The 2015 World Congress on
Advances in Civil, Environmental, and Materials Research (ACEM15)
Incheon, Korea, August 25-29, 2015

Crack progress analysis of plain concrete test prisms by HPM

* Atsushi Kambayashi[1)], Yoshihiro Fujiwara[2)], Norio Takeuchi[3)]
and Tadahiko Shiomi[4)]

[1)] *Research & Development Institute, Takenaka Corporation, Chiba 270-1395, Japan*
[2), 4)] *Mind Inc. Chiba 274-0825, Japan*
[3)] *Dept. of Engineering and Design, Hosei Univ., Tokyo 162-0843, Japan*
[1)] *kanbayashi.atsushi@takenaka.co.jp*

ABSTRACT

Analytical results of cracking of concrete test prisms using hybrid penalty method (HPM) are discussed. This method allows a correct analysis of the developing crack width between elements. While the objective is to develop a method for setting suitable stress release after cracking, fracture energy is not considered in this study. Analysis of prisms of 100mm x 100mm x 400mm size subjected to the three-point bending shows that the progressive failure.

1. INTRODUCTION

The authors have developed a computer program based on the HPM (hybrid penalty Method) to analyze structural members of reinforced concrete structures. Cracking of concrete is a progressive damage process, where without applying a load from the outside, cracks continue to progress due to the released force by initial cracks.

In this paper, the displacement control analysis method was adopted into the developed HPM program, crack propagation analysis of concrete test prisms was carried out and the validity of the crack progress analysis using the proposed analytical method was discussed.

2. FEATURES OF HPM

As shown in Figure-1, in HPM, the displacement field within the element is defined by the displacement {u,v, } of a point in the element and the strain { x, y, xy} in the element. In this paper, triangular elements are adopted and the strain field is considered uniform. Sufficiently rigid penalty spring is set at the element boundary. The relative displacement of the penalty spring is determined from the displacement of the element. Element boundary force is calculated from the relative displacement of the penalty spring.

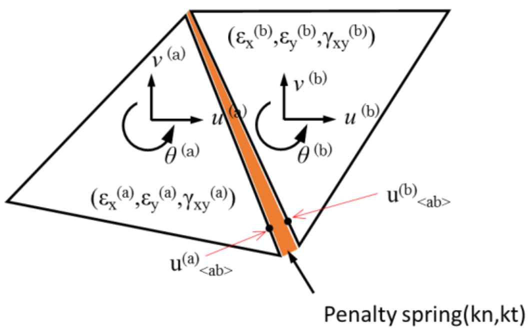


Fig. 1 Degrees of freedom and penalty spring of HPM

3. Implementation of forced displacement control

A function for analyzing the forced displacement was implemented using the following procedure. First of all, the incremental displacement of each loading stage is given. In the first step of the loading stage, the load term of the displacement control points is set. Cracks will be opened using r_{min} method. Release forces at the boundary of the cracked components are added to the load term in the next analysis step.

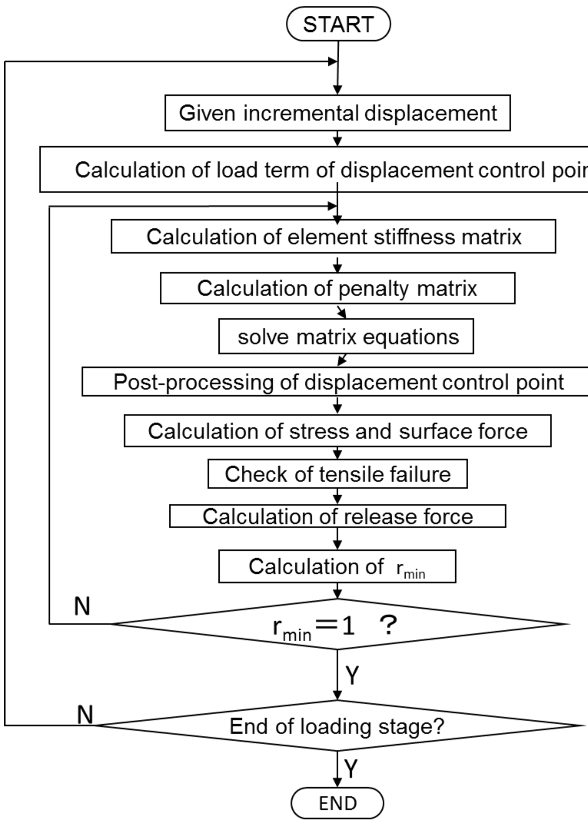


Fig. 2 Flow of forced displacement control

4. Analysis by equal-mesh elements

To determine whether the displacement control analysis is working correctly, an analysis was carried out using the equal element meshing shown in Figure 3 for plain concrete test prisms of 400mm × 100mm × 100mm size. Table 1 shows the material constants used in the analysis.

First, analyses were performed using a model without notch and a model that is subsequently notched at the prism center. The deformation and cracking condition of the analysis results are shown in Figure 4. The crack progressed from the lower surface at the beam center.

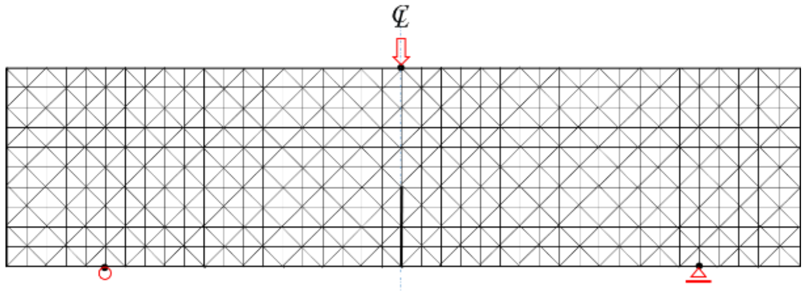


Fig. 3 Simulation model by equivalent elements

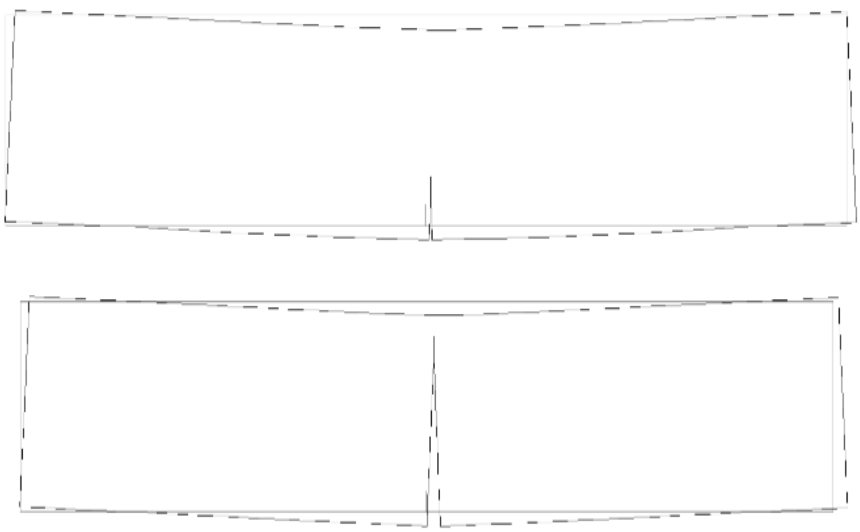


Fig. 4 Defomation and Progress of cracks

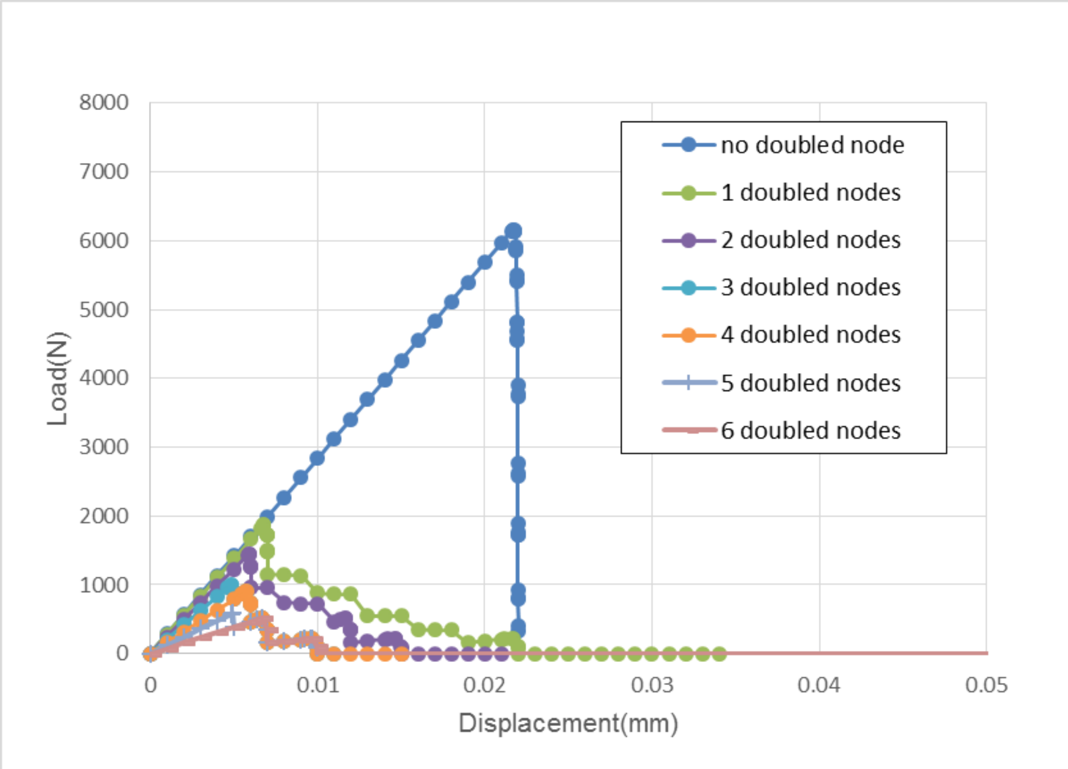


Fig. 5 Load- displacement relationship

Load-displacement relationship curves illustrating the analysis results are shown in Figure 5. The parameter of the studied cases was the number of doubled nodes from the lower surface of models. The number ranged from no doubled nodes to six doubled nodes.

If there is no notch, the model would progressively crack from the loading stage of the initial crack until the last stage, where the residual reaction force finally becomes almost zero.

If there is a notch, the load value causing the initial crack gradually decreases as the depth of the notch increases. Figure 6 shows a comparison of the analysis value for a model notched to half of its section height (six doubled nodes) and a model with shorter notch depth (five doubled node).

Table-1 Material constants

Tensile strength f_t (MPa)	3.0
Young’s modulus E (GPa)	30.0
Poisson’s ratio	0.2
Thickness (mm)	100.0

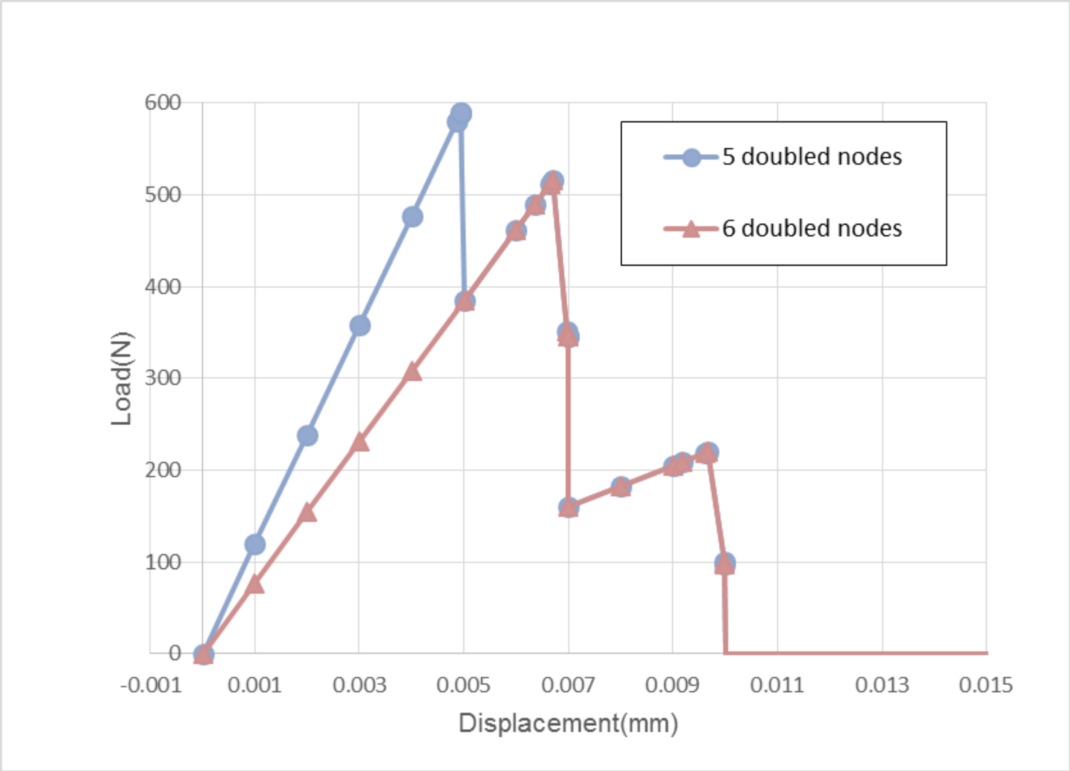


Fig. 6 Load-displacement relationships relative to a model with a short notch depth and a model notched to half of its section height

5. Analysis using Delaunay triangular elements

An analytical model using Delaunay triangle elements, shown in Figure 7, and composed of 4011 nodes and 7722 elements was studied. The model is notched at its center to half of its section height. Material constants are the same as in Table 1.

Figure 8 shows the deformation and crack condition. The crack progressed almost linearly.

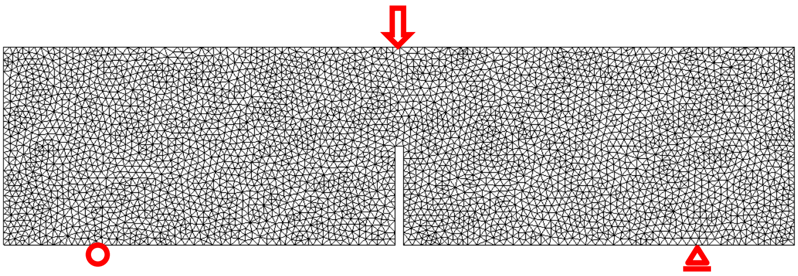


Fig. 7 element meshing using Delaunay triangle

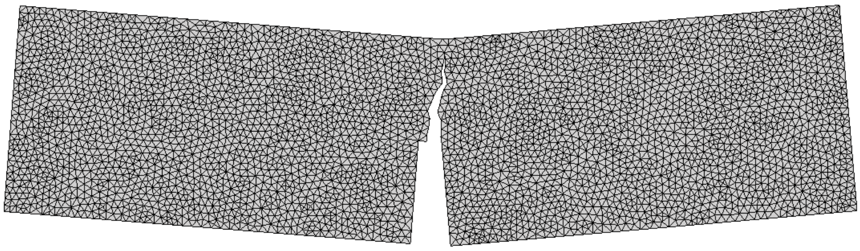
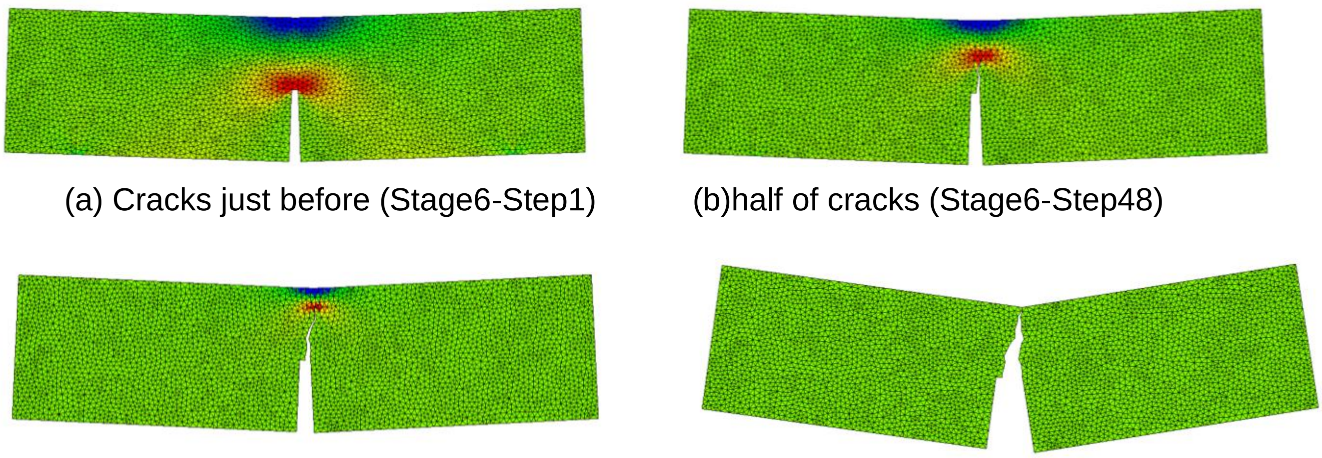


Fig. 8 Defomation and progress of crack

Figure 9 shows the stress distribution along the beam axis. The model would crack gradually from the loading stage of the initial crack until the stage where the residual reaction force becomes almost zero.

Figure 10 shows the load-displacement relationship of the model.



(a) Cracks just before (Stage6-Step1)

(b)half of cracks (Stage6-Step48)

(c)(Stage7-Step1)

(d)Final(Stage20-Step1)

Fig. 9 Stress distribution along beam axis

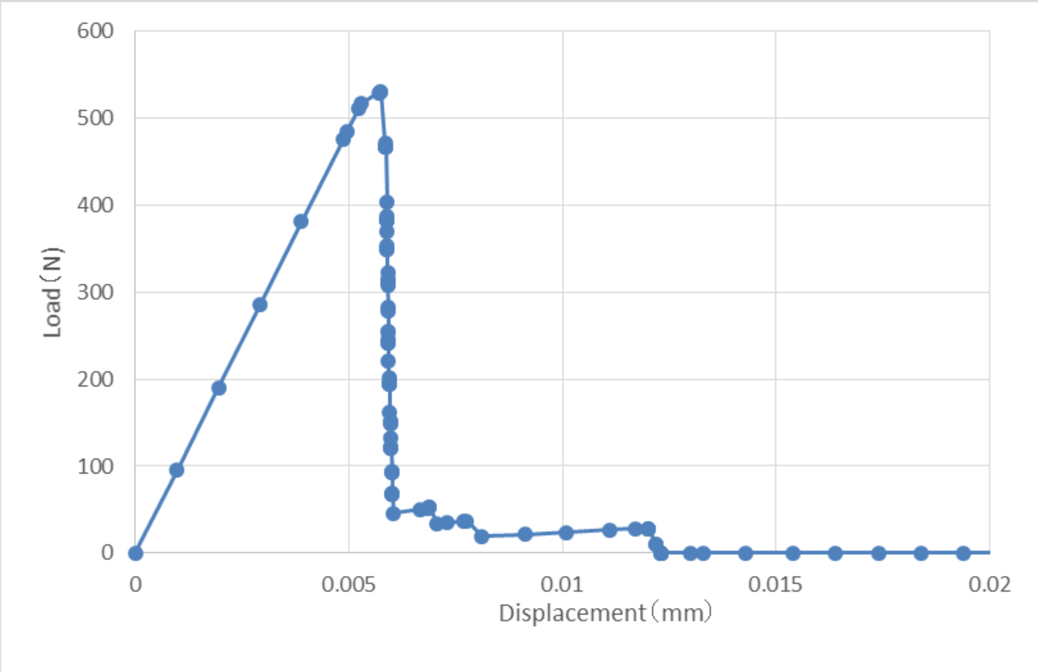


Fig.10 Load-displacement relationship(Delaunay triangular elements)

6. CONCLUSIONS

A function for analyzing the forced displacement method was implemented into a computer program based on the HPM (hybrid penalty Method) to study cracking in structural members of reinforced concrete structures.

Analysis of 100mm x 100mm x 400mm size prisms subjected to the three-point bending was performed. The following conclusions can be drawn.

1) In the case of no notch model, the rupture was led in a single loading stage.

2) In the case of notched models (some models with depth up to half the model section's height), using the equal element meshing, the analysis was able to track better the progress of cracks.

3) Delaunay triangle elements allowed a stable analysis and appropriate results.

REFERENCES

Fujiwara,Y., Takeuchi,N., Shiomi, T. and Kambayashi A. (2013), "Discrete crack modeling of RC structure using hybrid-type penalty method", Int. J. Aerospace and Lightweight Structures, 3(2), 263-275.