PROPOSAL OF LOCAL INDEX FOR DAMAGE EVALUATION OF RC BEAM FAILED IN SHEAR COMPRESSION MODE

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1. INTRODUCTION

Nowadays, FEM has become popular and, has significant importance for performance verification to understand load carrying capacity and failure mode of concrete structures. It is also possible to understand clearly the stress and strain behavior, strain localization behavior and the cracking behavior. Moreover, the requirement moves toward evaluation of the structure behavior by using local information combining with the damage evaluation. Therefore, the averaging methods of the local strain were proposed [Ueda et al. 2014], and the concept is adopted in JSCE standard specification [JSCE, 2012]. However, the method is complex because it needs the averaging technique over different elements in a specific area. This paper proposes the local index using only local information in an element and the applicability is investigated.

2. ANALYTICAL METHOD

3D Finite element analysis were performed in order to investigate the applicability of local index for damage evaluation. Constitutive model used in the analysis is Lattice Equivalent Continuum Model (LECOM) developed in Nagoya University [Itoh et al. 2004], which is one of the fixed smeared crack models and consists of combination of tension, compression and shear lattice and uniaxial stress-strain relationships are adopted in each lattice. The stress-strain relationship under compression used in the analysis can be modeled by compression softening model. In the model, Saenz equation is used up to the compressive strength and a linear softening branch is assumed as shown in Fig. 1. The slope of linear softening branch is defined by considering the compression fracture energy (G_{fc}) and element size (L_{eq}) in order to avoid element size dependency for load-displacement relationship.

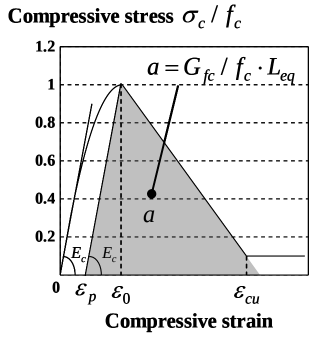

Fig. 1 uniaxial compression

In the analysis, two experimental beams with their specified material property (Table 1) are solved which were designed to fail by shear compression mode. The difference of the beams is the size. As the detailing of the beams are shown in Fig. 2 and Fig. 3, the left part (from center) shear span wasn't provided stirrup in order to have the shear compression failure. Modeling are done for both beam specimens with element size of 50 mm and 25mm cube.

Table 1: Material property

S/N		Concrete Property	
		Beam 1	Beam 2
Concrete property	Fc'(MPa)	30	30
	E (GPa)	24.8	24.8
Rebar property	Fy (Mpa)	404	1080
	E(GPa)	192	192
Stirrup property	Fy (Mpa)	500	
	E (GPa)	200	
	spacing	D-6/40mm	

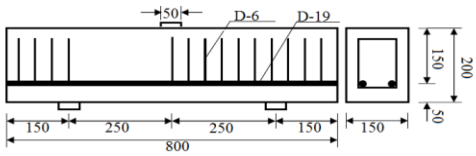

Fig.2 Beam 1 [all dimensions in mm]

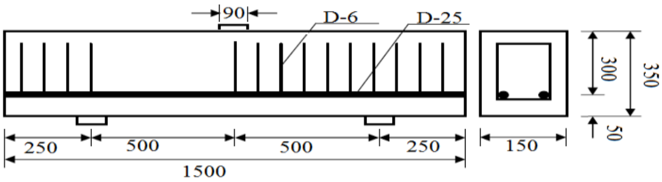

Fig.3 Beam 2 [all dimensions in mm]

3. LOCAL STRAIN BEHAVIOR FOR DIFFERENT ELEMENT SIZE

The load-displacement relationships of the analytical result are compared with the experiment result as shown in Fig. 4. The relationships for different element size are close to the experimental results and do not show the mesh dependency due to the fracture energy effect. Fig. 5 shows the minimum principal strain distribution at the peak load marked by ○ in Fig. 4. The strain localized near the loading point because the beam failed under shear compression mode. In Fig.4, minimum principal strain behavior in a localized element are superposed. The local strain behavior is sensitive for the mesh size variation and the value coresponding to the maximum load is quite different for different mesh sizes. This means that the local strain can not be used as local index to evaluate damage or load carrying capacity.

Keywords: Local Index, Fracture Energy, Element Deformation, Mesh Size Dependency, Shear Compression Failure
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4. PROPOSE OF LOCAL INDEX

Based on the discussion above, the requirement for local index is that the parameter does not show mesh dependency behavior and the value of index is related with damage progress such as maximum load. As the local index to satisfy the requirement, applicability of the localized element deformation and local element concrete fracture energy are investigated. A reason why the local strain show the mesh dependency is that the softening curve of stress-strain relationship considering fracture energy is dependent on element size L_{eq}, to insure same energy absorption in different size of localized element. In this concept, if the element size is multiplied to the softening curve, the softening curve show the unique behavior independent on mesh size. The curve is the function of stress and deformation. When we consider area of the softening curve, the value multiplied element size defines fracture energy. And, when we consider only strain value, it defines the localized element deformation. Fig. 6 show the change of fracture energy in a localized element for two beams with load-displacement relationships. In the figure, it can be seen that in both beams the fracture energy was increasing in constant rate in the pre-peak region and suddenly increase at peak load. That is, the sudden increase point corresponds maximum load for different specimen and different element size. Since this result satisfies the requirement for local index, the fracture energy can be used as a local index for load carrying capacity.
The localized element deformation values are drawn with the load-displacement relationship of the two beams as shown in Fig. 7. In both beams, the results show that the localized element deformations are independent of mesh size variation. The graphs also show unique behavior and the peak load corresponds to the localized element deformation of about 0.5mm. Therefore, it is possible to use local element deformation value as a local index for load carrying capacity. *[In all Fig. Red and grey color for 25mm mesh size and blue and green for 50mm]*

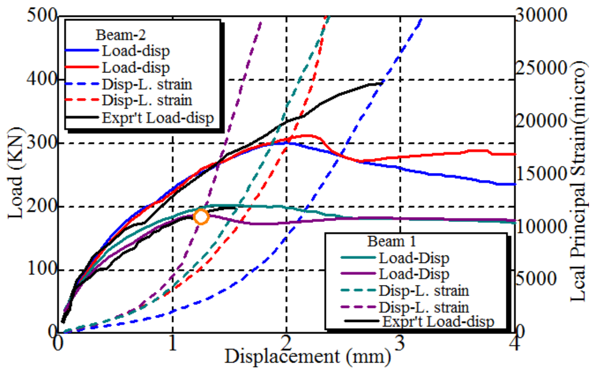

Fig. 4. Load-Displacement-local strain

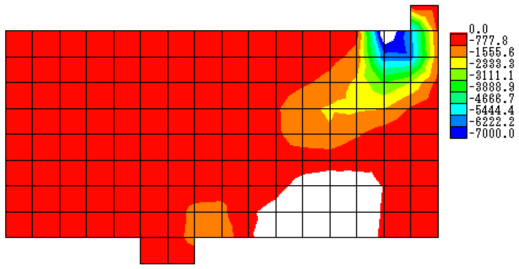

Fig. 5. Minimum principal strain distribution (Only left part of the beam)

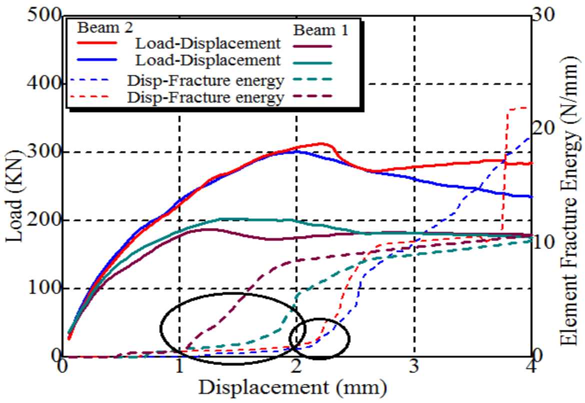

Fig. 6. Load-Disp.-Fracture energy

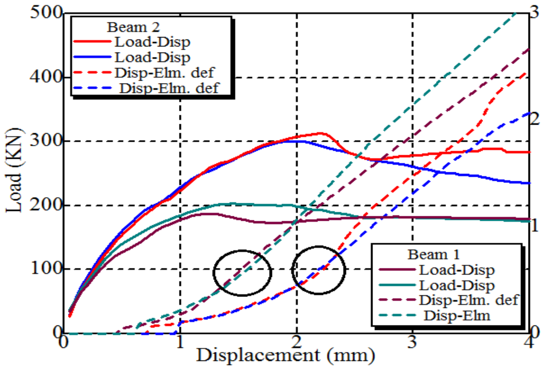

Fig. 7. Load-Disp.-Localized element deformation

5. CONCLUSION

The local strain behavior is quite mesh sensitive and difficult to use as local index parameter to estimate load carrying capacity or other damages. The localized element deformation and concrete fracture energy behavior exhibited mesh independency and it is possible to use as a local index to evaluate the damage occurred in the loading history of beams. In the element deformation behavior, the values of different mesh size result simultaneously and the peak loads corresponds to localized element deformation of about 0.5mm in both beams. The behavior of the localized element concrete fracture energy is also applicable to use it as a local index for damage evaluation. It needs further experimental and analytical study for variety of beam specimens in order to determine whether the element deformation or fracture energy can suit as the damage index.

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