Critical Review of Shear Design Method for Concrete Members Specified in Russian SNiP Code: Proposed Modification

Meirzhan Yerzhanov[1)], Hyunjin Ju [2)], Sung-Woo Moon[3)], Jong R. Kim[4)], and *Deuckhang Lee[5)]

[1), 2) 3) 4) 5)] *Department of Civil and Environmental Engineering, Nazarbayev University, Astana 010000, Kazakhstan*
[5)] *deuckhang.lee@nu.edu.kz*

ABSTRACT

Russian SNiP code is the design specification for reinforced and prestressed concrete structures through the Commonwealth of Independent States (CIS) countries. However, the shear design method specified in SNiP code has not been updated for the past several decades. In this study, the background of the shear design method specified in SNiP code was discussed in detail, and a new shear design method for updating SNiP code was developed under the Plane of Minimum Resistance concept. Moreover, a rational modification factor was developed to improve the accuracy of the shear design equation in SNiP code using a current up-to-date shear database for reinforced and prestressed concrete members in a unified manner.

1. INTRODUCTION

Russian SNiP code is widely adopted as design standard in the massive territory from Eastern Europe to Central Asia, which is defined as Commonwealth of Independent States (CIS) countries (United Nations 2011). It can be explained as engineering societies of these countries are strongly influenced by legacy from USSR (Union of Soviet Socialist Republics). The shear strength equation provided by SNiP code is semi-empirical. It means that its margin of safety and accuracy mostly depend on the shear experiment results. However, the shear design model in SNiP code has not been updated significantly since its official proposal in 1937 (SNiP 2.03.01-84 1985). The exceptions are only addition of prestressing factor and small changes in coefficients for safety reasons. Moreover, it is very challenging to identify the origin and philosophy of Russian SNiP code due industrial and language barriers to the rest of the

[1)] Ph.D. Student
[2)] Post-Doctoral Research Fellow
[3)] Assistant Professor
[4)] Professor
[5)] Assistant Professor, *Corresponding Author

world. In this study, shear model specified in SNiP code is deeply investigated and several modifications are proposed in order to improve performance of shear design equation.

2. BACKGROUND OF SNIP SHEAR DESIGN

2.1. Shear contribution provided by concrete (V_c)

The fundamental model of the shear design method specified in SNiP code is plane of minimum resistance (PMR) concept proposed by Borishansky (Placas 1969). PMR method states that the minimum section with the total shear resistance (i.e., $V_n = V_c + V_s$) or support reaction force (R) can be defined as critical section. In this concept, three assumptions were made by Borishansky, as follows: 1) The shear failure of concrete and yielding of shear reinforcements across shear cracks occur at the same time; 2) No dowel action; and 3) Total shear resistance can be expressed as the summation of shear resistances provided by concrete and shear reinforcements. 75 beams tested and reported in Gvozdev between the 1930s and 1940s were adopted in order to define the shear contribution provided by concrete (V_c). The results of experiments identified that shear capacity provided by concrete is clearly affected by dimension of the beam, tensile strength of the concrete, and inclination angle of the critical shear crack. Based on these results, a semi-empirical equation for the shear contribution provided by concrete (V_c) was proposed based on the concept of the plane of minimum resistance (PMR) by Professor Gvozdev (Palaskas and Darwin 1980), who is one of the developers of the SNiP code, as follows:

$$V_c = 1.5\varphi_n f_t b_w d \tan(\alpha) = \frac{1.5\varphi_n f_t b_w d^2}{c} \tag{1}$$

where c is the horizontal distance from the support to the end of the critical shear crack as shown in Fig. 1, b_w is the width of web concrete, d is effective depth of concrete member, f_t is the tensile strength of concrete, and α is the inclination angle of the principal stress, which was assumed to be equal to d/c (i.e., $\tan\alpha \approx d/c$), φ_n is prestressing coefficient. The prestressing coefficient should be taken as 1.0 for non-prestressed members, while it changes depending on the compressive stress estimated at the centroid of the concrete gross section due to prestress (σ_{cp}), as follows:

$$\varphi_n = 1 + \frac{\sigma_{cp}}{f_{cu}} \quad \text{for } 0 \le \sigma_{cp} \le 0.25 f_{cu} \tag{2a}$$

$$\varphi_n = 1.25 \quad \text{for } 0.25 f_{cu} \le \sigma_{cp} \le 0.75 f_{cu} \tag{2b}$$

$$\varphi_n = 5\left(1 - \frac{\sigma_{cp}}{f_{cu}}\right) \quad \text{for } 0.75 f_{cu} \le \sigma_{cp} \le f_{cu} \tag{2c}$$

where f_{cu} is the compressive strength of concrete cube.

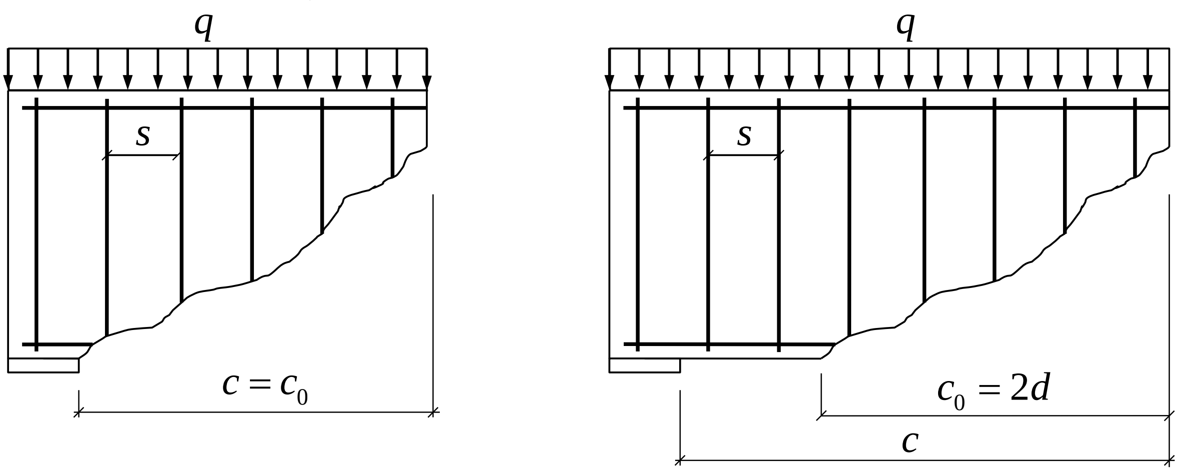
2.2. Shear contribution provided by shear reinforcements (V_s)

SNiP code equation for calculation the shear contribution of shear reinforcements (V_s) is the unique form of truss model. It was assumed that each shear reinforcement experiences tensile stresses non-uniformly across shear cracks due to the multiple shear cracking patterns in concrete member. Therefore, the stress distribution factor ($\kappa = 0.75$) was suggested to normalize tensile stresses and to estimate the shear capacity provided by stirrups. After this suggestion, shear reinforcements can be considered as they pass uniformly across the diagonal shear crack as shown in Fig. 1. Hence, shear capacity provided by shear reinforcements (V_s) can be expressed by the multiplication of the stress distribution factor (κ), the yield strength of stirrups per unit length (q_{sw}), and the horizontal length of the critical shear crack (c_o), as follows:

$$V_s = \kappa q_{sw} c_0 = 0.75 \frac{A_v f_{vy}}{s} c_0 \quad (3)$$

where A_v is are the nominal area of shear reinforcement, f_{vy} is yield strength of shear reinforcement, s is spacing of the shear reinforcement. Based on the Eqs (1) and (3), total shear capacity of the concrete member can be calculated as the summution of the shear capacities provided by shear reinforcement and concrete, as follows:

$$V_n = V_c + V_s = \frac{1.5 \varphi_n f_t b_w d^2}{c} + 0.75 q_{sw} c_0 \quad (4)$$



(a) Crack initiated from support (b) Crack initiated within shear span

Fig. 1 Description of possible failure planes in PMR approach

3. PROPOSED MODIFICATION FACTORS

As it was mentioned above, derivation of SNiP code equation was based on limited number of experimental results and derivation process was hold about 80 years ago. Therefore, several modifications are needed in order to be met requirements of modern design practices. The ACI 445-DAfStb shear database for reinforced and presressed concrete members presented by Reineck et al. (2013, 2014) was utilized to suggest new modification factors. Table 1 and 2 shows the summary of the ACI 445-DAfStb shear database for reinforced and presresssed concrete members, respectively. During the derivation of shear equation, Borishansky assumed that effect of longitudinal reinforcement has to be neglected. However, significant effect of longitudinal reinforcement ratio on shear capacity provided by concrete was shown in recent studies (Choi 2018). Hence, results of experiments on RC and PSC members with no stirrups were used to obtain following basic form of the model:

Table 1 Summary of shear database for reinforced concrete members

f_c' (MPa)	0-20	21-25	26-30	31-35	36-40	41-50	51-70	>70
No. of specimens	123	151	176	133	73	69	104	125
d (mm)	0-150	151-200	201-250	251-300	301-400	401-600	601-1000	>1000
No. of specimens	89	99	98	372	104	85	76	30

Table 2 Summary of shear database for prestressed concrete members

f_c' (MPa)	0-25	25-30	31-35	36-40	41-50	51-60	>60
No. of specimens	37	43	43	65	87	15	42
d (mm)	0-200	201-250	251-300	301-400	401-500	501-600	>600
No. of specimens	44	66	85	33	46	18	40

$$\beta_\rho = \sqrt{100\rho_{sw}} \leq 1.5 \tag{5}$$

where ρ_{sw} is the nonprestressed longitudinal reinforcement ratio ($A_s / b_w d$), A_s is the area of the nonprestressed longitudinal reinforcements, and b is the beam width.
Fig. 2 demontrates the distribution of β_ρ factor plotted using the shear experiment results, whose trend was represented in Eq. (5).

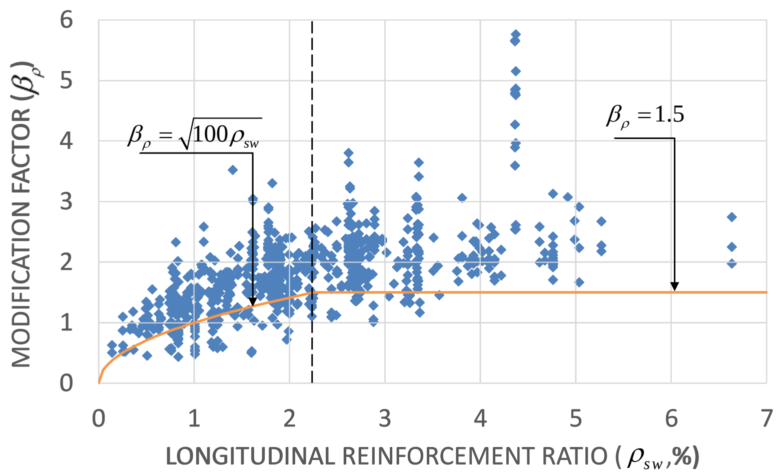


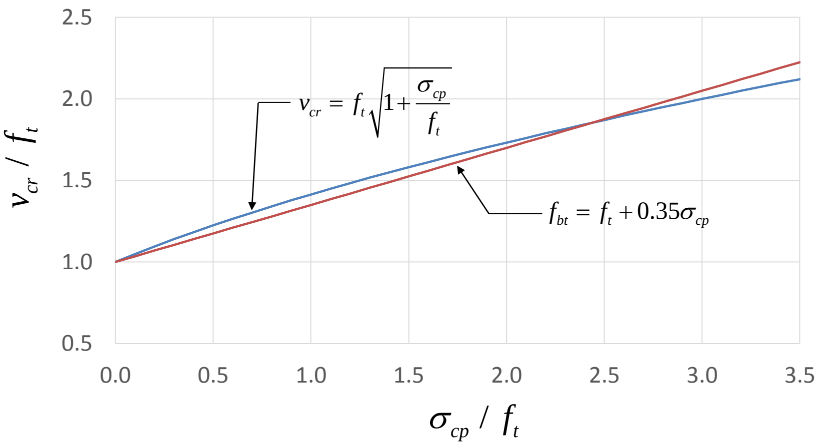
Fig. 2 – Derivation of β_ρ factor

Moreover, it can be seen that introducing prestressing can only increase shear capacity of concrete member up to 25% according to the prestressing factor (φ_n) in Eq. (2). However, modern prestressing techniques can effect on the shear resistance more significantly (Kim 2004). According to Collins (1991), the principle tensile stress for prestressed members can be estimated by combined effect of nominal compressive stress (σ_{cp}) and shear stress (v). In addition, it can be re-formulated for the sake of simplicity as shown in Fig. 3:

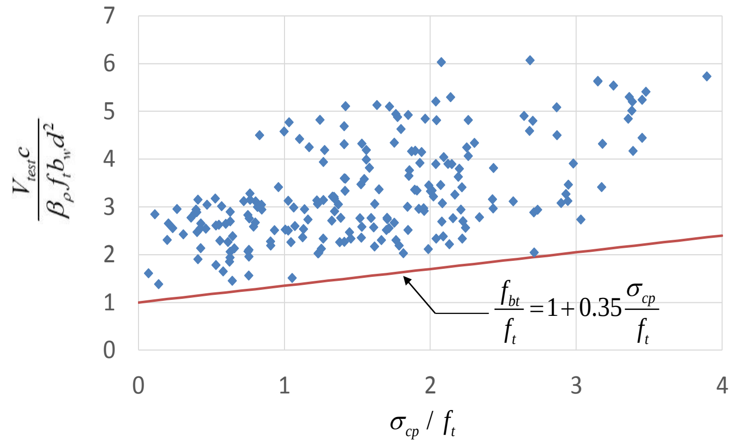
$$f_{bt} = f_t + 0.35\sigma_{cp} \tag{6}$$

Fig. 3(a) demonstrates good adjustment of Eq. (6) with principle tensile stress's equation, and coefficient, which is equal to 0.35, was chosen to ensure an adequate margin of safety, as shown in Fig. 3(b). Based on this, shear contribution of concrete can be estimated in unified form for RC and PSC members, as follows:

$$V_c = \frac{\beta_\rho f_{bt} b_w d^2}{c} = \frac{\beta_\rho \left(f_t + 0.35\sigma_{cp} \right) b_w d^2}{c} \tag{7}$$



(a) Simplification of Eq. (8)



(b) Verification

Fig. 3 Derivation of prestressing factor

4. CONCLUSION

This study discussed the shear design model for RC and PSC members in SNiP code, and introduced basic backgrounds of it. Moreover, the shear strength of RC and PSC members by SNiP code model is outdated and cannot meet modern requirements. Therefore, the modified factors were suggested by utilizing the large shear database to improve safety level and the analytical accuracy.

ACKNOWLEDGEMENT

This study was supported by the Social Policy Grant of the corresponding author in Nazarbayev University.

REFERENCES

Choi, K. K., Park, H. G., and Wight, J. K. (2017), "Unified Shear Strength Model for Reinforced Concrete Beams — Part I: Development," *ACI Struct. J.*, **104**(2), 142-152.

Collins, M. and Mitchell, D. (1991), *Prestressed Concrete Structures,* Englewood Cliffs, N.J.: Prentice-Hall.

Kim K. S. (2004), *Shear Behavior of Reinforced Concrete Beams and Prestressed Concrete Beams*, Ph.D. dissertation, Urbana, IL: University of Illinois at Urbana-Champaign.

Palaskas, M. N., and Darwin, D. (1980), *Shear Strength of Lightly Reinforced Concrete Beams*, SM Report No. 3, University of Kansas Center for Research, Inc., Lawrence, Kansas.

Placas, A. (1969), *Shear Strength of Reinforced Concrete Beams*, Ph. D. dissertation, London, UK, Imperial College of Science and Technology.

Reineck, K.-.H.; Bentz, E.; Fitik, B.; Kuchma, D.A.; and Bayrak, O. (2014), "ACI-DAfStb Databases for Shear Tests on Slender Reinforced Concrete Beams with Stirrups," *ACI Struct. J.*, **111**(5), 1147-1156.

Reineck, K.-H., Bentz, E. C., Fitik, B., Kuchma, D. A., and Bayrak, O. (2013), "ACI-DAfStb Database of Shear Tests on Slender Reinforced Concrete Beams without Stirrups," *ACI Struct. J.*, **110**(5), 867-875.

SNIP 2.03.01-84 (1985), *Concrete and Reinforced Concrete Structures*, Gosstroy USSR, Moscow, USSR. (In Russian)

United Nation (UN) (2011), Annex No. 9 to the Treaty on the Eurasian Economic Union Protocol on Technical Regulation within the Eurasian Economic Unions.