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DESIGN METHOD FOR LARGE REINFORCED CONCRETE CIRCULAR SLABS

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Abstract

To resist the groundwater uplift pressure, the bottom slab of an LNG in-ground storage tank is a thick reinforced concrete slab with a depth of 7 to 10 m. This paper describes the effect of size on the shear strength of circular slabs. To verify the effect of size on the shear strength of a thick reinforced concrete slab, experimental studies are conducted on large reinforced concrete circular slabs subjected to distributed loads. The shear strength of a reinforced concrete circular slab without shear reinforcement gradually decreases as the effective depth "d" of the slab increases. From the results of experiments on large slabs, the size effect on the shear strength of a circular slab is inversely proportional to the fourth root of the effective depth. Bottom slabs with depths of 7.4 m and 9.8 m were subjected to full and 85% design pressure. The result showed the validity of the design method.

Key words: Shear Strength, Size Effect, Reinforced Concrete, Circular Slab

1 Introduction

Figure 1 shows the dimensions of 140,000kl LNG underground tanks

A,B), and Fig. 2 shows their re-bar arrangement. Figure 3 shows the dimensions of a 200,000kl LNG in-ground tank, and Fig. 4 shows its re-bar arrangement. To resist the groundwater uplift pressure, the bottom slab of a LNG underground or in-ground storage tank is a thick reinforced concrete slab with a depth of 7 to 10 m. This paper describes the effect of size on the shear strength of circular slabs. To verify the size effect of a thick reinforced concrete slab, experimental studies on the shear strength of large reinforced concrete circular slabs subjected to distributed loads were conducted [Akiyama et al. (1996)]. The shear strength of a reinforced concrete circular slab without shear reinforcement gradually decreases as the effective depth "d" of the slab increases. From the results of experiments on large slabs, the relative shear strength of a circular slab was found to be inversely proportional to the fourth root of the effective depth. Bottom slabs with depths of 7.4 m and 9.8 m were subjected to full and 85% design pressure [Nakano et al. (1996)],[Sejima et al. (1996)]. The results showed the validity of the design method.

2. Size effect tests on large reinforced concrete circular slab

To verify the effect of thickness on the shear strength of reinforced concrete circular slabs, circular slabs were loaded up to shear failure under simply supported conditions. The cross sections of the slabs are shown in Fig. 5, and the method of testing is shown in Fig. 6. Properties of specimens are shown in Table 1.

Table 1. Properties of specimens

	specimen			re-bar			concrete
	effective depth d(mm)	diameter F (mm)	P / d	radial reinforcement ratio p_r (%)	circumferential reinforcement ratio p_θ (%)	shear reinforcement	compressive strength (N/mm^2)
No.1	872	7,800	9	0.32~0.74	0.45~0.74	no	22.2
No.2	780	7,800	10	0.40~0.75	0.49~0.75	no	29.8
No.3	872	7,800	9	0.32~0.74	0.45~0.74	few	28.5

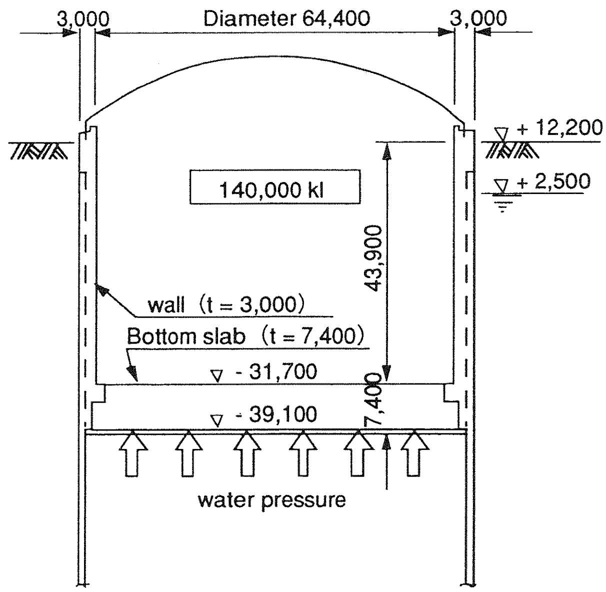

Fig. 1. Dimensions of 140,000kl LNG under-ground tanks (A,B)

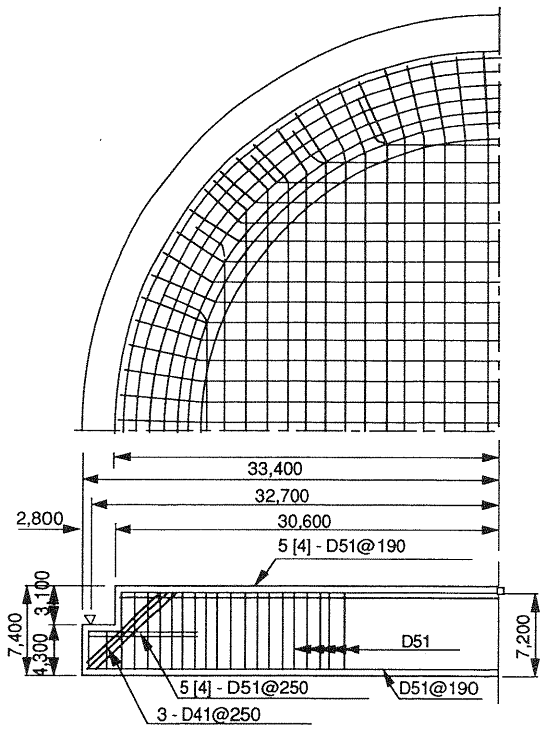

Fig. 2. Re-bar arrangement of Tank A and B

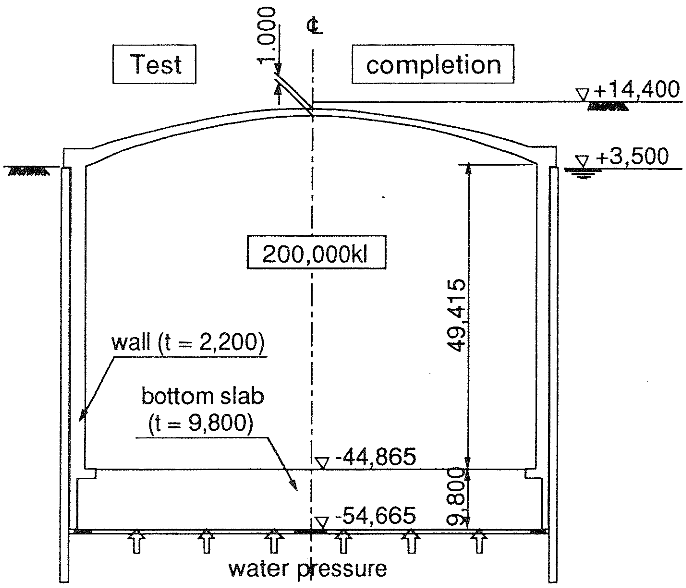

Fig. 3. Dimensions of 200,000kl LNG in-ground tank

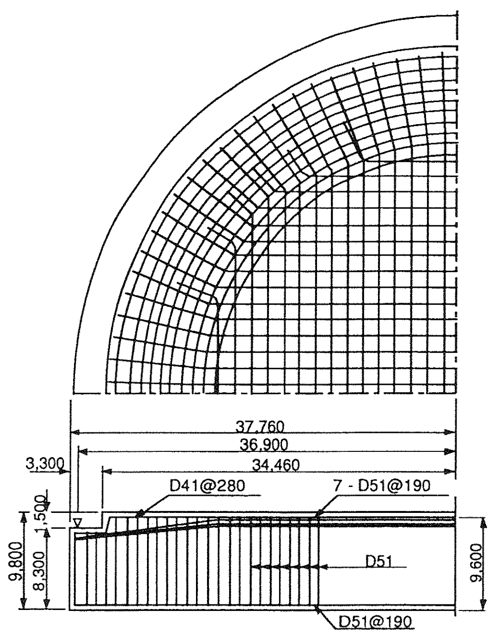

Fig. 4. Re-bar arrangement of the 200,000 kl tank

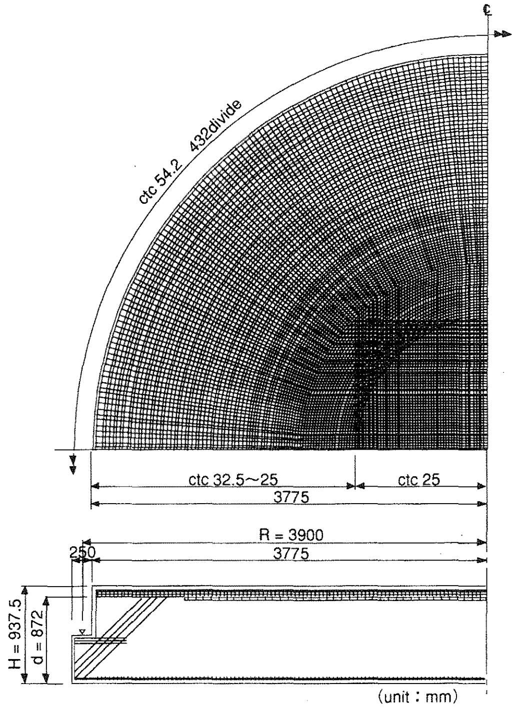

Fig. 5. Cross sections of slabs

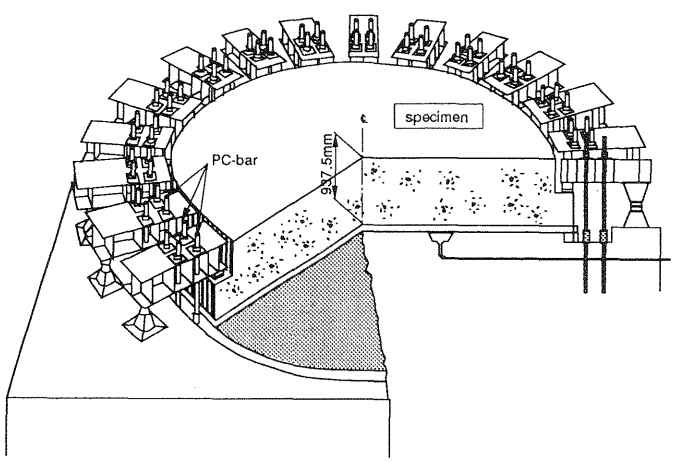

Fig. 6. Method of testing

Figure 7 shows pressure vs. displacement at the center of each specimen. All specimens failed in shear mode. However No. 2 specimen showed ductile behavior, due to reinforcement of the lapped end.

Figure 8 shows the shear strength of large reinforced concrete circular slabs, together with the results given in Iwaki et al., Iguro et al., Shioya et al..

According to beam test results, the shear strength gradually decreases as the effective depth increases; similar results were obtained in previous studies. The size effect exists even for d > 100 cm, and the relative shear strength is inversely proportional to the fourth root of the effective depth.

The results of the circular slab tests also showed that the shear strength gradually decreases as the effective depth increases. The relative shear strength of circular slabs is inversely proportional to the fourth root of the effective depth as in the case of beams.

In general, the shear strengths of a circular slab is higher than that of a beam. The shear strength of circular slabs was 1.2 to 1.5 times the shear beam shear strength calculated using the JSCE equation [JSCE].

In addition, within the scope of this experiment, circular slabs showed 1.5 times the shear strength of beam strength.

Restriction by circumferential re-bars is one reason for the high shear strength of circular slabs. Methods for calculating the shear strength of a circular slab are shown in Ref. [Akiyama et al.(1996)],[Iwaki et al. (1985)].

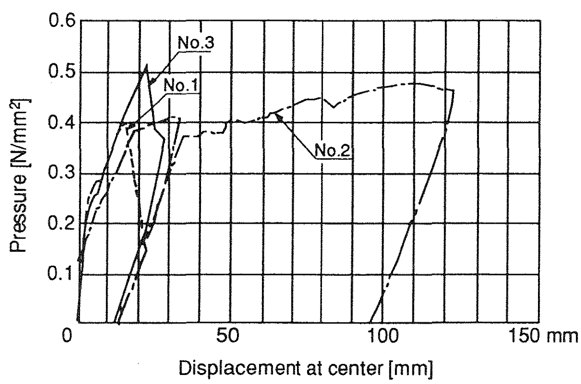

Fig. 7. Pressure vs. displacement

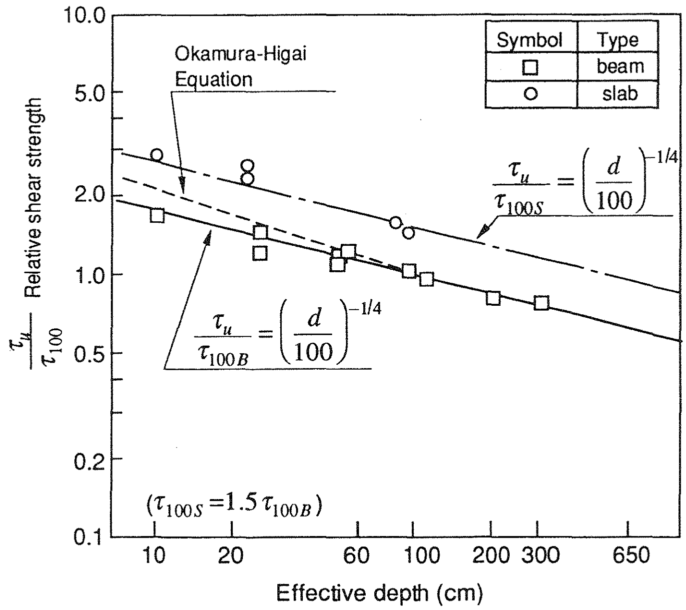

Fig. 8. Effect of depth of beams and slabs on shear strength

3. Effect of size on shear strength of circular slabs

Design equations for the shear strength of a circular slab are as follows. The design shear capacity V_{yd} may be obtained using Eq.(1). When both bent bars and stirrups are used for shear reinforcement, at least 50 % of the shear force provided by shear reinforcement shall be carried by stirrups.

$$V_{yd} = V_{cd} + V_{sd} + V_{ped}, \tag{1}$$

where V_{cd} : design shear capacity of linear members without shear reinforcement, obtained using Eq. (2),

$$V_{cd} = f_{vcd} \cdot b_w \cdot d / \gamma_b \ , \tag{2}$$

$$f_{vcd} = 0.2\beta_d \cdot \beta_p \cdot \beta_n \cdot \sqrt[3]{f'_{cd}}(N/mm^2), \tag{3}$$

$\beta_d = \sqrt[4]{100/d}(d:cm)$, when β_d>1.5, β_d is taken as 1.5

$\beta_p = \sqrt[3]{100p_w}$, when β_p>1.5, β_p is taken as 1.5

$\beta_n = 1 + M_0 / M_d(N'_d \geq 0)$, when β_n>2, β_n is taken as 2.

$= 1 + 2M_0 / M_d(N'_d < 0)$, when β_n<0, β_n is taken as 0.

β_n is a function of circumferential reinforcement ratio
where γ_b: 1. 3 may be used in general,

$p_w = A_s/(b_w \cdot d)$,

V_{sd} : design shear capacity of shear-reinforcing steel and obtained using Eq. (4),

$$V_{sd} = [A_w f_{wyd}(\sin\alpha_s + \cos\alpha_s)S_s + A_{pw}\sigma_{pw}(\sin\alpha_p + \cos\alpha_p)/S_p]z/\gamma_b, \tag{4}$$

where, $\sigma_{pw} = \sigma_{wpe} + f_{wyd} \leq f_{pyd}$,

f_{wyd}: not greater than 400 $(\mathrm{N/mm^2})$,

z: generally, may be taken as $d/1.15$,

γ_b : 1.15 in general,

V_{ped} : component of effective tensile force on longitudinal tendon parallel to the shear force and obtained using Eq. (5).

$$V_{ped} = P_{ed}\sin\alpha_p/\gamma_b, \tag{5}$$

where γ_b :1.15 in general.

As shown in the above design equations, β_d is a function for size effect on the shear strength of reinforced concrete structures.

4. Bottom slabs test

Bottom slabs with depths of 7.4 m and 9.8 m, with shear reinforcement, were subjected to full and 85% design pressure [Nakano et al.],[Sejima et al.] in order to investigate the validity of the design method for circular slabs.

The design compressive strength of the concrete was 23.5 $\mathrm{N/mm^2}$. The main reinforcement ratio of the cross section was 0.6 % to 0.8 %. The cross sections of the slabs and the method of testing are shown in Figs. 1 to 4. Shear reinforcement ratio was 0.15 to 0.2 %.

Figure 9 shows pressure vs. displacement at the centers of 140,000kl LNG underground tanks. Figure 10 shows reinforcement stress. Figure 11 shows the crack pattern of Tank A. Figure 12 shows pressure vs. displacement at the center of a 200,000kl LNG in-ground tank. Figure 13 shows the crack pattern of a 200,000kl LNG in-ground tank. From these figures, it was confirmed that LNG underground tanks behaved as designed.

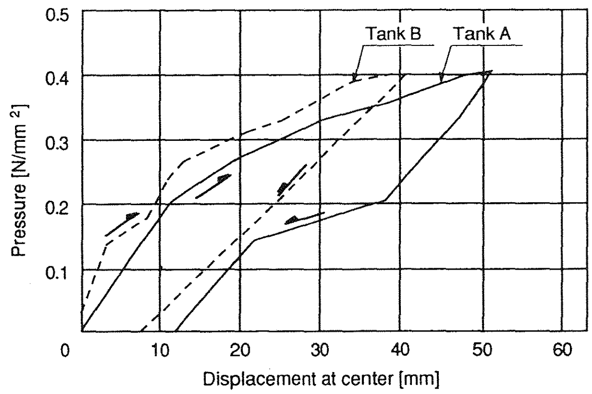

Fig. 9. Pressure vs. displacement

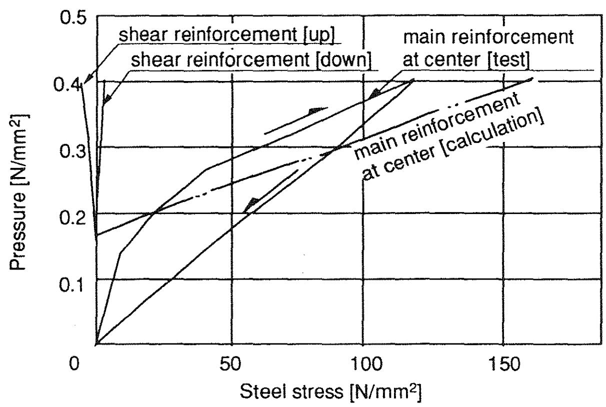

Fig. 10. Pressure vs. steel stress

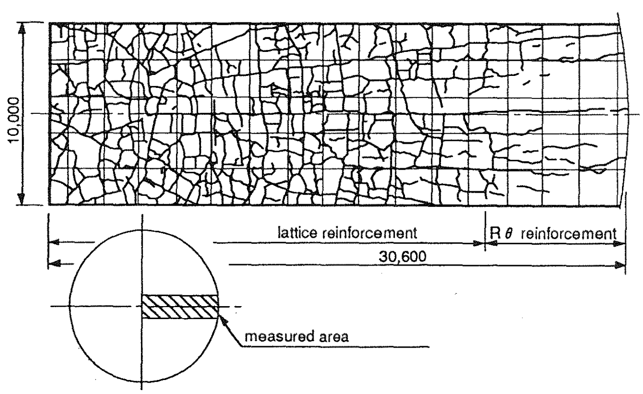

Fig. 11. Crack pattern (Tank A)

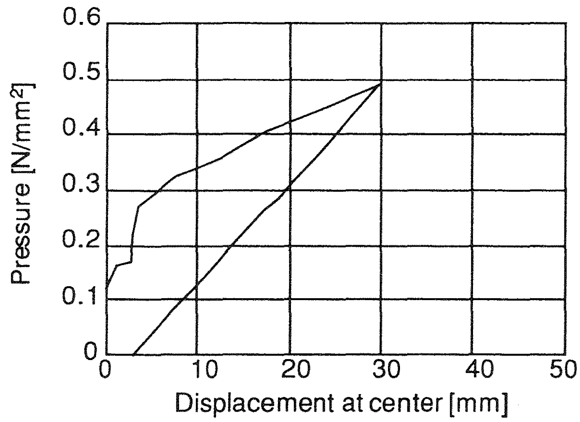

Fig. 12. Pressure vs. displacement

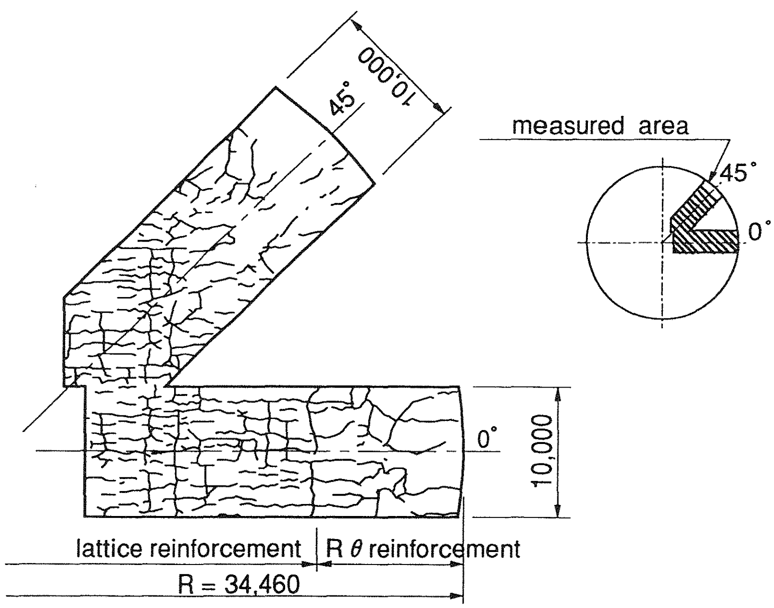

Fig. 13. Crack pattern (200,000kl Tank)

Figure 14 shows the result of the experiment with the values of shear strength calculated using the Okamura-Higai (1980) equation. This equation gives the shear strength of a reinforced concrete beam, without shear reinforcement, for which the ratio of the shear span to the effective depth "a/d" is greater than 2.5-3.0.

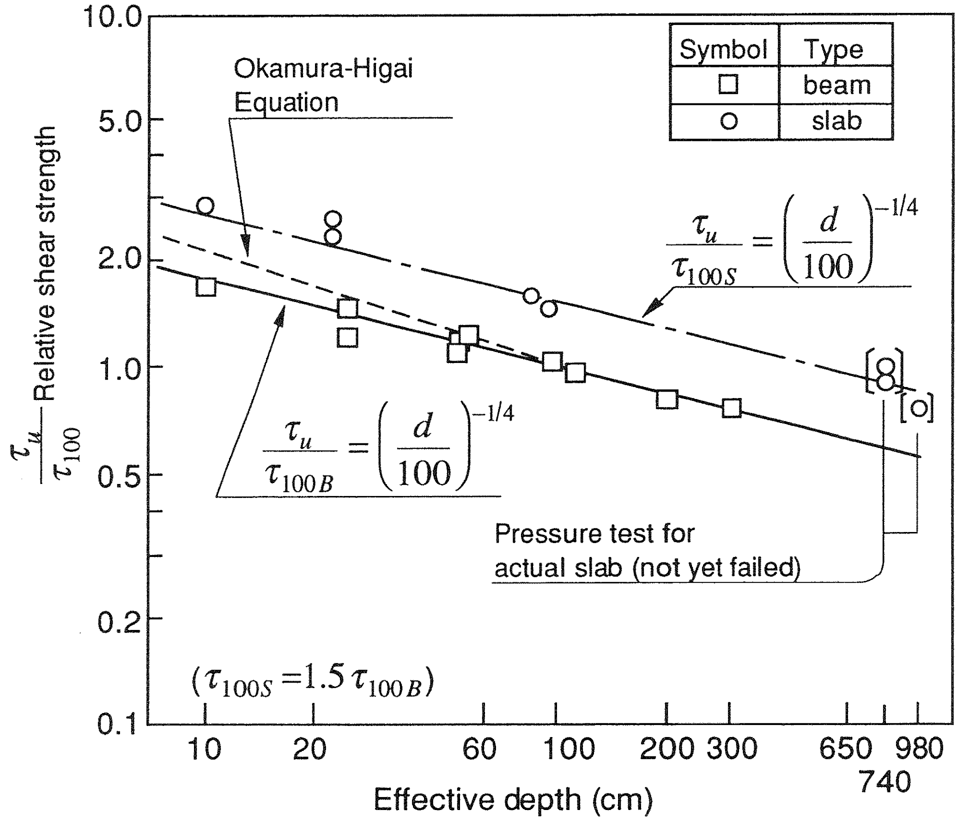

Fig. 14. Effect of depth of beams and slabs on shear strength

$$\tau_c = 0.2 f'_c{}^{1/3}(1 + \beta_p + \beta_d)[0.75 + 1.4/(a/d)], \tag{6}$$

where τ_c: ultimate shear strength (N/mm^2),

f'_c: compressive strength of concrete (N/mm^2),

The results show the validity of the design method.

5. Conclusion

Bottom slabs with depths of 7.4m and 9.8m were subjected to full and 85% design pressure. The results showed the validity of the design method.

6. References

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