SOIL-STRUCTURE INTERACTION IN BUILDINGS WITH PIER FOUNDATION ON EXPANSIVE SOIL

INTERACTION SOL-STRUCTURE DANS DES BÂTIMENTS AVEC FONDATION PAR PILES SUR SOL EXPANSIF

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Five buildings with pier foundation on expansive clay have suffered slight structural and non-structural damage, but the foundation beams, resting on the ground were broken. The urbanization presents widespread damage. The water supply pipes have suffered continuous ruptures. Soil-structure interaction has been studied through a finite element method, discretizing the several soil layers, the piers, the foundation beams and the wall.

Cinq bâtiments fondés sur piles dans une argile gonflante ont souffert de légers dommages structuraux et non-structuraux, mais les poutres de fondation reposant sur le sol se sont cassées. Des dommages assez étendus ont été constatés sur l'urbanisation. Des canalisations d'adduction d'eau ont été rompues en de nombreux points. L'interaction sol-structure a été étudiée à l'aide d'une méthode basée sur l'utilisation des éléments finis, en discrétisant les différentes couches de sol, les piles, les poutres de fondation et les murs.

INTRODUCTION, STRUCTURE AND FOUNDATION

Five buildings, ten storeys high, near Seville, have suffered slight - structural and non-structural damage, but some foundation beams, resting on the ground, have become broken.

Figure 1 shows the foundation plan of one of the buildings. The structure is formed by concrete frames in the transverse direction of the blocks, and crossbeams. The structural floor of the ground floor is separated - from the soil by a crawl space, but the foundation beams rest on the -- soil.

The buildings were ended in 1976. Some fissures in the beams of the two end frames of one block appeared two or three years later, and have not changed up to now.

The water supply pipes have suffered continuous ruptures, and water has flooded the crawl space (fig. 1) from long ago.

The urbanization presents widespread damage: broken sidewalks, leaning walls, and cracks, roughness and distorsions in pavements.

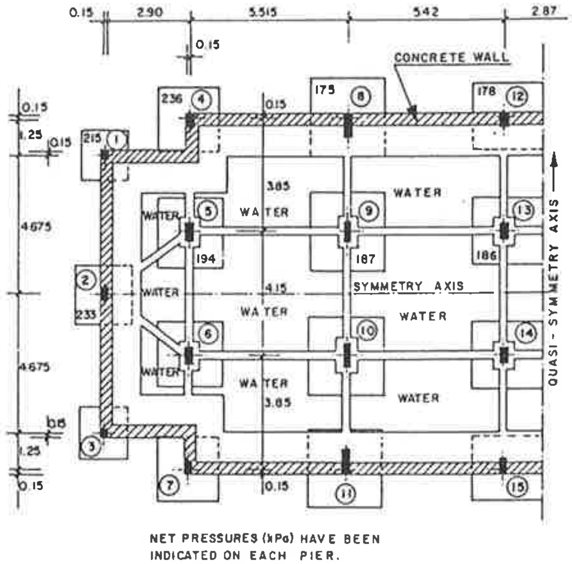

Fig. 1. Foundation of one building

The foundation depth is 2.5 m (fig. 2), and there is a perimetral wall. Foundation beams have suffered upward displacements up to 3 cm, shear displacements up to 1.2 cm, and flexural cracks with a width up to 4 mm.

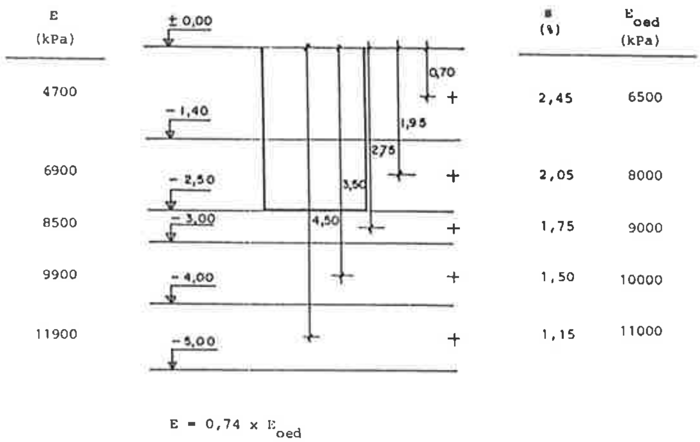

Fig. 2. Vertical swelling (s), edometric (E_{oed}) and Elasticity (E) moduli of the different soil layers, under its self weight

GEOLOGY AND SOIL PROPERTIES

The urbanization is placed in the slope of Aljarafe. Aljarafe is a plateau at an average height of somewhat more than 100 m above sea level. The slope that joints Aljarafe with the Guadalquivir valley is formed by old clays with an average slope around 14°, and is unstable (v. Justo, 1980).

The average characteristics of the soil are indicated in table I (v. Jus-to, 1985). The symbols approved by the International Society have been used (ISSMFE, 1981).

The depth of the water table ranges from 21 to 24.5 m.

Table I
Average characteristics of the soil

Soil layer	Depth m	w_L	I_P	N	q_u kPa	Swelling pressure kPa
Green-brown clay	7-15	61	38	22	460	230
Miocene blue marl		60	30	39	630	

q_u = unconfined compressive strength

SOIL-FOUNDATION-STRUCTURE INTERACTION IN SWELLING AND COLLAPSING SOILS

The authors of this paper have been working for a long time in the theme of foundations in expansive or collapsing soils (v. Justo et al., 1987).

The soil-structure interaction in these soils is rather complex, and is generally limited to the calculation of the heave or descent of the footings, assuming each one as isolated, from the data of expansivity, the loads and the thickness of the active layer.

This oversimplification forgets important factors of the problem, as the side friction between some elements of the foundation and the soil, the interconection between isolated foundations through the foundation beams, the influence of displacements of the foundation in swelling, etc...

We are applying to the solution of this problem a finite element method whose characteristics have been described by Justo et al. (1986).

SWELLING CHARACTERISTICS OF SOIL

Figure 2 shows the vertical discretization for types 1 and 2 below, and the swelling characteristics and Elasticity moduli of the soil layers used as an input in our finite element method, obtained from laboratory tests (Justo, 1985; Justo et al., 1984).

DISCRETIZATION

We have made use of the two symmetry axes of figure 1, and only a quarter of the foundation plan has been discretized.

We have considered the following discretizations:

Type 1. Only the piers, without foundation beams (fig. 3).

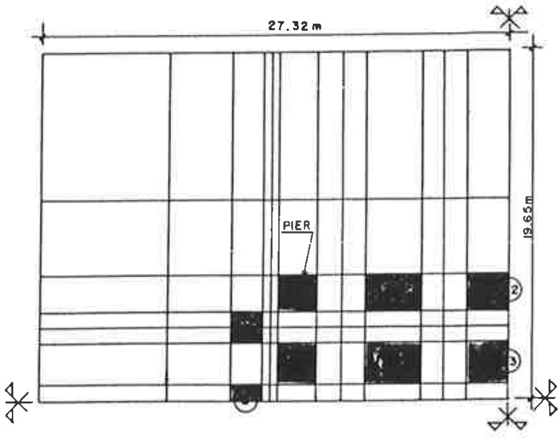

Fig. 3. Type 1 discretization

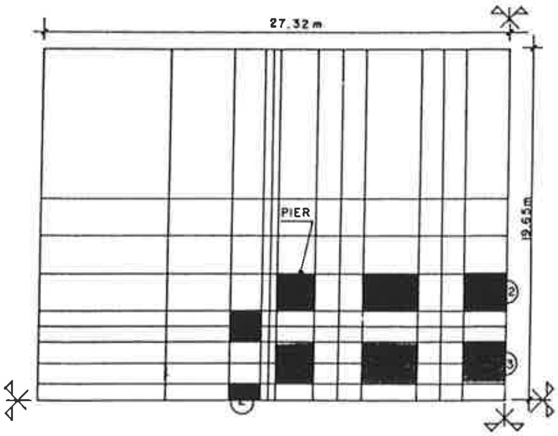

Fig. 4. Type 2 discretization

Type 2. As type 1, but with more dense discretization (fig. 4).

Type 3. As type 2, but with foundation beams and walls (fig. 5).

Type 4. As type 3, but with more dense discretization in foundation beams (fig. 6).

Two variants have been considered:

a) No horizontal displacements are allowed.

b) Horizontal displacements are allowed, except in symmetry axes.

The details of the discretization are given by Justo et al. (1986).

RESULTS

Table II shows the calculated heaves. Only the main conclusions will be commented here, for more details v. - Justo et al. (1986).

The introduction of - the foundation beams greatly decreases the rotation of the piers when horizontal displacements are allowed.

The densification of the discretization produces little change in the heaves (v. table II), but is important when stresses are considered.

If only vertical displacements are allowed, we diminish in an important way the number of equations and computer time. This restriction increases the calculated heaves (v. table II). On the other hand, only allowing horizontal displacements may we calculate the flexural stresses in the foundation beams.

STRESSES IN FOUNDATION BEAMS

Bending moments, shear and axial forces for beam A (fig. 6) are shown in figure 7.

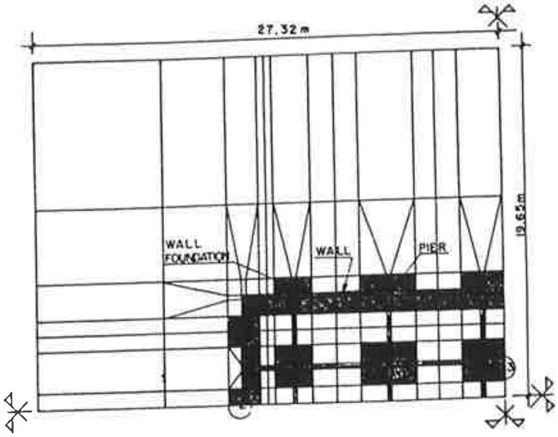

Fig. 5. Type 3 discretization

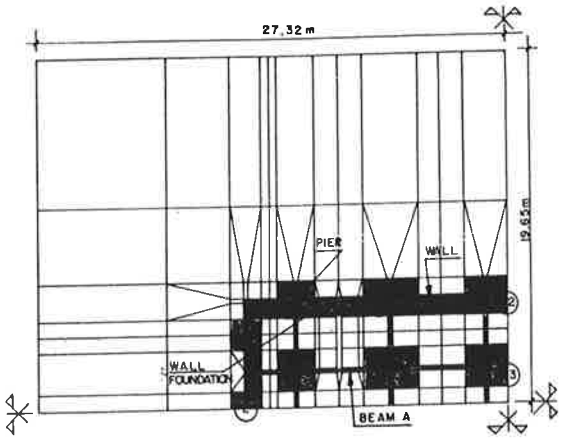

Fig. 6. Type 4 discretization

fissured.

The ultimate bending moment of the foundation beams is 31.5 kN.m. Several beams - are subject to larger moments (89.8 kN.m in figure 7), which justifies the rupture of the beams that has - beam observed.

SLOPE STABILITY

Many cases of slope - instability in the area have been regis - tred in the past (v. Justo, 1980).

An inclinometer was - installed near the - buildings in June 1985. In October 86, a linear displacement, - down the slope, from the surface to a depth of 30 m was registered, with a displacement at surface of - 21.8 cm. That gives an average displacement of 16.4 cm/year. From the last date - till January 87 no - new movements have - been registered.

Some signs of this - creep may be seen in the cracks of the road at the foot of the urbanization. A master pipe of the Seville - water supply has been

SOLUTIONS

To eliminate the water from the crawl space below the buildings, and to avoid the acces of water to different zones of the urbanization and slope, it is necessary to remake the water supply network.

In the new water supply system the joints must be specially studied. - Cast iron pipes with "automatic-flexible" joints have been recommended. The pipes must be placed on a sand bed, and its depth should be 1 to - 1.5 m.

Table II
Heave of ground and piers (cm)

Zone		Case					
		1b	2b	3a	3b	4a	4b
Ground surface	Point remote from building	9.21	9.21	9.20	9.20	9.20	9.20
	Point at centre of building	5.83	5.83	6.72	6.50	6.70	5.65
Piers	1	2.96	3.02	2.24	1.97	2.23	1.90
	2	2.72	2.86	2.24	1.98	2.23	1.87
	4	2.89	2.86	2.24	1.84	2.23	1.77
	5	2.56	2.63	2.24	2.00	2.23	2.03
	8	3.07	3.08	2.24	1.67	2.23	1.55
	9	2.74	2.74	2.26	2.08	2.24	2.15
	12	2.80	2.79	2.24	1.61	2.23	1.47
	13	2.37	2.42	2.23	1.82	2.22	1.79
	Average	2.76	2.80	2.24	1.87	2.23	1.82

Note: Numbers of piers in figure 1, and 3 to 6

It has been recommended also to excavate below the foundation beams, to separate the beams from the soil below a minimum distance of 15 cm.

Finally it has been recommended to install a drainage system in the - crawl space below the buildings, to eliminate any water entering this space.

Adequate transverse slopes (2%) must be given to all pavements to not allow the ponding of water on them (v. Justo, 1985).

New inclinometers will be installed, and new measurements will be taken. The tilt of the buildings will be measured.

CONCLUSIONS

The damage that present the buildings, and the distorsions of the pavements in the urbanization (fig. 8) are produced by the access of water from the water supply to the soil: the access of water to the soil induces swell which, in turn, produces new ruptures.

There is an important creep in the slope, perhaps activated also by - this access of water, which might have contributed to some of the damages in the urbanization and buildings, but the rupture of the founda - tion beams, distorsions in pavement and retaining wall movements are -

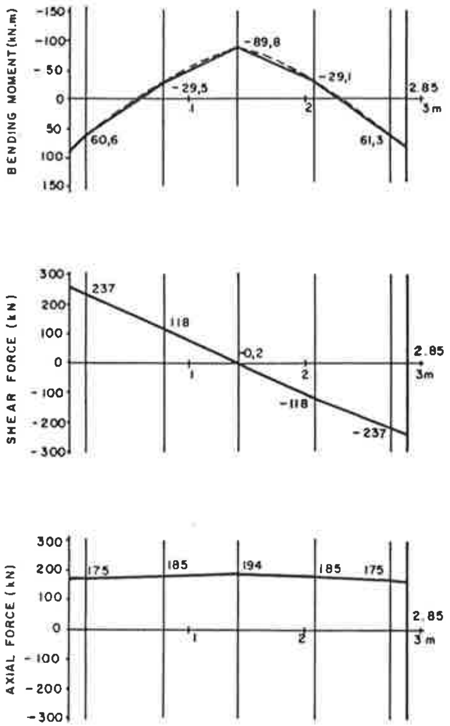

Fig. 7. Bending moments, - shear and axial forces in case 4b and beam A (fig. 6)

Fig. 8. Distorsions in pavement

clearly due to swell phenomena.

The finite element method is a useful tool to study the problem of soil-foundation-structure interaction. The rupture of the foundation beams has been adquately reproduced in the results obtained by this method.

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