개구부를 갖는 콘크리트 전단벽의 탄성안정

Elastic Stability Of Perforated Concrete Shear Wall

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요 지

개구부를 갖는 콘크리트 전단벽을 두께가 얇은 직사각형 평판으로 모델화 하였다. 판의 두가지 경계 조건에 대한 안정해석 결과를 판좌굴계수 k로 표시하였다. 경계 조건이 다른 변수로는 휨으로 인한 힘/연직하중비 α, 수평 전단력/연직하중비 β 및 개구부의 위치 및 크기 변화이다. 유한요소법에 의한 결과를 얻기 위하여 예제의 판을 27×9의 정사각형 요소로 분할하였으며 node에서 3가지 자유도를 갖는 c^0 유한요소를 택하였다. 일반적으로 개구부의 크기가 증가함에 따라 판 개구부가 판 중앙에서 자유연(free edge)으로 접근할수록 좌굴계수는 감소하는 현상을 보이고 있다.

Abstract

Concrete shear wall with opening is modeled as a rectangular thin plate. The stability analysis results are presented by the buckling coefficient, k, for two different boundary conditions. The other parameters whose variation have been considered are the ratio of the bending induced force to gravity force, α, the ratio of the horizontal shear force to the gravity force ratio, β, and the change of location and the size of perforated part. To obtain the results by finite element method, an example plate has been divided into 27×9 square elements. Four node rectangular c^0 continuous finite elements having three degrees of freedom per each node is adopted. It is generally concluded that the buckling coefficients decrease as the size of hole increases, and the location of hole moves to free edge of the wall.

Keywords : *perforated concrete shear wall, Kirchhoff hypothesis, stability analysis, buckling coefficient, buckling mode*

1. INTRODUCTION

Concrete shear wall systems are commonly adopted in high-rise residential apartment buildings.[5] During construction stage, a rectangular opening is often made in the shear wall (see Fig. 1) for rapid horizontal movement of construction workers and construction materials. This cutout part is filled with cement bricks just before the final stage of

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room finishing. In this case, one can not expect perfect monolithic shear wall behavior especially when subjected to horizontal loads, such as, due to wind and earthquake. Thus the perforated part in this imperfect shear wall can be a critical factor in the structural design of multi-story shear wall buildings.

To investigate the stability behavior of perforated concrete shear wall, a typical wall with cutout shown in Fig. 3 is selected. For numerical stability analysis of this shear wall, the wall is modeled as thin plate. In the case of example shear wall of Fig. 1, $a/t=270\text{cm}/18\text{cm}=15>10$ and so it is assumed that given shear wall satisfies Kirchhoff hypothesis.[4]

2. ANALYTICAL FORMULATION

Fig. 3 shows the example thin plate, having length L_x in the x-direction, width L_y in the y-direction and thickness t. The plate is divided into 27×9 square elements, which are assumed to be connected one another only at the corners.

A typical element, like the one in Fig. 2 (a), has four nodal points at each of which three displacement components are defined as shown in Fig. 2(b). Given element is subjected to the constant in-plane shear force, $T_X=T_Y=T$, and axial compression force, N_X and N_Y which assumes constant value under gravity load, while for "bending moment" due to horizontal force, this takes linearly varying form.

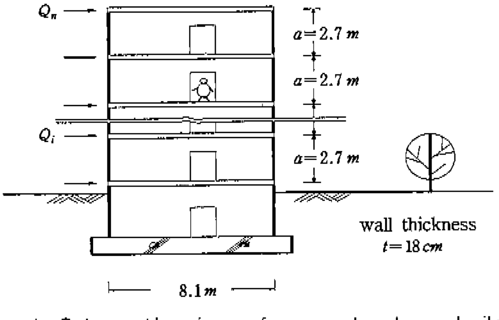
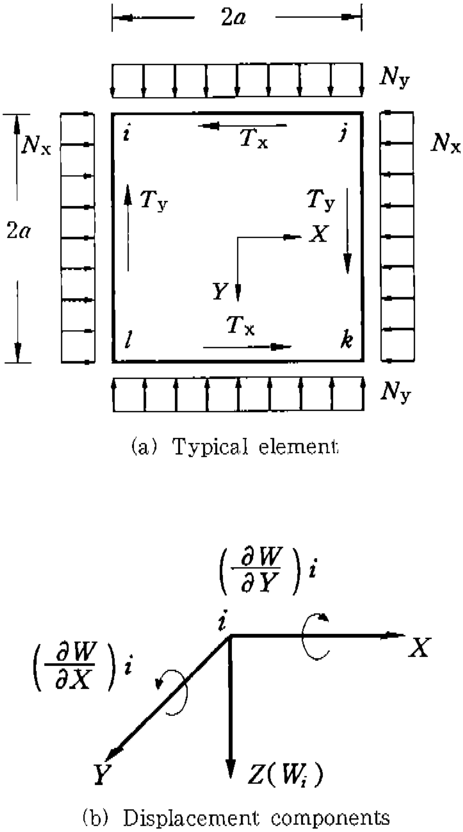


Fig. 1 Schematic view of example shear building

Derivation method of element flexural stiffness matrix, $[k]_b$ for pure bending and geometrical stiffness matrix, $[k]_g$ for the influence of in-plane forces on the flexural stiffness, is described in detail else where. For example, one can find them in the texts by Zienkiewicz or by Chajes.[1),2),4)]

Here one change should be made in the geometrical stiffness matrix $[k]_g$. Originally $[k]_g$ is expressed by

$$[k]_g=\int_{-a}^{a}\int_{-a}^{a}[B]^T[N][B]dx\,dy \qquad (1)$$



(a) Typical element

(b) Displacement components

Fig. 2 Finite element

in which the first derivatives of shape function matrix, $[B]$, has no change.
The in-plane forces matrix, $[N]$, however,

$$[N]=\begin{vmatrix} N_X & T_X \\ T_Y & N_Y \end{vmatrix} \quad (2)$$

should be predetermined for each element by the plane stress analysis of thin plate under the loading condition of Fig. 3(a)

Here deleting the perforated parts, flextural and geomatrical stiffness matrices are assembled into their counter parts $[K]_b$ and $[K]_g$, then the principle of stationary total potential allows the buckling equation to take the usual form.[3)]

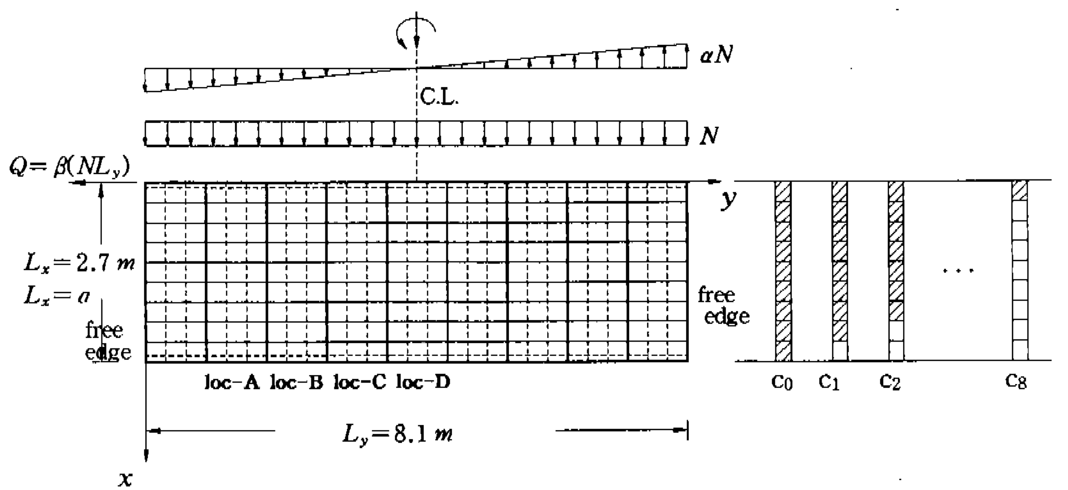
$$([K]_b-\lambda[K]_g)\ \{\Delta\}=\{0\} \quad (3)$$

in which $\{\Delta\}$ is the displacement vector of plate modal deformation.

For buckling, the determinant of $([K]_b-\lambda[K]_g)$ should be zero, which can be solved for buckling load factor(first eigenvalue), λ, using standard eigenvalue extraction techniques.[2),5)] The associated eigenvector $\{\Delta\}$ represents the global buckling degrees of freedom which yield the buckling mode shape.

3. ILLUSTRATIVE EXAMPLES

The finite element stability analysis for example shear wall has been programmed. In Fig. 3(a), it is assumed that unloaded edges are unsupported, that is, they are free edges. In order to evaluate the accuracy of the developed program, two cases of the non-perforated plates with the loaded edges-the one is simply supported and the other clamped edges-have been analysed. These two cases correspond to the columns with the same boundary conditions and with length a. As can be seen in Fig. 6 and 7, the results obtained from the developed program yield somewhat lower bound errors when compared with the exact values, that is, $N_{cr}=\pi^2 D/a^2$



(a) Cutout location & loading (b) Cutout size

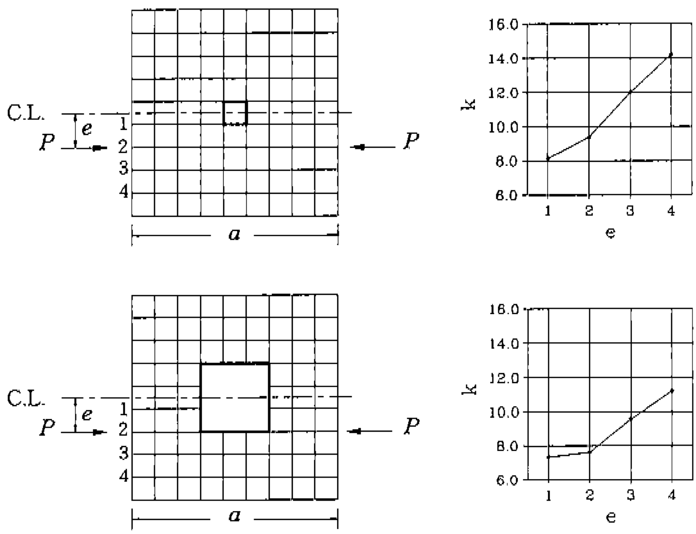
α: the ratio of the bending induced force to the gravity force
β: the ratio of the horizontal shear force to the gravity force

Fig. 3 Perforated example plate under combined loading and $N_{cr}=4\pi^2D/a^2$ (D : flexural rigidity of plate), the critical loads corresponding to simply supported and fixed plates, respectively. No one knows the exact values of critical load of perforated plates. The results by developed program, Fig. 4(b), however, show similar patterns to Fig. 4(c), which is originally chosen by C.J. Brown.

Fig. 5 shows some of the buckling mode shapes and Fig. 6 and 7 show the buckling coefficient, k, obtained from the stability analysis program. Here k is defined as

$$k=N_{cr}a^2/(\pi^2D) \qquad (4)$$

As can be seen in these pictures, buckling coefficient, k decreases with increasing values of α and β. Also one can see that k de-



(a) Opening size & eccentricity　　(b) Eccentricity vs buckling coefficient

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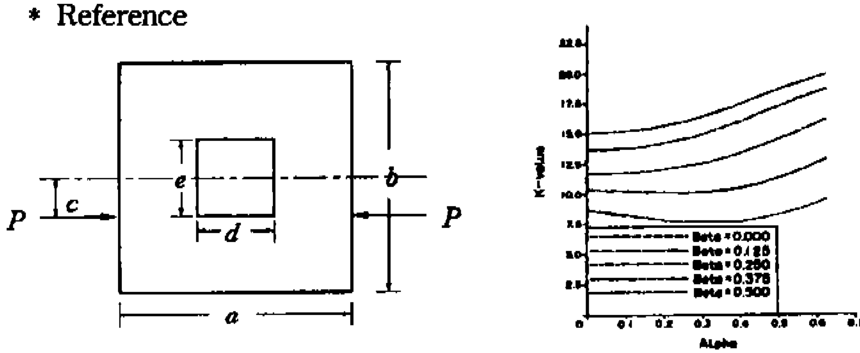


(c) C.J. Brown, Elastic buckling of perforated plates subjected to concentrated loads, Computers and Structure, Vol. 36, No. 6, pp 1103-1109

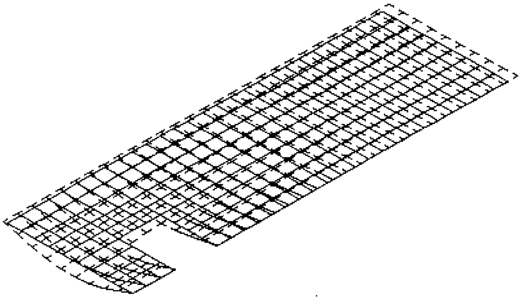
Fig. 4 k-values for simply supported square plates ($P_{cr} = k\frac{\pi D}{a}$)

creases with increasing hole size and its distance from the plate center.

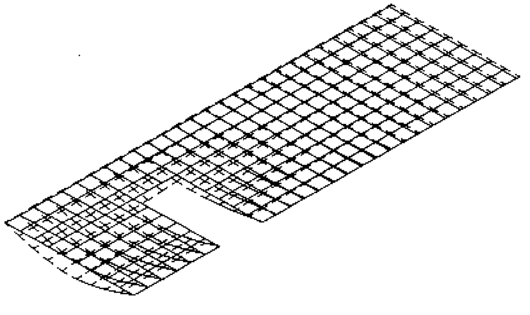
4. CONCLUSIONS

Stability analysis results for rectangular perforated shear walls with two different boundary conditions-one plate with simply supported loaded edges and the other plate with clamped loaded edges-have been presented by using finite element techniques. The parameters considered in the analysis are the ratio of the bending induced force to gravity force, α, and the ratio of the horizontal shear force to gravity force, β, and the change of size and location of perforated part.

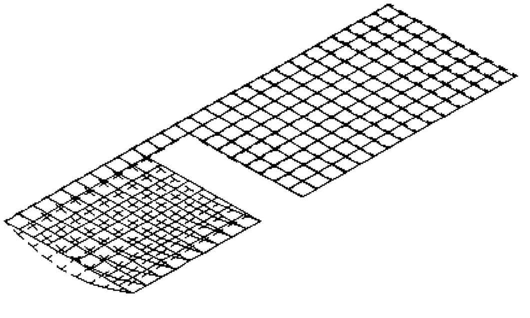
With increasing values of α and β and also with increasing size of cutout part, buckling coefficient decreases. In order to ensure the stability of shear wall under horizontal load, the cutout part around the center of the wall is preferable to the hole near the free edges.



(a) Cutout location : loc-A, C4 (α=0.2, β=0.0)



(b) Cutout location : loc-B, C6 (α=0.6, β=0.05)



(c) Cutout location : loc-C, C8 (α=0.4, β=0.15)

Fig. 5 Buckling mode shapes

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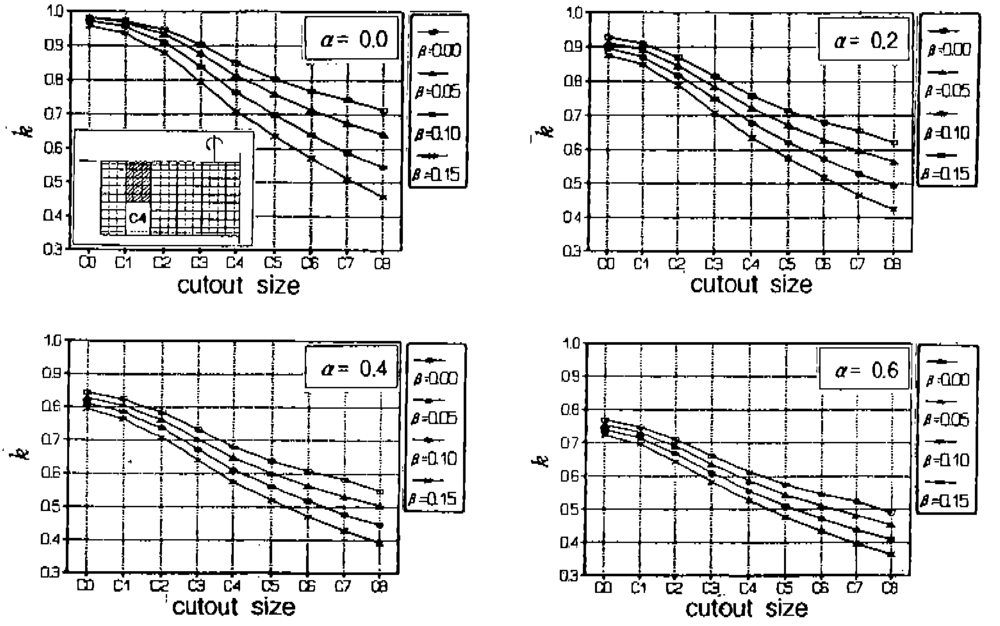
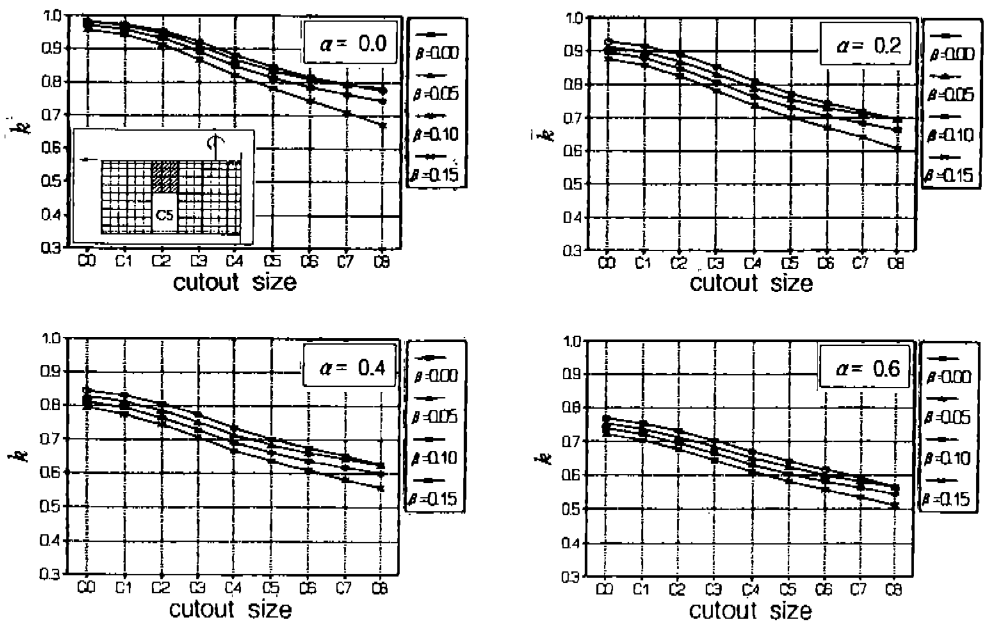
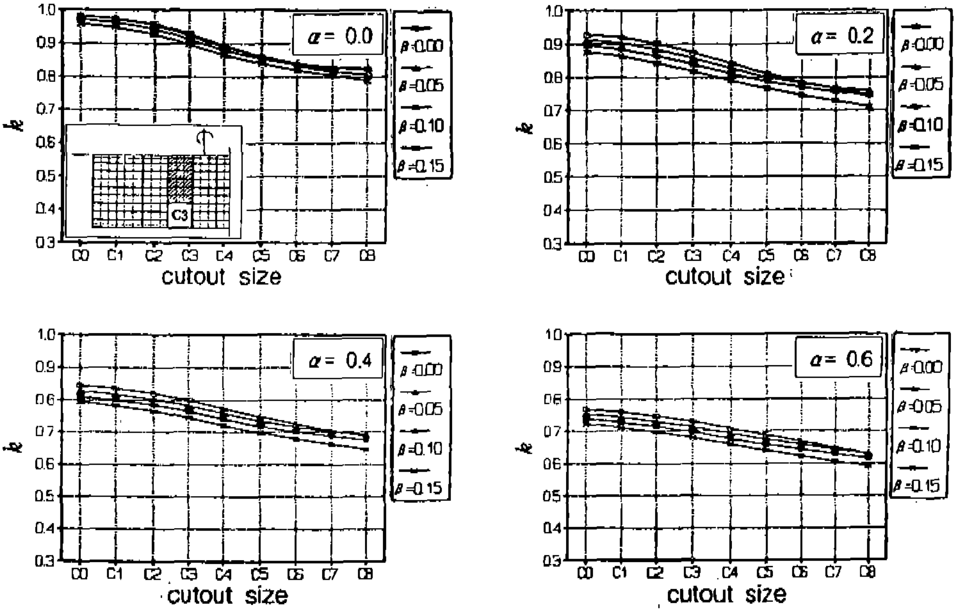


(a) Cutout location : loc-A

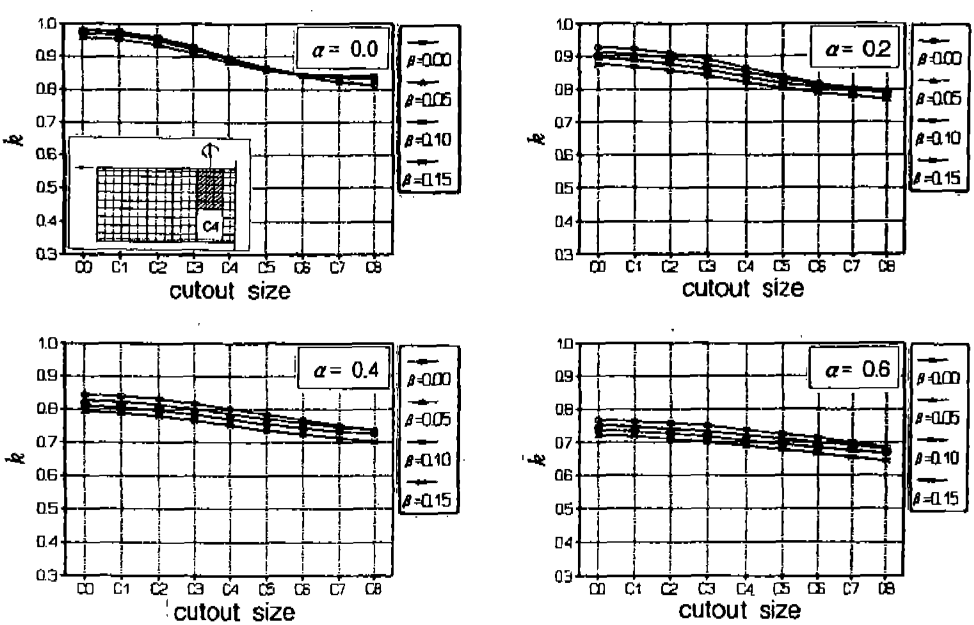


(b) Cutout location : loc-B

Fig. 6 Simply supported edges (continued)

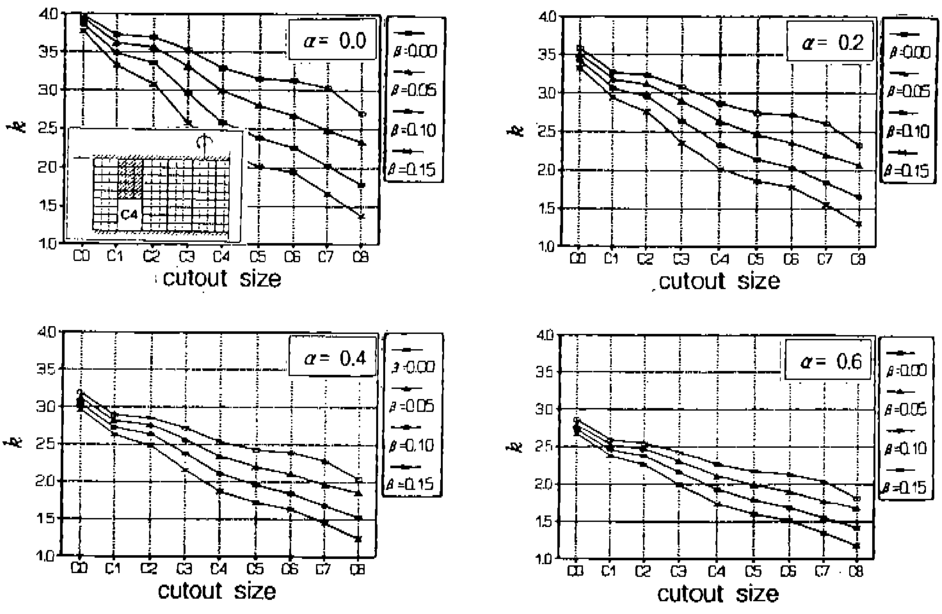


(c) Cutout location : loc-C

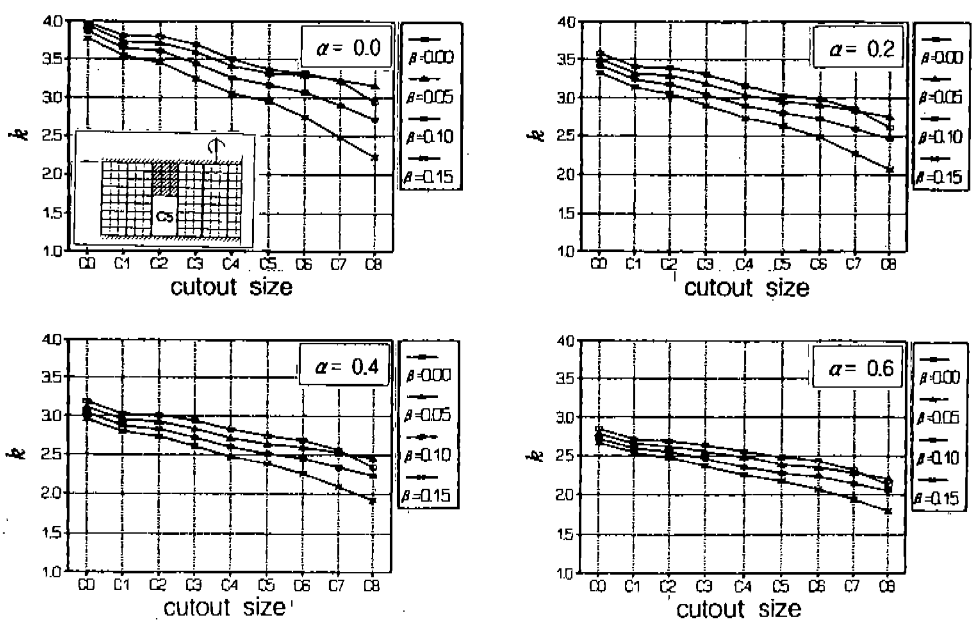


(d) Cutout location : loc-D

Fig. 6 Simply supported edges

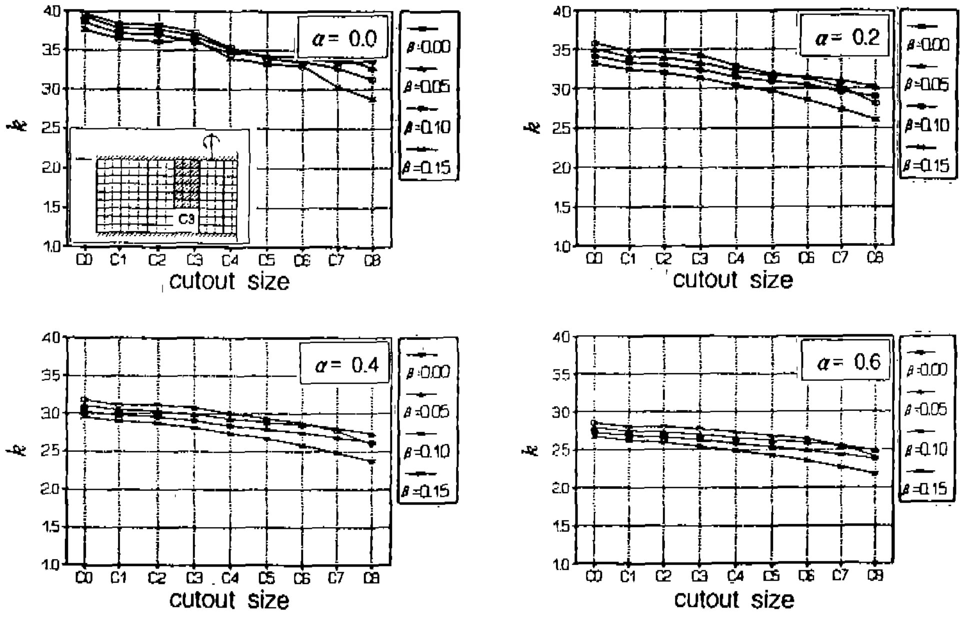


(a) Cutout location : loc-A

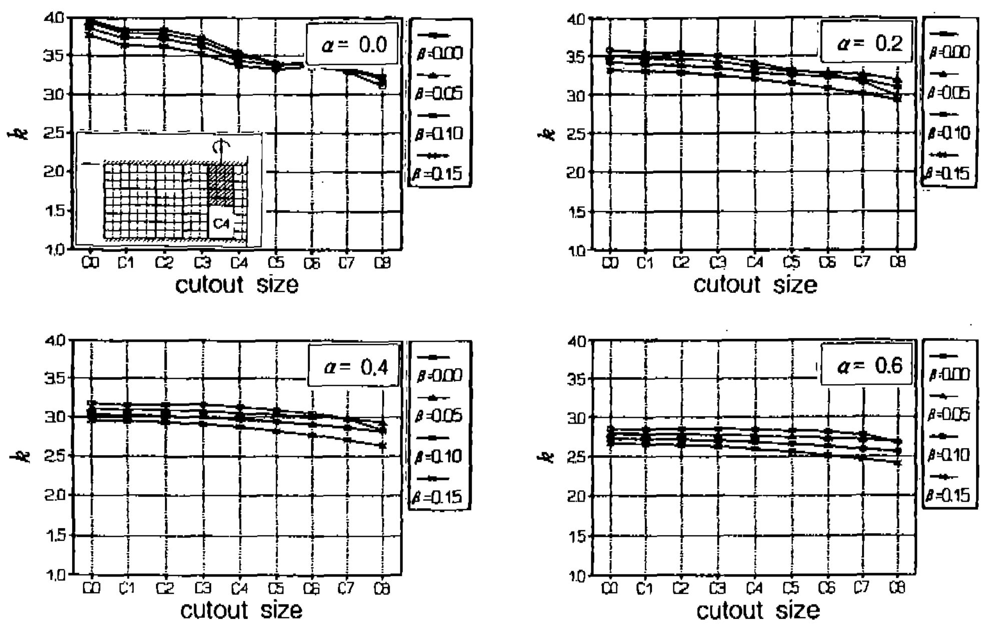


(b) Cutout location : loc-B

Fig. 7 Fixed edges (continued)



(c) Cutout location : loc-C



(d) Coutout location : loc-D

Fig. 7 Fixed edges