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FINITE ELEMENT ANALYSIS OF BLAST DEMOLITION OF FRAMED STRUCTURES BY USING THE ASI TECHNIQUE

by

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1 INTRODUCTION

The Adaptively Shifted Integration (ASI) technique, using the relations between the locations of numerical integration points and those of plastic hinges, could produce the highest computational efficiency in the finite element analyses of framed structures[1][2] including dynamic collapse analyses[3]. Advantages of the ASI technique which is applied to the geometrically nonlinear, elasto-plastic analysis as well as the geometrically linear, plastic collapse analysis for large-scale framed structures have been shown in the recent paper[4].

In this paper, the ASI technique with the linear Timoshenko beam element is applied to the blast demolition analysis of framed structures. As the occurrence of extremely large rotations and strains are anticipated in the analysis, the updated Lagrangian formulation is used as the incremental theory. In order to maintain the high computational efficiency, the dynamic explicit code is chosen for the time integration.

2 BLAST DEMOLITION ANALYSIS USING THE ASI TECHNIQUE

By considering the equivalence conditions between the strain energy approximations of the linear Timoshenko beam element and the physical model, the rigid-bodies spring model(RBSM), the relation between the location of numerical integration point(s_1) and that of occurrence of plastic hinge(r_1) in the linear Timoshenko beam element ($-1 \leq r_1, s_1 \leq 1$) is obtained. It is expressed by the following equation:

$$s_1 = -r_1 \; or \; r_1 = -s_1 \tag{1}$$

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When the entire region in an element behaves elastically, the midpoint of the element($s_1 = 0$) is the most adequate integration point from the point of view of accuracy and symmetry. Thus the internal force vector at the n th incremental time step in updated Lagrangian formulation is expressed as

$$\{{}^n_nF\} = \int_{{}^nl} [{}^0T]^T \cdot [{}^uT]^T \cdot [{}^n_n\bar{B}_L(0)]^T \cdot \{{}^n_n\bar{R}(0)\}dl \tag{2}$$

where $[{}^0T]$ is a transformation matrix from the global coordinates to the elemental coordinates, $[{}^uT]$ is a transformation matrix from the initial elemental coordinates to the elemental coordinates at the n th incremental time step, the value in a parenthesis in $[{}^n_n\bar{B}_L]$ indicates the location of the integration point, and the one in $\{{}^n_n\bar{R}\}$ indicates the point at which stresses are evaluated, respectively.

In the blast demolition analysis using the ASI technique, the blast or fracture is expressed by shifting the numerical integration point according to the equation (1) immediately after the occurrence of fracture surface on either end of the element, and by reducing the resultant forces of the element simultaneously.

Assuming that the destructive surface has first occurred at the left end of an element, the released force vector which operates to the element at the following incremental step is then expressed by the following equation:

$$\{{}^n_nF\} = \int_{{}^nl} [{}^0T]^T \cdot [{}^uT]^T \cdot [{}^n_n\bar{B}_L(1)]^T \cdot \{{}^n_n\bar{R}(-1)\}dl \tag{3}$$

The general concept of the ASI technique in blast demolition analysis is shown in Fig.1.

3 NUMERICAL EXAMPLES

The ASI technique has been applied to the blast demolition analysis of a 2 stories-2 span portal frame structure. The blasts has taken place at certain points, and in the procedure as shown in Fig.2.

The deformed configurations for the models with 2 elements per member, 4 elements per member, and 8 elements per member are shown in Fig.3(a),(b),(c), respectively. We can see a slight difference in the dropping speed of upper beams. However, the deformed cofigurations seem reliable enough for the practical use.

Those maximum incremental time and the total computational time taken in the dynamic explicit code analyses are compared with those taken by using the implicit scheme on Table.1. It is known that the incremental time Δt for the explicit scheme is obliged to satisfy the following condition.

$$\Delta t < \Delta t_{cr} = \frac{l_{min}}{v_L} \tag{4}$$

where v_L is the velocity of the longitudinal wave in an elastic solid, and l_{min} is the length of the shortest element in the structure. Δt_{cr} on the Table indicates the theoretical maximum incremental time for 2 elements per member which is calculated from the equation above. Although the total value of incremental time steps used in the explicit scheme is more than 1.5 times the total steps by the implicit scheme, the computational time taken is nearly half of the time taken by the implicit scheme.

Fig.4 shows a space frame model used for another blast demolition analysis. The assumed material constants are as same as those shown in Fig.2. The blasting precedure is positively changed in this case to detect the faster and the safer destruction mode. In order to keep the members from scattering around, we started the blasts at the center of the structure. The deformed configurations for the space frame is shown in Fig.5. The computing time on the EWS (Sun SPARC station 10) for this analysis was about 19 minutes.

4 CONCLUDING REMARKS

By using the ASI technique with updated Lagrangian formulation and explicit scheme algorithm, sufficiently reliable solutions for practical use have been obtained in the blast demolition analyses of a portal frame and a space frame. The difficulties of simulating this kind of problem which has strong nonlinearity, are reduced by using this technique.

It is also to be noted that the present technique can be easily implemented with a minimum effort into the existing finite element codes utilizing the linear Timoshenko beam element.

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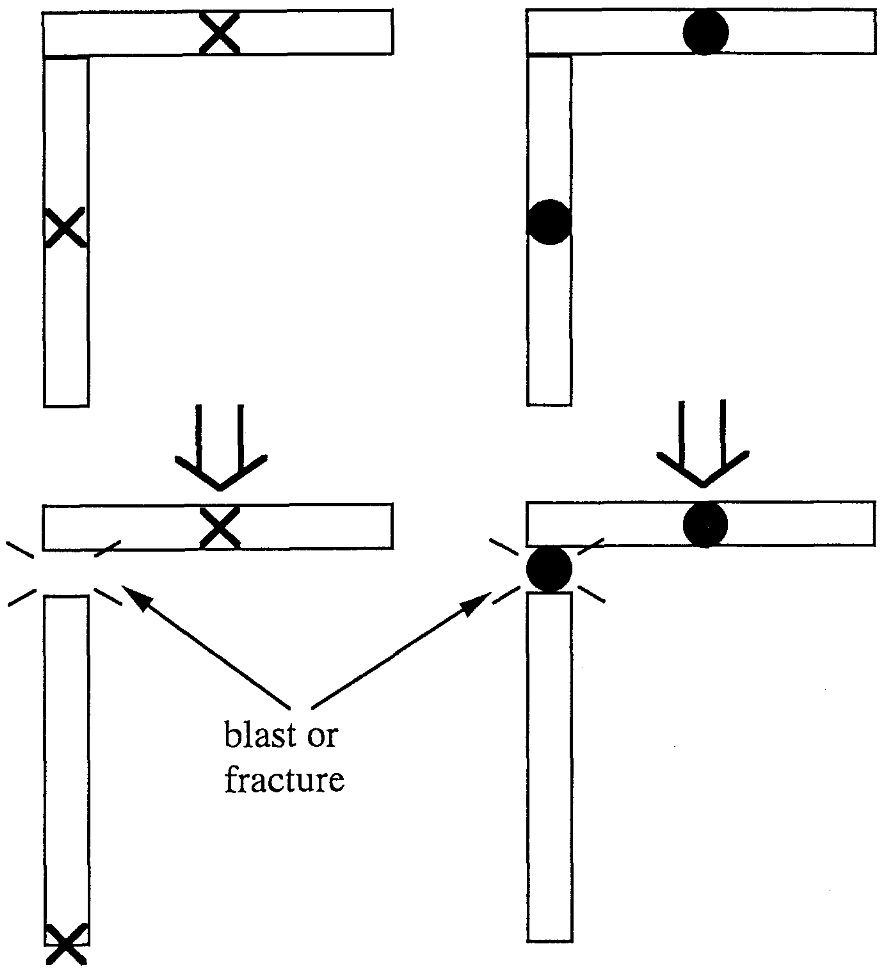
Table.1 Incremental time steps used in the analyses

($\Delta t_{cr}=0.97\times 10^{-3}$ [sec])

Number of elements	Incremental time	Computational time (SUN Sparc 10)
explicit scheme		
2 elements/memb.	0.95×10^{-3} [sec] (3160 step)	1 min. 45 sec.
4 elements/memb.	0.47×10^{-3} [sec] (6380 step)	6 min. 55 sec.
8 elements/memb.	0.21×10^{-3} [sec] (14280 step)	30 min. 34 sec.
implicit scheme		
2 elements/memb.	0.15×10^{-2} [sec] (2000 step)	3 min. 10 sec.



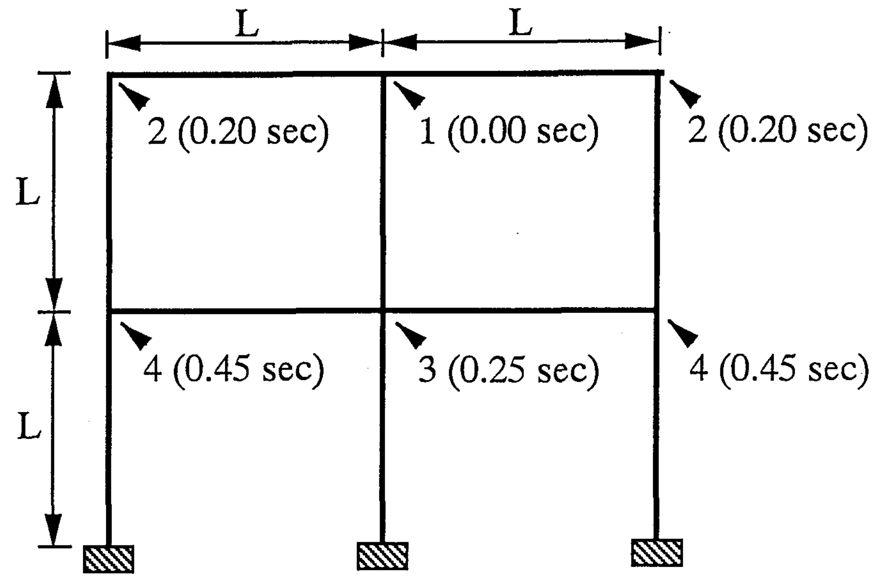
× Numerical integration point

● Rotational and shear springs connecting rigid bars

(a) Linear Timoshenko beam element

(b) RBSM model

Fig.1 Blast demolition analysis using ASI technique

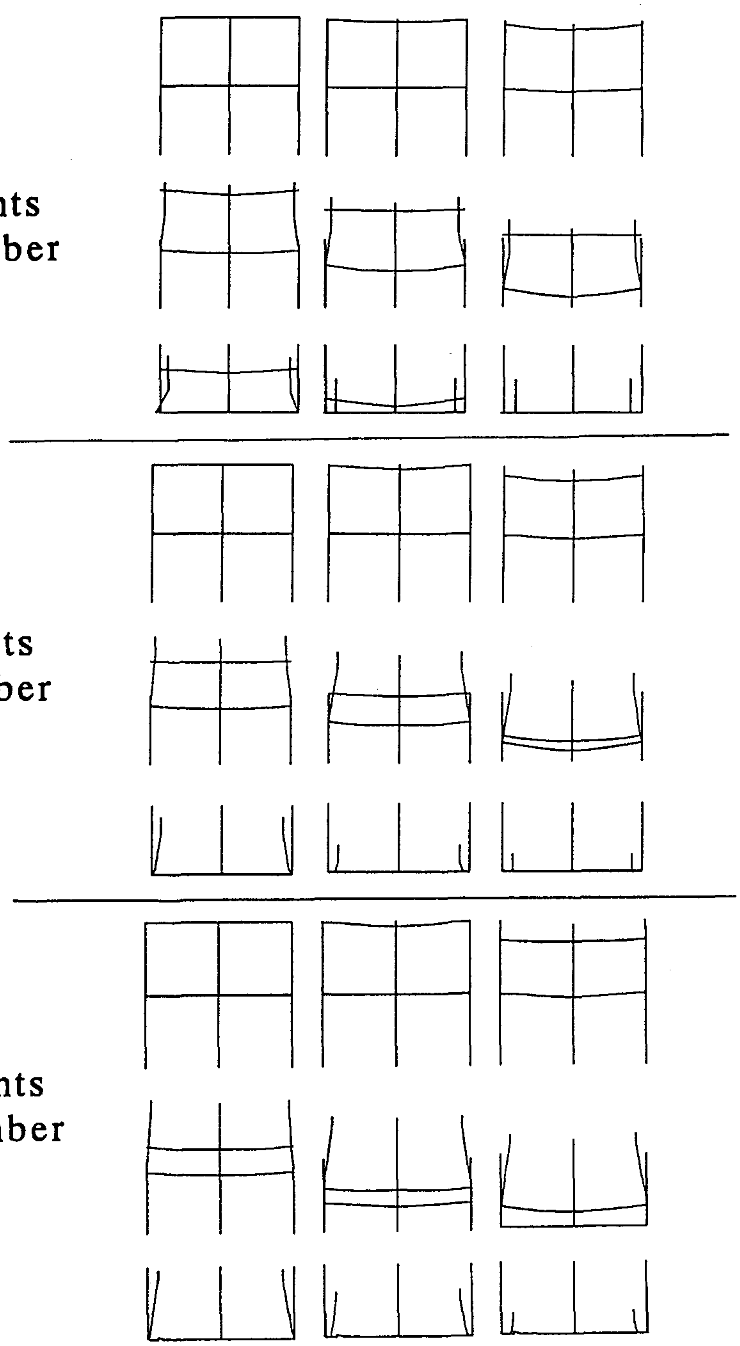


$E=2.1\times10^{4}$ [kgf/mm^2]
$\nu=0.3$
$\sigma_y=33.0$ [kgf/mm^2]
$\rho=7.8\times10^{-6}$ [kgf/mm^3]
$\kappa_{cr}=1.0\times10^{-4}$ [1/mm]
$L=1.0\times10^{4}$ [mm]

Column
$A=1.390\times10^{5}$ [mm^2]
$M_{x0}=M_{y0}=1.086\times10^{9}$ [kgf・mm]
$M_{z0}=9.855\times10^{8}$ [kgf・mm]

Beam
$A=5.979\times10^{3}$ [mm^2]
$M_{x0}=M_{y0}=1.406\times10^{7}$ [kgf・mm]
$M_{z0}=1.124\times10^{7}$ [kgf・mm]

Fig.2 Blast demolition analysis of a portal frame using ASI technique



(a) 2 elments
/member

(b) 4 elments
/member

(c) 8 elments
/member

Fig.3 Deformed configurations of a portal frame

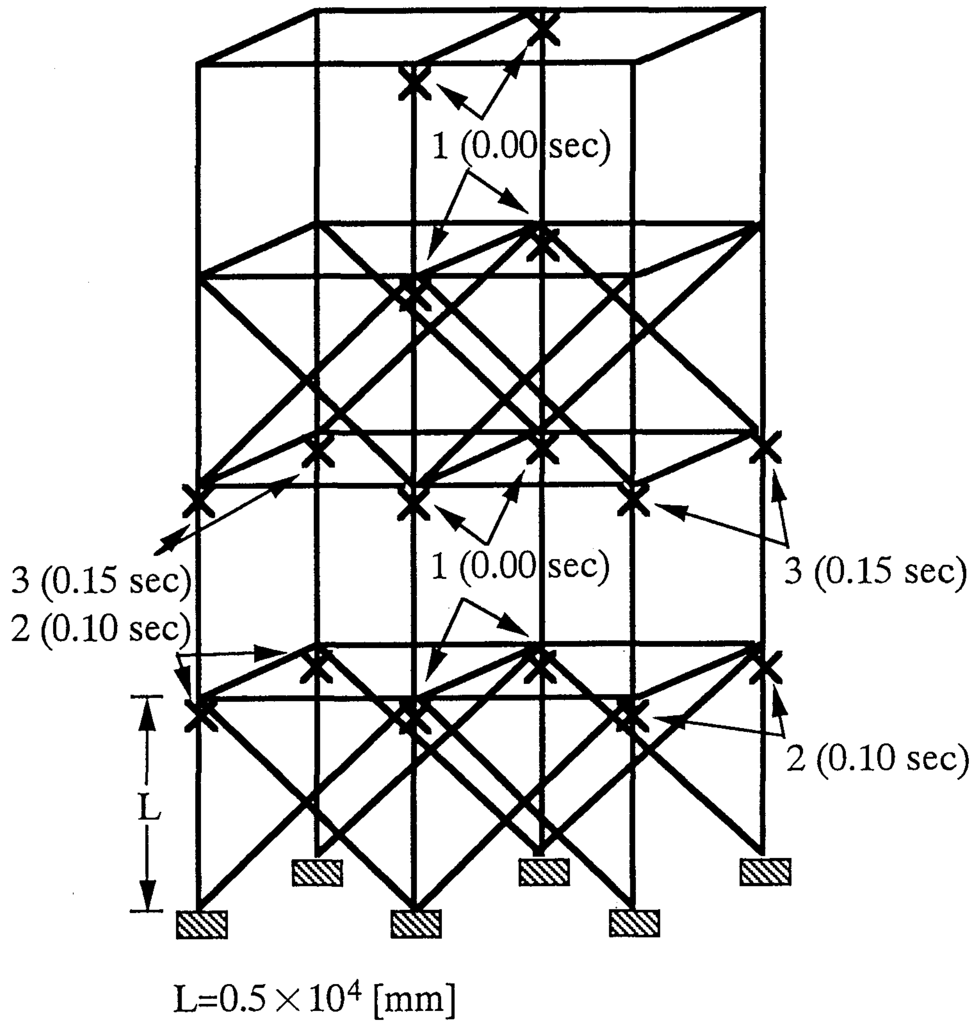


Fig.4 Blast demolition analysis of a space frame using ASI technique

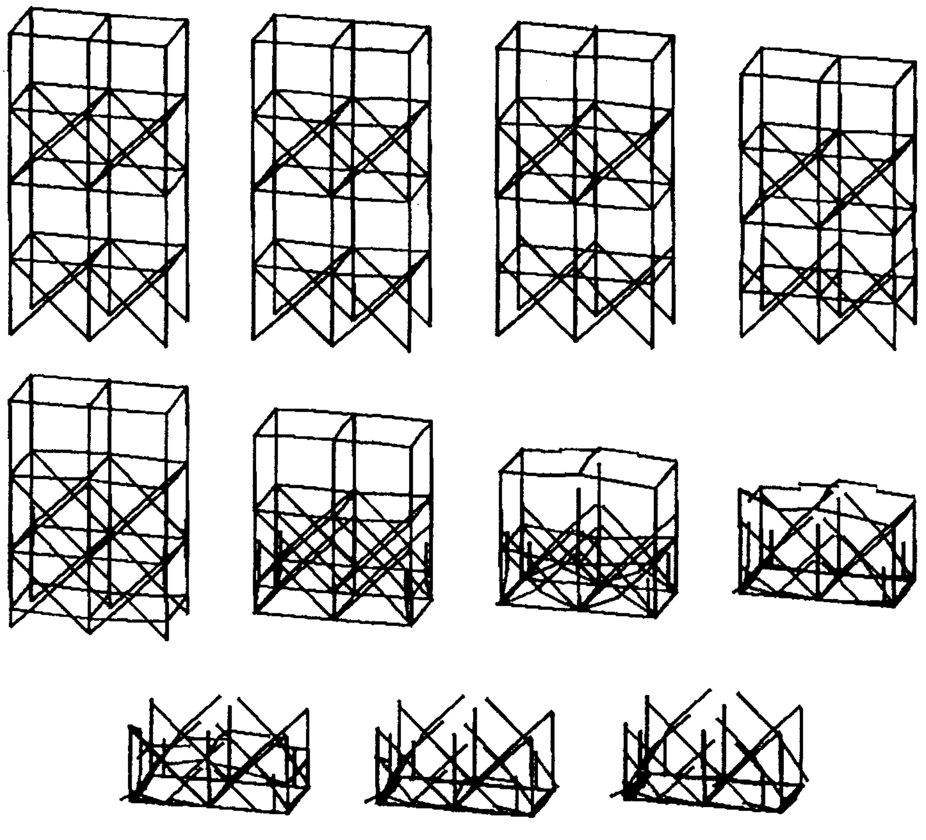


Fig.5 Deformed configurations of a space frame