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Prediction of ultimate strength of reinforced geopolymer concrete wall panels in one-way action

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HIGHLIGHTS

- Studied the behaviour of OPC and GPC wall panels.
- Loading was one-way in-plane action.
- Influence of SR and AR were studied for both OPC and GPC panels.
- Predicted the ultimate load of GPC wall panels.

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ABSTRACT

An experimental investigation has been carried out to study the strength and behaviour of Ordinary Portland cement concrete (OPC) and geopolymer concrete (GPC) wall panels. A total of 20 wall panels were tested under uniformly distributed axial load in one-way in-plane action. Out of these, 10 wall panels were made of OPC and the remaining was of GPC. The main variables considered in this study were slenderness ratio (SR) and aspect ratio (AR) of the walls. Also a method was proposed to predict the ultimate load of reinforced GPC wall panels.

1. Introduction

In recent years, reinforced concrete wall panels are considered as important load bearing structural members as beams, slabs and columns. Load bearing walls resist primarily in-plane vertical loads acting downward on the top of the wall. In comparison with other dimensions, the thickness of the wall is small, which introduces the slenderness effect, leading to problems of stability. Also depending on the relative ratio of height to length, the behaviour of a wall panel under load would vary from a short, wide compression member to a deep, narrow member [1]. Various investigations have been made in the past to study the strength and behaviour of load-bearing reinforced concrete wall panels under one-way action and equations have been proposed to predict the load carrying capacity [1–6]. Attempts have also been made to compare some of the equations available in the literature with the experimental values reported by other researchers [7–9]. Strength and behaviour of reinforced Self Compacting Concrete (SCC) wall panels have been studied and an equation was proposed for the ultimate strength [10].

The process of cement production is highly energy intensive and also causes the emission of green house gas like CO_2 [11,12]. Also under certain environmental conditions, Portland Cement Concretes are less durable [13]. In this respect, geopolymer technology introduced by Davidovits provides an alternative binder to the Ordinary Portland cement [14]. 'geopolymer concretes' (GPCs), as proposed by Davidovits are inorganic polymer composites; with the potential to form a substantial element of an environmentally sustainable construction by replacing or supplementing the conventional concretes [15]. These concretes are obtained by alkali activation of industrial waste materials such as fly ash in the presence of sodium hydroxide and sodium silicate solution, which is a polymerization process that differs widely from Portland cement hydration [16]. Also it is reported that fly ash, when used in high volumes in concrete reduces the alkali aggregate reaction [17]. GPC have high strength, with good resistance to chloride penetration, acid attack, etc. and have a very

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Nomenclature

P_u	ultimate load (N)	Fy	yield strength of steel (N/mm^2)
fc'	cylinder compressive strength of concrete (N/mm^2)	Asc	area of compression reinforcement (mm^2)
L	length of the wall panel (mm)	Ag	gross area of the section (mm^2)
T	thickness of the wall panel (mm)	Ø	strength reduction factor
H	height of the wall panel (mm)		

small greenhouse footprint when compared to conventional concretes [18–21]. The extensive research works carried out by several investigators support the potential of GPC as a prospective construction material [14,18,22–24]. In the past many studies have been carried out using alkaline activators such as sodium hydroxide and sodium silicate solution as they leads to higher strength [18–22]. However as indicated by Rashad et al. [25], none of them exists naturally and their manufacturing process is quite energy intensive. In view of this, Rashad et al. [25] carried out studies with sodium sulphate, which can be obtained from natural resources. Their studies indicates that increasing the slag fineness is a more effective approach than increasing sodium sulphate dosage for increasing both the early and long term strength of sodium sulphate activated slags.

High-early strength gain is a characteristic of geopolymer concrete when heat cured or steam cured [18,23]. Hence it has been used to produce precast railway sleepers, sewer pipes and other prestressed concrete building components. Studies on the flexural behaviour of reinforced GPC beams have been done and were compared with OPC beams [26,27]. Analysis of reinforced GPC columns were carried out and was reported that the design provisions contained in the current standards and codes can be used to design reinforced fly ash-based geopolymer concrete columns [26,28]. Informations regarding the strength and behaviour of reinforced geopolymer concrete wall panels are not yet reported. Considering this gap in the literature, an attempt was made to investigate the behaviour of GPC wall panels along with the development of a method to predict the ultimate load.

2. Experimental programme

The experimental programme consisted of casting and testing of 20 wall panels under one-way in-plane action. Out of these, 10 were made of OPC and the remaining 10 of GPC. For the present study, 3 different SR and 3 different AR were used. Table 1 gives the details of wall panels and variables used.

2.1. Materials and mix proportion

Ordinary Portland cement concrete (OPC) was designed for a characteristic compressive strength of M40 grade as per IS 10262-2009 [29] and the mix proportion thus obtained are presented in Table 2. Standard mix design approaches are not available for GPCs, as they are a new class of construction materials. In the present experimental work, GPC mix proportion for M 40 grade was obtained by trial and error method, based on the guidelines given by Rangan [30]. Low-calcium (ASTM Class F) fly ash obtained from Mettur Thermal Power Plant in Tamil Nadu was used as the base material [31]. Table 3 shows the chemical composition of fly ash as revealed by scanning electron microscope (SEM). Fig. 1 shows the SEM image of fly ash. River sand passing through 4.75 mm IS sieve conforming to grading zone II of IS:383-1970 (reaffirmed 2002) [32], having a fineness modulus of 2.83 and specific gravity of 2.50 was used. The maximum size of coarse aggregate used was 12.5 mm with a fineness modulus of 7.10 and specific gravity of 2.72. Strong alkaline activators such as sodium silicate and sodium hydroxide were mixed to form the alkaline solution [16,18,25]. In order to improve the workability of concrete a naphthalene based superplasticizer (Conplast SP 430) was employed during mixing operations. The objectives for performing the trial and error procedure was to obtain the desired compressive strength at the end of 28 days and to obtain a good cohesive mix with satisfactory workability (slump of 75–125 mm). The ratio of sodium silicate-to-sodium hydroxide by mass was kept as 2.5 [33], and the ratio of activator solution-to fly ash was selected as 0.36. The details of mix proportions are given in Table 4.

2.2. Casting of specimens

2.2.1. GPC specimens

For the preparation of test specimens, fly ash, river sand, coarse aggregate, sodium silicate and sodium hydroxide were used. Sodium hydroxide was available in the pellet form which was mixed with water to form 14 Molar solution [34,35]. It was then mixed with sodium silicate to form the alkaline solution, 24 h prior to casting. All the aggregates were prepared in saturated surface dry condition. Mixing of dry materials was carried out first in a drum type mixer with 1.5 cft (0.062 m^3) capacity. Superplasticizer was mixed with alkaline solution and was then added to the dry materials.

Reinforcement consists of High Yield Strength Deformed bars (Fe 415) of 6 mm diameter in the form of rectangular grid. It was placed in a single layer at mid thickness of the panels. The bars were equally placed in both directions with a clear side cover of 10 mm. The vertical and horizontal reinforcement was 0.88% and 0.74% respectively. Typical arrangement of reinforcement is shown in Fig. 2a and the reinforcement grid placed in steel mould is given in Fig. 2b. The freshly mixed GPC was poured in three layers, into the mould. Each layer was vibrated for 15 s in a vibrating table. The top surface was levelled using a smooth trowel after compaction. The moulds were then covered by plastic sheets in order to prevent loss of moisture. The covered specimen were given a rest period of 3 days and then transferred to the steam curing chamber (Fig. 3). Curing was done for 24 h at a temperature of 60 °C.

Table 1
Details of wall panels and variables.

Type	Panel designation	Specimens tested (Nos.)	Panel size (height × length × thickness) mm	Variables	
				SR	AR
OPC	OPCSR-1	2	480 × 320 × 40	12	1.5
	OPCSR-2	2	600 × 400 × 40	15	1.5
	OPCSR-3	2	840 × 560 × 40	21	1.5
	OPCAR-1	2	600 × 320 × 40	15	1.875
	OPCAR-2	2	600 × 560 × 40	15	1.07
GPC	GPCSR-1	2	480 × 320 × 40	12	1.5
	GPCSR-2	2	600 × 400 × 40	15	1.5
	GPCSR-3	2	840 × 560 × 40	21	1.5
	GPCAR-1	2	600 × 320 × 40	15	1.875
	GPCAR-2	2	600 × 560 × 40	15	1.07

Table 2
Mix proportions of Ordinary Portland cement concrete.

Materials	Quantity (kg/m^3)
Coarse aggregates	1140
Sand	896
Cement	350
Water	140
Superplasticizer	7

Table 3
Chemical composition of fly ash.

Element	Weight (%)
Alumina (Al_2O_3)	27.74
Silica (SiO_2)	55.36
Pottasium oxide (K_2O)	2.55
Calcium oxide (CaO)	1.07
Titanium dioxide (TiO_2)	3.55
Iron oxide (Fe_2O_3)	9.74