Proposed mathematical model for stress- strain behaviour of geopolymer concrete

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Abstract. In the present study, appropriate analytic stress-strain mathematical model is developed that can capture the real (observable) stress-strain behaviour of geo polymer concrete. The geo polymer concrete mixes have shown improved stress values for the same strain levels compared to that of controlled concrete mix in M20 grade. The analytical equations for the stress-strain response of conventional and geopolymer concrete mixes have been proposed in the form of y = Ax / (1+Bx+Cx2), both for ascending and descending portions of the curves with different set of values for constants. The proposed equations have shown good correlation with experimental values. The proposed empirical equations can be used as stress block in analyzing the flexural behavior of sections of controlled and geo polymer concrete. The stress-strain curves obtained in the experiment for M20 & G20 grades of controlled and geo polymer concrete exhibit a similar trend when compared to the empirical equations of modified Saenz model. So Saenz mathematical model is successfully evaluated and validated for geopolymer concrete.

1 Introduction

One of the most essential tasks in studying the stress-strain behaviour of Geopolymer concrete is to develop adequate analytic stress-strain models that represent the true (observable) behaviour. The more accurate the stress-strain model, the more trustworthy the estimation of concrete structural member strength and deformation behaviour. The development of an appropriate analytic stress-strain mathematical model that can represent the real (observable) stress-strain behaviour of geo polymer concrete is completed. This may be accomplished by combining the best features of previous models to develop a stress-strain model that accurately represents the total stress-strain behaviour of Geopolymer concrete. Empirical equations are constructed to characterise uni-axial stress-strain behaviour of conventional and Geo polymer concrete mixes of standard grade concrete after experimentally acquiring the stress-strain behaviour of conventional and Geo polymer concrete (M20). Theoretical stresses for conventional and Geo polymer concrete are computed using these empirical formulae and compared to experimental data. Numerous models for predicting concrete stress-strain behaviour have been developed by many researchers. The following are some important models to consider:

1) The models of Desayi and Krishnan (1964)
2) Saenz Model with Changes (1964)
3) Model Hognestad (1955)
4) Model by Wang et al (1978)
5) Models Carriera and Chu (1985)

Simplified and modified single variable polynomial equations based on modified Saenz's model that fit with the produced normalised stress-strain curves appear to be valid for both ascending and descending sections of the curve, out of all the aforementioned stress-strain models.

The equations derived for the ascending and descending sections of the analytical stress-strain curve are in the form of

$$y = \frac{Ax}{1 + Bx + Cx^2}$$

and

$$y = \frac{Dx}{1 + Ex + Fx^2} \quad (1)$$

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where y is the stress at any level; x is the corresponding strain at that level; A, B, C are the constants for the ascending section of the analytical stress-strain curve, and D, E, F are the constants for the descending portion.
The equations for the ascending and descending sections of a non-dimensional stress-strain curve (normalised) are similar.

$$f / f_o = A^1(\in / \in_o) / (1+ B^1(\in / \in_o) + C^1 (\in / \in_o)^2) \quad (2)$$

and

$$f / f_o = D^1 (\in / \in_o) + / (1+ E^1 (\in / \in_o) + F^1(\in / \in_o)^2) \quad (3)$$

The constants for the climbing section of the non-dimensional stress-strain curve are A1, B1, C1, while the constants for the descending portion are D1, E1, F1. The normalised stress (stress ratio) is equal to f / fo, and the normalised strain is equal to f / fo (strain ratio). The boundary conditions of normalised stress-strain curves for both conventional and geopolymer concrete are used to estimate constants. Boundary conditions for ascending and descending portions of stress-strain curves are,
(1) At the origin the ratio of stresses and strains are zero
i.*e.* at $(\in / \in_o)= 0,(f / f_o) = 0$
(2) The strain ratio $(\in / \in_o)$ and stress ratio at the peak of the non-dimensional stress-strain curve is unity.
i.*e* at $(\in / \in_o)= 1, (f / f_o) = 1$
(3) The slope of non-dimensional stress-strain curve at the peak is zero
i.*e* at $(\in / \in_o)=1.0, d(f / f_o) / d(\in / \in_o)= 0$
(4) At 85% stress ratio, the corresponding values of strain ratio is recorded
i.*e* at $(f / f_o) = 0.85$, $(\in / \in_o)$=strain ratio corresponding to 0.85 stress ratio
where fo denotes peak stress and strain at peak stress; f denotes stress and strain values at any other moment; and g denotes stress and strain values at any other point.
The constants A1, B1, C1 in the ascending section of the normalised stress-strain curve are determined by boundary conditions (1), (2), and (3), whereas the constants D1, E1, F1 in the descending portion of the curve are determined by boundary conditions (2), (3), and (4). Equations are then used to get the corresponding A, B, C constants for the ascending section and D, E, F constants for the descending portion of the analytical stress-strain curve.

$$A= A^1 (f_o / \in_o), B= B^1 (1/ \in_o) \text{ and } C= C^1 (1/ \in_o)^2 \quad (4)$$

And

$$D= D^1 (f_o / \in_o), E= E^1 (1/ \in_o) \text{ and } F= F^1 (1/ \in_o)^2 \quad (5)$$

2 Theoretical Stresses

Theoretical stresses were computed using provided empirical equations for conventional and geopolymer concrete obtained from a modified Saenz model in the form of

$$y = \frac{Ax}{1+Bx+Cx^2} \quad \text{For ascending portion} \quad (6)$$

$$y = \frac{Dx}{1+Ex+Fx^2} \quad \text{For descending portion} \quad (7)$$

Where y is the stress at any level ; x is the corresponding strain at that level.

Table 1. Experimental stress strain values of normal concrete

Strain	Stress N/mm^2	Normalized stress	Normalized strain
0.0000	0.00	0.00	0
0.0001	2.26	0.079	0.018
0.0002	4.43	0.155	0.050
0.0004	6.58	0.230	0.101
0.0008	8.45	0.295	0.181
0.0013	11.82	0.413	0.295
0.0015	13.79	0.481	0.350
0.0018	15.83	0.553	0.407
0.0020	17.09	0.597	0.462
0.0023	19.23	0.671	0.522
0.0026	21.62	0.755	0.602
0.0032	24.36	0.851	0.741
0.0036	25.42	0.888	0.819
0.0040	27.68	0.966	0.920
0.0044	28.64	1.000	1.000
0.0048	28.41	0.992	1.103

0.0051	27.67	0.966	1.162
0.0052	23.54	0.822	1.185

Table 2. Experimental stress strain values of geopolymer concrete

Strain	Stress N/mm2	Normalized stress	Normalized strain
0.0000	0	0	0
0.0001	2.26	0.074	0.018
0.0003	4.43	0.145	0.061
0.0006	6.58	0.216	0.104
0.0008	8.05	0.264	0.151
0.0014	11.82	0.387	0.247
0.0016	13.79	0.452	0.283
0.0019	15.83	0.519	0.337
0.0021	17.09	0.560	0.380
0.0023	19.23	0.630	0.419
0.0028	21.62	0.708	0.493
0.0032	23.85	0.781	0.566
0.0035	25.25	0.827	0.622
0.0044	28.88	0.946	0.785
0.0049	29.79	0.976	0.885
0.0052	30.34	0.994	0.935
0.0056	30.52	1.000	1.000
0.0057	29.02	0.951	1.029
0.0059	26.62	0.872	1.056
0.0060	24.89	0.816	1.066

Table 3. Constants for ascending and descending portions of non-dimensional stress strain curve

Grade of Concrete	Conventional Concrete						Geo polymer concrete					
	Ascending portion Constants			Descending portion constants			Ascending portion Constants			Descending portion constants		
	A^1	B^1	C^1	D^1	E^1	F^1	A^1	B^1	C^1	D^1	E^1	F^1
M20	0.51	-1.49	1	0.16	-1.84	1	1.07	-0.93	1	0.02	-1.98	1

Table 4. Analytical equations for non-dimensional stress-strain curve

Grade of Concrete	Conventional Concrete		Geopolymer concrete	
	Ascending portion	Descending portion	Ascending portion	Descending portion
M20	$y=\frac{0.51x}{1-1,.49x+x^2}$	$y=\frac{0.16x}{1-1.84x+x^2}$	$y=\frac{1.07x}{1-0.93x+x^2}$	$y=\frac{0.02x}{1-1.98x+x^2}$

Table 5. Constants for ascending and descending portions of dimensional analytical stress-strain curve

Grade of Concrete	Conventional Concrete					
	Ascending portion Constants			Descending portion constants		
	A	B	C	D	E	F
M20	3342	-341	52365	1049	-421	52365
	Geopolymer concrete					
G20	5791	-167	32117	109	-355	32117

Table 6. Experimental and theoretical stress-strain values of M20 and G20

Conventional concrete			Geopolymer concrete		
Strain	Experimental Stress N/mm2	Theoretical stress	Strain	Experimental Stress N/mm2	Theoretical stress
0.0000	0.00	0.00	0.0000	0	0.00
0.0001	2.26	0.27	0.0001	2.26	2.24
0.0002	4.43	0.79	0.0003	4.43	4.39
0.0004	6.58	1.71	0.0006	6.58	6.51
0.0008	8.45	3.46	0.0008	8.05	7.97
0.0013	11.82	6.66	0.0014	11.82	11.70
0.0015	13.79	8.51	0.0016	13.79	13.65
0.0018	15.83	10.64	0.0019	15.83	15.67
0.0020	17.09	12.86	0.0021	17.09	16.92
0.0023	19.23	15.40	0.0023	19.23	19.04
0.0026	21.62	18.89	0.0028	21.62	21.40
0.0032	24.36	24.34	0.0032	23.85	23.61
0.0036	25.42	26.57	0.0035	25.25	25.00
0.0040	27.68	28.26	0.0044	28.88	28.59
0.0044	28.64	28.65	0.0049	29.79	29.49
0.0048	28.41	26.99	0.0052	30.34	30.04
0.0051	27.67	25.06	0.0056	30.52	30.21
0.0052	23.54	24.23	0.0057	29.02	28.73
			0.0059	26.62	26.35
			0.0060	24.89	24.64

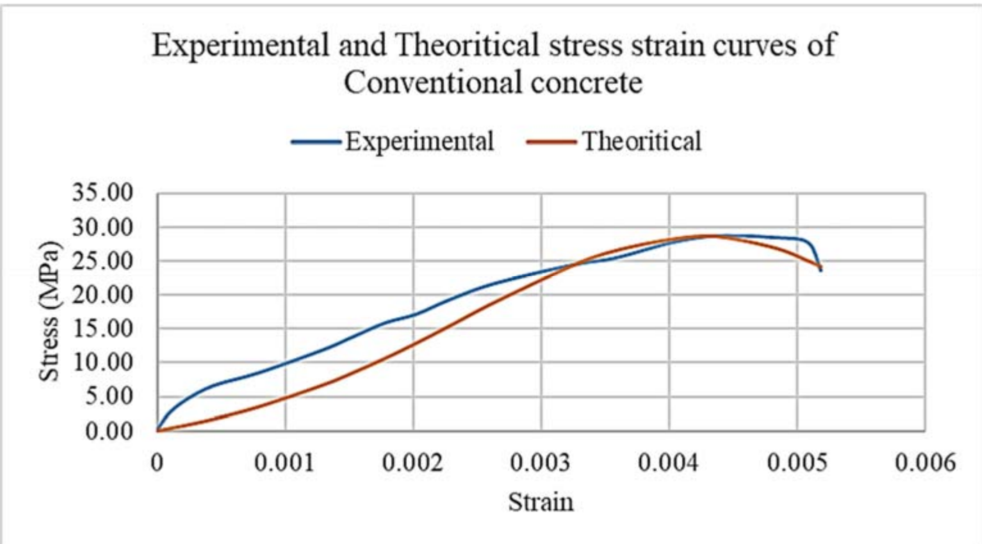

Fig.1. Experimental and theoretical stress-strain curves of conventional concrete

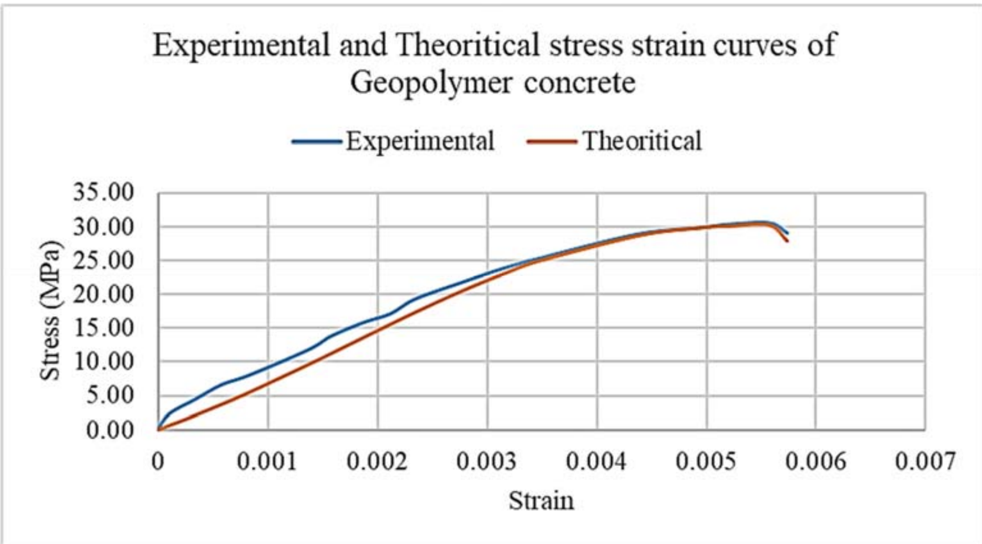

Fig.2. Experimental and theoretical stress-strain curves of geopolymer concrete

3 Discussions

Theoretical non-dimensional stress-strain data is derived from experimental non-dimensional stress-strain data. The practical and theoretical results correspond well, indicating that the suggested model for studying the stress-strain behaviour of controlled and geo polymer concrete of grade M20 is viable. The stress-strain curve for mix is drawn using the values of stresses and strains, using the average values of the three cylinders' findings. The related normalised stress-strain values are derived by dividing each stress value by the peak stress and dividing each strain value by strain at peak strain from the stress-strain values of controlled and geo polymer concrete mixes. The average normalised stress-strain curves for controlled and geo polymer concrete mix are plotted separately from the normalised stress-strain values, and empirical equations in the form of y= Ax/(1+Bx+Cx2) are proposed for ascending and descending portions of controlled and geo polymer concrete mix for M20 grade of concrete. Theoretical stresses are assessed and compared to experimental stress levels, and it is discovered that there is very little fluctuation, indicating that the mathematical model presented is correct. The stress-strain behaviour of all the controlled and geopolymer concrete mixes is virtually same, according to the observations derived from stress-strain curves. The main difference is that when compared to controlled concrete mixes, geo polymer concrete mixes have demonstrated better stress values for the same strain levels. The form of the ascending section of the stress-strain curve for typical concrete is more linear and steeper, as can be seen from stress-strain curves.

In comparison to standard strength concrete, the strain at peak stress is somewhat greater, and the slope of the falling section is steeper. This was because the degree of internal micro cracking in greater strength concrete was reduced. The suggested equations have demonstrated satisfactory agreement with experimental results for grade M20 of controlled and geo polymer concrete. According to the literature, the modified second degree polynomial proposed by L.P. Saenz looks to be a better match with acceptable constants for the current curves.

4 Conclusions

The following conclusions may be derived from the experimental data gathered during the course of this study:

1. When compared to a controlled concrete mix in M20 grade, the geo polymer concrete mixes showed better stress values at the same strain levels.
2. The average strain at peak stress for controlled and geo polymer concrete is extremely near to the strain at peak stress for controlled concrete in axial compression, which is 0.002 according to IS 456-2000.
3. In the form of y = Ax / (1+Bx+Cx2), analytical equations for the stress-strain response of conventional and geopolymer concrete mixes have been developed, both for ascending and descending sections of the curves with various sets of constants. The suggested equations exhibit a high degree of agreement with experimental results.
4. The suggested empirical equations may be utilised to analyse the flexural behaviour of sections of controlled and geo polymer concrete as a stress block.
5. When compared to the empirical equations of the modified Saenz model, the stress-strain curves produced in the experiment for M20 and G20 classes of controlled and geo polymer

concrete show a similar tendency. As a result, the Saenz mathematical model for geopolymer concrete has been effectively assessed and verified.

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