Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 80 (1999)

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DOI: https://doi.org/10.5169/seals-60755

The Test and Research on Design Method of Diaphragm Wall-type Foundation of Bridge

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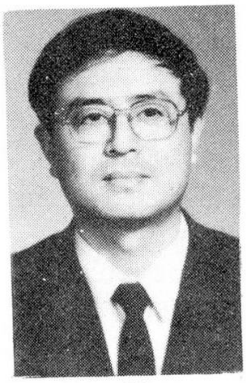

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Summary

This paper discusses the field test and finite element analysis of the solid digging well foundation and the diaphragm wall-type foundation in scale 1:2 with same dimension. These foundations had been built in loess Q3. The results show that the vertical friction force and the horizontal resistance are not given by soil column inside the diaphragm wall-type foundation. The calculating model of hollow foundation had been established in the design of this foundation. This paper also introduces a practical case of the first diaphragm wall-type foundation of bridge in China.

1. Introduction

At present the underground Diaphragm Wall-type Foundation(DWF), which is a kind of rapidly developed foundation form, has been widely used to bridge structure in Japan. In comparison with the Solid Foundation(SF), DWF has better bearing capacity and stability because of its owing more base and outside surface area. In Japan, "The Guide of the Design and the Construction in Underground Diaphragm Wall Foundation" [1] pointed out that one portion of vertical friction force of internal soil body can be taken into account while designing.

The Baoji-zhongwei Railway, which was built in the Northwestern areas of China in the early nineties, was located in loess area. The underground DWF was put to use in design, and a model test research was carried out to serve the design.

2. Model Test

2.1 The General Information of Model Test

Two circular foundation models whose diameter is 2.5m, depth is 5m (the model scale is 1:2 with a practical bridge) are adopted. Concrete was poured into it after the foundation had been dug successfully on the spot. The steel earth-pressure celles which had been calibrated in advance were fully arranged on bottom of the model. Along with the height of the side wall, Φ150mm steel earth-pressure celles were disposed every 0.6m*(Fig.1)*. Tiltmeter and displacement transducer were installed on the top of the foundation so that the parameters such as displacement and rotation can be measured. The test spot was in Q3 collapse loess area and its physics-mechanics properties is listed in *table 1*.

Table 1. The Main Properties of Physics-mechanics in Q3 Loess

natural Density	natural water content	natural void-ratio	plastic limit	liquid limit	triaxial test	shear	compression coefficient	coefficient of collapsibility
P(g/cm^3)	W(%)	e	Wp(%)	Wl(%)	C(Kpa)	Φ(°)	a(Mpa^{-1})	(under the pressure of 0.3Mpa)
1.48-1.50	15.5-18.0	1.101-1.142	17.6-19.5	27.9-30.1	16-56	17.7-20.5	0.435-0.725	0.064-0.104

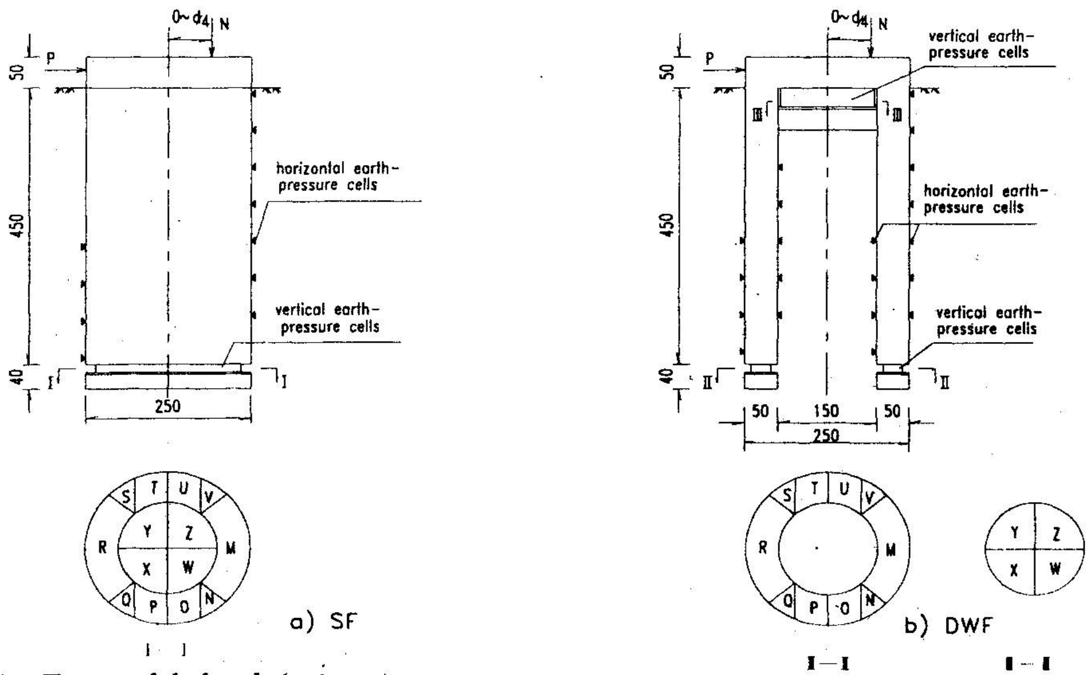


Fig.1 Test model sketch (unit:cm)

Loading equipment is composed of loading beam, anchor stake and two jacks of 3.0MN. First, vertical eccentric loading of the model is made (the distance of eccentricity is one fourth of base diameter) and the horizontal loading (from grade 10 of zero to 780KN.) are carried out after unloading.

2.2 Main Results of the Test

2.2.1 The Vertical Eccentric and Central Loading

(1) The limit load-bearing of SF is obviously greater than that of DWF as shown in *table 2*.
Drawn from the N (load)-S (sinking displacement) curve, the displacement of DWF is greater than that of SF when the loads are same (see *Fig.2* and *Fig.3*).
(2) The resistance force at the foundation bottom increases when the load increasing. When the damage reached, the total resistance force for DWF in about 35% of the total loads and 42% for SF.

Table 2. The Limit Load-bearing of Two Foundations

type of foundation	vertical eccentric loading (MN)	vertical central loading (MN)
DWF	1.6	2.0
SF	2.4	2.8

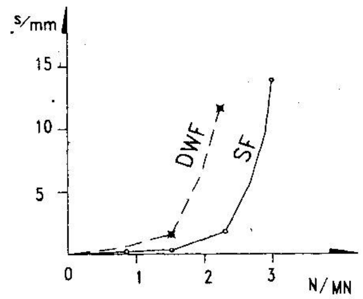


Fig.2 N-S curve for vertical eccentric loading

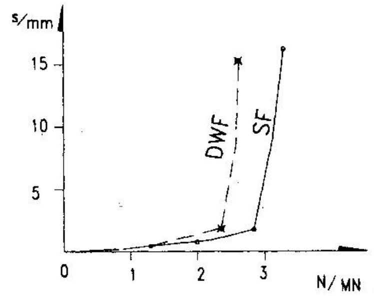
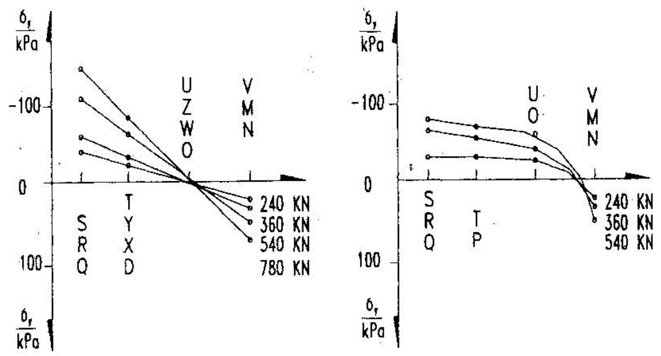


Fig.3 N-S curve for vertical central loading

(3) The bearing resistance of contact surface (area x,y,z,w) between the bottom of the top deck of the diaphragm wall and the top of soil column is small, which is only about 4% of the total ground resistance, while the vertical friction force of the two foundations is almost equal under the same loading condition.
(4) The pressure stress distributions of the two foundation bottoms are slant straight line when the load is small and it matches well with the theory of elasticity. When the load increases and the plastic behavior of the earth is obvious, the stress distribution occurs and shows "∽" curve. *(fig.4)*.



a) SF b) DWF

fig.4 The distribution of base stress under vertical eccentric loading

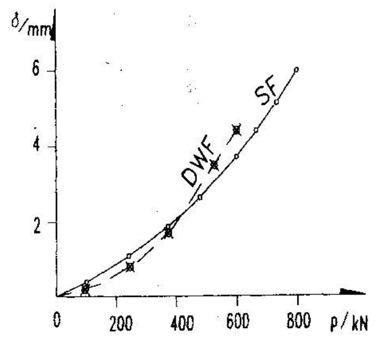


fig.5 P- δ curve when horizontal loading

2.2.2 Horizontal Loading

(1) From the P (load)- δ (horizontal displacement) curve (*fig 5*), we can see that the horizontal anti-push stiffness of DWF is similar to that of SF, which is different to some degree from the test results of diaphragm wall-type sinking well by the Japanese 饭坂. In this field test of the viaduct, the horizontal displacement of ordinary sinking well is four times as much as that of DWF. [2]

(2) The stress of the two foundations is pulling stress (*Fig 6*) and the foundation bottom turns around the front end of the bottom and tends to be up. The distribution and its value of horizontal earth pressure at the external wall of the two foundations is almost same(*fig 7*); but there is almost no earth pressure in the internal side wall of DWF.

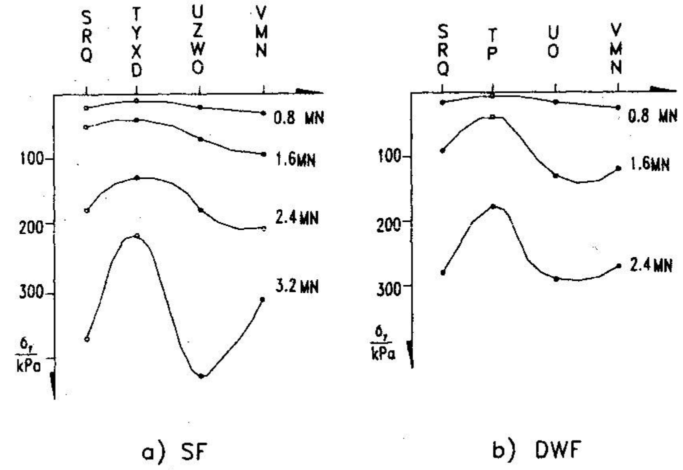


Fig.6 stress distribution of the foundation bottom when horizontal loading

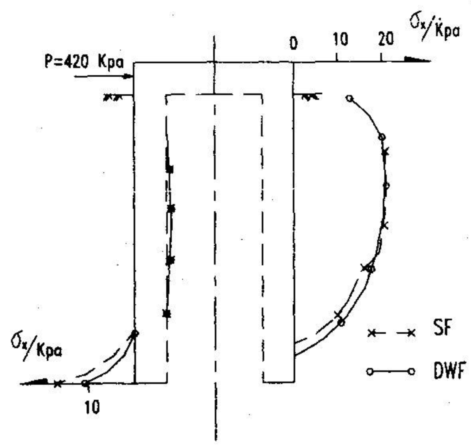


Fig.7 the distribution of horizontal earth pressure of side wall

3. Finite Element Analysis

By using a finite element program of calculation, the stress and deformation of the earth-foundation are calculated when the vertical load is 1.6MN and horizontal load is 420KN. In calculating, 400 three dimensional solid units with six surfaces are divided. The elastic modules E of the foundation concrete is 27×10^3 Mpa; the passion ratio v is 0.17; the elastic modules Es of the soil is 17 Mpa. The calculation model is shown is *Fig 8*.

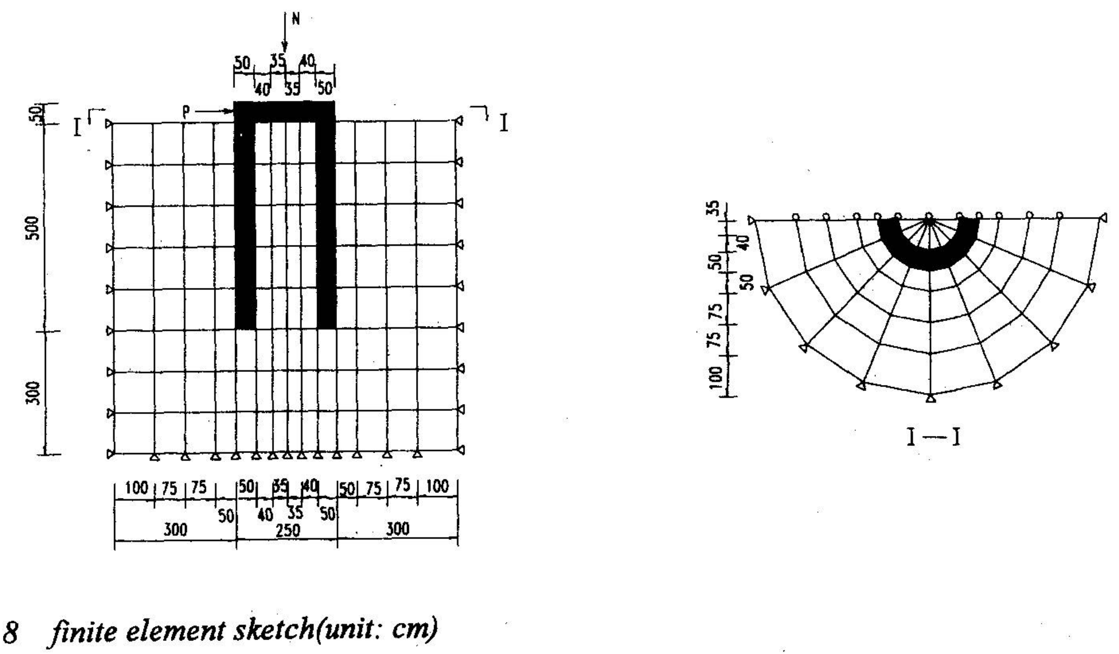


Fig. 8 finite element sketch(unit: cm)

3.1 Main Results of Calculation

3.1.1 Vertical Central Loading

Under the same loading, the pressure stress at the bottom of DWF is about 26% larger than that of the SF; the friction force of the external side-wall are almost equal, the earth pressure at the top of soil column of DWF is one fifth of that of SF, the vertical friction force of internal side-wall is almost zero. All these results match with the test(*Table 4*).

3.1.2 Horizontal Loading

Under the same loading, the average stress of DWF and SF is almost zero, which shows that the areas of its pulling part and its pressing part are equal. The earth's horizontal resistance of external side-wall is about one second of that of the actual measured data, which is different from the test results to some extent (*table 5*). The main reason is that the actual anti-pulling capacity of soil is very small and the finite element calculation cannot simulate this feature.

Table 4 Comparison of Results under Vertical Loading of 1.6MN

type	DWF		SF	
	test	FEM	test	FEM
base pressure stress (Kpa)	101.8	90.0	63.7	71.5
external side-wall fractional force (Kpa)	35.7	18.0	37.1	18.9
internal side-wall fractional force (Kpa)	/	-0.8	/	/
base stress on earth column top (Kpa)	10.1	22.6	50.7	45.2
vertical displacement (mm)	0.28	0.72	0.21	0.67

Table 5 Comparison of Results under Horizontal Loading of 420KN

type	DWF		SF	
	test	FEM	test	FEM
average pulling stress force at the base (Kpa)	37.2	3.3	36.1	0.8
horizontal resistance force of external side earth at 1/2 height (Kpa)	22.3	12.0	22.4	16.9
horizontal displacement (mm)	2.66	2.63	2.74	4.26

4. Discussion on Load-bearing Capacity of DWF

Hai (海野隆哉) [3] consider that internal side earth has certain vertical and horizontal stiffness when they analyze the load-bearing capacity of DWF. When analyzing by the finite element theory, Yan(岩田敏雄) assumed that the friction force between the surface of internal side wall and the earth body is one half that of the external wall and is not beyond the limit load-bearing capacity of the bottom opening of the base.

The test results and the finite element analysis of this paper show as follows: To Q3 loess area, because the soil of earth column top within the diaphragm wall is not suppressed by the surrounding earth body, the earth column density is low, the deformation is high and the stiffness is small, the vertical and horizontal loading capacity of the earth column is small and its influence on the loading capacity of the whole foundation is very slim. Besides, by analyzing the Chinese test document about sinking of well, it can be obviously seen that the surrounding earth body also sinks when the sink well sinks and the scope of its influence is at least bigger than the diameter of sinking wells [4]. But in this test, the diameter of the soil column within diaphragm wall is only 2/3 of the outside diameter of the foundation and its sinking along with the external side soil body is inevitable. For these reasons, the author of this paper believer that when the foundation is loaded, the whole earth body sinks along with the sinking of the whole foundation and the vertical frictional force can not be formed. Therefore, when designing this kind of foundation, the influence of the internal lateral soil column will not be taken into account. It is reasonable and safety to consider DWF as hollow foundation whose support reaction provided by the ring base as well as friction provided by the external force.

5. Engineering Example

A bridge located at 169 Km railway between Baoji and Zhongwei in northwest of China was chosen as the test spot. The bridge, which was completed in 1995, is a simple-supported girder bridge whose span is 4×32m+24m. The height of its NO.3 pier is 26.5m and its foundation is DWF. The height of the well (H) is 7.5m; the outside diameter (D) is 7m; the thickness of the wall is 1.5m and 15# concrete is used. While designing, the function of the internal earth body was not considered. The designed maximum pressure stress on base ground is 725 Kpa, the allowed load-bearing capacity is 728 Kpa.

Compared with the scheme of SF, 10% of constructing volume was saved by using DWF and the constructing period was also shortened under the same condition.

6. Conclusions

(1) The horizontal load-bearing capacity of DWF is almost the same as that of SF under the same external dimensions and the vertical load-bearing capacity of the former is less than that of the latter.

(2) The influence of internal earth column on the load-bearing capacity of the whole foundation is very small so that the function of the internal earth column is not considered in design and the calculation model can be based on the hollow foundation.

(3) The engineering example shows that DWF designed according to the above theory can obviously save the engineering cost compared with SF.

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