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PROPOSED DESIGN METHOD OF THE SHEAR STRENGTH OF REINFORCED CONCRETE FOOTINGS

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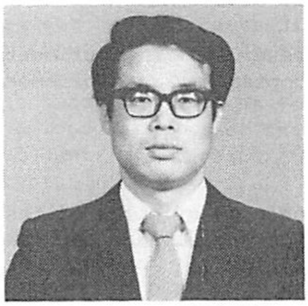


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SYNOPSIS

Recently, footings with few large caliber piles have been frequently used from economical and environmental point of view. Since a footing of this type behaves like a deep beam, however, its shear design method has been firmly established despite of great efforts devoted by many researchers.

In order to clarify shearing strength properties of footings, and furthermore to propose rational design method in terms of shearing strength, experimental studies have been conducted using specimens on reduced scale 1/5 with various kind of performance. This study examines the results of both experiment and analysis, based on which rational design method of those footings can be proposed.

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1. OUTLINE OF EXPERIMENT

1.1 Test pieces

Test pieces with which experiment was carried out were 37 specimens on reduced scale 1/5. Main elements focused on were as follows;

(1)	shear span depth ratio	a/d
(2)	reinforcement ratio	ρ_x, ρ_y, ρ_x', ρ_y'
(3)	shear reinforcement	Av
(4)	effective width	B
(5)	cantilever length	L

Pressure durability of concrete used in experiment was 20.6 MPa (JIS A 5308) and SD 35 (JIS G 3112) was adopted for reinforcement bar.

1.2 Loading procedure

Footings were loaded from the side of piles of test pieces by four loading oil jacks which were linked together to balance the loading force. Main items measured in the test are as follows;

(1) ultimate load per pile in shearing failure of footings
(2) strain of main reinforcement bar, distribution bar, and shearing bar measured by an electric resistance strain gauge
(3) displacement at loading point measured by an electric resistance displacement gauge
(4) crack pattern described from visual inspection of cracks
(5) measurement by chipping a part of failure

2. RESULTS OF EXPERIMENT

2.1 Properties of failure

Almost all test pieces were failed just after diagonal cracks were rapidly growing in the direction of between piles and the front of piers in the last stage of loading. According to the examination of cracks and failure surface, namely, concentric circular cracks as the center of piles and failure as a form of circular cone, it was concluded that bending and punching shear worked coincidently.

Based on the hypothesis in which the line drawned by the center of shearing surface is located at equal distances from the supporting point and the edge of pile, formula of failure surface as described in Figure-1 is;

$$y = \sqrt{(a_1 - y)^2 + x^2} - D/2 \qquad (BN = CN)$$

which can be arranged as follows;

$$y = \frac{1}{2a_1 + D} x^2 + \frac{1}{4}(2a_1 - D) \quad \cdots\cdots\cdots\cdots \quad (1)$$

Thus the line stemed from the center of failure surface results in a parabola, which tells that the failure line obtained from the experiment fits the estimated failure line well around point M in Figure-1.

2.2 Influence of primary factors on shearing strength of footings

The following properties are findings of the experimental studies.

(1) The influence on shear strength was approximately proportioned to square root of main reinforcement ratio. (ρ_x)
(2) Little impact was obserbed with respect to distribution bar ratio (ρ_y) and upper side distribution bar ratio. ($\rho_{y'}$)
(3) Shear span depth ratio (a_1/d_1) had great influence upon it.
(4) The result was that unexpectedly decreased as Av increased. Although the experiment was also conducted in case of smaller diameter of reinforcement bar and dense distribution, shear strength decreased without effect of shear reinforcement bar using vertical U-shape stirrup.
(5) Although the ultimate load increased as footing width (B) did, the increment rate of the load was smaller than that of B.
(6) It was confirmed that cantilever length (L) had influence on shear strength to some extent.

2.3 Synthetic examination of primary factors for shear strength of footing

Dr. Okamura and Dr. Higai propose the following formula (2) which is a shearing strength formula for a beam without shearing reinforcement bar. [1]

$$V_u = 0.70\ f_c'^{\frac{1}{3}}\ (0.75 + 1.4\ d/a)\ (1 + \beta_p + \beta_d)\ bwd \quad \ldots\ldots \ (2)$$

$$(\beta_p = \sqrt{100\rho w} - 1 \leqq 0.73 \qquad \beta_d = \sqrt[4]{100/d} - 1 \geqq 0)$$

Although the formula (2) is proposed for ordinary beams ($a/d > 3.0$), all of the experimental data is analyzed in various kind of shear strength formula in order to meet the formula (2) for the values less than 3.0 of a/d. As a result, the best fitted formula is one obtained form the hypothesis in which shear strength is in proportion to $(a_N/d_N)^{-1.166}$ and becomes close to the existing normal formula (2) for shear strength of beam if $a_N/d_N = 2.5$.

Within the interval of $a_N/d_N < 2.5$, the formula is shown as follows;

$$V_{uN} = 0.761\ (a_N/d_N)^{-1.166}\ f_c'^{\frac{1}{3}}\ (1 + \beta_p + \beta_d)\ \Delta\ell d_N \quad \ldots\ldots\ldots \ (3)$$

Shearing strength as a whole can be calculated by the integrated strength of each point obtained on the following conditions;

* shearing strength is calculated by the formula (2), (3)
* failure surface strength is calculated by the formula (1)
* $\overline{CNB}$ is adopted as shearing span (a_N) at point N in Figure-1
* effective height (d_N) is determined at point N
* shear strength (V_{uN}) for minute length ($\Delta\ell$) around point N is integrated within the interval of effective width (b). effective width (b) of footing is admitted as long as less than twice of "a_1" (if the width ($\overline{OE}$) of one side of footing is less than "a_1", however, $\overline{OE}$ is effective from the point "O" to the edge, and the effective width "b" is determined to be "$a_1 + \overline{OE}$")

With respect to the influence of L/d_1, the calculated strength (V_u) is revised by the following formula;

$k = 1/(1.35 - 0.35\ L/d_1)$	$(1 \leqq L/d_1 \leqq 2)$
$k = 1/0.65$	$(L/d_1 > 2)$
$k = 1.00$	$(L/d_1 < 1)$

The followings are the mean value, standard deviation, and fluctuation factor of the ratio of the calculated strength (V_u) to the ultimate load (Pmax).

<all test pieces>

Number of data	$n = 35$
Mean value	$x = 1.054$
Standard deviation	$\sigma_n = 0.109$
Fluctuation factor	$V = 10.3\%$

Fiscal 79'	Fiscal 80'	Fiscal 81'
$n = 12$	$n = 12$	$n = 11$
$x = 1.105$	$x = 1.003$	$x = 1.053$
$\sigma_n = 0.115$	$\sigma_n = 1.112$	$\sigma_n = 0.0618$
$V = 10.4\%$	$V = 11.2\%$	$V = 5.87\%$

As shown above, the results were enough to be significant.

3. SIMPLE DESIGN METHOD FOR SHEARING STRENGTH OF FOOTING

Since great efforts would be needed for practical use of the method in which shearing strength is integrated along failure surface, which has been shown in chapter 2, practical simple design method can be described as follows;

Surface A-A parallel to the front surface of pier at the bisection point of the distance "a_1" between the center of pile and the front of pier is supposed to be an examined surface. Shearing strength for this surface is obtained from the formula (2) and (3) in which a_N is considered as a_1 (the distance between the center of pile and the front of pier). D_N is determined as d_2 - the effective height for the surface. Effective width $\Delta\ell$ is defined as $2a_1$ (or $a_1 + e$). If a_1/D is less than 1.5, however, calculated strength is revised by $3/2\ (D/a_1)$.

Figure-2 is an example of the ratio of shearing strength ($Vcal_1$) calculated in this simple method to shearing strength ($Vcal_2$) obtained from the integration shown in the section 2.3. From the examination of this method for the practical values, such as, the grade of surface of footing (0, 0.05, 0.10, 0.15), the diameter of pile (100, 150, 200cm), a_1/d_1 (0.5, 1.0, 1.5, 2.0, 2.5), and effective height "d_1" (100, 150, 200cm), it has been confirmed that the ratio ($Vcal_2/Vcal_1$) is always more than 1. It seems that the practical simple method can be, therefore, reliably used as an design method of footing with few piles for shear strength.

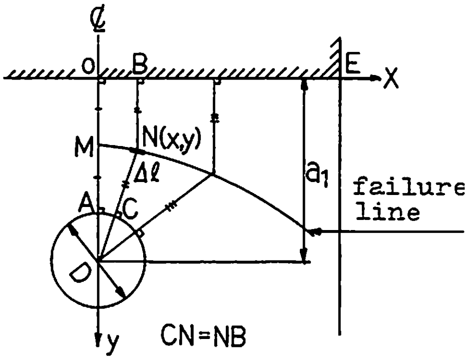

Figure - 1

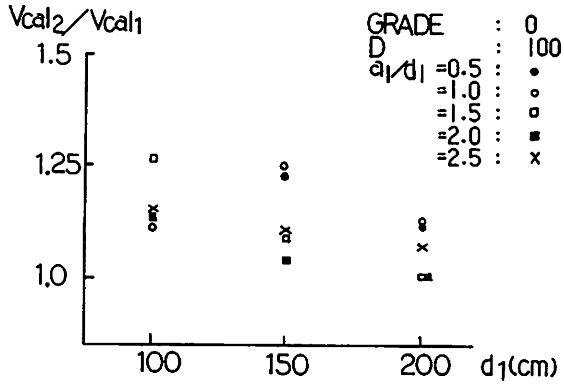

Figure - 2

References

[1] Okamura and Higai, "Proposed Design Equation for Shear Strength of Reinforced Concrete Beams without Web Reinforcement" Proc. of JSCE, No.300, August, 1980.