NUMERICAL MODELING FOR BACKBONE CURVE AND ULTIMATE POINT FOR FLEXURE-SHEAR DOMINANT REINFORCED CONCRETE COLUMNS

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ABSTRACT

A displacement based evaluation approach, namely Axial Shear Flexure Interaction (ASFI), is used in determining backbone curve and ultimate point for flexure-shear dominant reinforced concrete columns, considering interaction among axial, shear and flexure mechanisms. Conventional section analysis technique is employed to predict flexure behaviour and Modified Compression Field Theory is adopted to determine the shear behaviour. Ultimate point and backbone curves were estimated using this approach for four reinforced concrete columns which were critical in shear and flexure-shear, and then compared with experiment results. Prediction of ultimate point and backbone curve are not satisfactory using ASFI for the columns. Considering many aspects of material constitutive laws, their definitions in the analytical model and different mechanisms acting inside the model, concrete compression softening is thought to be a very influencing variable to predict the ultimate point and backbone curve for shear and flexure-shear dominant reinforced concrete columns. A parametric study is conducted considering different degrees of concrete compression softening with increasing principal tensile strain to find out the sensitivity of strength reduction in cracked concrete for predicting these structural parameters. From this study, one of the options for simulating the continuous weakening behaviour of cracked concrete found to be effective in determining ultimate point and backbone curve for shear and flexure-shear dominant reinforced concrete columns.

Keywords: Concrete Compression Softening, Axial Strain at Inflection Section.

1. INTRODUCTION

On introduction of performance-based design concept, response estimation of structures has become one of the main performance criteria in the design process considering ductility and deformability of the structure. So from the view point of performance and also economy, design of reinforced concrete structures is dependent on the ductility of the structure. Therefore, developing suitable analytical tool to estimate the ultimate deformation or ductility of reinforced concrete column with certain level of precision is a growing demand. To fix the level of required retrofit or assessment of the vulnerability of a structure for earthquake damage needs evaluation of strength and deformation capacity of the structure. Recently a displacement-based analytical approach is developed by Mostafaei and Kabeyasawa (2007) to estimate response of reinforced concrete elements considering interaction among axial, shear and flexural mechanisms. The objective of this study is to predict the ultimate point and backbone curve modifying the ASFI approach for reinforced concrete columns which are critical in shear or shear after flexural yielding.

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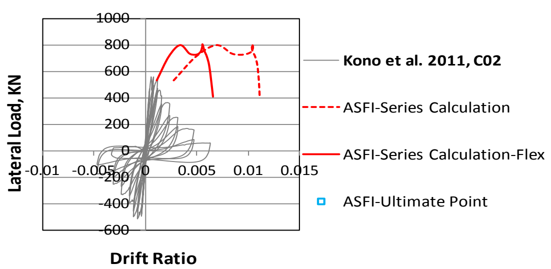
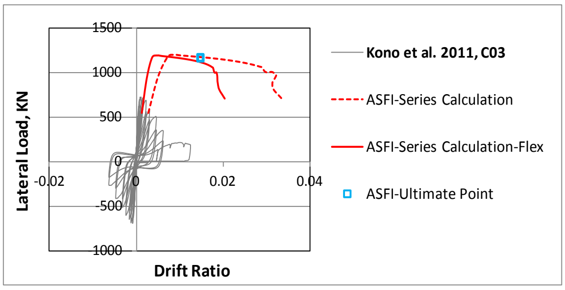
2. BASIC CONCEPT OF ASFI AND PREDICTION USING THIS APPROACH

The basic concept and methodology of the axial-shear-flexure interaction (ASFI) method is based on the axial deformation and concrete compression softening interaction between the two models: a flexure model based on traditional uniaxial section analysis principles, and a shear model based on a biaxial shear element approach.

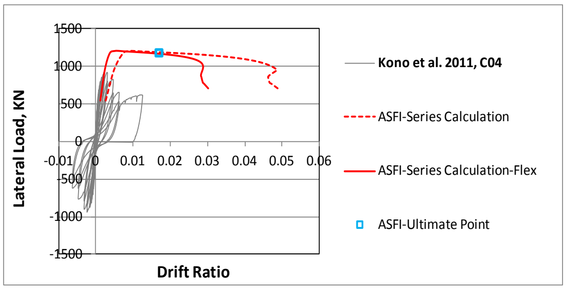
ASFI is applied to the four reinforced concrete column specimens, which were tested by Kono et al. (2011) in the Kyoto University. The column specimens were critical in shear and flexure-shear. After application of ASFI in the specimens' ultimate point and lateral load bearing capacity were found too high than the experiment results shown in Figure 1. In the figure ASFI-Series Calculation-Flex refers to backbone curve for flexural behaviour including shear effect in it. ASFI-Series Calculation refers to the combination of shear and flexural behaviour. A large yield plateau is obtained in all the specimens. No degradation of strength for flexure shear type specimen is achieved in backbone curve determined by ASFI method.



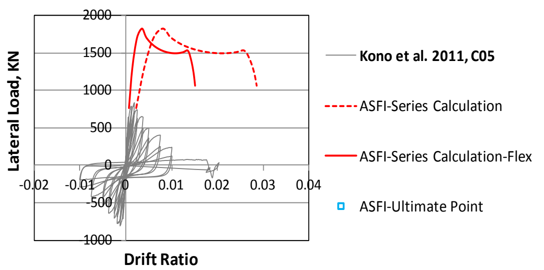
Column Kono et al. 2011, C02



Column Kono et al. 2011, C03



Column Kono et al. 2011, C04



Column Kono et al. 2011, C05

Figure 1. Backbone curve and ultimate point for different columns using ASFI method

3. PARAMETRIC STUDY WITH THE ASFI APPROACH

3.1. Probable options for parametric study

With a view to modify the ASFI approach developed by Mostafaei and Kabeyasawa (2007), three different options for modifying concrete compression softening model are used for this parametric study, namely Opt-1, Opt-2 and Opt-3. All of these three options are thought considering different level of concrete compressive strain. Shear reinforcement above 0.5% is assumed as high shear reinforcement ratio. Basic idea of choosing these options is to take into account the effect of shear cracks due to principal tensile strain in concrete starting from a very small range that is immediately after cracking of concrete to ultimate state for a column specimen. It is assumed that the reduction of compressive strength in cracked concrete due to compression softening starts from this stage.

1. Determine ε_{ci} as shown in Figure 2.

2. Using ε_{ci} determine axial strain ε_{xam} at the inflection section of the column using the following equations:

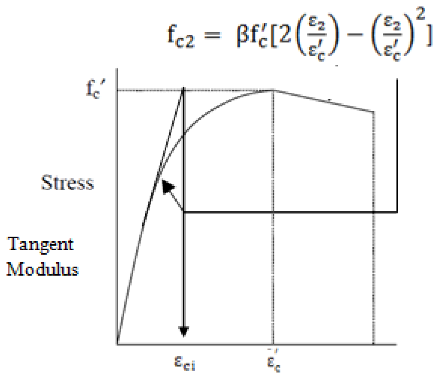


Figure 2. Determination of strain level for developing different options for parametric study in the stress strain curve of concrete

<u>Opt-1</u>

For Low Shear Reinforcement Ratio

$$\varepsilon_{xam} = \frac{0.33f_c'}{\left(2\frac{f_c'}{\varepsilon_{ci}} + E_s\rho_{sx}\right)} \tag{1}$$

For High Shear Reinforcement Ratio

$$\varepsilon_{xam} = \frac{0.33f_c'}{\left(1.5\frac{f_c'}{\varepsilon_{ci}} + E_s\rho_{sx}\right)} \tag{2}$$

<u>Opt-2</u>

For Low Shear Reinforcement Ratio

$$\varepsilon_{xam} = \frac{2X0.33f_c'}{\left(2\frac{f_c'}{\varepsilon_{ci}} + E_s\rho_{sx}\right)} \tag{3}$$

For High Shear Reinforcement Ratio

$$\varepsilon_{xam} = \frac{2X0.33f_c'}{\left(1.5\frac{f_c'}{\varepsilon_{ci}} + E_s\rho_{sx}\right)} \tag{4}$$

3. Determine ε_{pim} by multiplying confinement factor K, $\varepsilon_{pim} = K\varepsilon_{xam}$
4. The value ε_{ci} obtained in step 1 is used in Opt-3 and values of ε_{pim} obtained in step 2 are used in Opt-1 and Opt-2 respectively, instead of peak strain ε_c' in the model developed by Vecchio and Collins (1986). Hognestad Parabola is used as a base curve and compressive strength reduction factor is determined modifying Eq. (5) in the following form in Eq. (6) and Eq.(7):

Original Model developed by Vecchio and Collins (1986)

$$\beta = \frac{1}{0.80 - 0.34\frac{\varepsilon_{c1}}{\varepsilon_c'}} \leq 1.0 \tag{5}$$

For Opt-1 and Opt-2

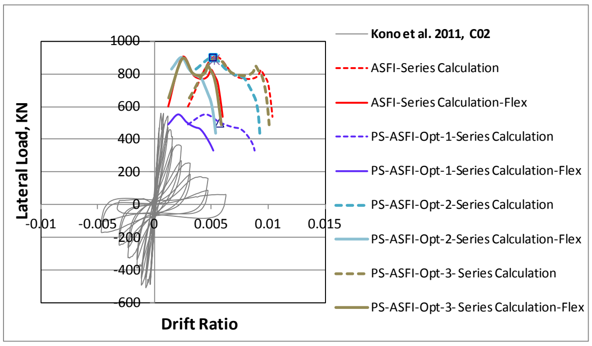
$$\beta = \frac{1}{0.80 - 0.34\frac{\varepsilon_{c1}}{\varepsilon_{pim}}} \leq 1.0 \tag{6}$$

For Opt-3

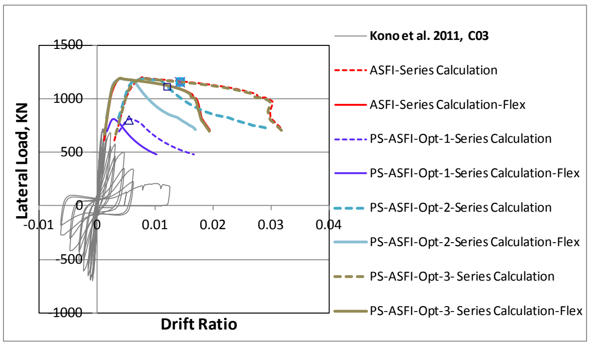
$$\beta = \frac{1}{0.80 - 0.34\frac{\varepsilon_{c1}}{\varepsilon_{ci}}} \leq 1.0 \tag{7}$$

3.2. Implementation of Parametric Options and Comparison of Results

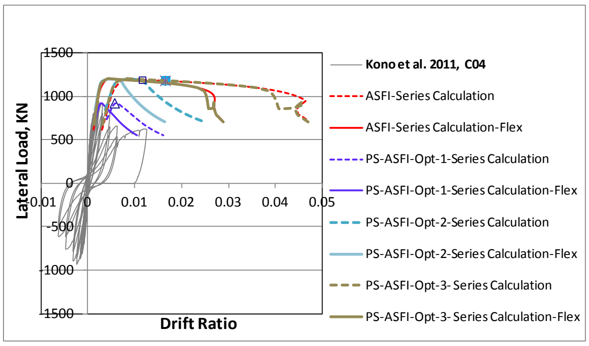
Using the parametric options described in section 3.1 concrete compression softening factor is calculated for the column specimens selected for this study. After obtaining compressive strength reduction factors using three options for each of the selected columns, these are applied to the respective specimens. Results are shown in Figure 3. Modifications are made to both the peak stress and strain at the peak stress by multiplying each of them with the reduction factor β. It is observed that Opt-1 is giving better fit of the experimental load deformation data for all the column specimens. Hence, this option is chosen for further investigation and analyses for all the column specimens.



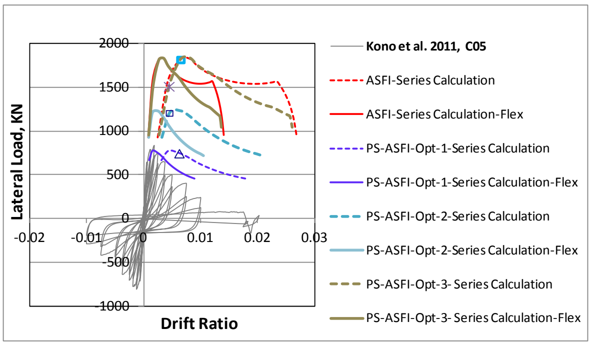
Column Kono et al. 2011, C02



Column Kono et al. 2011, C03



Column Kono et al. 2011, C04



Column Kono et al. 2011, C05

Figure 3. Backbone curve and ultimate point for selected columns using ASFI and three different options of concrete compression softening.

5. RESULTS AND DISCUSSION

Stress-strain relationship for cracked concrete is derived by reducing both peak stress and peak stress combined with strain at peak stress as shown in Figure 4 for column C02 as a representation of the procedure, in order that the ASFI method and Opt-1 can be used to detect the sensitivity of reduction of strain at peak stress. In Opt-1 a significant drop in maximum stress and strain are noticed for all the column specimens after occurring a large tensile strain in the cracked concrete. This is because in the case of Opt-1, the degree of softening is much higher than the softening

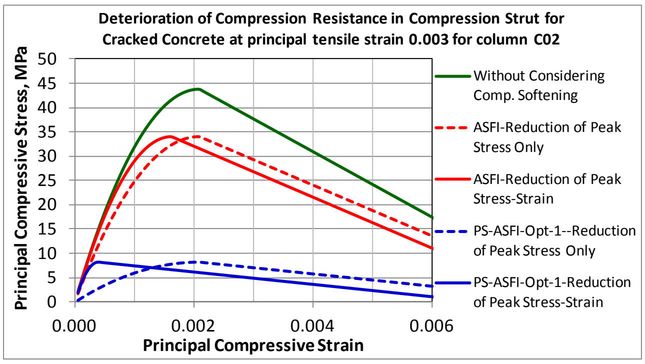
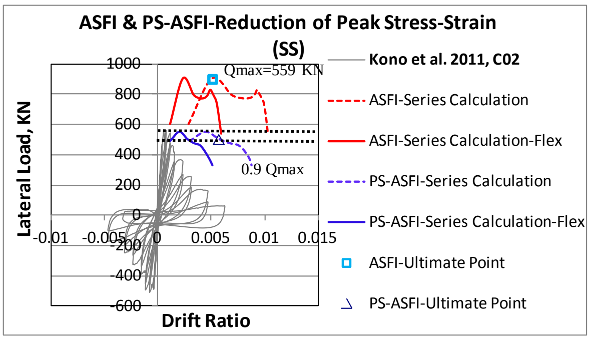
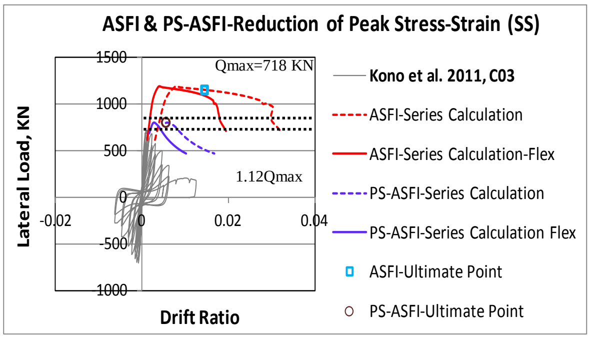


Figure 4. Deterioration of compression resistance in compression strut for cracked concrete at an arbitrary point of large principal tensile strain for column C02

mechanism adopted in ASFI. Figure 5 shows the final results obtained from ASFI and Opt-1 for the columns chosen for this parametric study. Ultimate point and backbone curve are shown for both the above mentioned cases. From the result we can see that only in case of column C02 and C05, prediction of ultimate points are almost same in terms of drift ratio both for ASFI and Opt-1, but in estimating capacity, value obtained from ASFI is very high than experiment result and for Opt-1 this estimation is close to experiment result. In case of column C02, C03 and column C04 ASFI could not predict either capacity or the ultimate point at all. Whereas prediction of ultimate point and backbone curve using Opt-1 is consistent with the experiment result in terms of capacity, but overestimation in terms of drift ratio. In estimating ultimate point and backbone curve using both the ASFI method and Opt-1, there is an overestimation in terms of drift ratio. However this over estimation is sometime very large in case of ASFI. Reduction of stress only (SO) and reduction of stress and strain at peak stress (SS) shown in Figure 4, that is softening of strength only and softening of both strength and strain, were applied for ASFI and Opt-1. Reduction of peak stress and strain at peak stress could predict a better ultimate point and backbone curve in terms of capacity among these four different predictions for all the specimens. Therefore result obtained from softening of both the strength and strain is considered as the final output from this study and these are shown in Figure 5.



Column Kono et al. 2011, C02



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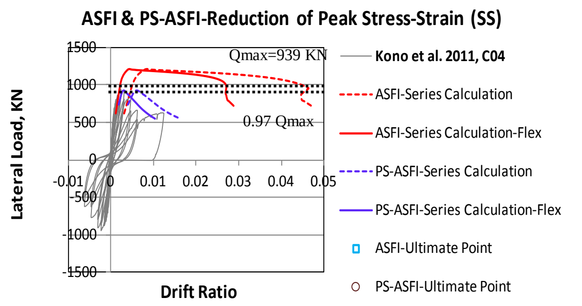

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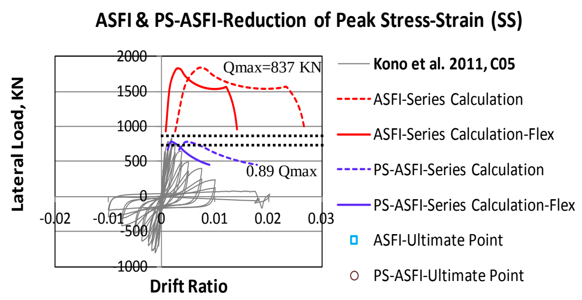

Column Kono et al. 2011, C05

Figure 5. Backbone curve and ultimate point for different columns: ASFI and Opt-1 for compression softening; Softening of both the strength and strain

5. CONCLUSIONS

Ultimate point and backbone curve are determined using the ASFI approach for four shear and flexure-shear dominant reinforced concrete columns, which were tested by Kono et al. (2011) in the Kyoto University. Predictions of these parameters applying ASFI are found too high comparing with the test result in terms of capacity and drift ratio. Therefore three different options have been examined considering different degrees of concrete compression softening and Opt-1 is found to be the most efficient among these options and ASFI approach. Using this option, prediction of backbone curve and ultimate point in terms of capacity is satisfactory, but still overestimation in terms of drift ratio. At the same time, only softening of strength for cracked concrete was found to be insufficient for predicting the backbone curve properly, rather softening of both the strength and strain can predict better backbone curve using Opt-1. On the other hand, prediction of ultimate point using Opt-1 is near identical with each other both for softening of strength only and softening of both the strength and strain for cracked concrete. After analyzing the calculated result, concrete compression softening is found a key parameter to predict the ultimate point and the backbone curve for these types of columns. Several parameters like concrete principal tensile strain, principal tensile stress, and ratio of principal tensile to compressive strain are usually considered as the prime variables influencing the softening effect. In addition to these, axial strain at inflection section is found to have significant influence in determining the degree of softening for cracked concrete acting together with reinforcement. This in turn effects the prediction of ultimate point and backbone curve.

6. RECOMMENDATION

The degree of concrete compression softening with increasing principal tensile strain is very sensitive for determining ultimate point and backbone curve for shear and flexure-shear dominant reinforced concrete columns, hence further experimental studies are recommended in this regard. As the behaviour of bond slip is not considered in the ASFI approach, it is also not considered in this parametric study. So future attempt can be made to incorporate it in the ASFI approach.

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