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## Studies on the provisions of confining reinforcement for high-strength concrete column

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### Abstract

It is general knowledge that the design of earthquake-resistant structures for high-strength concrete columns requires confining-reinforcement with a relatively high volumetric ratio to ensure the ductility of the structure. This implies that the mechanical behavior of high-strength concrete differs significantly from the behavior of normal-strength concrete. However, the provisions on the minimum volumetric ratio of confining-reinforcement contained in the Indonesian Concrete Code (SNI 2847-2013) is essentially derived from the test results for normal-strength concrete. This paper studies the confining-reinforcement provisions used in several standards, i.e., SNI 2847-2013, ACI-2011, NZS-2006 and CSA-2004, to determine the ductility of the concrete columns. The case study is based on the analysis of the cross-section of high-strength concrete columns, the parameters that affect the strength, and by evaluating the value of the column's cross-section curvature ductility. The study results showed that the equation for confining-reinforcement adopted in the SNI 2847-2013 is very conservative compared to other codes when applied to low axial load levels ( $\leq 0.2$ ), but is relatively less conservative if the axial load level is greater than 0.3.

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*Keywords:* high-strength concrete; column; confinement; reinforcement; ductility

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## 1. Introductions

### 1.1. Background

Numerous comprehensive studies concerning the behavior of materials and structural components made of high-strength concrete have been conducted [1-3]. The resulting design equations have also been proposed and partially implemented in planning standards in each corresponding country. High-strength concrete has a brittle behavior; therefore, the structural ductility behavior becomes a major issue in the design of high-strength concrete structures, especially ductility in structural columns located in high earthquake zones. The assemblage of lateral reinforcement as confining-reinforcement is intended to improve the ductility of concrete columns, underlining the importance of the role of reinforcement [2,4]. The confining-reinforcement design equations contained in the applicable Indonesian Concrete Code today is the SNI [5]. The equations for square cross-sections are:

$$\frac{A_{sh}}{sh_c} = 0.3 \left( \frac{A_g}{A_c} - 1 \right) \frac{f'_c}{f_y} \quad (1)$$

$$\frac{A_{sh}}{sh_c} = 0.09 \frac{f'_c}{f_y} \quad (2)$$

Equation (1) is used to design the structure under static loading, and equation (2) is to design structures under seismic loads. The design equations show a direct relationship between the volumetric ratio of confining-reinforcement and the concrete compressive strength. The use of high-strength concrete structures will have implications on the required increase in the confining-reinforcement volumetric ratio. To achieve the appropriate confining-reinforcement volumetric ratio for circular cross-section columns as mandated by the above design equation, a technique of spacing reduction can be applied. Meanwhile, in the case of a square cross-section column, besides a spacing reduction, one can also conduct a variation in confining-reinforcement configuration. To maintain sufficient confining-reinforcement spacing for concrete casting purposes, medium-strength to high-strength confining steel can be used [6,1,7]. The experimental test results also show that the ductility of high-strength concrete columns can be maintained properly if high-strength steel is used. The research development of high-strength concrete columns has not been implemented into the design equations of the SNI [5], since the standards are derived from the research results on normal-strength concretes. The behavior of high-strength concrete therefore needs to be studied in greater depth, in particular the provision of confining-reinforcement applied to high-strength concrete columns as adopted in the SNI [5].

### Nomenclature

|                     |                                                                       |           |                                                         |
|---------------------|-----------------------------------------------------------------------|-----------|---------------------------------------------------------|
| $A_{sh}$            | = area of confining reinforcement                                     | $f_{lat}$ | = lateral stress                                        |
| $b_c$               | = width of core column                                                | $f_y$     | = yield stress of confining reinforcement / steel       |
| $E_c$               | = modulus elasticity of concrete                                      | $f_{yl}$  | = yield stress of longitudinal reinforcement            |
| $\varepsilon_c$     | = strain of concrete                                                  | $f_r$     | = residual stress of confined concrete                  |
| $\varepsilon'_{co}$ | = peak strain of unconfined concrete                                  | $f_s$     | = stress of confining reinforcement at peak response    |
| $\varepsilon'_{cc}$ | = strain of confined concrete at peak response                        | $h_c$     | = length of core column                                 |
| $\varepsilon_{85c}$ | = strain of confined concrete at 85% of confined concrete peak stress | $K$       | = strength enhancement of confined concrete             |
| $f'_{co}$           | = peak stress of unconfined concrete                                  | $s$       | = spacing of confining reinforcement (centre to centre) |
| $f'_c$              | = stress of concrete                                                  | $\rho_s$  | = volumetric ratio of confining reinforcement           |
| $f'_c$              | = compressive strength of concrete cylinder 150/300 at 28 days        | $\rho$    | = ratio of longitudinal reinforcement                   |
| $f'_{cc}$           | = peak stress of confined concrete                                    | $n_l$     | = number of longitudinal reinforcement                  |

## 1.2. Objective

This paper discusses the design equations adopted in the SNI [5] and assesses these with the confining-reinforcement design provisions as mandated in the ACI [8], NZS [9] and CSA [10] standards. The objective of this study is to evaluate the feasibility of confining equations based on the SNI in the design of high-strength concrete columns. The discussion is focused on the behavior of the resulting ductility because it is very closely related to structures located in the earthquake zone. This case study is limited to columns with square cross-sections, since for this type of column the configuration in confining-reinforcement can be varied. Further, the design equations are limited for columns under static loadings only.

## 2. Code provisions of confining reinforcement for square section

The confining-reinforcement design equation used by the SNI [5] and ACI [8] for square cross-sections is as seen in equation (1). The difference lies in the upper limits of the yield stress. In the SNI [5], a limit yield stress up to 700 MPa was set, as upper bound, while for the ACI a value up to 10,000 psi yield stress (~ 688 MPa) is allowed. The design equation in the SNI [5] and the ACI [8] were derived with the philosophy that the cross section of the concrete core can maintain its strength after the concrete cover spalls. The equation does not directly express the degree of ductility of the structure

Meanwhile the minimum confining-reinforcement volumetric ratio based on the NZS [9] is as follows:

$$\frac{A_{sh}}{sh_c} = \frac{(1.3 - \rho_t m) A_g f'_c}{3.3 A_c f_{yt} \phi'_c A_g} \frac{N_o^*}{A_g} - 0.006 \quad (3)$$

To prevent buckling of longitudinal reinforcement, the volumetric ratio also must satisfy the following equation:

$$A_{tie} = \frac{\sum A_b f_y s_h}{96 f_{yt} d_b} \quad (4)$$

where:

$$m = \frac{f_{yt}}{0.85 f'_c} \quad (5)$$

The above NZS [9] equation accommodates the influence of axial load levels on a structure to the volumetric confining-reinforcement ratio. This statement is also explained by Kristianto & Imran [11]. A provision in the NZS noted that the reinforcement used for confinement purposes is permitted to reach a yield stress of 800 MPa. According to Li & Park [1], the equation above is the result of research conducted by Watson et al. [12], and it was noted that these equations are not directly applicable to the design of high-strength concrete columns with normal- to high-strength steel.

The confining-reinforcement design equation based on the CSA [10] for a square cross-section column is as follows:

$$\rho_s = 0.2 k_n k_p \frac{A_g f'_c}{A_c f_y} \quad (6)$$

Where  $k_p$  is the level of axial load, and  $k_n$  is the effect of the amount of longitudinal reinforcement of the section, with:

$$k_n = n_\ell / (n_\ell - 2) \quad (7)$$

The CSA [10] limits the yield stress of confining-reinforcement ( $f_y$ ) to 500 MPa. The CSA [10] equation actually accommodates the influence of the axial load and the amount of longitudinal reinforcement.

The design equation in the two standards is based on the required confining-reinforcement that increases significantly when the structural column is designed for strong earthquakes, since this will escalate the axial load acting on the column. It can be concluded that the necessary confining-reinforcement is highly dependent on the size of the acting axial load.

### 3. Comparative study

This comparative study was carried out for all the design provisions as outlined in the previous chapters, and was performed on two types of confining-reinforcement configurations of columns A and B as shown in Fig. 1. Material properties are as follows:

- Two cases of concrete compressive strength ( $f'_c$ ), 70 and 90 MPa
- cross-sectional dimensions are 500x500 mm
- concrete cover is 40 mm
- longitudinal reinforcement diameter is 22 mm with a yield stress ( $f_{yt}$ ) of 480 MPa
- the confining-reinforcement has a diameter of 12 mm, with a yield stress ( $f_y$ ) ranging from 400 MPa, 600 MPa to 800 MPa

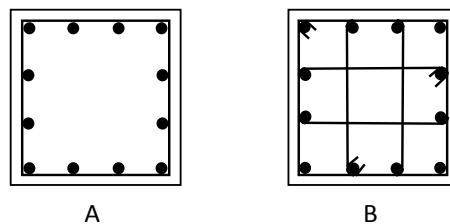


Fig. 1. Sectional column.

Fig. 2 and Fig. 3 show the design provision comparison as a function of the minimum volumetric ratio to the axial load levels, for columns A and B. The steel has a yield stress of 400 MPa.

The figures show that for concrete with a compression strength of 70 and 90 MPa and for axial loading levels up to 0.2, the provision of the NZS [9] and CSA [10] are significantly lower than the SNI [5] and ACI [8]. At axial loading levels of 0.3, only the CSA [10] provision was lower, when compared to the SNI [5] and ACI [8]. For an axial load level of 0.4, the confining-reinforcement provisions as mandated by the NZS and CSA are higher than the requirement in the SNI [5] and ACI [8].

Additional results are shown in Fig. 4 and Fig. 5. Here the yield stress of the confining-reinforcement is increased to 600 MPa. Similarly to the previous findings, for an axial load level of 0.2 the provisions for the minimum confining-reinforcement based on the NZS [9] and CSA [10] are also lower than the provisions mandated by the SNI [5] and ACI [8]. At an axial load level equal to 0.3 the same result as was observed for the confining-reinforcement with a yield stress of 400 MPa, i.e., the CSA [10] provisions are below that of the SNI [5] and ACI [8]. However, the result of the NZS [9] provision is higher than those of the SNI [5] and ACI [8]. But for axial load levels of 0.4, the SNI [5] and ACI [8] predicted are lower outcome than the other two standards, the NZS [9] and CSA [10].

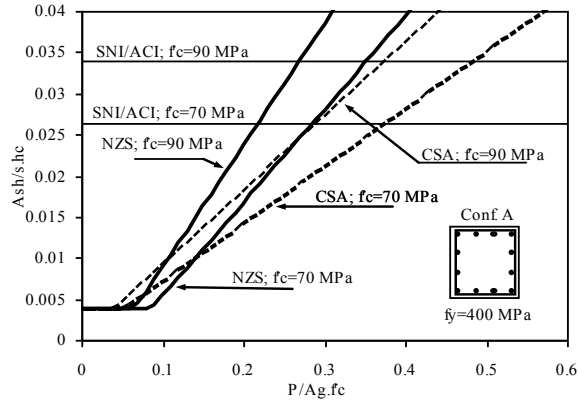


Fig. 2. Comparison of minimum confining reinforcement provisions; A configuration,  $f_y = 400$  MPa.

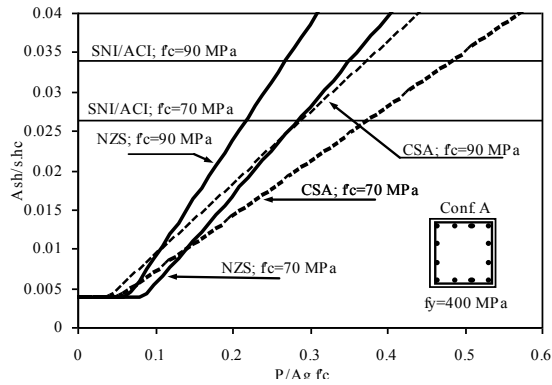


Fig. 3. Comparison of minimum confining reinforcement provisions; B configuration,  $f_y = 400$  MPa.

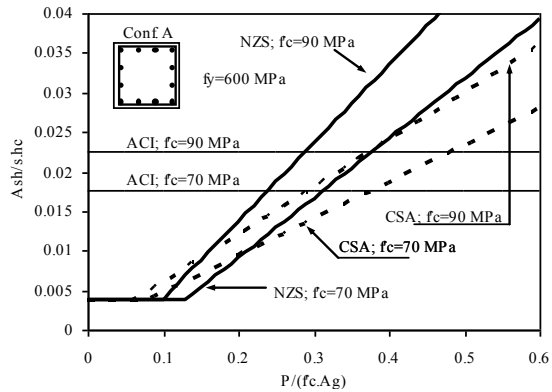


Fig. 4. Comparison of minimum confining reinforcement provisions; A configuration,  $f_y = 600$  MPa.

The utilization of high-strength confining-reinforcement steel ( $f_v=800$  MPa) also has consequences for the minimum confining-reinforcement that should be assembled. Fig. 6 and Fig. 7 show that based on the SNI [5] and CSA [10] standards for an axial load of 0.3 the confining-reinforcement volumetric ratio decreases, when compared to the lower yield strengths. However, the values approach the provisions of the NZS [9] and CSA [10] closely. At axial load levels of 0.4 the provisions of the NZS [9] are the most conservative when compared to the SNI [5] and ACI [8].

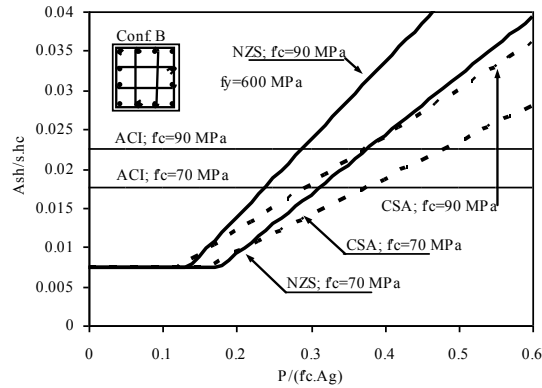


Fig. 5. Comparison of minimum confining reinforcement provisions; B configuration,  $f_y = 600$  MPa.

The result of the comparison indicates that for minimum confining-reinforcement steel for moderate axial load levels of 0.2 to 0.3, the SNI [5] and ACI [8] are very conservative. However, for the higher axial load levels, the provisions for the confining-reinforcement are below than the NZS [9] and CSA [10]. These findings implicate that the SNI [5] and ACI [8] standards are less profitable for low to moderate axial load levels.

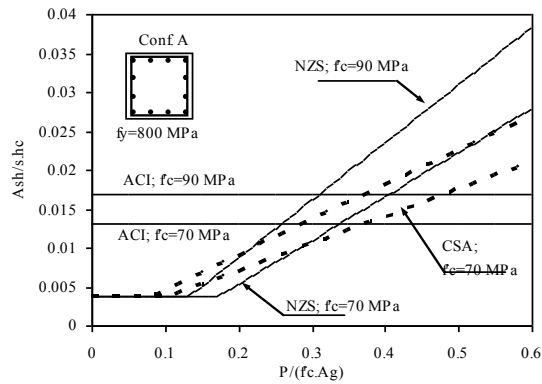


Fig. 6. Comparison of minimum confining reinforcement provisions; A configuration,  $f_y = 800$  MPa.

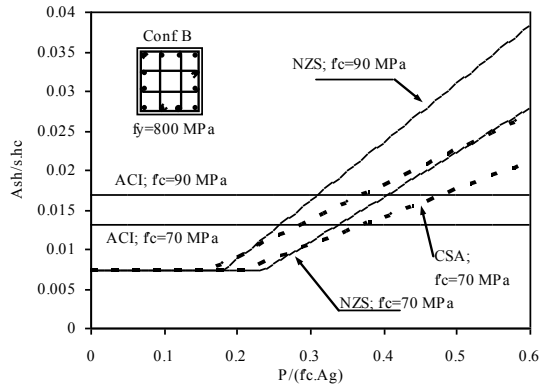


Fig. 7. Comparison of minimum confining reinforcement provisions; B configuration,  $f_y = 800$  MPa.

#### 4. Column ductility behaviour

At further stages, the influence of minimum confining-reinforcement designed based on the above-mentioned standards to the ductility behavior is evaluated. The evaluation is based on the moment-curvature cross-section behavior of the column. For this study, a concrete compressive strength of 70 MPa was taken. The specifications and strengths of the material remained unchanged, and the reinforcement configurations were as shown in Fig. 1. The level of applied axial load is set to the highest, equal to 0.4. This was favored since at this load level the provisions from the SNI [5] and ACI [8] provisions are lower than that of the NZS [9] and CSA [10]. The high-strength concrete confinement model was based on the model as proposed by author [13]; the stress-strain model is shown in Fig. 8.

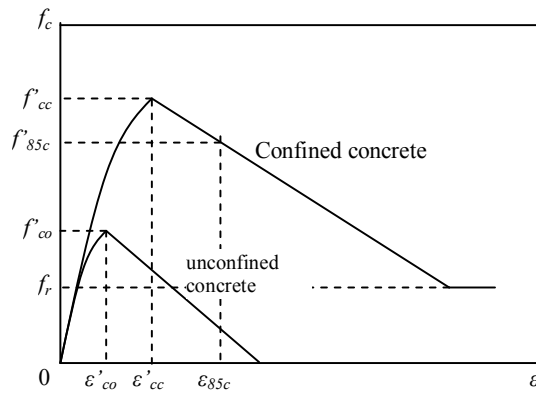


Fig. 8. Stress-strain model of confined high-strength concrete [13].

From the figure above, the following mathematical expressions were derived.

$$f_c = \frac{f'_{cc} \left( \frac{\epsilon_c}{\epsilon'_{cc}} \right)^r}{r - 1 + \left( \frac{\epsilon_c}{\epsilon'_{cc}} \right)^r} ; \epsilon_c \leq \epsilon'_c \tag{8}$$

$$f_c = f'_{cc} - (\epsilon_c - \epsilon'_{cc}) \frac{0.15 \cdot f'_{cc}}{(\epsilon_{85c} - \epsilon'_{cc})} \quad ; \quad \epsilon_c > \epsilon'_c \tag{9}$$

$$r = \frac{E_c}{E_c - (f'_{cc} / \epsilon'_{cc})} \tag{10}$$

$$E_c = 3400\sqrt{f'_c} + 4800 \tag{11}$$

$$K = \frac{f'_{cc}}{f'_{co}} = 1 + 3.7 \left( \frac{f_{lat.}}{f'_{co}} \right)^{0.9} \tag{12}$$

$$\epsilon'_{cc} = \epsilon'_{co} [1.94(K - 1) + 1] \tag{13}$$

$$\epsilon_{co}' = 0,0004 \cdot (f'_{co})^{0.45} \tag{14}$$

Stress of the confining-reinforcement at peak response for a square section is:

$$f_s = E_s \left\{ 0,0004 \cdot \ln \left[ \frac{\left( \frac{s}{D_c} \right)}{\rho_s \sqrt{f'_c}} \right] + 0,002 \right\} \leq f_y \tag{15}$$

$$\epsilon_{85c} = \epsilon_{cc}' + 10^{-5} \cdot e^{3.7K} \tag{16}$$

$$f_r = 0,25 f'_{cc} \tag{17}$$

The ductile column behavior refers to the definition as expressed by Li & Park [1]. After the spalling of the concrete cover, the moment in the column increases, exceeding or at least equaling the moment at the first peak. Alternately, a relatively flat curve will result (condition 1). On the other hand, a less ductile column is characterized by a reduction in moment capacity, subsequent to cover spalling. It can also be said that the moment is lower than the first peak (condition 2). A more detailed description of the column's ductility behavior is shown in Fig. 9.

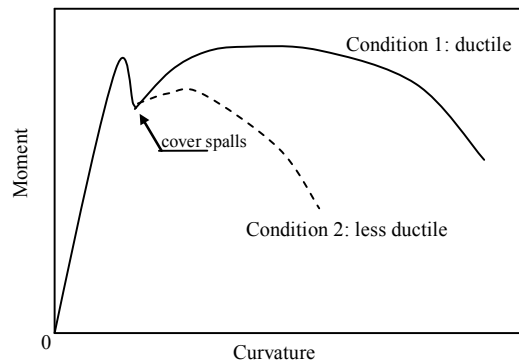


Fig. 9. Definition ductile columns.



4.1. Effect of axial load level

Fig. 10 shows the moment-curvature behavior of a columns with the A configuration. The confining-reinforcement steel yield stress varies from 400, 600 to 800 MPa. At the relatively low axial load levels of 0.2 it is shown that the curve is relatively flat after cover spalling. The opposite is seen for high axial load levels of 0.4.

The moment-curvature behavior for column B is based on the minimum confining-reinforcement design of the SNI [5] and ACI [8]. It is shown that the moment declines after cover spalling. This phenomenon is true for both normal and high-strength confining-reinforcement steel (Fig. 11).

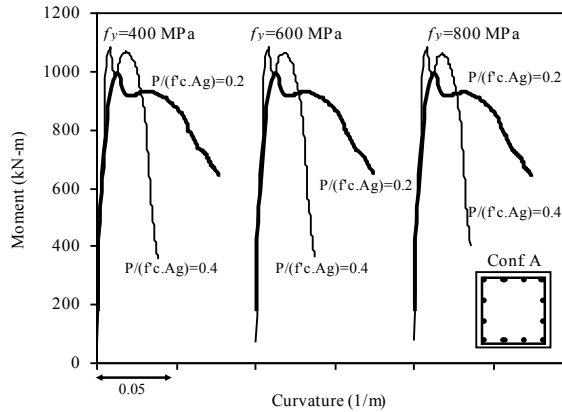


Fig. 10. Behavior of Moment-curvature configuration A, the variation  $f_y$ .

4.2. Behavior based moment-curvature each standard

The column ductility behaviors based on each standard are demonstrated by their moment-curvature curves and are shown in Fig. 12, Fig. 13 and Fig. 14. Generally, the column ductility as provided by the provisions of the NZS [9] and CSA [10] are better when compared to the SNI [5] and CSA [10], although the graphs also suggested that the reinforcing provision confinement adopted in the NZS [9] is the most conservative. Observing the column with the A reinforcement configuration, it can be seen that the moment as predicted by the NZS [9] provision always increases significantly after cover spalling. The increase in moment even exceeded the first peak.

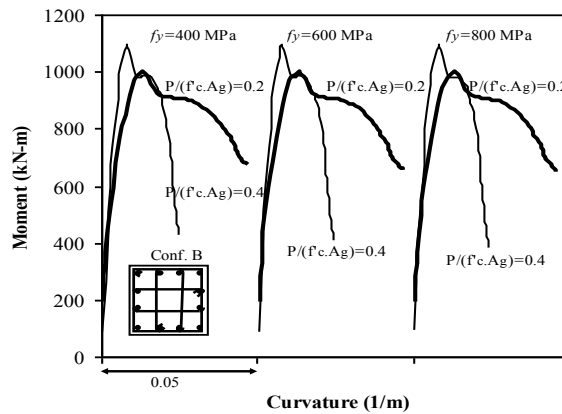


Fig. 11. Behavior of Moment-curvature configuration B, the variation  $f_y$ .

The ductility behavior evaluation of column B is based on the minimum volumetric ratio, resulting in a maximum spacing which is far below the spacing of column A. The observation of curves suggested that after cover spalling all standards tend to result in a less ductile behavior.

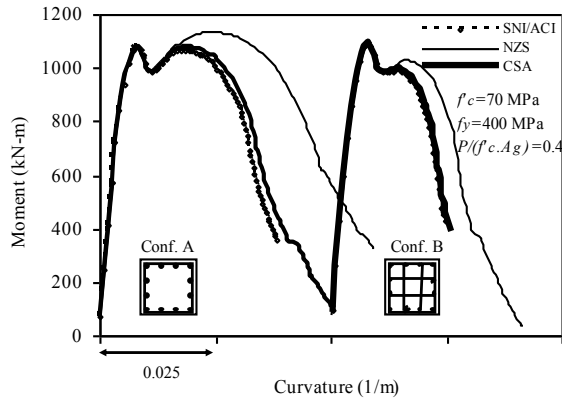


Fig. 12. Comparison of moment-curvature of each standard,  $f_y=400$  MPa.

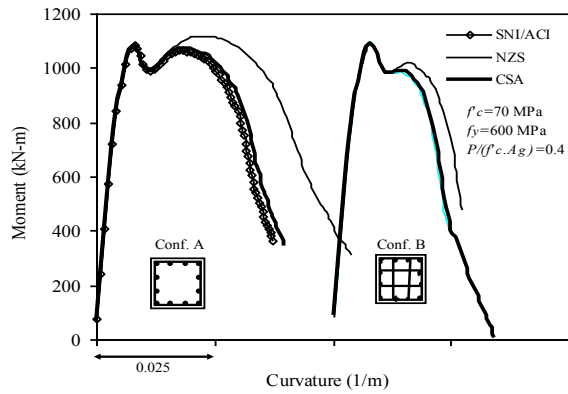


Fig. 13. Comparison of moment-curvature of each standard,  $f_y=600$  MPa.

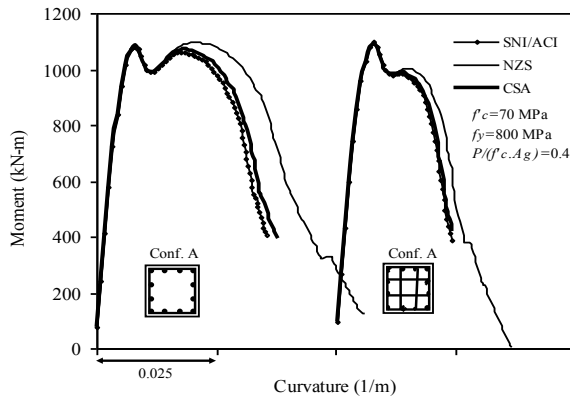


Fig. 14. Comparison of moment-curvature of each standard,  $f_y=800$  MPa.

Furthermore, high-strength confining-reinforcement steel is used to improve the ductility of high-strength concrete columns. The confining-reinforcement for column B is reduced to a minimum so that the volumetric ratio of the assembled confining-reinforcement will be higher than what is required (resulting in an approximately similar spacing as column A). It was found that the ductility of the column increased significantly (Fig. 15).

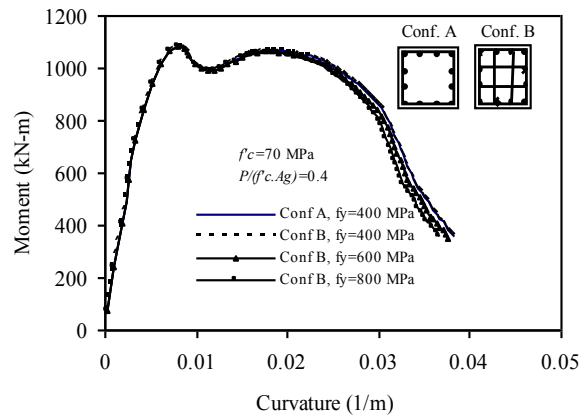


Fig. 15. Improved ductility of the column configuration B.

## 5. Conclusion and recommendation

### 5.1. Conclusion

From the result of the studies as discussed, the following conclusions can be drawn:

1. The provisions for minimum confining-reinforcement based on the SNI and ACI does not consider variability in axial load levels so that the ductility behavior remains unchanged, despite a change in the earthquake magnitude.
2. Since the provisions of confining-reinforcement of the SNI and ACI code do not take into account the effects of axial load levels, the outcome will be underestimated if the structure is located in a strong earthquake-zone.
3. The use of high-strength confinement steel is one solution to maintain a column's ductility.
4. The ductility of columns can be improved by simulating the design parameter (i.e., the configuration); utilizing the confining-reinforcement volumetric ratio, and optimizing the spacing as well as utilizing the use of high-strength steel.

### 5.2. Recommendation

Accommodating the level of axial load on the minimum confining-reinforcement provisions into the SNI [5] is highly recommended. However, for this purpose, it is necessary to develop a comprehensive research on the behavior of columns with variations in axial load levels, both analytically and experimentally

## References

- [1] Li, Bing, R. Park, Confining Reinforcement for High-Strength Concrete Columns, *ACI Structural Journal*, 101(3), 2004. pp. 314-324.
- [2] P. Paultre, F. Legeron, Confinement Reinforcement Design for Reinforced Concrete Columns, *Journal of Structural Eng. ASCE*, 134(5), 2008. pp. 738-749.
- [3] Antonius, I. Imran, Experimental Study of Confined Low, Medium and High-Strength Concrete Subjected to Concentric Compression, *ITB Journal of Engineering Science*, 44(3), 2012. pp.252-269.
- [4] N. Subramanian, Design of Confinement Reinforcement for Reinforced Concrete Columns, *The Indian Concrete Journal*, 2011. pp. 1-9.
- [5] SNI 2847-2013, Requirements of Structural Concrete for Building, (in Indonesian), 2013.

- [6] O. Bayrak, S.A. Sheikh, Seismic Performance of High Strength Concrete Columns Confined with High Strength Steel, 13<sup>th</sup> World Conference on Earthquake Engineering, Vancouver, Canada, August 1-6, 2004.
- [7] Antonius, Performance of High-Strength Concrete Columns Confined by Medium Strength of Spirals and Hoops, *Asian Journal of Civil Engineering*, 15(2), April, 2014. pp. 245-258.
- [8] ACI 318.2011, Building Code Requirements for Reinforced Concrete, ACI, Farmington Hills, 2011.
- [9] NZS 3101.2006, Concrete and Structures Standard, Part 1-The Design of Concrete Structures, 2006.
- [10] CSA Standard A23.3-04, Design of Concrete Structures, 2004.
- [11] A. Kristianto, I. Imran, Comparison Study of Requirement of Confinement Reinforcement for Rectangular Column in the Several Code and Propose Research, Proc. of 7<sup>th</sup> National Conf. of Civil Eng., 24-26 Oct., Surakarta, S163-S170, 2013.
- [12] S. Watson, F.A. Zahn, R. Park, Confining Reinforcement for Concrete Columns, *Journal of Structural Eng. ASCE*, 120(6), 1992. pp. 1798-1823.
- [13] Antonius, Confinement Effects on High-Strength Concrete Columns Subjected Eccentric Loading, Proc. of the 4<sup>th</sup> ASEAN Civil Eng. Conference, Yogyakarta, Indonesia, 22-23 Nov., 2011.