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Influence of Nano Particle on the Permeability of Fly-Ash Sand Mixture

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Abstract

In this study, the effect of silicon dioxide nano particle and fly-ash on the permeability of sand were investigated. For this purpose, various combinations of fly ash and sand were investigated to examine the impact of mixing of fly with sand. We can make a least permeable mass by mixing 80% of fly ash with 20% sand. According to specific gravity of sand, fly ash, nano silica and weight of the mould with a porosity of 0.4 these materials has been mixed manually. Fly ash is mixed with the fine sand in increasing proportions of 5%, 15%, 25%, 35%, 45%, 55%, 65%, 75%, 85%, 100%. According to the results of present study, 80% fly ash mixed with 20% sand provides the least permeable combination compared to the rest. The percentage-mix of fly ash and sand is taken different from previous study but least combination was achieved with a similar combination of 80% fly ash and 20% sand which was also reported by Gupta and Alam 2004. To make the least permeable sample to almost impermeable, nano silica mixed with least permeable sample in increasing percentage by 5%, 7.5%, 10% and 12.5%. A falling head and constant head method was used to test all samples for hydraulic conductivity.

Results of present study revealed that when 20% of sand mixed with 80% of fly ash gives value of permeability (6×10^{-05} cm/s) which are 86 times lower than the permeability of sand.

It was observed that a mixture of 20% sand and 80% fly ash mixed with 12.5% of nano silica gives a permeability (2.20×10^{-06} cm/s) *i.e* in the range of clay which is 2340 times lower than the permeability of sand.

The permeability property was found to be highly improved on addition of fly ash and nano particles to sand.

Comprehensive results proving the improvement in the permeability properties have been obtained in the specimen containing 12.5% nano silica with least permeable sample of fly ash–sand mixture.

Keywords: Comprehensive • Permeability • Nano technology • Permeable • Encompass

Introduction

Nano technology is one of the most active studies regions that encompass a number of disciplines, such as civil engineering and construction industry. Now days, nanotechnology has been concerned with development in various fields like microbiology, medicine, electronics chemical and material science however, the scope of application of nano technology is growing in the field of civil engineering [1].

Nano technology has benefited different ield of civil engineering including construction and materials. Better properties of cementitious materials, reduced thermal transfer rate of ire retardant and insulation. Nano-coating, nano steel, bactericidal capacity, nano-glass, nano particle for fire protection, environment and construction are the field that nano technology has benefited. But most important aspect from the previous researches for the present study is that the incorporation of nano paticles reduced the permeability of some engineering materials like sand, fly ash, cement and soil.

The problem of seepage is significant in water supply and sewage treatment works, design percolation through and around the earth and rock fill dam is utmost importance to a civil engineer. Many of the difficulties faced in the design and construction of hydraulic structure such as weir, embankment and other engineering works involving drainage are due to extreme variation of permeability of earth and rock masses. Undetected joints and strata of high permeability in the foundation and abutments of the dams create serious leakage and uplift problems.

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Pavement infrastructure projects require large amount of soil for construction very often massive amount of soil is found to be weak, highly plastic and expansive in nature, which is unsuitable for construction. Several studies in the past reveal favorable results for application of problematic soils with additives like cement, fly ash, etc. Since enormous quantity of fly ash is available from proximity of thermal power plant [2].

In the past several decades, fly ash plays an important role as resource material in the several field of utilization. Permeability of construction materials can be improved by mixing some easily available material like fly ash.

The point of present is to use well the circumstances where sand is accessible in plenitude. Very often civil engineers ought to construct works like dikes, guided bund, detention dams and debris dams etc.

Earthen dam or embankment dam have been utilized to store and control river water. Seepage is one of the most important parameter which has to be considered while construction and designing of an earthen dam. The permeability property was found to be highly improved on addition of fly ash and nano-particles to sand.

With the rapid development of nanotechnology and multidisciplinary cross application present study can be bene ited to seepage problem.

This study aims to utilize waste material fly ash as resource material and smartly utilize nano-technology to the problem of seepage in earthen dams [3].

Thought of nanotechnology was first presented in the 1959 by Richard Feynman in his lecture there's plenty of room at the bottom. At that Tim, the term nanotechnology had not at this time been authored. This innovation gained significant and rapid progress year later. Nano innovative accomplishments gave a modern approach in civil engineering.

In 1970 the colloidal nano-silica was used for the treatment of concrete in the oil and gas industry to reduce the permeability of undersea well caps, acting as a capillary and pour filling agent to reduce oil loss into sea water.

But today, application of nano-materials has been widely adopted. Some investigation has been done in the course of recent many years and it is found that with the incorporation of nano particles the properties of engineering materials has been improved [4].

Nano silica has been used by several researchers to investigate the effect of nano particles on sand. Such as Yonekura and Mitwa used nano particle to increase the compressive strength of sand. They found that with the addition of 30% nano silica by weight, soil resistance increased by 3.5 times after 1000 days. Utilizing nano silica in sand could decrease the permeability and absorption of metal from the solutions. Persoff, et al. revealed that in Sandy soils, the compressive strength of soil increases with the increase in percentage of nano silica. As per field study conducted by the Moridis, et al. in 1996 effectively utilized 30% colloidal nano-silica to create subsurface barrier in unsaturated, heterogeneous deposits of silt sand and gravel. Because of its smaller sized nano particle field test revealed that nano-silica solution penetrate an opening of less than 50 micron. In view of this attributes, a later use of colloidal nano silica was utilized as a method of sealing narrow fractures in tunnels where sealing efficiency is found to be 70% by the hydraulic test Funehag and Fransson.

Gupta and Alam reported reduction in permeability of course sand and fine sand by mixing fly ash.

Shrinkage strength and hydraulic conductivity could be reduced by increase in compaction efforts. Increase in compaction effort results in increase in dry density and decrease in optimum water content but for higher water content, increase in the compaction effort does not found any significant effect on shrinkage reduction [5].

According to findings in sandy soil, adding nano-silica increases the soil compressive strength by 400 Kpa. The hydraulic conductivity decreases with increased silica nano particles.

According to Chang, et al. adding fly ash to oil-cement mixture reduced permeability by 971 times.

One experiment in 2016 Idrus, et al. examined the effect of additives (nano clay and bentonite) on permeability and CBR values of Batu Pahat soil and observed that if soil was mixed with 5% of additive, permeability decreased to 32%. In addition, mixing 10% additive with soil caused the permeability to decrease to 56.4%. Mixing 15% of additive with soil resulted in a reduced permeability of 76%. This study has also shown that nano particles promote soil pore filing compared to the non-nano particle additive. The same behavior was observed when lime, slica, nano lime and nano silica used as additives on clay soil improvement in 2016 Anandha Kumar, et al.

Again, it was observed that nano additives cause permeability reduction to be higher than non-nano additives.

A research was conducted in 2017 on locally available powai soil that was collected from the premises of IIT Bombay. This powai soil was mixed with fly ash to modify its properties, and then the mixture was treated with nano solution. By mixing 30% fly ash with soil the permeability decreased to 86%, mixing 30% fly ash with soil and treating it with nano solution reduced permeability to 98.89%.

A study by Pranjal Shrivastava reported reduction in permeability of sand when sand was mixed with nano particle of sand. In a similarly study Moosi Raza observed reduction in permeability of fly ash when it was mixed with nano particle of fly ash.

Reserchers Zainuddin, et al. reported that nano bentonite reduced clayey soil permeability. It was observed that bentonite itself met the low permeability criteria when mixed with soil without utilizing nano bentonite. However, permeability of clay fell by 240000 times by mixing with nano bentonite. In china a similar research was conducted. According to the results of permeability test, the coefficient of permeability decreased as the percentage of nano bentonite increased at low consolidation pressure 500 KPA.

In study by Bhadra, et al. permeability values was reduced when nano particles were mixed with soil-fly ash mixture. As a result of mixing 1% nano particle with fly ash and soil mixture, the permeability value decreased by 22.58% [6].

The strength and permeability of concrete containing nano cement were investigated. A high energy ball grinding mill was used to grind commercial available 53 grades Portland cement into nano-cement. Several grades of concrete were cast, including M_{20}, M_{30}, M_{40} and M_{50}. The cement of each grade of concrete was replaced with nano cement. It was found that the permeability value fell by 92.75% of M_{20} grade of concrete (Table 1).

S. No	Year	Author	Original material before mixture	Additive/Nano-material used	Permeability reduction
1	2016	M.Mohd.Idris	BHT soil	Nano clay	56%
2	2004	Gupta and Alam	Sand	Fly ash and cement	1392
3	2016	Jamal M.A.A lsharef, et al.	Residual soil	CNT AND CNF	56% and 65%
4	2017	Prasanna P.Kulkani (2017)	Locall soil	Fly ash+colloidal nano	98.89%
5	2016	Mr. S. Anandha Kumar, et al.	Soil	Lime+silica, nano lime+nano silica	41%, 91.02%.
6	2018	Poorva Taghvaei, et al. 2018	Sandy soil	Mont morrionite nano clay	887 times
7	2019	Atiqah Najwah Zainuddin, et al. 2019	Bentonite	Nano bentonite	240000 times aprox
8	2017	Mazidah Mukri, et al.	Kaolin	Nano kaolin	19.14% reduced
9	2020	Bhadra SM, et al.	Soil	6% fly ash+1% nano calcium silicate	22.58% reduction with respect to 6% lies ash mixture.
10	2016	MM MOH Idrus, et al.	Soft soil	Nano clay	76.26%
11	2011	Taghi Ebadi, et al.	Kahrizak clay	Nano clay	39 times
12	2011	Dave Ta Teh Chang, et al.	Soil-cement mixture	Fly ash	971 times

Table 1. Effect of nano material/admixture when mixed soil/sand.

Above table showing the reduction in permeability of soil and sand with the addition of admixtures (nano particle, fly ash, cement, nano fibers, bentonite and nano bentonite). This analysis is overview of past researches. Gupta and Alam and Atiqah Najwah Zainuddin reported reduction in permeability more than 1000 times. One of the major finding from the past study is nano bentonite reduced the permeability 240000 times. It was confirmed from the finding of Gupta and Alam study that permeability of sand reduced up to more than 1000 times with addition of 80% fly ash and very less percentages of cement mixed with sand (Figure 1) [7].

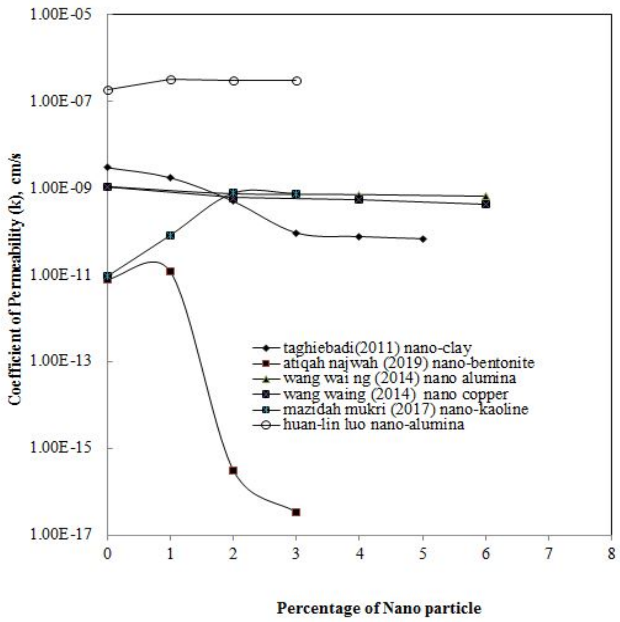

Figure 1. Difference between coefficient of permeability and percentage of nano particle.

Materials and Methods

Sample preparation and methodology

Fly ash: Fly ash was procured from a thermal power station Harduaganj in the district of Aligarh Uttar Pradesh. Table 2 below represents the physical properties of fly ash.

Properties	Values
Specific gravity	2.01
Coefficient of permeability, k (cm/sec) 1	1.0×10^{-04}
D_{10}	0.013
D_{30}	0.02
D_{60}	0.04
Uniformity coefficient (Cu)	3.37
Coefficient of curvature (Cc)	1.24

Table 2. Physical properties of fly ash.

Nano material: Nano material, basically a silicon oxide compound, was obtained from nano research lab, Jamshedpur, Jharkand, India. Nano silica is a white powder which is insoluble in water (Table 3).

Properties	Values
Melting point	1830ºC-1850ºC
Boiling point	2500ºC-300ºC
Density at 20ºc	2.4 gm/cm^3
Water	Insoluble
Purity	95%

Table 3. Physical properties of nano silica.

Various combinations of fly ash and sand were investigated to examine the impact of mixing of fly with sand on permeability. According to specific gravity of sand and fly ash, fly ash is mixed with the fine sand in increasing proportions of 5%, 15%, 25%, 35%, 45%, 55%, 65%, 75%, 85%, 100%. It has been found that 80% fly ash mixed with 20% sand gives the least permeable combination out of all (Figures 2 and 3). Further least permeable sample is mixed with nano silica in increasing order by 5%, 7.5%, 10%. A falling head and constant head method was used to test all samples for hydraulic conductivity (Tables 4-6).

Sieve size (mm)	Weight retained (gm)	Percentage weight retained	Cumulative Weight retained	Percent finer (N)
600	0.3	0.061	0.061	99.93
450	3.5	0.72	0.781	99.21
300	6	1.23	2.011	97.98
212	10.6	2.18	4.19	95.81
150	3.5	0.72	4.91	95.09
75	74.4	15.36	20.27	79.73
45	275.5	56.89	77.16	22.84
PAN	110.4	22.8	100	0

Table 4. Particle size distribution of fly ash.

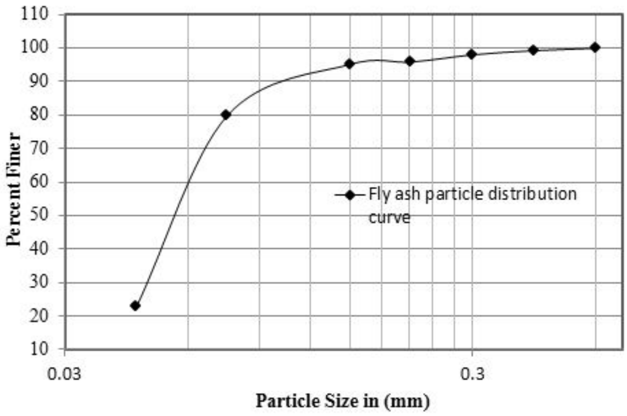

Figure 2. Fly ash particle distribution curve

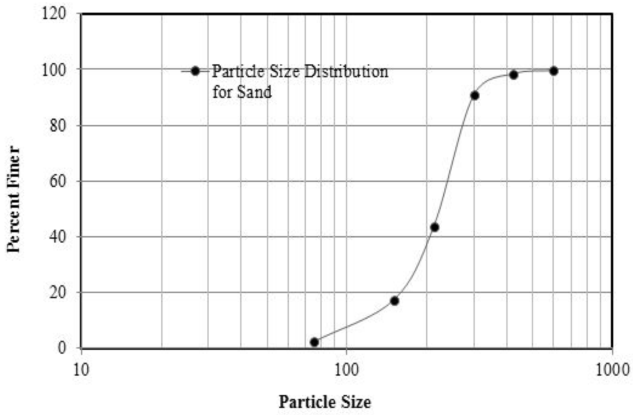

Figure 3. Particle size distribution for sand.

Sieve size (mm)	Weight retained (gm)	Percentage weight retained	Cumulative weight retained	Percent finer (N)
600	0.3	0.061	0.061	99.93
450	3.5	0.72	0.781	99.21
300	6	1.23	2.011	97.98
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150	3.5	0.72	4.91	95.09
75	74.4	15.36	20.27	79.73
45	275.5	56.89	77.16	22.84
PAN	110.4	22.8	100	0

Table 5. Particle size distribution of sand.

Sand	Fly ash	K (constant head) cm/s	K (falling head) cm/s
100%	0%	5.15E-03	6.87E-03
95%	5%	-----------	8.19E-04
85%	15%	5.83E-04	3.11E-04
75%	25%	3.18E-04	1.82E-04
65%	35%	------------	1.24E-04
55%	45%	1.40E-04	1.44E-04
45%	55%	1.26E-04	1.32E-04
35%	65%	7.50E-05	7.27E-05

25%	75%	7.00E-05	7.01E-05
20	80%	6.01E-05	5.73E-05
15%	85%	9.78E-05	9.94E-05
0%	100%	1.08E-04	1.14E-04

Table 6. Coefficient of permeability results (sand-fly ash mix) before mixing of nano particles.

Observation was carried to investigate the minimum value of coefficient of permeability when fly ash was mixed with sand. Results indicates that with the increase in percentage of fly ash in sand the permeability value was decreases, this deduction of permeability happens up to certain limit (80% fly ash+20% sand) (Figure 4). After achieving its optimum value the permeability value change its pattern and suddenly starts increasing (Table 7).

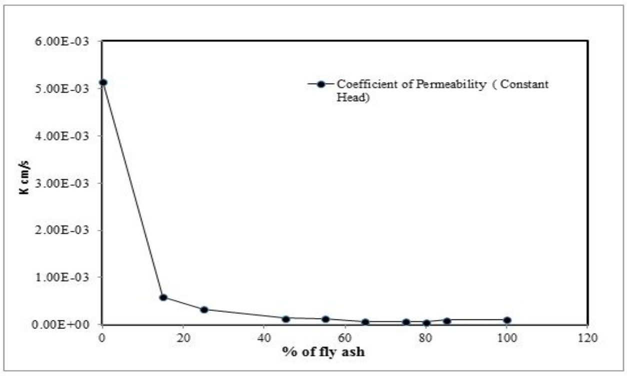

Figure 4. Coefficient of permeability (constant head).

S. No	Time	Coefficient of permeability
1	2 hour	1.36E-05
2	1 day	9.33E-06
3	2 day	7.73E-06
4	7 day	7.95E-06

Table 7. Observation of effect of 5% nano on the permeability of fly ash-sand mix with time.

Observation was carried out to investigate the optimum time required for the complete saturation of nano silica particle when it is mixed in fly-ash sand mix. To perform this research 5% of nano silica in powder form was mixed with (80% fly-ash+20% sand) mix. Above results indicates that the coefficient of permeability was decreased as we increase the time initially up to 24 hours after that it was noticed that the permeability value achieved its constant limit (Table 8).

S. No.	Percentage of nano	K (cm/s)	Percentage reduction
1	0	6.00E-05	0
2	5	7.95E-06	86%
3	7.5	3.48E-06	
4	10	2.70E-06	22%
5	12.5	2.20E-06	18.50%

Table 8. Coefficient of permeability result nano mixed with 80% fly ash+20% sand.

After achieving minimum permeable combination of fly ash sand mix, another investigation was carried out. In this observation nano silica was mixed in dry state in different percentage with 20% sand+80% fly ash. Results clearly indicated with the incorporation of nano silica permeability value of sand-fly as mix was decreased up to almost impermeable value (Figures 5-8).

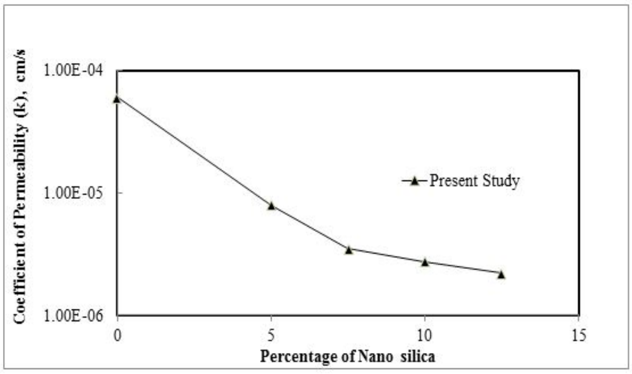

Figure 5. Variation of permeability after mixing nano particles.

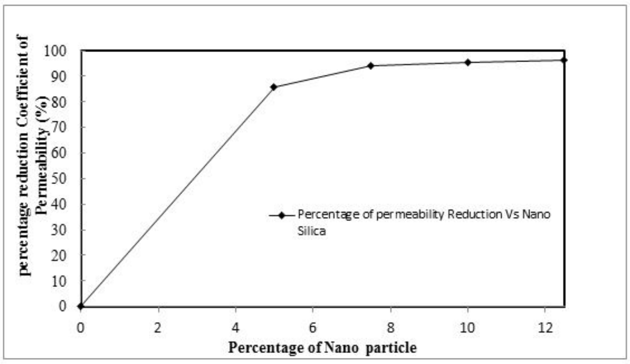

Figure 6. Reduction in permeability after mixing of nano particles.

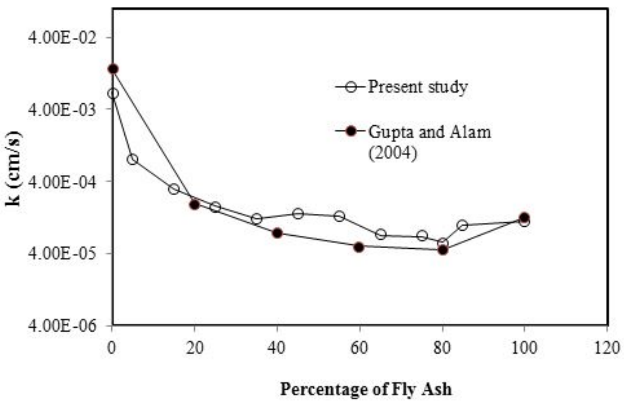

Figure 7. Graphical comparison of present study and past study (Gupta and Alam) on permeability of fly ash-sand mixture.

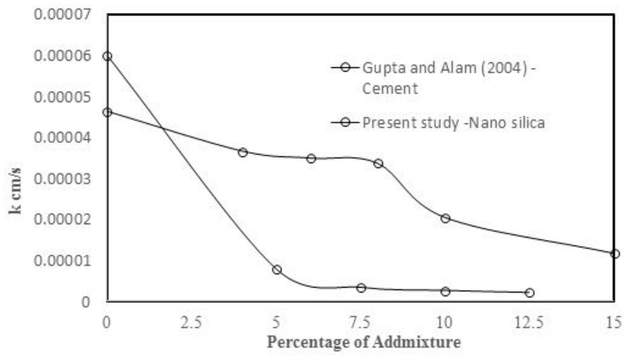

Figure 8. Graphical comparison of past study (Gupta and Alam) and present study.

In present study nano silica is used to mix with fly ash-sand mixture but in past study (Gupta and Alam) cement is used to mix with fly ash-sand mix.

Discussion

Figure 8 showing the variations in results in the value of coefficient of permeability which was examined by few researchers in their researches. This might be due to many reasons such as improper chemical bonding, the size, shape and chemical composition might affect the proper bonding of nano particle with soil. Figure 8 showing the variation in results despite the fact that most of the time permeability value decreases with the incorporation of nano particle but still we can see in some researches that with the incorporation of nano particle the permeability value increases. Nano particle in some of past study increased the permeability of soil this might be due to the variation of nano particles size shape and chemical composition. The different size and shape of nano particles influence the reactivity. Moreover, soil properties might also effect the interaction with nano particle. This consequently altered the properties while bonding of nano particles with soil.

Particle size distribution curve/gradation curve is important characteristic while comparing the results of permeability. Coefficient of permeability was also affected with particle size distribution. Figure showing almost same pattern of graph but with different intercept of ordinate that might be due to difference in material property. The reason behind is that different type of soil have different coefficient of permeability because the coefficient of curvature and coefficient of uniformity are varying with different type of soil. The size of nano particle is very fine and when it mixed with different type of material like soil and sand it fill the voids of this porous material. If the mixing of these materials with nano particles is not taken care of than there chance of negative effect on permeability value might be seen with the incorporation of nano particles. If nano particles are not mixed properly with these porous materials, then nano material should be coagulate to the other fine particles of sand and soil and this effect cause them to combine an even bigger particle. This phenomenon might allow the inner structure of producing gaping or even some large void may be produced and due this negative effect the smooth drainage path should be available for the flow of liquid inside the matrix.

In Figure 8 it was observed from the graph of present study and the graph of past study that both of study follows the same graphical pattern but still there is a minute variation in the permeability value.

These variations have some different aspects and different parameters and different reasons. One of the major reason should be consider that in past study (Gupta and Alam) used standard sand in present study local available sand are used to investigate. Also fly ash used in the present study is different from the past study.

Every pattern has threshold limit for example when performing optimum dry density experiment on sand it has been noticed that by adding water content dry density of sand increase up to optimum moisture content after that it decreased by further adding of water content. Similarly, in present study when the permeability test was conducted the permeability value decreased up to certain value when fly ash mixed with sand (80% fly ash-20% sand). Further adding of quantity of fly ash increases the value of permeability this might be due to the increase in fly ash quantity that eventually reduced the void filling capacity.

Table 8 is showing the value of coefficient of permeability with variation in different percentage of fly ash was mixed with sand. Results of coefficient of permeability has been obtained by performing both falling head and constant head experiment. Results indicates that with the increase in percentage fly ash in fly ash-sand mix the permeability value was decreases, this reduction of permeability value occur up to certain limit (80% fly ash and 20% sand). After attaining its threshold value the permeability value changes its pattern and suddenly starts increasing.

Overall these findings are in accordance with findings reported by past study Gupta and Alam. Even though we did not replicate the previously reported study, present study results suggest that minimum permeability achieved by mixing 80% of fly ash by 20% sand a similar conclusion was reached by past study Gupta and Alam.

After achieving minimum permeability combination in fly ash-sand study a further novel finding is effect of permeability with further treating of nano silica with fly ash-sand combination. Table 8 showing the results of coefficient of permeability with mixing of nano silica with minimum permeable combination. Present study demonstrates two things. First, coefficient of permeability decreased significantly with the increase of nano silica dosage. Second, the rate of deduction of permeability decreases as increases in nano dosage. From the results it is cleared that permeability value decreases with increase in nano dosage but the rate of permeability deduction is also decrease.

Conclusions

From the present study following conclusion can be drawn:

- It was observed that when 20% of sand mixed with 80% of fly ash gives value of permeability (6×10^{-05} cm/s) which is 86 times lower than the permeability of sand.
- It was observed that a mixture of 20% sand and 80% fly ash mixed with 12.5% of nano silica gives a permeability (2.20×10^{-06} cm/s) *i.e.* in the range of clay which is 2340 times lower than the permeability of sand.
- The above finding confirms that the incorporation of nano silica in the sand-fly ash mix reduced the permeability significantly. These findings should be replicated where seepage problem occur such as earthen dam and canals. In addition, these findings provide additional information about nano silica of 95% purity can still effectively reduced the permeability without using 99% pure nano silica.
- As we saw in the results, the percentage deduction in permeability value is slightly less in the range of 10 to 12.5% of nano mixed as compared to initial range of nano mixed.
- It might be conclude that if we go further mixing of nano silica dosage over 12.5% then the permeability value may fall even further but not considerably. Nano material is expensive, so 5% nano dosage is sufficient to reduce the value of permeability of sand fly ash mix.
- As the literature review reported permeability coefficient (k) should be around of 10^{-7} cm/sec for impermeable material. Our results suggest that we still have a long way to go. Nevertheless we found that present study almost achieve the impermeable value.
- Researcher of geotechnical field reported good results in deduction of permeability but availability of suitable soil is major problem. To overcome this problem present study is beneficial because fly ash and sand are easily available without any cost issue.
- Present study might be beneficial in the field of hydraulic structure especially earthen dam where seepage is major problem.
- Nano-materials and nanotechnologies have attracted considerable scientific interest due to the new potential uses of particles in nanometer scale and, consequently, large amount of funds and effort have being utilized.
- Even though construction materials may constitute only a small part of this overall effort, it could pay enormous rewards in the areas of technological breakthroughs and economic benefits.

Scope of Future Study

In the present study the efficacy of nano silica on sand fly ash mixture has been attempted to get the low permeable mass. It is suggested that for further study in this area instead of nano silica powder nano fluid of different concentration with different percentage of some binding materials like cement, nano cement can be attempted for the further refinement of results.

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