A CONSIDERATION ON THE DAMAGES TO COLUMNS OF REINFORCED CONCRETE BY THE TOKACHIOKI EARTHQUAKE, 1968

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The collapse of columns was conspicuous in the badly damaged buildings of reinforced concrete by the Tokachioki earthquake, 1968. For instance, the school-building of Hakodate College was destroyed by the collapse of all the columns in the first story, and the Municipal Office of Mutsu City was partly destroyed because of the collapse of columns in the third story.

By picking up many examples of the badly damaged columns from the "Report of Architectural Institute of Japan on the damages by the Tokachioki Earthquake, 1968", the ultimate strength for bending, for shearing as well as for bond of axial reinforcement were estimated under the following assumptions:

(1) Compressive strength of concrete F_c is equal to the specified strength in the structural design, or the presumed lowest value by the Schmidt hammer test.

(2) Yield strength of reinforcement is assumed to be 3000 kg/cm^2 for the axial reinforcement and 2400 kg/cm^2 for the hoop of column.

(3) Axial force of column was estimated by assuming that the total load was 0.9 t/m^2 for each floor.

(4) Shearing force, $_MQ_y$, corresponding to the ultimate flexural strength of column can be derived from linearized N-M interaction curves by a simplified ultimate strength theory. The specified points on the interaction curves for the analysis were defined in following manner:

i) For pure compression,

$$\frac{N_c}{BD} = F_c + (p_t + p_c)\sigma_y$$

ii) For pure bending,

$$\frac{M_B}{BD^2} = 0.95\left\{1-0.43\, p_t\, (1-30\, p_c)\frac{\sigma_y}{F_c}\right\}\frac{d}{D} p_t \sigma_y$$

iii) For pure tension,

$$\frac{N_T}{BD} = (p_t + p_c)\sigma_y$$

iv) For balanced condition,

$$\frac{N_o}{BD} = 0.4\, F_c$$

$$\frac{M_o}{BD^2} = p_t \sigma_y \frac{g}{D} + 0.1\, F_c$$

where,
- N = axial force in column
- M = bending moment in column
- F_c = compressive strength of concrete
- p_t = ratio of tensile reinforcement to gross cross-sectional area of column
- p_c = ratio of compressive reinforcement to gross cross-sectional area of column
- B = width of column

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D = depth of column
d = effective depth of column
g = distance between compressive and tensile reinforcements
σ_y = yield strength of reinforcement

(5) Shearing force, Q_S, corresponding to the ultimate shearing strength can be estimated by the following Dr. Arakawa's formula:

$$\tau_u = \frac{Q_S}{Bj} = k_u k_p \, (F_c + 180) \frac{0.12}{0.12 + a/d} + 2.7\sqrt{p_w \sigma_y}$$

where, τ_u = ultimate shearing strength (kg/cm^2)
Q_S = total ultimate shearing force
j = lever arm of internal couple
k_u = size coefficient for ultimate strength
k_p = axial reinforcement coefficient for ultimate strength
a = ratio of bending moment to shearing force
p_w = ratio of web reinforcement.

(6) Shearing force, Q_b, corresponding to the ultimate bond strength can be estimated according to the lowest limit in the test data by Dr. M. Katoh. In the case of vertical reinforcement, the bond strength is nearly proportional to the compressive strength of concrete according to his data. The relation between the bond strength and the compressive strength in the lowest limit can be approximately expressed as follows:

$$\tau_a = 2 + 0.1\ F_c$$

where, τ_a = bond strength (kg/cm^2)

The ratio of shearing strength to flexural strength, $Q_S/_MQ_y$, and the ratio of bond strength to flexural strength, $Q_b/_MQ_y$ are shown in Fig. 1., where the sketches of typical patterns of cracks are also indicated. In these examples, the ratio of a/d was distributed in the range of 0.86~4.32, where "a" means the half of the clear length of column and "d" means the effective depth of column as the bending member.

It seems that there is a certain relation between the feature of failure and the estimated ratios of the shearing forces. For most cases of the examples, the ratio of bond strength was less than 1.0, and the crack patterns were complicated. Small value of this ratio would be rather fatal to the strength of column.

In the cases of the buildings No. 5 and No. 9, the ratios of bond strength were remarkably low and the columns were badly damaged by the shearing failure of concrete with the severe bond cracks.

The columns in the building No. 3 and the column $_2C_{B2}$ of the building No. 8 had the similar feature of failure to the columns in the buildings No. 5 and No.9, in spite of moderate ratios of bond strength. However, as the concrete strength was presumed by the specification only, some questions might still be remained if the actual strength of concrete was rather lower.

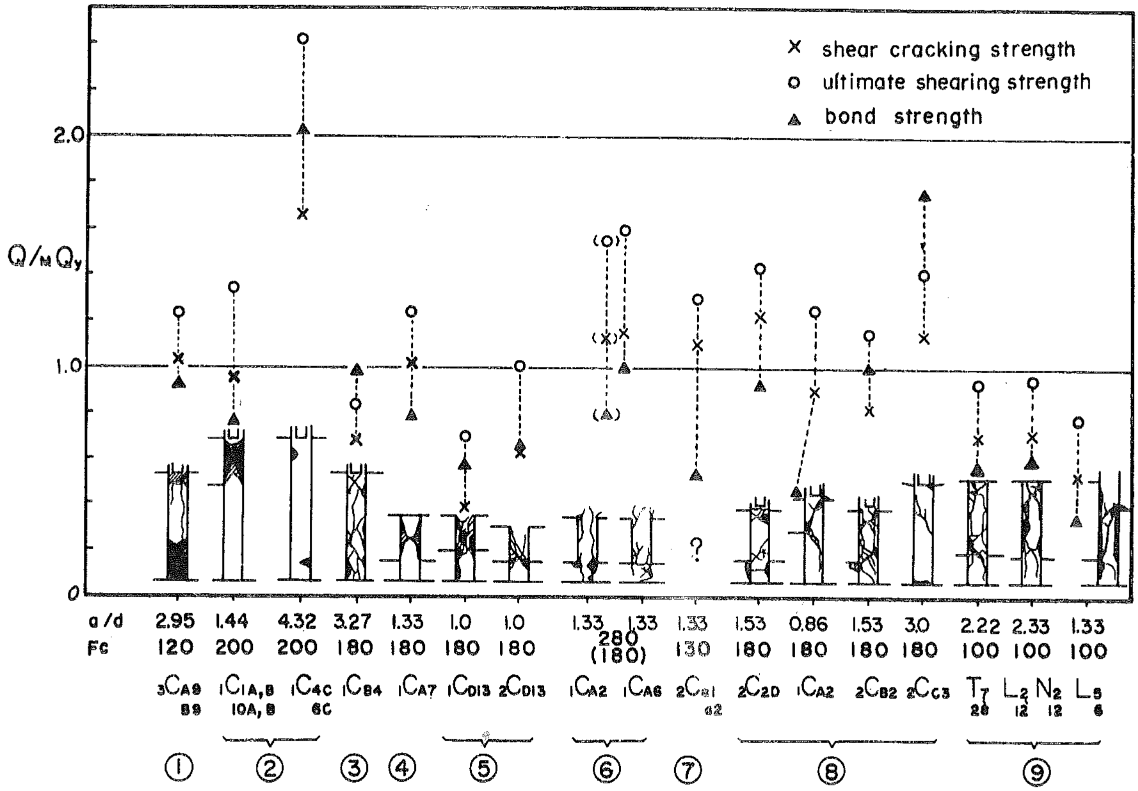
The crack pattern of column $_2C_{c3}$ in the building No.8 is different from the cracks generally observed in the other damaged buildings. Though the column had considerably large bending cracks at its ends, there is no crack in the middle part of the column except the isolated diagonal cracks It must be noticed that the ratio of bond strength was remarkably high in this case.

The columns $_1C_{4C}$ and $_1C_{6C}$ in the building No. 2 had not only the high ratio of bond strength but also the high ratio of shearing strength. The columns were little damaged except the bending cracks near their both ends. The positions of the cracks were at a distance almost equal to the column size apart from the column ends.

The columns $_1C_{1A}$, $_1C_{1B}$, $_1C_{10A}$, and $_1C_{10B}$ of the same building had severe shearing cracks. They had high ratios of shearing strength, but low ratio of bond strength.

The columns $_1C_{A2}$ and $_1C_{A6}$ of the building No. 6 had some bond cracks, but they had almost no shearing crack. In this case, the ratio of shearing strength was considerably high and the ratio of bond strength was almost equal to 1.0.

Comparing these features of crack formations with the result of the experimental study by authors, one could be concluded that the bond strength of concrete has a large influence on the brittle failure of column, when the shearing forces are repeated by an earthquake. It seems that not only a high shearing strength but also a ~~high~~ bond strength are required to secure the ductility of the reinforced concrete column. At least, the column should be designed so that the shearing force corresponding to the bond strength would almost be equal to the shearing force corresponding to the ultimate bending strength.



① Municipal Office of Mutsu City

② Noheji Station of Japan National Railway

③ Agricultural Co-op. Assoc. of Kamikita District

④ Misawa Commercial High School

⑤ Okamisawa Primary School

⑥ Kamikubo Primary School

⑦ Towada Technical High School

⑧ Municipal Office of Hachinohe

⑨ Hachinohe Technical College

Fig.1. Ratios of shearing and bond strength to flexural strength