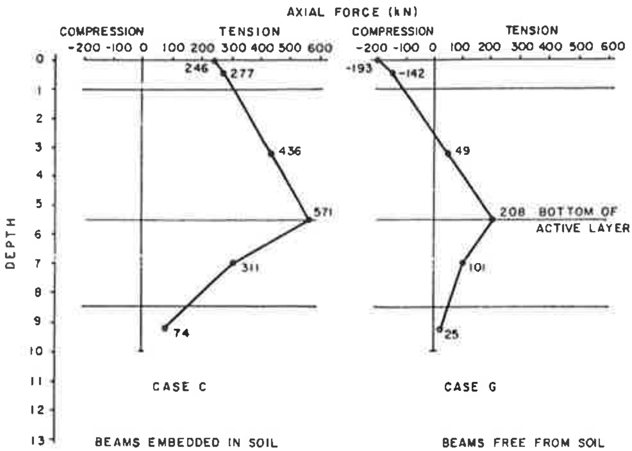

Fig. 5. Axial forces in 35 cm pile for 0.37% swelling

of soil-structure interaction. Stresses and displacements are easily - found, and the influence of different parameters may be ascertained.

2. Very small swelling produces the rupture of piles and beams when the se are not freed from the soil (table IV).

3. The calculated maximum heave when the rupture of piles is produced - is of the order of 3 mm. As, in this case, differential heaves of 55 mm have been measured, the piles must be broken at a dept around 8 m.

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