Numerical Study on Impact Resistance of RC Beam Retrofitted with CF panel

Kyushu University Student Member JIANHENG ZENG
Kyushu University Fellow Member YOSHIMI SONODA
Kyushu University Individual Regular Member HIROKI TAMAI

1. Introduction

To improve load carrying performance and impact resistance performance of existing structural members such as RC beams, it is common to install supporting sheets under the bottom of the members. Many researchers have been working on how to improve structural impact resistance by utilizing carbon fiber reinforced materials such as CFRP and AFRP. The authors have also been studying the retrofitting effect of continuous fiber composite panel (CF panel) on RC beam under free fall impact load. However, CF panel is a sandwich structure in which carbon fiber sheet is sandwiched between two flexible boards made of fiber reinforced cement. When CF panel was retrofitted on existing RC beam, the structure becomes multilayered and its failure behavior becomes extremely complicated under impact load. In this study, the authors conducted a validation for CF panel retrofitting experiment. On considering the modeling of each layer in CF panel and peeling model, the CF panel retrofitting effect and RC beam impact response were discussed.

2. Numerical validation for falling weight impact experiment

2.1 Experiment overview

RC beam and CF panel figuration in previous[1)] experiment were shown in Fig.1&2. The bonding material between panel and the surface of the beam is low-viscosity epoxy resin. It was anticipated that thickness of bonding material could be controlled around 0.5mm in average. The experimental facilities are shown in Fig.3. The weight hammer was 100kg. The impact velocity was 3m/s.

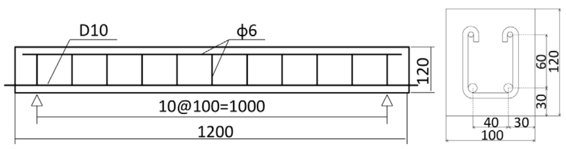

Fig.1 Reinforcement arrangement of RC beam (unit: mm)

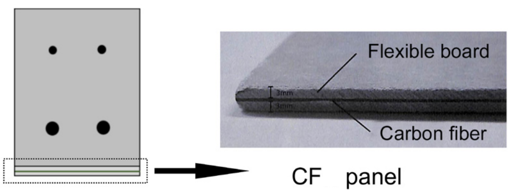

Fig.2 CF panel Installation

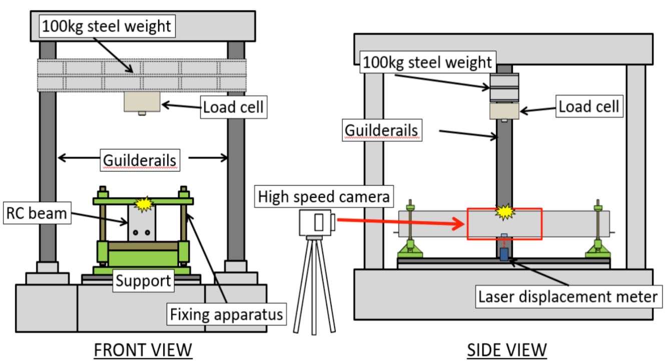

Fig.3 Falling weight impact machine

2.2 Numerical analysis

(1) Geometric properties

A numerical analysis study was made based on finite element method shown in Fig.4. In RC beam, the stirrup was set as 3-dimensional linear straight truss element with constant cross section. Tensile reinforcement bars inside the concrete adopted 3-dimensional 8-node arbitrarily distorted brick solid element. The concrete was divided into 8-node hexahedral elements.

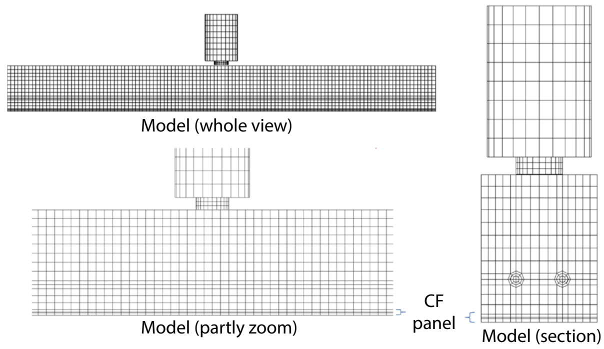

Fig.4 Numerical model in FEM analysis

(2) Material properties

The reinforcement bars and stirrup that made of steel were commonly taken as encountered isotropic ductile material that based on von Mises yield criterion. The average yield strength of reinforcement bars was reported as 358N/mm^2 in the experiment. The generalized Mohr-Coulomb model developed by Drucker and Prager was applied into concrete material. The average compressive strength of concrete is 45.5N/mm^2, average tensile strength is 2.6N/mm^2. Drucker–Prager yield criterion was applied for concrete. Flexible board was considered as a material possessing similar properties with cement. With the maximum compressive stress of 47.2 N/mm^2 and the tensile stress of 18.5 N/mm^2. The carbon fiber was assumed to be suitable for von Mises criteria with an equivalent high value of yield stress at 3400N/ mm^2.

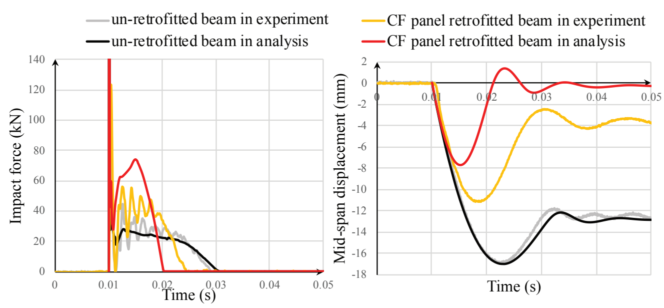

Fig.5 Experimental and analytical results without considering CF panel delamination

(3) Validation results

In both experiment and analysis, the CF panel retrofitted beam has smaller displacement than un-retrofitted beam. It also displayed more hysteretic impact response and larger impact force than un-retrofitted beam (shown in Fig.5). The effectiveness of CF panel retrofitting for RC beam was

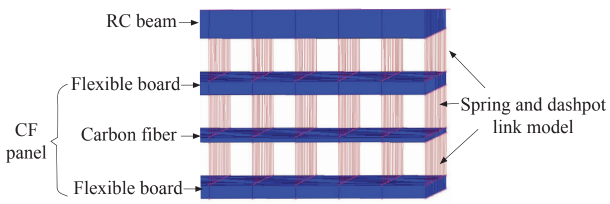

Fig.6 Spring & dashpot link in FEM software

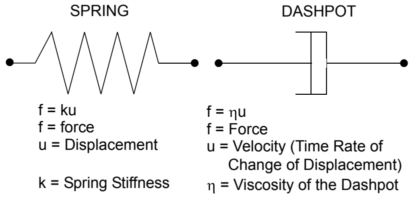

Fig.7 Elastic spring model & viscous dashpot model

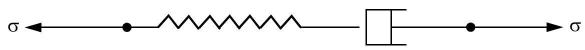

Fig.8 Maxwell model

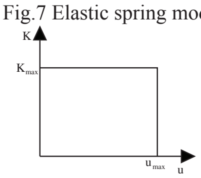

Fig.9 Spring stiffness model

confirmed. However, impact force and displacement of un-retrofitted beam in analysis was well consistent with that in the experiment, while CF panel retrofitted beam in analysis displayed larger impact force and smaller displacement than that in experiment. It was considered that when the CF panel was assumed to be perfect bonded with RC beam, the structure behaved larger stiffness.

Above these, it is necessary to reconsider the modeling of CF panel and clarify how CF panel failure influences RC beam impact resistance effect.

3. CF panel delamination analysis

3.1 Modeling for CF panel delamination

In experiment, CF panel delamination occurred after impact load. As introduced before, CF panel was bonded to RC beam using bonding material epoxy resin. Though delamination inside CF panel was observer, the interface between epoxy resin and RC beam or the interface between epoxy resin and CF panel may also peeled. Nonlinear link was built for simulating CF panel delamination (shown in Fig.6)

Epoxy resin is a kind of material possessing both viscous and elastic behavior. Viscoelastic materials can be represented by models consisting of both springs and dashpots[2]. Spring model displays elastic effect and dashpot model displays viscous effect (shown in Fig.7).

Maxwell model (shown in Fig.8) a spring and a dashpot is connected in series was adopted. The mathematical relation which holds for the Maxwell solid is (1a). Between RC beam and CF panel, epoxy resin was modeled as spring connecting dashpot link model rather than element. Inside CF panel, interfaces of carbon fiber and flexible board was set as link as well.

$$\varepsilon = \frac{\sigma}{E} + \int \frac{\sigma}{\eta} dt \tag{1a}$$

Spring and dashpot properties could be input separated. In spring, the force is expressed as (1b).

$$F = K(u_2 - u_1) + C(v_2 - v_1) \tag{1b}$$

The spring stiffness K is the spring stiffness. In our model, for each interface link, spring stiffness in 6 degrees of freedom were all assumed as 10N/mm. However, the interface between RC beam and CF panel was evaluated about 0.5mm but interface inside CF panel was evaluated less than 0.2mm. It was assumed[3] that interface slip or debonding displacement start from 0 and could reach the maximum of its evaluated thickness with constant stiffness at each degree of freedom (shown in Fig.9).

Damping factor C in each degree of freedom was also set to be the same value 0.05. u_2 is the displacement of the degree of freedom at the second end of the spring, and u_1 is the displacement of the degree of freedom at the first end of the spring. v_2 and v_1 are the velocities of the nodes.

3.2 Analytical results discussion

When CF panel was perfectly bonded with RC beam and no peeling or delamination occurred, the structure had a better impact resistance effect that displayed smaller maximum and residual mid-span displacement. Considering CF delamination, when spring model was applied, a hysteretic and larger peak displacement was observed. The insufficient consideration for viscous property of bonding resulted in residual displacement becoming larger, which displayed a decreased impact resistance effect. However, When Maxwell model was applied considering viscoelasticity of bonding, both maximum and residual displacement matched with experimental result more precisely, yet vibration frequency decreased (shown in Fig.10).

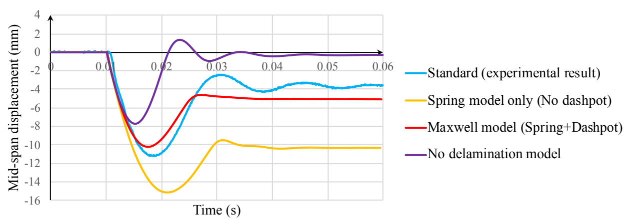

Fig.10 Impact response of different delamination model

4. Conclusion

(1) It has been confirmed that retrofitting CF panel to the bottom of RC beam could reduce the displacement and improve its impact resistance effect.

(2) CF panel delamination has significant influences on whole structure impact response. Delamination of CF panel would decrease structural impact resistance effect.

(3) Between layers of CF is viscoelastic adhesion. Maxwell model that accounting for viscoelasticity displays better applicability than simple elastic spring model for epoxy resin peeling model under impact load.

For further research, the modeling of CF panel delamination should be improved. Other models like Kelvin-Voigt model or Generalized Maxwell model are expected for a comparison validation study.

References

1) Jianheng ZENG, Hiroki TAMAI, Yoshimi SONODA and Hirotoshi OBI: Numerical Study on Failure Behavior of RC Beam Retrofitted by CFC Panel under Impact Load, Proceedings of the Japan Concrete Institute, Vol.41, No.2, pp.703-708, 2019.

2) S.A. Hadigheh, R.J. Gravina: Generalization of the interface law for different FRP processing techniques in FRP-to-concrete bonded interfaces, Composites Part B: Engineering, Vol.91, pp.399-407, 2016.04.