Discrete Crack Model for Reinforced Concrete Joints

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1. Introduction

In the finite element modeling of reinforced concrete shear walls, two dimensional smeared crack elements are usually used to model the core wall parts. However, local discontinuity such as pulling out of the re-bars from a concrete mass, and shear slippage along joint interfaces tends to take place. This paper presents an interface element to account for local discontinuous deformations at the boundary plane where members with different thicknesses are connected

2. Interface Element Formulation

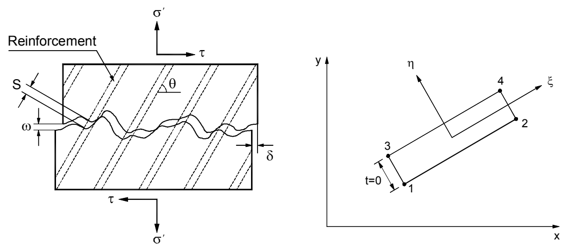
A one-dimensional RC interface element of four nodes is applied to model the reinforced concrete joint based on the interface elements [1] as shown in Figure 1. Two stress components of the shear and normal stresses in two mutually perpendicular directions of the interface are considered. Relative nodal displacements between the two adjacent boundary planes are taken into account. The constitutive relation of the element is given by:

$$\boldsymbol{\tau} = \mathbf{D}\mathbf{u}_r \qquad (1)$$

Total stresses $\boldsymbol{\tau}=[\tau,\sigma']^T$ transmitted across the interface can be calculated by combining all stresses due to concrete and reinforcing bars:

$$\begin{Bmatrix} \tau \\ \sigma' \end{Bmatrix} = \begin{Bmatrix} \tau_c \\ \sigma_c \end{Bmatrix} + \begin{Bmatrix} \tau_s \\ \sigma_s \end{Bmatrix} \qquad (2)$$

where τ and σ' are shear and normal stresses; suffices c and s denote concrete and steel, respectively.



(a) Local discontinuity (b) Idealization

Figure 1. An interface element

Next, the relative displacement vector $\mathbf{u}_r$ consists of shear slip δ and cracking width ω ($\mathbf{u}_r=[\delta,\omega]^T$) which is given by:

$$\mathbf{u}_r = \mathbf{BRu} \qquad (3)$$

where $\mathbf{u}$ is the vector of nodal displacements in a global coordinate system, $\mathbf{B}$ is the matrix relating interface displacements to nodal displacements given by Eq. (4) and $\mathbf{R}$ is the transformation matrix.

$$\mathbf{B} = \begin{bmatrix} -N_1 & 0 & -N_2 & 0 & N_1 & 0 & N_2 & 0 \\ 0 & -N_1 & 0 & -N_2 & 0 & N_1 & 0 & N_2 \end{bmatrix} \qquad (4)$$

where N_i are the linear shape functions.

Contrary to the finite element formulation of conventional continuum elements, the shape functions in the strain displacement matrix $\mathbf{B}$ are non-differentiated. From the principal of virtual work, the element stiffness matrix and the element force vector of the interface element can be obtained.

The slip-strain constitutive model proposed by Shima et al. [2] is used for the pull-out of reinforcing bars from the base foundation. The strain-slip model is formulated in terms of normalized slip s, defined as

$$s = \frac{w}{D} K_{fc}, \quad K_{fc} = \left(\frac{f_c'}{20} \right)^{2/3} \qquad (5)$$

where s is the normalized slip, D is the bar diameter and f_c' is the compressive strength of concrete in MPa.

The envelope of the slip-strain curve before steel yielding is uniquely expressed as a function of steel strain only [2]. The slip-strain relations can be inverted to obtain the steel strain as a function of slip. Hence, the steel stress can be calculated from the stress-strain relationship of steel.

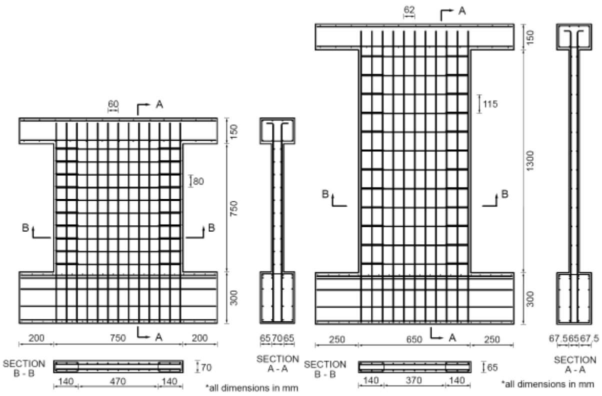
The shear slip model based on the concept of contact density [3] is applied for the modeling of stress transfer due to aggregate interlock along the crack surface. The shear and compressive stresses at the crack surface are calculated by the following equations:

$$\frac{\tau}{m} = \frac{\varphi^2}{1+\varphi^2}, \quad \frac{\sigma'}{m} = \frac{\pi}{2} - \cot^{-1}\varphi - \frac{\varphi}{1+\varphi^2} \qquad (6)$$

where $\varphi=\delta/\omega$, $m=3.8(f_c')^{1/3}$ (MPa). Eq. (6) expresses a unique relation between the normalized shear stress and the shear slip/crack width ratio. Since both shear and compressive stresses are functions of φ, the relationship between the shear stress and the compressive stress does not depend on shear slip or crack width [3].

3. Numerical Example

The discrete crack model was applied to the reinforced concrete shear walls tested by Lefas et al. [4]. Two wall specimens named SW13 and SW24 were selected for the analyses. The upper beam provides anchorage for vertical reinforcement and the lower beam for a rigid base. Figure 2 shows the nominal dimensions of test specimens together with the arrangements of vertical and horizontal reinforcements. The vertical and horizontal reinforcements comprised deformed steel bars of 8mm and 6.25mm diameter, respectively.



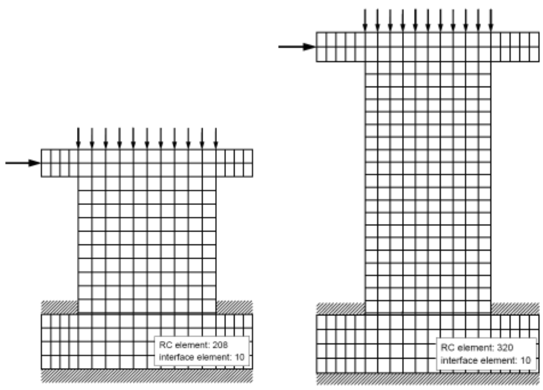
(a) SW13 (b) SW24

Figure 2. Geometries and reinforcement details of shear walls

Table 1. Loading conditions and material properties

Specimen	Axial load (kN)	f_c' (MPa)	f_t (MPa)	E_c (MPa)
SW13	355	-34.5	1.94	29,362
SW24	0	-41.1	2.12	33,132

Table 1 includes the material properties of the concrete and the loading conditions. The yield strength of vertical and horizontal reinforcements are 470MPa and 520MPa, respectively. All these values are from the experimental data by Lefas et al. [4].



(a) SW13 (b) SW24

Figure 3. Finite element mesh configuration used

Comparative analyses are conducted to examine the effect of the interface element, i.e. the discrete crack model. Figure 4 compares the analytical results of specimens SW13 and SW24 for the cases with and without using the interface element at the boundary plane. As shown in Figure 4, better agreement between the experimental and analytical results could be obtained using the interface element. This indicates that the modeling of local discontinuities using the interface element play a significant role in the load-deflection behavior and must be properly taken into account in the nonlinear analysis.

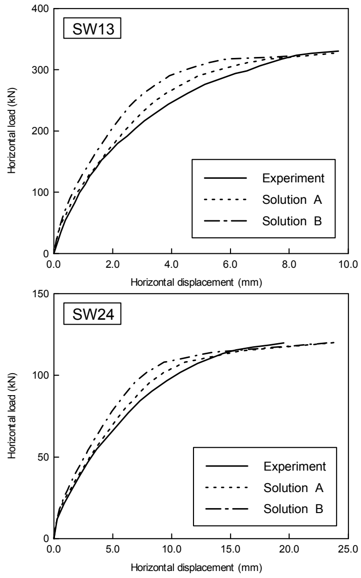


Figure 4. Load displacement relations of shear walls
Solution A: with interface element
Solution B: without interface element

4. Conclusion

In this study, an interface element was introduced for the analysis of reinforced concrete shear walls. The joint behavior was simulated by superposing the strain-slip model of re-bar and shear slip model of concrete. Inclusion of local discontinuities at the boundary plane using the interface element results in a more accurate prediction of displacements and ductility.

ACKNOWLEDGEMENT

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REFERENCES

[1] R. E. Goodman, R. L. Taylor, and T. L. Brekke, A Model for the Mechanics of Jointed Rock," Journal of Soil Mechanics and Foundations Division, ASCE, Vol. 94, No. 3, pp. 637-660, 1968.

[2] H. Shima, L. Chou, and H. Okamura, Micro and Macro Models for Bond in RC, Journal of The Faculty of Engineering, University of Tokyo (B), Vol. 39, No. 2, pp. 133-194, 1987.

[3] B. Li, K. Maekawa, and H. Okamura, Contact Density Model for Stress Transfer across Cracks in Concrete, Journal of The Faculty of Engineering, University of Tokyo (B), Vol. 40, No. 1, pp. 9-52, 1989.

[4] I. D. Lefas, M. D. Kotsovos, and N. N. Ambraseys, Behavior of Reinforced Concrete Structural Walls: Strength, Deformation Characteristics, and Failure Mechanism," ACI Structural Journal, Vol. 87, No. 1, pp. 23-31, 1999.