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SHEAR STRENGTH IN CORNER REGION OF REINFORCED CONCRETE DUCT TYPE STRUCTURES TO BE EMBEDDED IN SOIL

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ABSTRACT

Reinforced concrete ducts for accommodating emergency cooling water pipes are generally embedded in soil. The structures is classified as one of the most important structures in terms of earthquake resistant design. During a strong earthquake it is subjected to shear deformations in concerted movement with surrounding soil.

The corner regions of the duct should be designed against shear with moment combined. However, the complicated stress conditions in the region render the design more intricate in comparison with the case of simple determinate RC beam type structures.

With the above situation in mind an experimental study was conducted, in which prototype as well as one half scale models representing the stress conditions in the region of interest were loaded and brought to failure in shear.

The cross section of the prototype test model without shear reinforcements was 60 (height) × 30cm (width), and the tensile reinforcement ratio was 2.58%.

The following results were obtained within the limit of the experimental study.

(1) The shear capacity predicted by Japanese Design Code for linear RC members over-estimated the experimental ones with a considerably large safety margin of 4.4~5.0.

(2) An improved design procedure to be applied to the specific structure was proposed, which gave a reasonable safety factor against shear failure of 1.7~2.0.

(3) Combined smeared and discrete cracking model was utilized to simulate the shear failure mechanism, which could realistically pursue experimental behaviors.

1. INTRODUCTION

In the process of drafting a design guide for reinforced concrete duct type structures for accommodation of emergency cooling water pipes (Fig. 1), which are to be embedded in soil in nuclear power stations, a problem was raised as to how to design the structures against shear forces mainly induced by earthquake loading. This particular structure is subjected to rather complicated distributed sectional forces, which was feared to lead to an irrational design if the conventional design approach is to be followed. Therefore, a structural shear test was planned and conducted, in which two part models were loaded to fail in shear by multi-point loadings similar to those deemed to occur in design conditions.

2. TEST PROCEDURES

Two part models were tested : one was a prototype model and another one was 1/2 scale model. Reinforcement arrangement for prototype model is shown in Fig. 2. The region, where shear failure was expected, no stirrups were arranged. The longitudinal reinforcement ratio was 2.60 ~ 2.70 %, which was extremely high compared with the ratio employed in actual structures. The measure was necessitated to cause shear failure in the designated area.

The models were subjected to multi-point loading to simulate the distribution of sectional forces in the region of potential shear failure (Fig. 3). The load condition considered was the case, in which earthquake load was superimposed with ordinary earth pressure. The loading scheme is illustrated in Fig. 4.

The strengths of concrete at the time of test are given in Table 1. During the loading tests, load values, displacements, strains in concrete and steel as well as the shear crack widths were measured and recorded.

3. TEST RESULTS

The cracking patterns with the increment of load are sketched in Fig. 5 for prototype model. The cracking modes for the both models were found to be basically the same. After the first flexural crack had been observed on the outer face of corner region, a diagonal shear crack appeared at the load equivalent to 50 ~ 60 % of the ultimate load. Further increment of load caused the extension of the shear crack. At the load close to the ultimate a new shear crack occurred parallel to the existing one, which led to the crushing of concrete at the root of haunch. The longitudinal tensile reinforcement remained within the limit of yield point at the time of failure. The main mode of shear failure was considered to be the crushing of compression strut.

The ultimate experimentally obtained loads were compared with the characteristic loads calculated by the current Japanese limit state design code, and are shown in Table 2. The ratios of experimental and calculated values are 5.04 and 4.36 for 1/2 scale and prototype models, respectively, which motivated the revision of the Japanese code for the particular case.

4. COMPARISONS OF FEM ANALYSIS WITH EXPERIMENTAL RESULTS

A finite element analysis was conducted to clarify the shear failure mechanism, employing both smeared and discrete crack models. The crack patters estimated by the analysis (Fig. 6) has a similitude with the experimental results depicted in Fig. 5. The failure mechanism of crushing in compression strut was confirmed also by FEM analysis.

5. PROPOSED METHOD FOR ESTIMATING SHEAR CAPACITY

As was mentioned, current Japanese design code for civil engineering reinforced concrete structures was found to give excessively high margin of safety to the specific structures investigated. Therefore, a new design approach was presented to calculate the structure, taking into account the effect of distributed load as well as the presence of inflexure points within the region considered. Followings are the proposed procedures to be taken for the case of the members without web reinforcements.

5.1 Definition of equivalent shear span

When there is an inflexure point in the region designed, referring to Fig. 7, equivalent shear spans of a_1 and a_2 should be identified. a_1 and a_2 are defined as the distances between the inner face and the inflexure point, and as that between the inflexure point and the maximum moment in the span, respectively. When inflexure point is absent, the distance between the inner face of column and the maximum moment point should be specified as in the ordinary case. The sections to be investigated for shear should be located at the middle of the each equivalent shear span, but the distance x_1 and x_2 in Fig. 7 must satisfy the inequity.

$$h/2 \le x_1 \text{ and } x_2 \le 1.5d \tag{1}$$

where, h : height of beam (cm); d : effective depth of beam (cm).

5.2 Calculation of shear capacity

The larger of the two values calculated by the following formulas is adopted for design.

$$V_{cd,s} = 0.9 \cdot \beta_d \cdot \beta_p \cdot \beta_n \cdot \beta_a \cdot [f'_{cd}]^{1/3} \cdot b_w \cdot d/\gamma_b \tag{2}$$

$$V_{cd,d} = 0.6 \cdot \beta_d \cdot \beta_p \cdot \beta_n \cdot \beta'_a \cdot [f'_{cd}]^{1/2} \cdot b_w \cdot d/\gamma_b \tag{3}$$

where, $V_{cd,s}$: design shear capacity for ordinary shallow beams;

$V_{cd,d}$: design shear capacity for deep beams;

$\beta_d = [100/d]^{1/4} \leq 1.5;$

$\beta_p = [100/p_w]^{1/3} \leq 1.5;$

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

A_s : area of tensile longitudinal reinforcements (cm^2);

b_w : width of beam (cm);

$\beta_n = 1 + M_0/M_d, \quad 0 \leq \beta_n \leq 2;$

$M_0 = \dfrac{h}{6} N'_d$ (decompression moment, kgf-cm) ;

N'_d : design axial compression force;

M_d : design moment;

$$\beta_a = \left(0.75 + \frac{1.4}{a/d}\right);$$

a : equivalent shear span length (cm);

$$\beta'_a = \frac{5}{1 + (a/d)^2};$$

f'_{cd} : design compressive strength of concrete (kgf/cm^2); and

γ_b : partial safety coefficient for shear, for earthquake load = 1.56.

6. COMPARISONS OF EXPERIMENTAL SHEAR CAPACITY WITH CALCULATED RESULTS

The experimental ultimate shear capacities are compared with the computed ones to check the validity of the proposed formulas. As can be seen in Fig. 8, more appropriate safety margins are secured by the newly proposed than by the conventional method.

7. CONCLUSIONS

The 1/2 scale and prototype models for reinforced concrete ducts for emergency cooling water pipes were tested in shear to rationalize the design procedures. The main conclusions obtained within the limit of experimental study may be summarized as follows.

(1) The shear failure model of the particular structure is classified as crushing of compression strut with precedent extension of diagonal shear cracks.

(2) The failure mechanism can be predicted by a finite element method employing smeared cracks together with discrete cracks.

(3) The proposed method for calculating shear capacity of duct type reinforced concrete structures provides more realistic safety margins than are estimated by conventional method.

LITERATURE

Standard Specification for Design and Construction of Concrete Structures - 1986, Part I (Design) - Concrete Library Special Publication I - Japan Society of Civil Engineers.

ACKNOWLEDGEMENT

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Table 1. Mechanical Properties of Concrete and Steel

Properties		1/2 scale model	Prototype model
concrete	compressive strength	303 kgf/cm^2	316 kgf/cm^2
	modulus of rupture	31.3 kgf/cm^2	42.1 kgf/cm^2
	tensile strength	25.0 kgf/cm^2	24.1 kgf/cm^2
	Young's modulus	2.14×10^5 kgf/cm^2	2.23×10^5 kgf/cm^2
steel	yield point	3,700 kgf/cm^2	
	Young's modulus	2.1×10^6 kgf/cm^2	

Table 2. Comparisons of Test Results with Current Japanese Code Values

	1/2 scale model	Prototype model
(1) Experimental nominal ultimate shear stress	60.2 kgf/cm^2	42.9 kgf/cm^2
(2) Characteristic nominal shear stress without considering partial safety coefficients	11.9 kgf/cm^2	9.8 kgf/cm^2
(1)/(2)	5.04	4.36

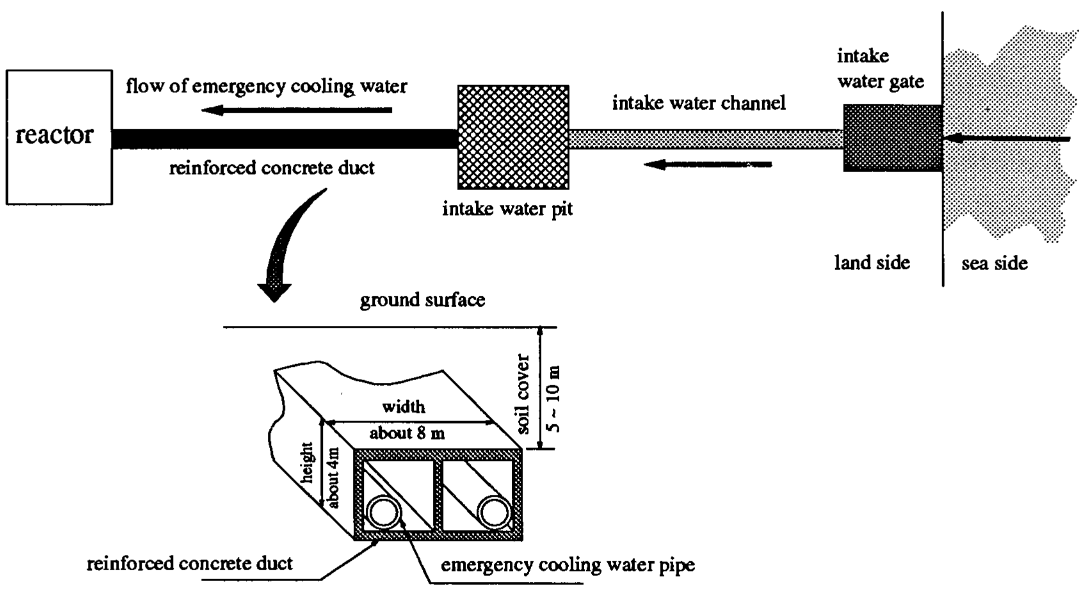

Fig. 1 Position and Structural Outline of Reinforced Concrete Duct for Emergency Cooling Water Pipes.

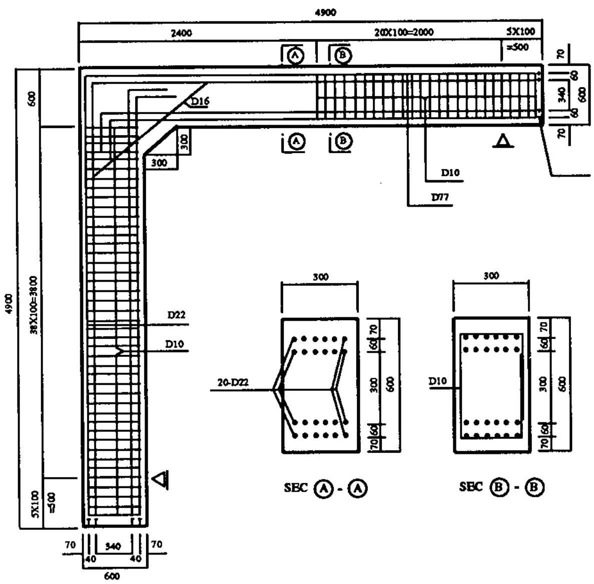

Fig. 2 Reinforcement Arrangement for Prototype Model.

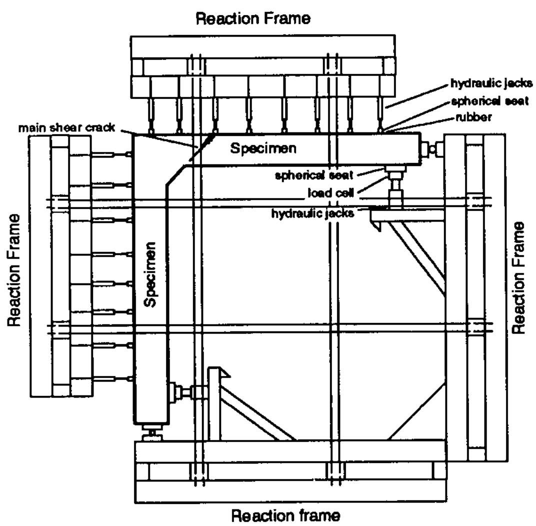

Fig. 4 Loading Scheme.

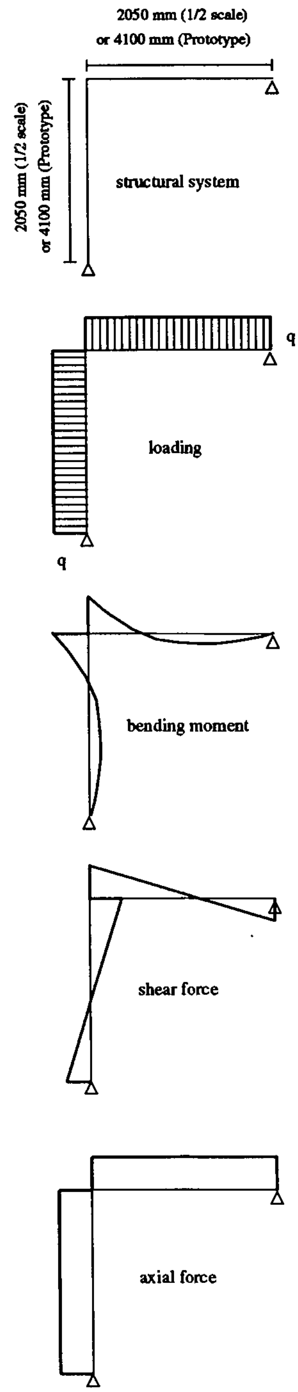

Fig. 3 Schematic Diagrams for Distributions of Load and Sectional Forces in Models.

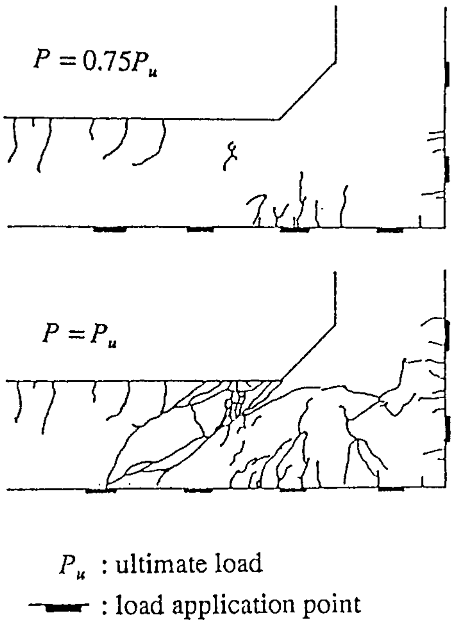

Fig. 5 Cracking Patterns for Prototype Model.

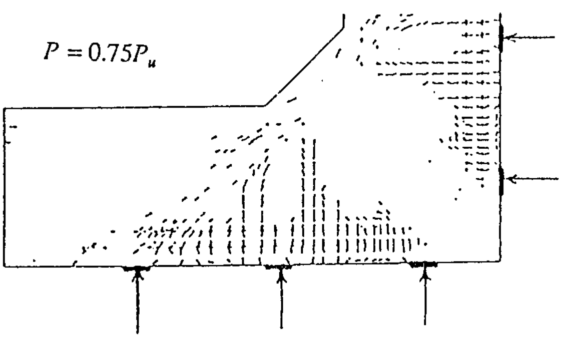

Fig. 6 An Example of Calculated Crack Patterns by FEM.

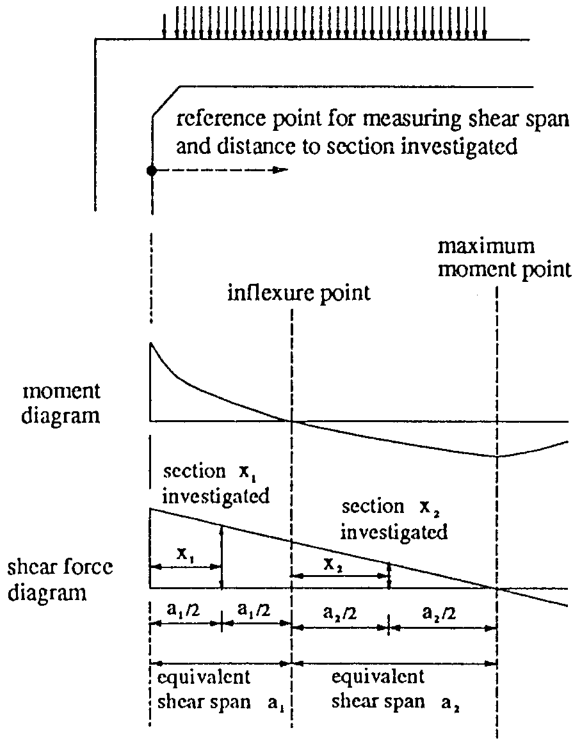

Fig. 7 Definition for Equivalent Shear Span and Position of Section Investigated.

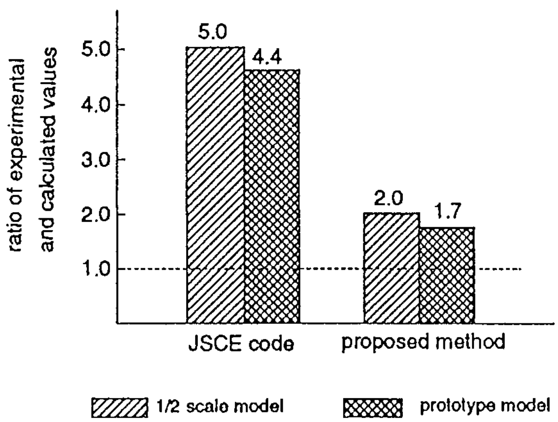

Fig. 8 Comparisons of Test Results with Those Calculated by Current JSCE Code and by Proposed Method.