The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 2019

Volume 7, Pages 117-122

IConTES 2019: International Conference on Technology, Engineering and Science

Analysis the Strength Reduction Factor in the Shear Strength of Geopolymer Concrete Beams

Sema ALACALI
Yıldız Technical University

Mehdi OZTURK
Yıldız Technical University

Guray ARSLAN
Yıldız Technical University

Abstract: In recent years, the rapidly developing and growing construction sector has brought about an increase in environmental concerns. Therefore, within the framework of sustainable development, researchers intensify their work on the reuse of environmentally friendly materials called geopolymer concrete. As a result of the studies of many researchers, geopolymer concrete which composed of sustainable materials has been proposed instead of traditional concrete. While a substantial amount of researches has focused on the flexural behavior of geopolymer concrete beams, there exists a relatively limited amount of studies concerning the shear behavior of geopolymer concrete beams with stirrup. Design codes use a strength reduction factor that reflects the degree of uncertainty associated with the probability of the design equations. In this study, the strength reduction factor in predicting the shear strength of geopolymer concrete beams with stirrups according to ACI318 was investigated for different coefficients of variation of concrete compressive strength by using the first-order second moment approach.

Keywords: Geopolymer concrete, Beam, Shear strength, Reduction factor

Introduction

In recent years, natural resources are consumed in an unplanned and wrong way, nature and environment is rapidly destroyed as the increasing population of the world urbanization and industry have developed. In order to prevent this negative situation, many institutions and organizations carry out various campaigns to raise awardeness. One of them is the concept of sustainability that suggests the reuse of waste materials in the industry. The usability of various environmentally friendly materials is being investigated in the construction sector. One of these research topics is the use of more economical and sustainable materials instead of portland cement, which is known for its harm to nature during production. Scientists conducting many experimental and analytical studies on this subject have found geopolymer concrete formed by activating pozzolan substances with various alkalis. Portland cement consumes very high energy and produces carbon dioxide (CO_2). As a result of this production, 1 ton of CO_2 is released to nature for 1 ton of cement production. Approximately 7% of the world's CO_2 emissions are generated by the Portland cement production process (Roy, 1999). It is recommended to use many pozzolanic wastes instead of this substance which has a serious impact on global climate change. Thus, this serious harm to nature will be eliminated.

Nowadays , the most commonly used pozzolans for geopolymer concrete production are accepted as kaolin clay, metakaolin, fly ashes, blast furnace slag, red sludge, silica fume and zeolite. However, sodium hydroxide, sodium carbonate, sodium sulfate and sodium silicate are the best alkalis to activate these pozzolanic substances. The materials produced by changing the chemical composition and crystal structure of natural minerals by various methods are called "geopolymers".

- Selection and peer-review under responsibility of the Organizing Committee of the Conference

Technological developments and recent studies have given cause for using new materials instead of traditional construction materials. Various researchers have studied on the shear and flexural strength prediction and safety factor of traditional construction materials. But, it has not been observed on the literature related to the safety factor of geopolymer concrete materials. Safety factor provisions utilize load and strength reduction factors. These factors for elements made of traditional concrete materials have been evaluated in many studies (Arslan et al. 2015, Alacalı and Arslan 2018). However, in the literature, there is no study on the reduction factor of shear strength for geopolymer concrete elements. In this study, when the shear strength relation given for traditional concrete according to ACI318 is used for geopolymer concrete, it has been investigated which value the safety factor corresponds.

The strength reduction factor ϕ considered in design of structural components to insure performance correspond to specified reliability index *β.* The main concept in most reliability-based design codes is to determine the target reliability index *β.* The scope of current codes for building design is to maintance the reliability index as close to the target index as possible. For this purpose, the 1995 edition of ACI 318 ‘‘Building code requirements for reinforced concrete’’ suggests a ϕ of 0.85 for shear design of the reinforced buildings. However, in ACI 318 (2002, 2011), the ϕ for shear design is decreased to 0.75.

This study assesses the change of the ϕ in predicting the contribution of geopolymer concrete to shear strength by using second-moment approach according to ACI318. The change in the ϕ against the coefficient of variation of geopolymer concrete compressive strength (V_{f_c}) and the failure probability (p_F) were examined through the database of 9 shear test results obtained from literature (Chang, 2009).

Design recommendations for RC Beams

According to ACI318, the nominal shear strength (v_n) is comprised two components: concrete and stirrups. This relationship is given as follows;

$$v_n = v_c + v_s \tag{1}$$

in which v_s is the shear strength of stirrup based on yield and v_c is the shear strength of concrete, respectively. ASCE-ACI426 (1973) reported that the shear strength of RC beams is given as follows;

$$v_n = \frac{1}{6}\sqrt{f_c} + \rho_w f_{yw} \tag{2}$$

in which ρ_w is the ratio of stirrups, f_c and f_{yw} are the compressive strength of concrete and yield strength of stirrup in MPa, respectively.

In the codes (ACI318, TS500), the basic requirement for strength design may be explained that the design shear capacity of a member must exceed the shear demand as shown in Eq. (3).

$$\phi v_n \geq v_u \tag{3}$$

In which ϕ is the shear strength reduction factor and given as 0.75 in ACI318 (2002, 2011) and 0.85 in ACI318 (1995), v_u is the ultimate shear strength. In this study, the change in the strength reduction factor considered in predicting the shear strength according to ACI318 (1995) was investigated and compared for different failure probabilities and coefficients of variation of geopolymer concrete compressive strength.

The Reliability Problem

In probability theory, the capacity *R* and the load *S* involve different basic variables. Hence the performance function, $Z = R - S = g(X_1, X_2 ....X_n)$, contains uncertainties in the all design variables. When the performance function equals to zero, $Z = 0$, it is called a failure surface. The safety or reliability is defined by the condition $Z > 0$ and therefore, failure by $Z < 0$. The probability of safety or reliability is $p_S = \Phi(\beta)$, and the probability of failure is $p_F = 1 - \Phi(\beta)$. In the case of with normal distribution of *R* and *S*, the failure probabilities p_F corresponding to different reliability indexes β (5.2, 4.75, 4.27, 3.72, 3.09, 2.33) are 10^{-7}, 10^{-6}, 10^{-5}, 10^{-4}, 10^{-3} and 10^{-2}, respectively.

In the reliability based design, the problem is to determine the partial safety factors of the variables according to target reliability index β. In this study, the first-order second moment approach (FOSM) was used and the design points $(\gamma_i . m_{X_i})$ corresponding to the target reliability index β were obtained. This method is generally used by committees in calibrating codes for the evaluation of partial safety factors (Ang and Tang, 1984, Ranganathan, 1990).

The performance function g(**X**) for the shear failure mode is expressed as

$$g(\mathrm{X}) = \gamma_i . v_n - \gamma_j . v_{u,\exp.} \tag{4}$$

in which v_n is the nominal shear strength, $v_{u,\exp}$ is the experimental shear strength, γ_i and γ_j are the safety factors corresponding to the related variables. By calculating weighted averages of these factors (γ_i), the strength reduction factor ϕ, defined in Eq.(3) is determined. The change in the ϕ considered in predicting the shear strength according to ACI318 against the different V_{f_c} (0.10, 0.12, 0.15, 0.18, 0,20) and p_F (10^{-7}, 10^{-6}, 10^{-5}, 10^{-4}, 10^{-3}, 10^{-2}) was investigated by using experimental studies available in the literature (Chang, 2009).

Uncertainties of random variables

The uncertainties included in the prediction of shear strength were modelled as random variables. Since there is no information about the measurement sensivity in the experiments, the values of the coefficient of variation taken into account in the calculations were determined by considering the previous statistical studies.

The coefficient of variation of concrete compressive strength (V_{f_c}) under average construction quality control usually depends on the concrete strength and varies in between 0.10 and 0.21 through the literature (Arslan et. al 2015). The standard deviation for geopolymer concrete was measured in between 5.0% and 7.8% of concrete compressive strength (Pan et al. 2010). This value corresponds to a coefficient of variation of 0.08 for the geopolymer concrete samples examined this literature. In this study, the coefficient of variation of geopolymer concrete compressive strength (V_{f_c}) ranges from 0.10 to 0.20.

Although the stirrup ratios depend on the structural dimensions, they are assumed to be statistically independent from each other and from the other random structural parameters. In the study of Hao et al. (2010), it is assumed that the coefficient of variation of stirrup ratio (V_{ρ_w}) is 0.15, which is the value used in this study. The coefficient of variation of reinforcement strength ($V_{f_{yw}}$) were also reported by many researchers. Slightly different values were given by different researchers, where the $V_{f_{yw}}$ ranges from 0.05 to 0.15 (Arslan et al. 2015). It is taken as 0.10 in the present study to model variations of $V_{f_{yw}}$. In the studies of Hognestad (1951) and Mirza (1996), it is assumed that the coefficient of variation of strength due to test procedure is 0.04, which is the value used in this study.

Analysis of the strength reduction factor in predicting the shear strength

The properties of the beams in the database of 9 shear test results are shown in Table 1 (Chang, 2009). As seen in Table1, f_c varies from 44 MPa to 56 MPa. In this study, normal strength geopolymer concrete (NSGC) is defined as concrete having compressive strength less than 50 MPa, and high strength geopolymer concrete (HSGC) having compressive strength equal to or more than 50 MPa. The shear span-to-depth ratio (a/d) and stirrup yielding strength (f_{yw}) equal to 2.5 and 597 MPa, respectively, for all beams. The stirrup percentage (ρ_w) ranges from 0.1 to 0.168.

Table 1. The properties of the beams (Chang, 2009)

Name of beams	a/d	f_c (MPa)	ρ_w%	f_{yw} (MPa)	v_u (MPa)
S1-1	2.5	45	0.100	597	4.06
S1-2	2.5	45	0.126	597	3.95
S1-3	2.5	44	0.168	597	3.63
S2-1	2.5	56	0.100	597	5.03
S2-2	2.5	50	0.126	597	5.10
S2-3	2.5	50	0.168	597	5.07
S3-1	2.5	49	0.100	597	5.13
S3-2	2.5	49	0.126	597	5.42
S3-3	2.5	56	0.168	597	6.54

The change in the strength reduction factor ϕ for the shear design of geopolymer concrete beams obtained from the analysis is compared for different values of V_{f_c} and p_F in Table 2. As shown in Table 2, ϕ decreases as β increases and the reduction in the ϕ increases with V_{f_c}. For given V_{f_c} and p_F, the ϕ for HSGC beams were found to be greater than the one for NSGC beams, so it can be inferred that the ϕ for HSGC beams is more safe than the one for NSGC beams. In ACI318 (1995), the ϕ considered in predicting the shear strength equals to 0.85. It is indicated that this value corresponds to the target values of $p_F = 10^{-4}$ $(\beta = 3.72)$ and $V_{f_c} = 0.10$, for NSGC and HSGC beams (Figure 1). It is observed that this value is conservative for $p_F > 10^{-4}$ and a variation coefficient of 0.10. In ACI318 (2002) and ACI318 (2011), the factor of 0.85 was replaced by a factor of 0.75, which corresponds to the target values of $p_F = 10^{-7}$ $(\beta = 5.2)$ and $V_{f_c} = 0.20$ for all beams. According to the study published by Arslan et al. (2015) for traditional concrete, the ϕ of 0.85 corresponds to the target values of $p_F = 10^{-2}$ (β=2.33) and $V_{fc} = 0.10$, and the ϕ of 0.75 corresponds to the target values $p_F = 10^{-5}$ $(\beta = 4.27)$ and $V_{fc} = 0.10$ for all beams.

Table 2. Changing the average values of ϕ

V_{f_c}	p_F (β)						Beams
	10^{-7} (5.2)	10^{-6} (4.75)	10^{-5} (4.27)	10^{-4} (3.72)	10^{-3} (3.09)	10^{-2} (2.33)	
0.10	0.811	0.823	0.836	0.853	0.873	0.899	NSGC (5 beams)
0.12	0.798	0.811	0.826	0.843	0.865	0.892	
0.15	0.778	0.792	0.808	0.827	0.851	0.882	
0.18	0.757	0.780	0.789	0.811	0.836	0.869	
0.20	0.742	0.758	0.776	0.798	0.825	0.861	
0.10	0.820	0.831	0.844	0.859	0.878	0.903	HSGC (4 beams)
0.12	0.808	0.820	0.834	0.850	0.870	0.897	
0.15	0.790	0.803	0.818	0.836	0.858	0.887	
0.18	0.770	0.784	0.800	0.820	0.844	0.875	
0.20	0.756	0.771	0.788	0.808	0.834	0.867	
0.10	0.815	0.826	0.839	0.856	0.875	0.901	NSGC & HSGC (9 beams)
0.12	0.803	0.815	0.830	0.846	0.867	0.894	
0.15	0.783	0.797	0.812	0.831	0.854	0.884	
0.18	0.762	0.782	0.794	0.815	0.839	0.872	
0.20	0.748	0.764	0.781	0.803	0.829	0.864	

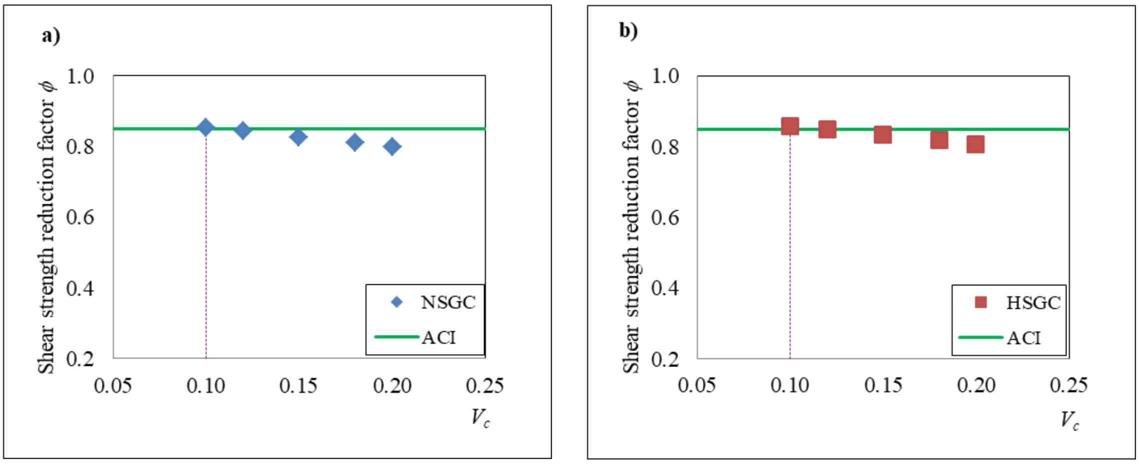

Figure 1. ϕ values for $\beta = 3.72$ ($p_F = 10^{-4}$) and V_{f_c}

In this study, the effects of f_c, a/d, ρ_w and f_{yw} on the ϕ are discussed below.

Figure 2a shows the variation of ϕ with f_c for $\beta = 3.72$ ($p_F = 10^{-4}$) and $V_{f_c} = 0.10$ for all (NSGC & HSGC) beams. It is observed that the ϕ increases with increasing f_c for all beams. This result means that the shear reliability of the beam increases as the strength of the geopolymer concrete increases. Figure 2b shows the variation of ϕ with ρ_w for $\beta = 3.72$ ($p_F = 10^{-4}$) and $V_{f_c} = 0.10$ for all (NSGC & HSGC) beams. It is observed that the ϕ decreases with increasing ρ_w for all beams.

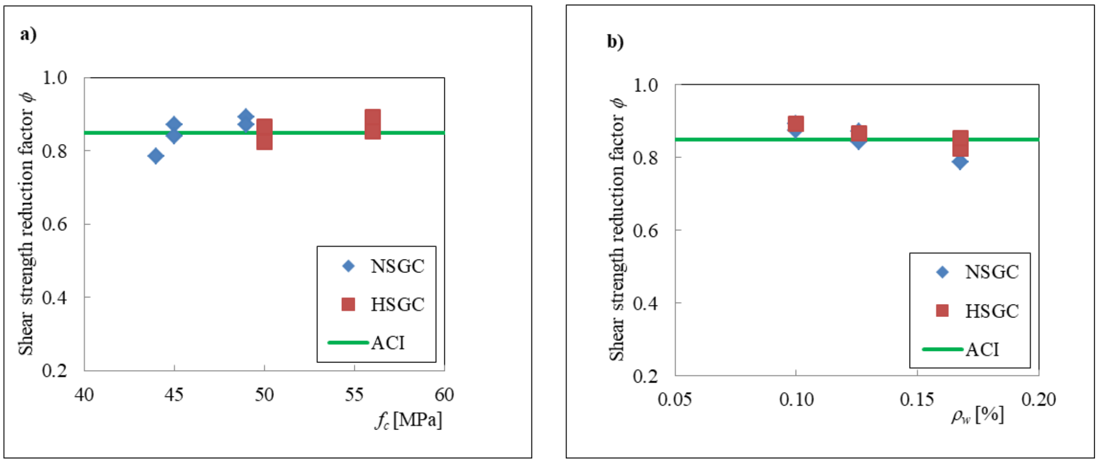

Figure 2. Range of ϕ values determined using evaluation database for $\beta = 3.72$ ($p_F = 10^{-4}$) and $V_{f_c} = 0.10$

It can be stated that the ϕ values are not equally distributed with respect to f_c, a/d and f_{yw}. The beams with a/d higher than 2.5 ($a/d = 2.5$) are limited for all (NSGC & HSGC) beams; further research is therefore required to verify the founded p_F .

Conclusions

The change in the shear strength of geopolymer concrete beams with stirrups according to ACI318 is investigated for different coefficients of variation and failure probabilities. On the basis of results obtained in this study, the following conclusions are drawn:

- It is found that a ϕ of 0.85, which is a value recommended by ACI318 (1995), corresponds to the target values of $p_F = 10^{-4}$ ($\beta = 3.72$).

- It is shown that the ϕ increases with increasing f_c for all beams. So, this result means that the shear reliability of the beam increases as the strength of the geopolymer concrete increases.
- It is observed that the ϕ decreases with increasing ρ_w for all beams.
- For given V_{f_c} and p_F , the ϕ for HSGC beams was found to be greater than the one for NSGC beams, so it can be inferred that the ϕ for HSGC beams is more safe than the one for NSGC beams.

References

American Concrete Institute Committee 318 (ACI 318). (1995). *Building Code Requirements for Structural Concrete (ACI 318M-95) and Commentary*. Farmington Hills, MI.

ACI (American Concrete Institute). (2002). ACI 318: Building Code Requirements for Structural Concrete (ACI 318M-02) and Commentary. Farmington Hills, MI.

Alacalı, S., & Arslan, G. (2018). Assessment of the strength reduction factor in predicting the flexural strength, *Journal of Theoretical and Applied Mechanics*, 56, 4, pp. 1043-1053.

American Concrete Institute Committee 318 (ACI 318). (2011). *Building Code Requirements for Structural Concrete (ACI 318M-11) and Commentary*. Farmington Hills, MI.

Ang, A.H.S., & Tang, W.H. (1984). *Probability concepts in engineering planning and design. V.II, Decision, risk, and reliability*, Wiley, New York.

Arslan, G., Alacalı, S.N., & Sagiroglu, A. (2015). The investigation of the strength reduction factor in predicting the shear strength. *Journal of Theoretical and Applied Mechanics* 53, 2, pp.371-381, Warsaw

ASCE-ACI 426. (1973). The shear strength of reinforced concrete members. *Proc Am Soc Civil Eng*, 99; ST6, 1091–1187.

Chang, E.H. (2009). Shear and Bond Behaviour of Reinforced Fly Ash-Based Geopolymer Concrete Beams. *Doctoral Thesis*, Curtin University of Technology.

Hao, H., Stewart, M.G., Li, Z.-X., & Shi, Y. (2010). RC Column Failure Probabilities to Blast Loads. *International Journal of Protective Structures* -Volume 1, Number 4.

Hognestad., E. (1951). A study of combined bending and axial load in reinforced concrete members. *Engineering Experiment Station Bulletin*, No. 399, University of Illinois, Urbana.

Mirza, S.A. (1996). Reliability-based Design of Reinforced Concrete Columns. *Structural Safety* Vol. 18, No. 2/3, pp. 179-194.

Pan, Z., Sanjayan, J.G., & Rangan, B.V. (2010). Fracture properties of geopolymer paste and concrete. *Magazine of Concrete Research*, Volume 63, Issue 10.

Ranganathan R. (1990). Reliability analysis and design of structures. *tata McGraw-Hill offices*. New Delhi.

Roy, D. (1999). Sulfoaluminate-Belite Cement From Low-Calcium Fly Ash and Sulfur-Rich and Other Industrial by-Products", *Cement and Concrete Research*, 29(8):1305-1311.

TS500 (2000). Requirements for design and construction of reinforced concrete structures, Ankara, *Turkish Standards Institute* (in Turkish).

Author Information

Sema Alacali
Yıldız Technical University
Faculty of Civil Engineering, Civil Engineering Department,
Structural Engineering Division, 34210
Esenler-Istanbul- Turkey

Mehdi Ozturk
Yıldız Technical University
Natural and Applied Sciences
Esenler-Istanbul- Turkey

Guray Arslan
Yıldız Technical University
Faculty of Civil Engineering, Civil Engineering Department,
Structural Engineering Division, 34210
Esenler-Istanbul- Turkey