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Field Study of Foundation of Extension Project to Tongji University Library in Shanghai

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SYNOPSIS: The extended building to Tongji University Library is composed of two cantilever beam structure towers with hight of 50m and 11 floor. In order not to affect the normal serviceability of the original library the large and deep compensated box foundation is adopted and a diaphragm wall close against box is employed as an anti-permeability veneering structure. Practice in this extension project has shown that compensated foundation is one kind of the best foundations for tall buildings in the areas with dense buildings in Shanghai. This paper studies in detail the distribution of contact pressure beneath box foundation. It has been found such composite foundation structure can improve the distribution of contact pressure, then reduce the moment and settlement of foundation. Based on the measured values of contact pressure the friction between box foundation and diaphragm wall can be predicted.

PREFACE

The extended building to Tongji University Library started in 1985. On the condition of the limited space, in order not to disturb the quiet environment in the library and not to destroy the structure of the original library, basement and superstructure configurations developed during schematic planning indicated that a compensated box foundation would be the most suitable foundation for the building, while a diaphragm wall is used as well to encompass and brace to the foundation so that it can fulfill the construction of the heavy building.
From the analysis of the contact pressure of the box foundation, we can obtain the experience of constructing heavy buildings in closely constructed area, which can be taken as an example by other engineers.

DESCRIPTION OF BUILDING AND SOIL CONDITIONS

The extended building to Tongji University Library is composed of two cantilever beam structure towers. this main building is 50m high with 11 floor (load in fact is equivalent to 22 floor) in which the lower four floors near ground are only lift shafts while the upper seven floors, cantilever beam floors in octagon plan with outside dimension,25mx25m, made with post-tension method. The dimension of each core of towers is 8.5mx8.5m. The total floor area of building is 9130m^2.

The major difficulty is that the extended building should be situated in two centre courts with 2x27.6mx23.0m of original library, a two storey brick and inner frame structure, sensitive to settlement. Furthermore, the space between the new and existed buildings is only 2.0m. In order not to affect the normal serviceability of the original library the large and deep partially compensated box foundation with 52mx20m and 9.4m high is adopted and the base is 8.9m below the average level of the ground surface. The bearing stratum is silty fine sand;and the static load of the super structure is 160000KN and the self-weight of the foundation is 9000KN. Meanwhile, a diaphragm wall with 0.6m thick and 17.1m long, an outer area of 21.2mx53.2m close against box is employed as an anti-permeability veneering structure. Its base is 16.5m below the ground surface and falls on the very soft clay.

The water table is lm below the ground surface. The properties of foundation soil are shown in Table I.

TABLE I. Properties of Foundation Soil

No.	Soil type	Thick -ness (m)	γ (kN/m^3)	w (%)	e	φ (°)	c (kPa)
1	Fill	0.6					
2	Yellow silty clay	2.1	19.1	31.1	0.866	16.8	15
3	Very soft silty clay	4.6	18.6	35.6	0.973	15.6	9
4	Grey silty fine sand	3.7	18.7	29.8	0.867	19.6	2
5	Very soft clay	8.1	17.6	47.8	1.313	7.7	12
6	Very soft silty clay with thin silt layer	11.4	18.4	35.1	0.999	16.8	10
7	Grey silty clay	10.9	18.3	33.6	0.995	16.1	10
8	Grey-greenish silty clay	3.6	19.3	33.2	0.817	20.3	28
9	Grey silty clay		19.3	30.8	0.843	15.4	9

FIELD EXPERIMENTAL STUDIES

To provide factual information on soil-box foundation-diaphragm wall interaction, 30 earth pressure cells were installed to measure the contact pressures on the base of the box foundation. Pressure cell locations are indicated by circular symbols in Fig.1 (unshaded symbols indicate units that have become inoperative). Most of these units are located in the southwest quadrant with duplicate cells placed at other locations around the building to determine variations in contact pressures. Despite that 16 earth pressure cells broke down one after another in 4 years, those cells at key points fortunately keep running very well, and then make the analyses possible.

In addition, to record the movements of the box foundation and wall with respect to time, 15 & 10 permanent reference points were established on the top of the box foundation and the wall respectively at the locations indicated by triangular symbols in Fig.1.

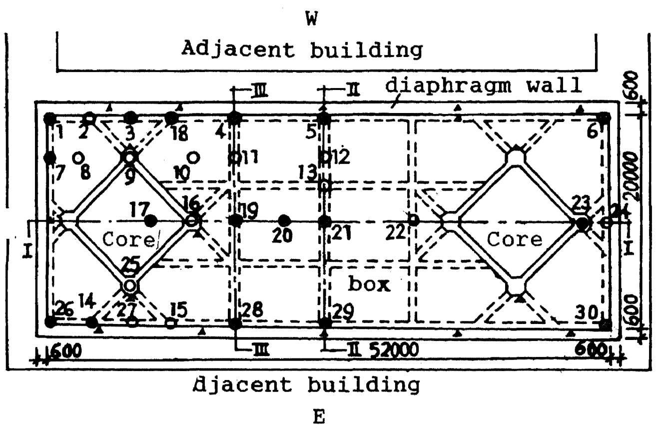

Fig.1. Building Plan and Instrumentation Layout

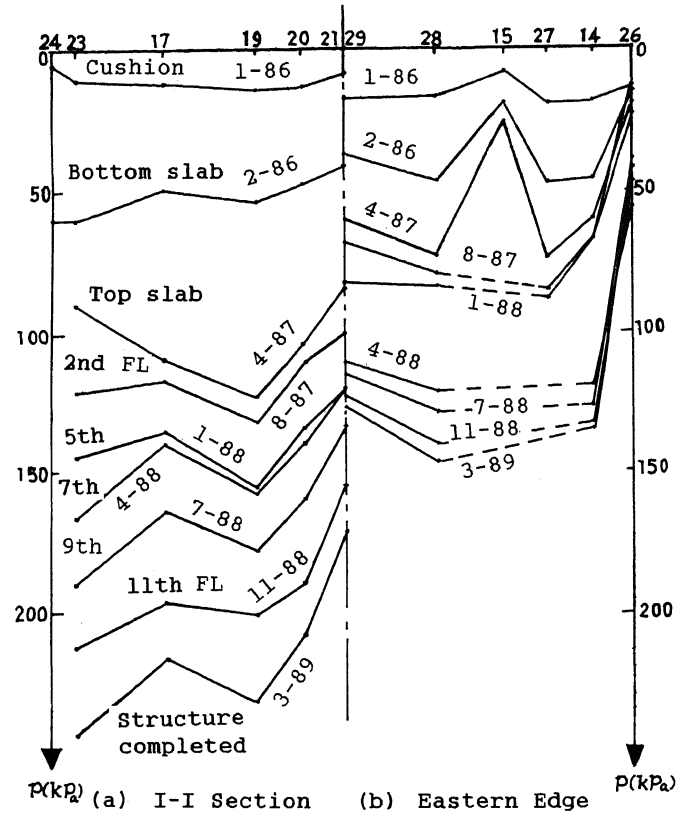

Fig.2. Contact Pressure Profiles of Box

DISTRIBUTIONS OF CONTACT PRESSURES

Distributions of contact pressures for I-I section are shown in Fig.2(a). The distributions curves of contact pressure on this figure are relatively even during early stages of construction. With the construction of the basement, the building of the two core structures from the bottom slab near the both flanks of the box foundation, makes the contact pressure under the core and heavily loaded wall greater than that at other positions,and their difference is as high as 72kPa , this is apparently distinct from the a common box foundation. In tube-structure consequently design, the proper arrangement of the tubes will be conducive to the reduction of the whole bending moment caused by the contact pressure; it is necessary to add some shear resistance bars in the joints of the box and the tube to increase the rigidity of the box-tube structure.

Fig.2(b) shows that the magnitude of the contact pressure at the eastern edge of the box foundation is remarkably smaller. Figures 3(a)

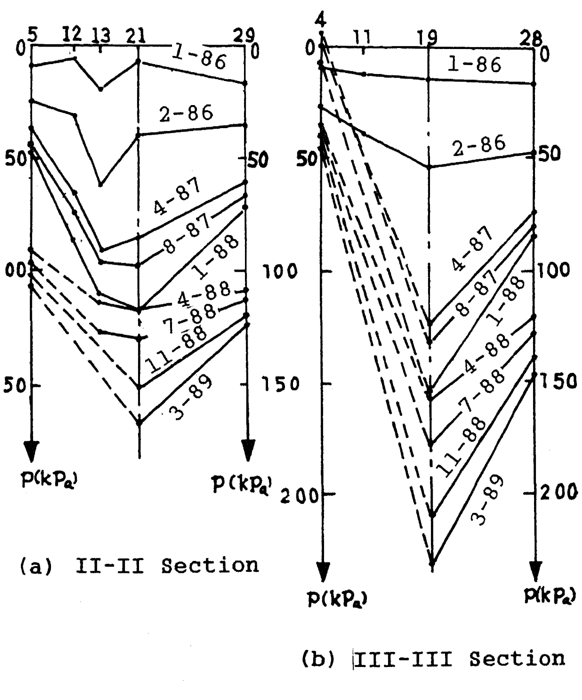

Fig.3. Contact Pressure Profiles of Box

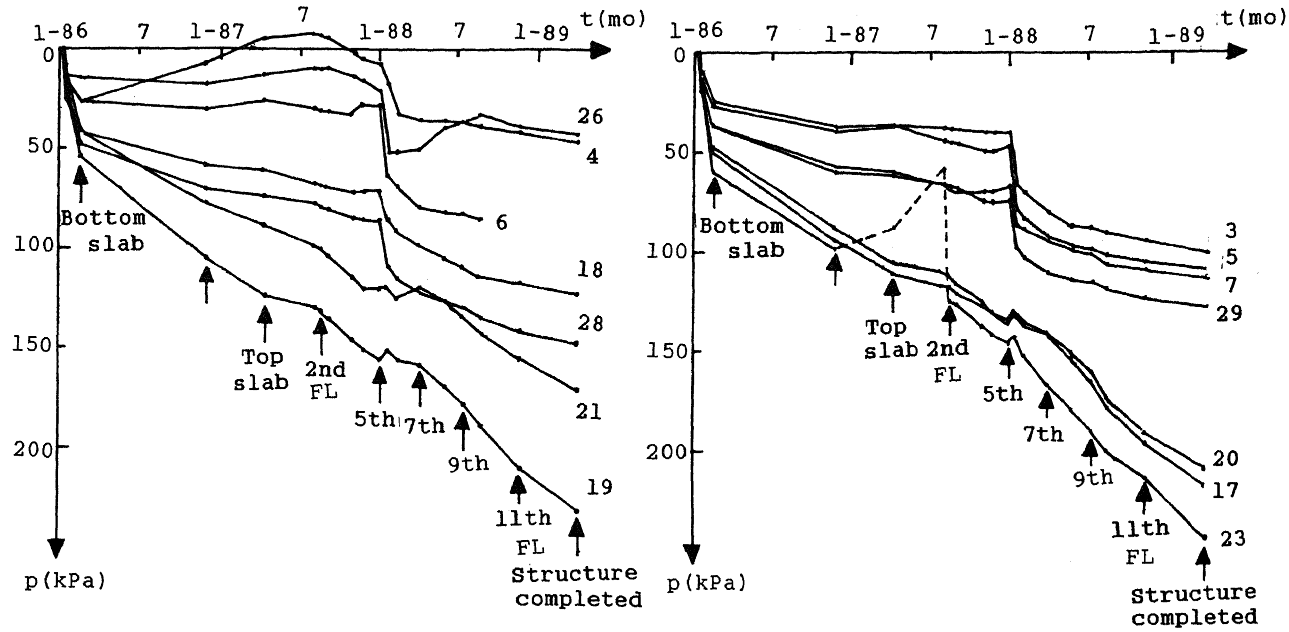

Fig.4. Contact Pressure-Time Curves

and 3(b) also show that the contact pressure at the edge is greatly lower than that in the middle,this phenomenon is perceptibly different from that of a non diaphragm wall close against box foundation. On the other hand , from the settlement data, the wall and the box foundation settle together. At the same time, due to the settlement of the wall, the soil under the edge of the box foundation bottom is brought to settling, therefore, the contact pressure at the edge of the box foundation wrapped by the diaphragm wall is far smaller.
According to the comparison between contact pressures from the 5th floor to the 7th floor in Fig.3(a) and 3(b),it can be seen that the contact pressures at the edge area of box foundation increase far larger than that in the middle of the box foundation.

In general, the curves on Fig.4 obviously indicate that the increasing rate of the contact pressure at the edge of box is smaller than that in the middle. therefore, when the box foundation is tightly wrapped by the wall, the influence of the friction between the wall and the flank of the box foundation make the wall settle, cause additional settlement of the soil at edge of the box bottom,and consequently reduce the contact pressure of that area, which in turn make longitudinal whole moment greatly lowered than that of the box foundation without a diaphragm wall.

It is interesting that from the measured pressure-time curves in Fig.4 shows that contact pressure at points of the edge of box (points 3,4,5,6,7,18,26,28,29) increase abruptly while the contact pressures at points (17,19,20,21,23) of middle part decrease when 5th floor was completed. The reason of the abrupt increase of contact pressure at the edge of box is that the settlement of the diaphragm wall is smaller than that of the box foundation at that time.

The comparison between theoretical, code[1] and measured coefficient α of longitudinal average contact pressure is shown in Table II. The theoretical value is obtained using the double extended substructure finite element-finite layer element method [2].

TABLE II. Comparison Between Theoretical, Code and Measured Coefficient of Contact Pressure, α & Moment, Mo

Case		α_1	α_2	α_3	α_4	Mo
Theoretical (No Diaphragm Wall)		2.054	0.568	0.687	0.691	19.970
Measured	Bottom slab	1.099	0.889	0.984	1.028	16.118
	Top slab	0.862	1.075	1.098	0.965	15.668
	2nd FL	0.930	1.055	1.073	0.942	15.946
	5th FL	0.849	0.967	1.179	1.005	15.320
	7th FL	0.966	0.950	1.069	1.015	15.734
	11th FL	0.960	0.951	1.060	1.029	15.684
	Structure completed	0.988	0.964	1.070	0.978	15.924
Code (No Diaphragm Wall)		1.059	1.128	0.951	0.862	16.768

The maximum longitudinal moment in Table II is

$$Mo = 7\alpha_1 + 5\alpha_2 + 3\alpha_3 + \alpha_4 \quad (1)$$

It can be seen from Table II that the case of the wall close against box foundation may reduce the value of Mo. namely, reduce the value of longitudinal whole moment of the box foundation. Besides, the variation of measured contact pressure coefficients α during different construction stages in Table II indicated that the influence of the wall was obvious. When the bottom slab with 94 cm thick was finished, the wall contacted with the bottom slab on a small surface, in that case the variation in measured value of α is similar to that in theoretical value. However, with increase of contact surface, from top slab to structure completed, the values of α_i are less than 1 and the values of Mo are smaller than that of bottom slab finished. It shows that a box foundation tightly wrapped by a diaphragm wall can reduce the longitudinal whole moment of the box foundation.

The comparison between the average measured contact pressure P and the real loading N in various construction stages listed in Table III fully demonstrates that there is friction between the four sides of the box and wall, this friction F reaches up to 20 % of the total loading of the structure.

TABLE III. Comparison Between The Average Measured Contact Pressure P and The Real Loading N

Construction Stage	N (kPa)	P (kPa)	P/N (%)	F (kN)
Top Slab	88.3	84.2	95.4	4260
2nd FL	96.1	94.2	98.0	1980
3rd FL	100.0	97.4	97.4	2700
5th FL	127.0	103.2	81.3	24750
7th FL	151.0	134.0	88.7	17680
11th FL	198.7	156.7	78.9	43680

THE BUILDING SETTLEMENT

The settlement of the diaphragm wall had been measured since foundation pit was excavated on August 27,1985. But reference points were, unfortunately, not extablished on the box foundation until October 27,1987. According to experience for foundation pit with the depth of 5-6m, the heave is about 1/100 of excavation depth; when the load of construction is equal to soil weight excavated off, the settlement of the structure is a little greater than the heave [2]. Now, the depth of foundation pit is 8.9m therefore settlement of box foundation is estimated about 10cm between August 27,1985 and October 27,1987. Later,the measured settlement of box foundation was 4.62cm between October 27, 1987 and December 4,1989 (structure completed), so, the average total observed settlement of the box foundation is about 14.62cm. It is seen that box compensated foundation can reduce settlement of the structure.

CONCLUSIONS

1. The box compensated foundation is a suitable foundation for heavy structures in a limited space within a group of close buildings.
2. A box foundation tightly wrapped by a diaphragm wall can reduce contact pressure at the edge of the box foundation, the longitudinal whole moment and settlement of box foundation.
3. A box foundation tightly wrapped by a diaphragm wall has a varying friction between the box foundation and the wall. The proportion of the friction in the total loading of the structure is within 20 %

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