RELIABILITY OF A RANDOMLY EXCITED DUCTILE REINFORCED CONCRETE FRAME.

by

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SYNOPSIS

A well designed reinforced concrete frame is subjected to an earthquake type lateral random force. Two variables, namely concrete strength σ'_c and steel ratio p at critical sections are considered to govern from the standpoint of material quality and workmanship, respectively. Functions for cost, ductility and reliability are derived in terms of σ'_c and p. Using the cost and ductility functions as restraints, the reliability function is maximized.

INTRODUCTION

It is a well established fact that earthquake induced forces are random by nature. It is also a well established fact in developing countries that the quality of construction material and workmanship are also quite "random" even if there are qualified designers for earthquake resistant structures. In a recent study conducted by the Istanbul branch of the Chamber of Civil Engineers of Turkey it was found that in a sample of 200 constructions under progress in that city, the sample mean of the strength of the 160 kg/cm^2 concrete was 96,7 kg/cm^2 with a standard deviation of 40 kg/cm^2(1). In other words if a normal distribution is assumed for the concrete strength, 90 % of the samples were below the design strength. No such data is available on workmanship but it would be very optimistic to expect better results on such a study.

In the present work, material quality and workmanship are assumed to be random. σ'_c is taken as an indicator of material quality and p (steel ratio in critical sections) is taken as an indicator of workmanship quality. The reason for the choice of these parameters is more pragmatic than theoretical. State produced steel exhibits little variation from standard norms and placement of the steel in critical sections of a reinforced concrete frame (i.e.detailing)which is the crucial factor in earthquake resistant behavior tends to be overlooked frequently by the construction workers because it takes more skill and is time consuming. It has also been assumed that the frame is well designed by the engineer (i.e.at least according to building code regulations) and that the variations are due to material and workmanship quality which to a great extent are outside his control. The reasons for these assumptions are again pragmatic and help in the focusing of the problem.

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FORMULATION AND SOLUTION

Suppose a reinforced concrete frame is designed as in Figure.1 carrying a total weight 2w and subjected to a random force γw. For a conventional frame design, the dimensionless quantities indicated in the figure are assumed to be bounded by the following values.

$$\alpha < 1.0 \ , \ \beta > 1.0 \ , \ \gamma < 1.0 \ , \ \delta \sim 1.0 \ , \ \varphi > 1.0 \qquad (1)$$

Under these assumptions and also that the combined mechanism will govern, the frame is designed and ultimate moment capacities of the beam, column and the beam-column connection are calculated based on this design. The following expressions are obtained.

$$M_{UC} > K_1 + K_2 \frac{I}{\sigma'_c} \qquad \text{(for the column)} \qquad (2)$$

where

$$K_1 = 2d''pbd\,\sigma_y + w\frac{d}{2} \ , \quad K_2 = \frac{w^2}{2b} \qquad (3)$$

$$M_{UB} > K_3 - K_4 \cdot \frac{1}{\sigma'_c} \qquad \text{(for the beam)} \qquad (4)$$

where

$$K_3 = p\,\sigma_y b\,(\beta' d)^2 \ , \quad K_4 = \frac{p^2 \sigma_y\, b(\beta' d)^2}{2\,k_2} \qquad (5)$$

$$M_{UBC} > K_5\,\delta' + K_6\,\sigma'_c = K'_5 p + K_6\,\sigma'_c \qquad (6)$$

where

$$K_5 = \beta'' dA \left[\sigma_y + \frac{E}{2}\,(7\varepsilon'_c - k_4)\right], \quad K_6 = bd^2 k_1 \beta' \left(\frac{\varepsilon'_c}{\varepsilon'_c + \varepsilon_{lim.}}\right)\left(\frac{\beta}{2} - \frac{\beta'}{2}\cdot\frac{k_1\varepsilon'_c}{\varepsilon'_c + \varepsilon_{lim}}\right) \qquad (7)$$

All the symbols are defined in Nomenclature.

Since the usual parabolic stress-strain relationship resulted in a transcendental equation in p, a trilinear stress-strain relationship is assumed for the concrete to compute the ductility (Figure.2) ϕ_u is computed by imposing an ε_{lim} where ε_{lim} is the maximum steel strain prescribed by building codes. Neglecting the higher order terms and solving for p,

$$P > \frac{K_7\,(\sigma'_c)^{3/2}}{\sigma'_c - K_8} \qquad (8)$$

where

$$K_7 = \frac{\varepsilon_{lim} - \Delta'\varepsilon'\mu}{2\sqrt{\Delta\varepsilon \cdot \sigma_y'}\,\mu} \quad , \quad K_8 = \frac{\sigma_y}{3k_1k_2} \qquad (9)$$

and $\mu = \phi_u/\phi_y$ is the ductility of the section. The cost function C can be written as,

$$C < K_9 p + K_{10}\sigma_c' \qquad (10)$$

where K_9 and K_{10} are price coefficients for workmanship and concrete respectively. Then the reliability safety margin S can be written in terms of the means and variances of the applied force and resistance parameters.

$$S = \frac{K_5 E[p] + K_6 E[\sigma_c'] - K_{11} E[\gamma]}{\sqrt{K_5^2 V(p) + K_6^2 V(\sigma_c') + K_{11}^2 V(\gamma)}} \qquad (11)$$

where K_{11} is a coefficients which expresses γ as an applied moment. Maximizing S under the restraints given by Equations (2),(4),(6),(8), and (10) the results given in figure.3 are obtained.

DISCUSSION

In structural optimization problems it has been customary to use cost as the objective function. In economically developing countries construction cost is generally quite rigid. Reliability on the other hand is a better objective function in that choosing the most reliable structure under given unfavorable conditions is usually necessary. This way, the original design can be altered to obtained the desired reliability even under unfavorable conditions. Also, a single reliability figure is generally meaningless, hence optimizing it is also theoretically sound.

The scope of this work can easily be extended to include the influence of shear forces, time dependent forces and secondary effects.

BIBLIOGRAPHY

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NOMENCLATURE

K_i (i=1,11) Defined in the text

b , d , d", ρd .... Defined in figure.1

E, V : Expectation and variance operators, respectively

S : Reliability safety margin

P : Reinforcing Steel ratio, percentage

σ_c' : Compressive strength of concrete

σ_y : Yield strength of reinforcing steel

ε_c' : Ultimate unit strain of concrete

$\varepsilon_{lim.}$: Imposed strain limit for reinforcing

$\Delta'\varepsilon'$: $2\varepsilon_A' - \varepsilon_o'$ as defined in figure.2

$\Delta\varepsilon$: $\varepsilon_o' - \varepsilon_A'$ as defined in figure.2

γ, k_1k_2 : Dimensionless constants

$M_{U(B,C)}$: Ultimate strength of beam or column sections

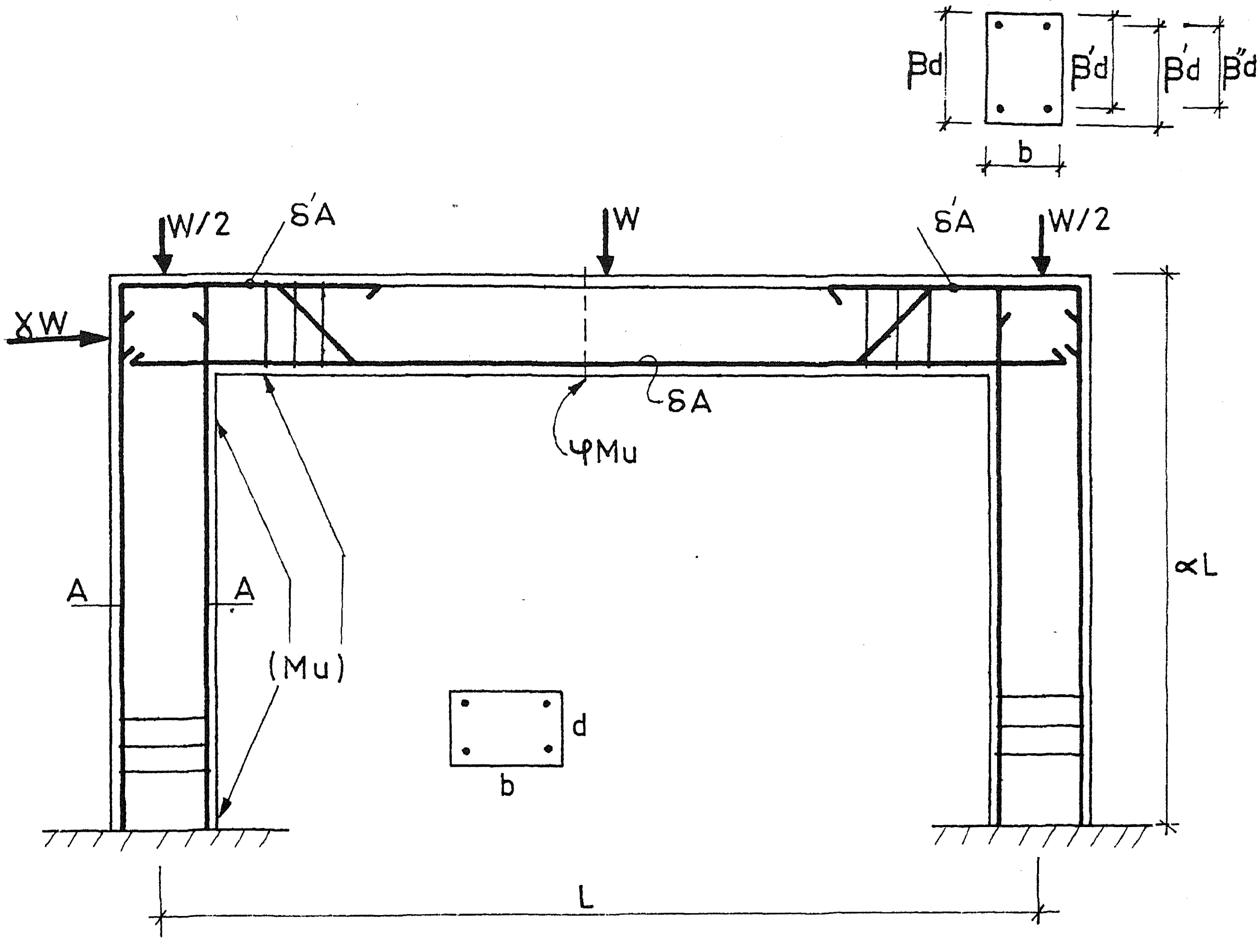

Figure- 1– Properties of the Studied Frame

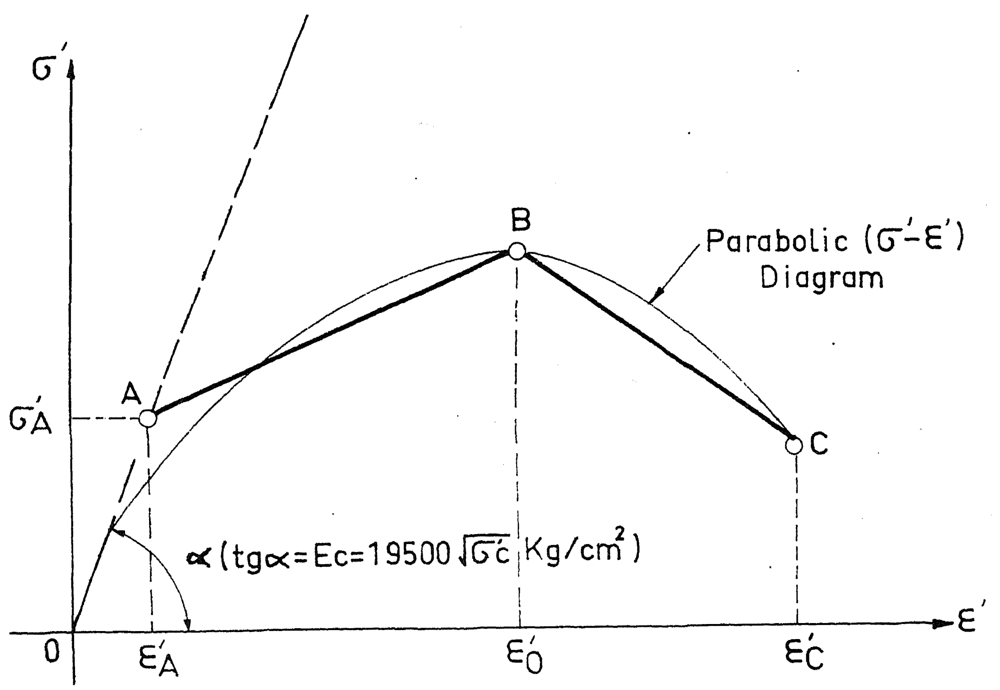

Figure-2– Trilinear (σ'–ε') Diagram For Concrete

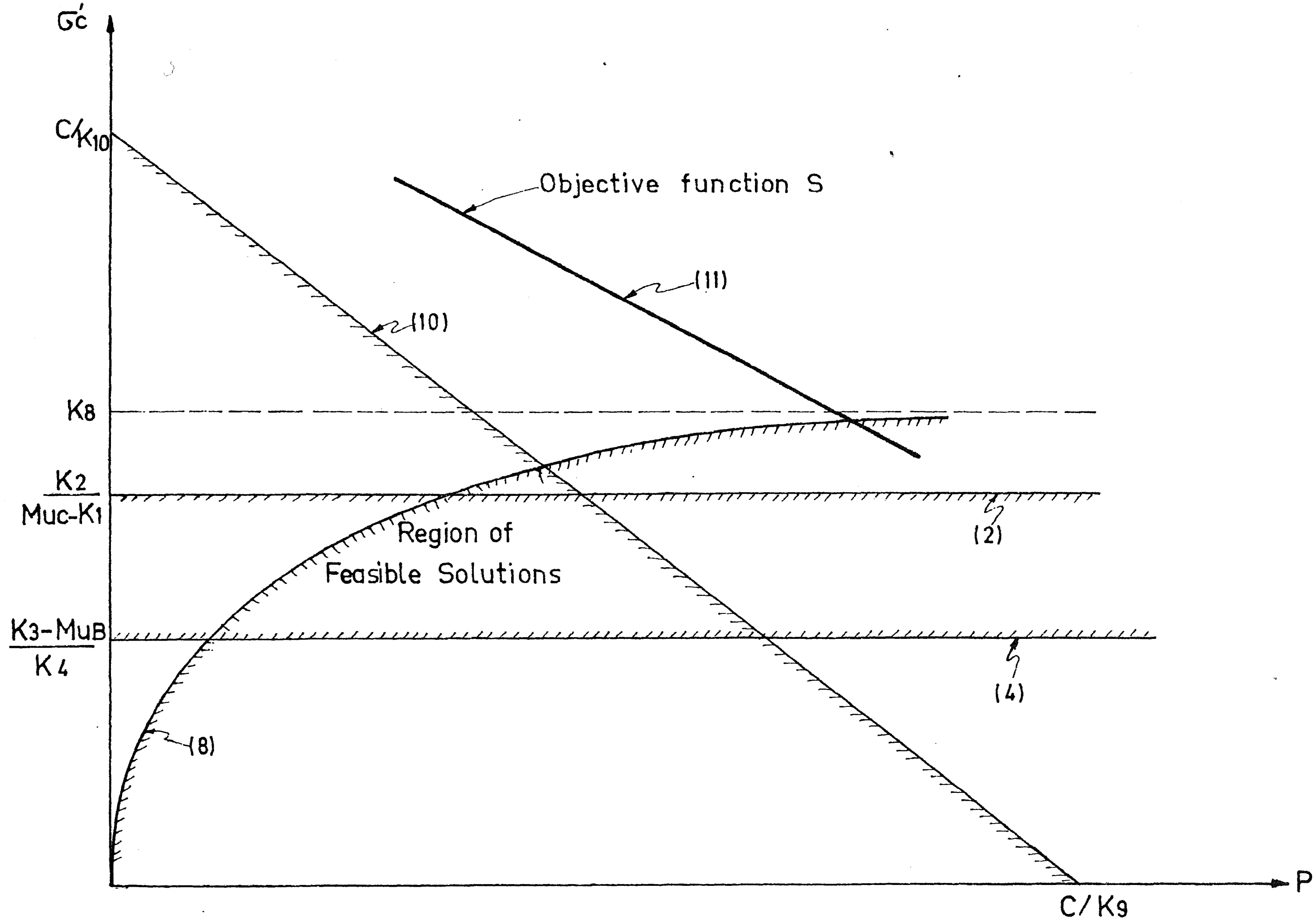

Figure. 3- Optimization of Reliability Safety Margin