Behavioural analysis of R.C.C Pile Foundation by using metakaolin as a partial replacement in concrete

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Abstract **–** Over the last few years, many developments are taking place and resulting in the construction of tall buildings due to insufficiency of land. The foundation is one of the most essential substructures on which a building stands. Many researchers hunt for various substitute materials nowadays. In that case, in this paper, a pioneering material, metakaolin is utilized as a limited substitution for concrete with 10% replacing cement. Using that concrete, the pile foundation is cast. M25-grade concrete is used for piles. The pile cast here includes a reduced scale ratio of 1:10 with 1m length and 7cm diameter. A steel tank of size 1m X 1m X 1m is made. The properties of soil filled in the tank are tested. An experimental program is performed to analyse the load vs deflection behaviour of the pile. In PyPile software, the piles are analysed. The results of both experiment analysis and software analysis are compared.

Keywords **–** Metakaolin, Pile Foundation, Load test, and Lateral loading

1. INTRODUCTION

Pile foundation transfer and circulate its own load and live loads to the ground in such a way that the load-bearing capacity of the pile foundation does not exceed its limit. The major purpose of the foundation is the proper transmission of a load of the structure to the soil in such a way that the soil is not overstressed and does not undergo deformations that would cause undesirable settlements. A building may experience settling or structural damage over time without a proper foundation. Therefore, it is crucial to construct a solid foundation that can transmit and distribute both its self-weight and the live loads to the ground to prevent the soil's overloading and deformation. Here in the project cement is partially replaced by metakaolin and lay the pile foundation.

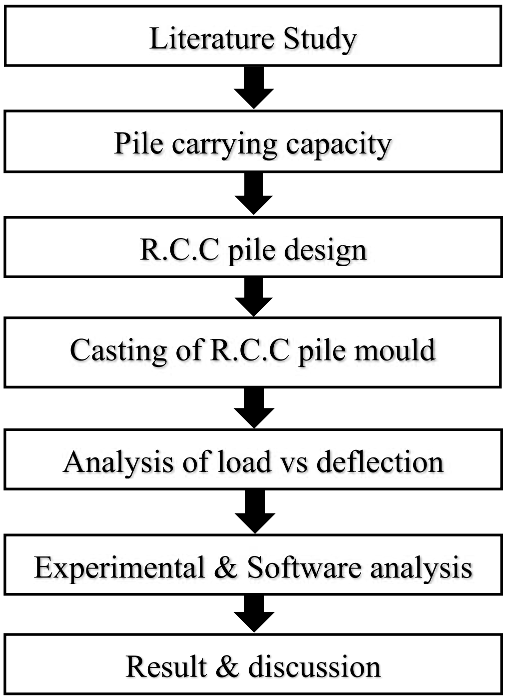
Metakaolin is a type of mineral admixture that is rich in active silica and alumina. When added to concrete, it reacts with calcium hydroxide at room temperature to form a paste called calcium silicate hydrate (C-S-H), which increases the concrete's density and reduces porosity. By filling the voids between cement particles, metakaolin acts as a filler and further improves the impermeability of the concrete. When used to replace cement at a 10% ratio by weight, the resulting concrete is typically more cohesive and less prone to bleeding. This can reduce the amount of effort required during the pumping and finishing processes. Additionally, using metakaolin in this way can increase the compressive strength of hardened concrete. Reduces shrinkage in concrete and it is eco-friendly by reducing CO_2 emissions.

2. OBJECTIVES

- To investigate the use of metakaolin as a limited substitution for cement in concrete.
- To evaluate the strength properties of concrete containing metakaolin.
- To determine the load-carrying capacity of the pile foundation.
- To design a reinforced concrete pile foundation using the IS 2911 code.
- To construct a reinforced concrete pile foundation using concrete containing metakaolin.
- To determine the load-deflection behaviour of the pile foundation using a load vs deflection test and study the settlement of the pile by gradually increasing the applied load
- To analyse the behaviour of piles by using PYPILE software.

3. METHODOLOGY

Metakaolin is partially replaced in place of cement in order to have a positive effect on the environment. The literature regarding metakaolin, and pile foundation are studied. The compressive strength of metakaolin concrete, pile length, and soil property are determined. An experimental box and pile mould were made by steel as per reduced scale. Metakaolin-incorporated piles are used for the analysis of pile. The model has been tested by loading frame in the name of load vs deflection test. By using the test values and soil profile the behavioural analysis of the pile is done using the PyPile software. Both the results of the experimental and software analysis values are compared. Then the conclusions are made.



4. DESIGN DETAILS

4.1 LOAD CARRYING CAPACITY OF THE PILE

By static formula as per **IS 2911 part 1 Sec 3**

$Q_u = A_p N_c C_p + \sum_{i=1}^{n} \alpha_i c_i A_{si}$

$Q_u = (0.28 \times 9 \times 70) + (0.9 \times 80 \times 10)$

$Q_u = 176.4 + 720$

$Q_u = 896.40$ KN

4.2 REINFORCEMENT DETAILS

Structural capacity = 1000 KN

Using M_{25} concrete and Fe415 steel

As per IS 2911 Sec. 2 part 2

Estimate permissible concrete stress

A minimum grade of concrete M_{25}

$f_c = f_{ck} / 4$

$= 25/4$

$= 6.25$ N/mm^2

Determining diameter required for 1000 KN capacity

$A = 100 \times 10000/6.25 = \pi D^2 / 4$

$100 \times 10000 \times 4 / 6.25 \times \pi = D^2$

$D \approx 451$

$\therefore D = 450$ mm

As per 2911

Estimate longitudinal steel

Min: longitudinal steel = 0.4%

$A_s = \pi \times 450 \times 450 \times 0.4 / 4 \times 100$

$= 636\ mm^2$

Providing 6 steel rods of 12 mm diameter gives an area of 678 mm^2, is greater than 636 mm^2

Estimate laterals required

Since 450 mm diameter, Provide laterals 6 mm @ 150 mm spacing

5. MATERIALS

Concrete is a necessary material used in the construction field. Once all of the ingredients such as cement, water, fine aggregate, coarse aggregate, and metakaolin are added in accordance with the mix design, the cement, and the water begin to react with one another and bind themselves into a mass called concrete and then the concrete is poured into the pile mould with reinforcement embedded in the pile mould. A tank of size 1m X 1m X 1m is made and the soil is filled in the tank and then the pile is fixed inside the tank and then the test is done. Materials collected are shown below in Table 5.1

Table 5.1 Materials used

S. NO.	MATERIAL	SPECIFICATION
1	Cement	OPC
2	Metakaolin	Pozzolanic material
3	Water	Portable water
4	Fine aggregate	Manufactured sand
5	Coarse aggregate	6mm coarse aggregate

6	Main rod	3 mm longitudinal rods
7	Distribution rod	2 mm helical steel rings
8	Pile mould	Steel mould of 1m height and 6 cm diameter
9	Experimental tank	Steel tank of 1m X 1m X 1m

6. TEST ON CONCRETE CUBE

At 0%, 5%, 10%, and 15% addition of metakaolin, cubes were cast. After the counting of 28 days of curing, cast samples were demoulded and testing was done. Of the 4 cubes 10% showed better result compared to others in Table 6.1

Table 6.1 Compressive strength in N/mm^2

GRADE	**CURING DAYS**	**Compressive strength % of metakaolin**			
		0%	**5%**	**10%**	**15%**
M_{25}	**7**	**16.3**	**17.3**	**18**	**15.1**
	14	**22.5**	**23.1**	**24**	**21.5**
	28	**25.5**	**26.7**	**27.1**	**24**

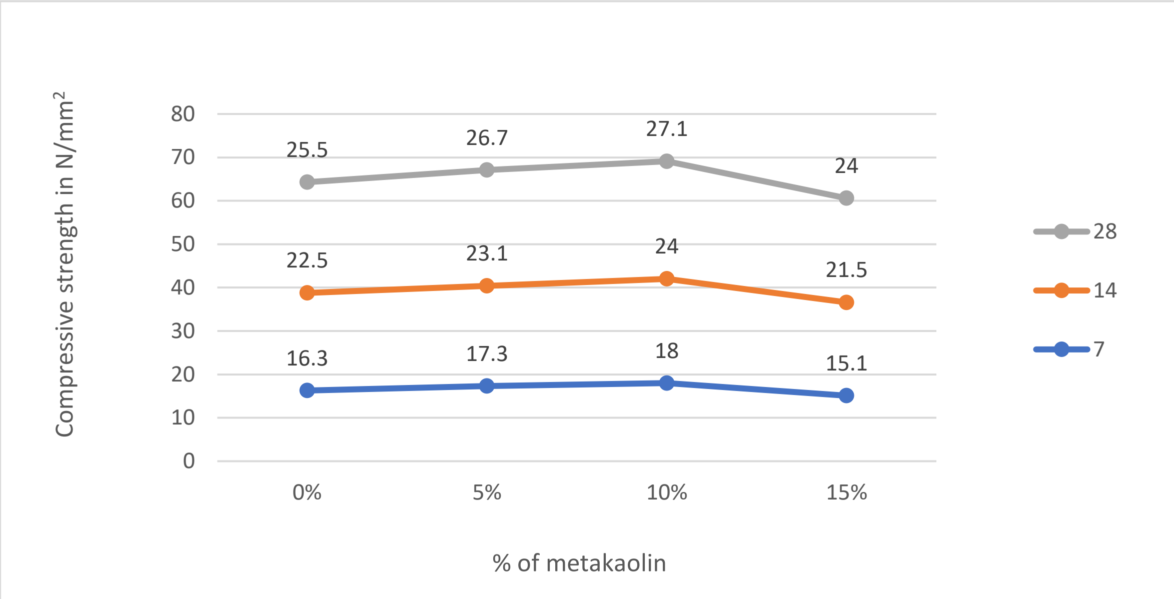


Fig 6.1 Graphical representation of compressive strength

Fig 6.2 Compressive testing of metakaolin incorporated cube

7. TEST ON SOIL

7.1 Specific Gravity Test

Specific gravity is done in the determination in need of soil properties like void ratio, degree of saturation, and sieve analysis using a hydrometer test. Also value of specific gravity is used to find out the relevancy of the clay soil as a filler substance for the experiment. The result is given in Table 7.1

Table 7.1 Test results for Specific gravity

Sample No.	Mass of the empty bottle M_1 (g)	Mass of the bottle and dry soil M_2(g)	Mass of the bottle filled with soil and water M_3 (g)	Mass of the bottle filled with water M_4 (g)	Specific gravity G	Average
1	660	1092	1783	1510	2.72	2.64
2	660	1089	1780	1515	2.62	
3	660	1078	1775	1519	2.58	

The specific gravity of the soil sample, **G = 2.64**

7.2 Sieve Analysis Test

Sieve analysis decides the size of the particle distribution of the soil by allowing the material to pass through a series of sieves. The clay soil is tested to fill the tank for the experiment. Percentage of soil retained on any sieve, $P_n = M_n/M \times 100$. The result of the sieve analysis test is given in Table 7.2

Table 7.2 Result on sieve analysis test

Is Sieve Size (mm)	Weight retained in g	% of soil retained	Cumulative % retained	% finer
4.75	0	0	0	100
2.36	4	1	1	99
1.18	7	1	2	98
0.6	13	3	5	95
0.425	13	3	8	92
0.3	33	7	15	85
0.15	38	8	23	77
0.075	79	16	39	61
PAN	292	61	100	0
Total	479	100		

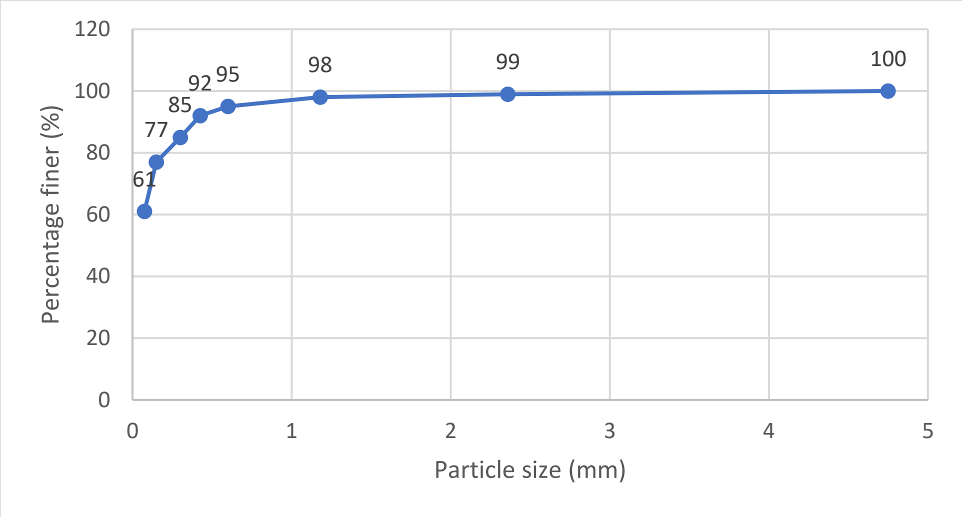


Fig 7.1 Relationship between Particle size and Percentage finer

7.3 Consistency of Soil

i) Liquid Limit

The liquid limit of soil is needed to know the plasticity of the soil. The liquid limit shows relative consistency. The liquid limit is the water content at which the narrow cut is made by a groove tool in the clay soil which is passed through the 425-micron sieve. The result for the liquid limit is given in Table 7.3

Table 7.3 Result of liquid limit

S.No.	Number of blows	Water content W_L	Average
1	17	35.38	31.8%
2	23	32.82	
3	27	30.52	
4	34	28.59	

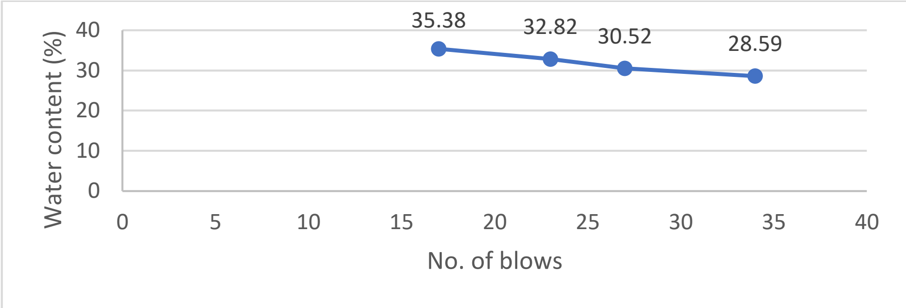


Fig 7.2 Relationship between No. of blows and water content

Fig 7.3 Casagrande liquid limit apparatus

ii) Plastic Limit

The plastic content of the soil is the moisture content under which the clay soil stops behaving as a plastic material. The test results of the plastic limit are given in Table 7.4

Table 7.4 Results of plastic limit

S.No.	Mass of empty container M_1 (g)	Mass of container with wet soil M_2(g)	Mass of container with dry soil M_3(g)	Water content W_P (%)	Average (%)
1	26.10	32.29	31.20	21.37	21.16
2	26	34.74	32.51	20.94	
3	25.9	30.15	29.06	21.17	

Result:

Plasticity index = 10.64

Consistency limit = 1

8. PILE LOAD TEST

Pile load tests were conducted in a test tank of 1m X 1m X 1m. Test is conducted with soil which passes through 4.75 mm sieve filling up to 90 cm which is compacted into different layers and poured into the tank. A hydraulic jack is attached to the loading frame which is connected to the proving ring of 50KN. The tip of proving ring is attached to the pile which is embedded in the soil. Dial gauge is used to find the settlement which is attached to the plate placed above the pile with magnetic effect it is attached to the tank for taking settlement values. The experimental setup is shown in Fig 8.1, Fig 8.2 and the results in Table 8.1

Fig 8.1 Steel tank

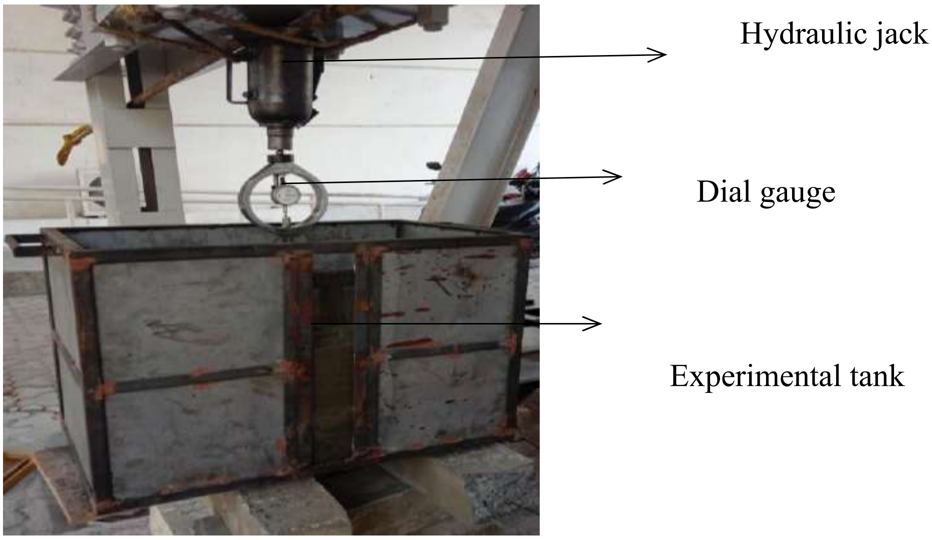


Fig 8.2 Experimental setup

8.1 TEST RESULTS OF LOAD VS SETTLEMENT

Length of pile = 1 m

Diameter of pile = 6 cm

Table 8.1 Result data by experiment

S.No	Load values in proving ring	Settlement value in dial gauge (mm)	Ultimate carrying capacity of pile (Kn)
1	0	0	0
2	0.8	83	2
3	1.3	74	3.25
4	1.6	65	4
5	2	59	5
6	2.2	53	5.5
7	2.5	49	6.25
8	2.9	45	7.25
9	3.1	41	7.75
10	3.5	39	8.75

8.2 ANALYSIS OF PILE USING PYPILE SOFTWARE

Pypile is a vertical pile analysis software program based on p-y curves. Pile deflection, bending moment, and shear forces can be analysed with different load case. Result is shown in Table 8.2

Table 8.2 Result data by software analysis

S.No	Pile load (KN)	Max deflection (mm)	Max shear force (KN)	Max moment (kn.m)
1	0	0	0	0
2	7.9	16.19998578	7.9	3.025396067
3	12.9	44.8200826	12.9	5.851854696
4	15.9	70.67012002	15.9	7.852339596
5	19.9	125.2737096	19.9	11.19601208
6	21.9	164.4506545	21.9	13.14535952
7	24.9	243.0024593	24.9	16.41506937
8	28.8	386.5151896	28.8	21.22076641
9	30.8	480.8411505	30.8	23.87414028
10	34.8	725.6410264	34.8	29.66424078

9. CONCLUSION

- Metakaolin can productively boost the tensile strength thus reducing the reinforcement ratio in pile foundations
- This solves the problem of the challenging task of insertion of reinforcement in the pile foundation.
- Reducing the cost of cement and also reducing the amount of CO_2 emission.
- In our experiment, we studied that the load-carrying capacity of a pile depends on the adhesion factor of clay soil.
- The settlement of a 6 cm diameter pile is 39 mm at a max load of 35 KN.
- Allowable pile settlement as per IS-1904(1966) is 65 mm in clayey soil.

- Settlement occurs when the load gradually increases.
- Settlement can be resisted to a point because clay soil resists the load.
- In cohesive soil, the adhesion factor creates more bonding and increases the load-carrying capacity.

10. FUTURE SCOPE

The cement content can be minimized by replacing metakaolin, a geopolymer-based material that reduces the cost and also reduces the emission of CO_2 which makes the material corrosion-resistant, and as it increases tensile strength the reinforcement ratio can be reduced.

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