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Experimental Investigations on Strength and Weight Loss Due to Chemical Attack on Self Compacting Concrete

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Abstract: *Concrete is the most versatile man made construction material, used around the globe. Durability of concrete structure is of great concern to the engineers since it has an indirect effect on economy, serviceability and maintenance. However, lack of skilled labors has affected the construction industry in terms of quality of construction work which in turn has lead to the development of Self Compacting Concrete (SCC). In recent years, self-compacting concrete has gained wide application in the construction industry due to its excellent deformability, segregation resistance and flows easily under its own weight without any vibration. The present investigation has focused to study SCC of M70 grade using fly ash as mineral admixture. Further, the durability properties are examined. From the studies it was observed that the percentage weight loss due to chemical attack increases with the time but percentage loss of compressive strength due to HCl attack was higher compared to* $MgSo_4$ *and NaCl.*

Keywords: *Durability, Self-Compacting Concrete (SCC), HCl, MgSo4 and NaCl.*

1. Introduction

Concrete is the most widely consumed and extremely versatile man made construction material in the world, after water. Being a key ingredient, concrete plays a key role in building a sustainable society. Till 1980 the research study was focused only on the flow ability of concrete, so as to enhance the strength. However, durability did not draw necessary attention of concrete technologists. The strength and the durability of concrete depend up on the degree of compaction. Compaction of concrete is often seen as the Achilles´ heel of traditional concrete, poor compaction affecting concrete´s physical appearance, strength and durability. Creation of durable concrete structure strongly depends on compaction by skilled labors. The complex and heavily reinforced structures showed that compaction of concrete by vibrating may be difficult in some cases and strongly depend on a human factor. Lack of skilled labors, malpractices, communication gap between designers and construction engineers had affected the construction industry which was reflected in the quality of construction work. These reasons have resulted in the development of Self Compacting Concrete (SCC) a much needed revolution in concrete industry to improve the performance of concrete in terms of strength and durability.

Self-compacting concrete (SCC) is an innovative concrete introduced in Japan in 1986 by Prof. Hajime Okamura. SCC does not requires vibration for placing and compaction as it is able to easily flow under its own weight, completely fill the formwork and achieves full compaction without segregation, even in the presence of congested reinforcement without compromising its engineering properties. Elimination of vibration for compaction had led to substantial advantages like better homogeneity, enhancement of working environment and improvement in the productivity by increasing the speed of construction and resulting cost reduction. Due to its high-fluidity and resistance to segregation SCC can be pumped to longer distances.

Nan Su et al., (2001) had developed an alternative method for composing SCC, referred as Chinese method. Paratibha Aggarwal et al., (2008) presented a procedure for the design of self-compacting concrete mixes without using VMA keeping the cement content around 350 kg/m3 to 414 kg/m3. Srinivas Rao et al., (2005) studied the behaviors of compressive strength, split tensile strength and flexural strength of M30 and M35 grade of self compacting concrete using EFNARC guidelines. The experimental investigations carried out by various researchers Jagadish Vengala, and

Ranganath (2004), Poppe and Shutter, (2005); Girish (2010) KS Johnsirani and A Jagannathan(2015) et al., on the effects of addition of mineral admixtures and partial replacement on the flowing ability and segregation resistance of SCC. Further, various researchers Lumbhar, and Badwade, (1997) Ganesan et al., (2006) , R.Sathia, et al., (2008), K.M.A.Hossain, and M.Lachemi (2010), Dhiyaneshwaran et al (2013) carried out studies on the durability of SCC.

Even though there has been a spectacular growth occurring in concrete production, the chemical exposure of concrete results in early deterioration of concrete structures. The seriousness of problem is reflected with high cost of repair and replacement of deteriorated structure. Thus durability of concrete has become an important issue today for the conservation of resources and to mitigate the environmental impacts. It is recognized that sustainability is not possible without durability. Although durability is a key factor of SCC, very limited work has been carried out in this regard. Hence, an attempt in this paper has been made to investigate the effects of chemical attacks (Nacl, MgSo4, HCl) on the durability properties like loss of weight and loss in compressive strength of SCC of M70 grade using mineral admixtures.

2. Materials Used

For the present work Birla super of grade 53 cement (IS: 12269-1987) with specific gravity of 3.17 was used. Locally available river-sand, free from silt and organic matters was used as fine aggregate (FA). The particle size of the sand used was passing through 4.75mm sieve conforming to zone II of IS: 383-1970. The specific gravity of FA used was 2.561. Locally available crushed granite aggregate passing through 12.5mm and retaining on 4.75mm was used as coarse aggregate (CA)for all of the mixes of SCC. The CA used was conforming to IS: 383-1970. The specific gravity of CA used was 2.66. Class F fly-ash from Raichur Thermal Power Plant was used as cement replacement material for SCC mixes. Addition of fly-ash to SCC paves the path to reduce the cement content and makes SCC most economical leads to sustainability. The specific gravity of the fly-ash used is 2.4. The water used for both mixing and curing was potable which is free from suspended solids and organic materials. Chemical admixtures such as high-range water reducer (HRWR) and viscosity modifying admixtures (VMA) are used for high workability requirement. The super plasticizer used in the present work is Glenium B233 which is commercially marketed by BASF Construction Chemicals (India) Private Limited. This super plasticizer conforms to ASTM C494 Types A and F and IS: 9103-2003.Viscosity Modifying Agent (VMA) used in the present work is Glenium Stream-2, water soluble polymer, which is commercially marketed by BASF Construction Chemicals (India) Private Limited.

3. Experimental Work

The experiment consists of two stages. In the first stage trials were carried out to find a suitable design mix for M70 grade for SCC. The second stage consists of casting 100mm x 100mm x 100mm size cubes specimen to study compressive strength and durability of self-compacting concrete subjected to different aggressive environments. Table 1 shows the materials required to obtain M70 grade SCC. For design mix of M70 grade the compressive strength were evaluated after 7 day, 14 day, 28 day, 56 day and 90 days. The durability tests were conducted after 7 day, 14 day, 28 day, 56 day and 90 days of curing by immersing the cubes in 0.1N HCl, 5% Sodium chloride (NaCl) and 5% Magnesium sulphate (MgSo4)solutions separately. The deterioration of specimens in the form of percentage reduction in weight and compressive strength of concrete on 7th, 14th, 28th, 56th and, 90th days were observed.

***Table 1**: Materials required for M70 concrete (Nan-Su et al method)*

Cement	445.71 kg/m^3
Fly ash	288.03 kg/m^3
Fine Aggregate	799.2 kg/m^3
Coarse Aggregate	645.2 kg/m^3
Water	205.45kg/m^3
High-Range Water Reducer (HRWR)	1.2%
Viscosity Modifying Admixtures (VMA)	0.2%

4. Results and Discussion

Various trial mixes were attempted to obtain M70 grade SCC using Nan-Su et al method. Table 1 gives mix proportion for M70 grade of SCC using mineral admixture. Water to cementatious material by weight was kept at about 0.28 for M 70 grade of concrete.

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Table 2 gives strength for trial mix of M70. It was observed that the average compressive strength of trial mix of M70 obtained was 75 MPa for 28 days - which was more than the required strength

***Table 2**: Compressive Strength for trial mix of M70*

Grade of Concrete	Average Compressive Strength(MPa)		
M70	3days	7days	28days
	35	58	75

4.1. Durability tests of self-compacting concrete using mineral admixtures

Durability of concrete is generally regarded as inability to resist the effects and influence of the environment, while performing its desired functions. For longer serviceability as well as maintenance of structures studies on durability aspect is very much needed. Out of all the factors influence the durability of concrete chemical attack is a chief factor which is responsible for deterioration of structures by causing volume change and cracking. The deterioration of specimens to chemical attacks has been carried out by immersing the concrete specimens in solution of 5% sodium chloride (NaCl), 5% magnesium sulphate (MgSo4) and 0.1N dilute hydrochloric acid separately. These specimens were tested at the intervals of 7days, 14 days, 28 days, 56 days, and 90 days. The resulting deterioration of specimens is represented as percentage loss of weight and percentage loss of compressive strength in tables 3 and 4 respectively.

When the specimens are subjected to attack with acids all the cement compounds are leached away by breaking in to pieces together with any carbonate aggregate material. When the specimens are subjected to sulphates a product called Ettringite is formed leading to cracking. Chloride attack is particularly important because it primarily causes corrosion of reinforcement.

4.1.1. Percentage Loss of Weight of Self Compacting concrete

The percentage loss of weight of SCC of M70 grade after immersing in 5 % NaCl, 5 % MgSo4, & 0.1N HCl are presented in table 3 and also in Fig.1 respectively

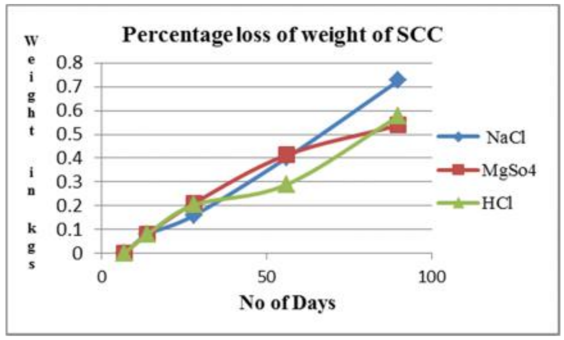

***Figure 1.** Percentage loss of weight after immersing in 5 % NaCl, 5 % MgSo4, & 0.1N HCl.*

***Table 3:** Percentage Loss of Weight of Self Compacting concrete*

Grade of Concrete	5% NaCl Solution				
M70	7 Days	14 Days	28 days	56 days	90 days
Percentage Loss of Weight	0.00	0.079	0.159	0.400	0.726

Grade of Concrete	5% MgSo4 Solution				
M70	7 days	14 Days	28 days	56 days	90 days
Percentage Loss of Weight	0.00	0.080	0.210	0.413	0.538

Grade of Concrete	0.1N HCl Solution				
M70	7 days	14 Days	28 Days	56 Days	90 days
Percentage Loss of Weight	0.00	0.081	0.203	0.288	0.576

Percentage Loss of weight of specimens after immersing in 5 % NaCl Solution:

Chloride attack is particularly important because it primarily causes corrosion of steel. From table 3 the percentage loss of weight of M70 grade concrete specimens immersed in solution of 5% NaCl was observed to be 0 for 7days, 0.079% for 14 days, 0.159% for 28 days, 0.40 % for 56 days and 0.726 % for 90 days respectively. The percentage loss of weight was observed to be increasing with the time.

Percentage Loss of weight of specimens after immersing in 5 % MgSo4 Solution:

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Generally, Sulphate exposure causes an increase in volume of cement paste in concrete or motor due to the chemical action between products of hydration and solution containing sulphate as well as sodium, magnesium and chloride. From table 3 the percentage loss of weight due to 5% MgSo4 was observed to be 0 for7 days, 0.080% for 14 days, 0.21% for 28 days, 0.413% for 56 days and 0.538 % for 90 days respectively. The percentage weight loss was observed to be increasing with the time.

Percentage Loss of weight of specimens after immersing in 0.1 N HCl Solution:

Concrete is not completely acid resistant. Acid affects concrete by dissolving the cement paste and calcareous aggregates. From table 3 the percentage loss of weight due to 0.1 N HCl was observed to be 0 for 7days, 0.081% for 14 days, 0.203% for 28 days, 0.288% for 56 days and 0.5575% for 90 days respectively. The percentage weight loss was observed to be increasing with the time.

From the above results it was observed that the percentage loss of weight due to chemical attack in all the three cases increases with the time as the above chemical causes broken down and leaching of cement compounds together with carbonate aggregate material.

4.1.2 Percentage Loss of compressive strength of Self Compacting concrete

The percentage loss of compressive strength of Self Compacting concrete of M70 grade was presented in table 4 and also in Fig.2 respectively.

Table 4: *Percentage Loss of compressive strength of Self Compacting concrete*

Grade of Concrete	5% NaCl Solution				
M70	7 Days	14 days	28 days	56 days	90 days
	0.823	7.532	7.659	8.150	7.075
Grade of Concrete	5% $MgSo_4$ Solution				
M70	7 days	14 days	28 days	56 days	90 days
	6.147	7.105	7.230	7.725	8.854
Grade of Concrete	0.1N HCl Solution				
M70	7 days	14 days	28 days	56 Days	90 Days
	9.01	10.04	12.766	19.739	22.120

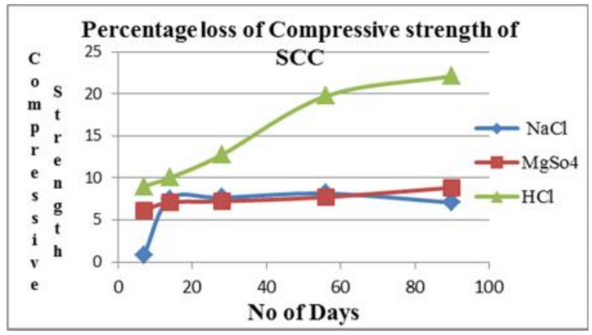

Figure 2. *Percentage loss of compressive strength after immersing in 5 % NaCl, 5 % MgSo4, &0.1N HCl*

Percentage Loss of compressive strength of specimens after immersing in 5 % NaCl Solution:

From table 4 the percentage loss of compressive strength due to 5% NaCl was observed to be 0.823 for 7days, 7.532% for 14 days, 7.659% for 28 days, 8.150% for 56 days and 7.075% for 90 days respectively. The percentage loss of compressive strength was observed to be increasing with the time.

Percentage Loss of compressive strength of specimens after immersing in 5% MgSo4 solution:

From table 4 the percentage loss of compressive strength due to 5% MgSo4 was observed to be 6.147% for 7days, 7.105 % for 14 days, 7.230% for 28 days, 7.725% for 56 days and 8.854% for 90 days respectively. The percentage loss of compressive strength was observed to be increasing with increasing time.

Percentage Loss of compressive strength of specimens after immersing in 0.1N HCl solution:

From table 4 the percentage loss of compressive strength due to 0.1N HCl was observed to be 9.01% for 7 days, 10.04% for 14days, 12.766% for 28 days, 19.739% for 56 days, and 22.120% for 90 days respectively. The percentage loss of compressive strength was observed to be increasing with the time.

From the above results it was observed that the percentage loss of compressive strength due to chemical attack in all three cases increases with the time. The percentage loss of compressive strength is almost uniform with time for the cubes subjected to MgSO4 and NaCl attack. However, compressive strength loss due to HCl attack was higher compared to the cubes subjected to MgSO4 and NaCl attack, as acid attack is more aggressive than

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attack due to chloride and sulphate which are alkaline in nature.

5. Conclusion

SCC is very promising construction material that can overcomes the problem of concrete placement in heavily reinforced sections, but when it is exposed to highly aggressive environment shows early deteriorations. Self-compacting concrete mix of M70 grade can be achieved with addition of 288.03 kg/m3 Fly ash, 1.2% SP and 0.2 % VMA. Addition of fly-ash reduces cement content makes SCC more economical, mitigating environmental pollution and helps to achieve sustainability. From study it was observed that the percentage weight loss and the percentage loss of compressive strength of self-compacting concrete increases correspondingly with the time after immersing in 0.1N HCl, 5% MgSo4 and 5% NaCl solution. The percentage weight loss is due to broken down and leaching of cement compounds together with carbonates aggregate material. The percentage loss of compressive strength is higher in 0.1N HCl compare to 5%NaCl and 5% MgSo4 since acid attack is more aggressive than chloride and sulphate which are alkaline in nature.

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Linear Interactive and Non-Linear Interactive Analysis of Buried Structures–A Parametric Study

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Abstract: *The finite element analysis has been carried out considering the effect of soil structure interaction of strip footing pressure on soil model. A linear interaction analysis of the footing pressure has been carried out under to effect of soil structure interaction. A non-linear interaction analysis has been carried out using multi-linear model in a non-linear elastic state for the soil.*

Keywords: *Interactive, Settlement, Multi linear, Vertical stress.*

1. Introduction

An analyst or a designer is mainly concerned with the analysis and design of a variety of structures. All these structures are exclusively supported by soil and hence the subject of soil structure interaction has come into existence. The settlement, contact pressure in the elastic soil affected by strip footing pressure and IRC class AA loading as buried structures.

2. Numerical Modeling

The finite element discretization has been carried out using plane83 element. The element is defined by eight nodes having two degrees of freedom (u,v) at each node, translations in the nodal x and y directions. Finite element discretization of the soil system with strip loading and degrees of freedom per node is shown in Fig 2. Due to symmetry left side nodes are constrained along x direction and both x and y direction nodes are constrained at bottom and right side. The mesh size is used for element is 0.5 m x0.5 m.

The geometrical details of the soil are tabulated in the table 1 and the material property of soil are tabulated in table 2. Strip footing pressure of 300 kN/m² is applied on width of 2m soil shown in Fig.1. ANSYS software package has been used for comparing with the analysis.

Table 1: *Geometric Details*

Sl.No	Structure	Width	Depth
1	Soil	10m	10m

Table 2*: Material Properties*

SL No.	Component	Elastic modulus kN/m²	Poisson's Ratio
1	Soil mass	80000	0.35

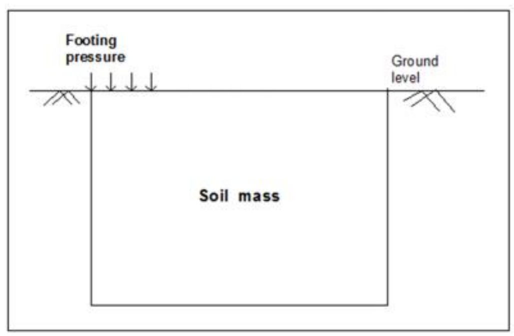

Figure 1. *Plane soil mass with strip footing pressure*

2.1. Discretization

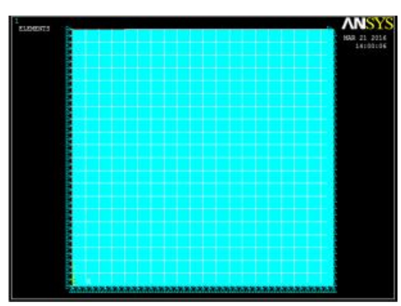

Figure 2. *Finite element discretization of soil system with strip footing pressure*

2.3. Constitute modeling

The behaviour of the most of the geological materials is non-linear. The non-linear, in general may be due to changes in the geometry and changes in the materials properties. To account for the material non-linearity of the soil media, non-linear elastic model multi-linear model has been selected for the study.

A multi-linear model can be defined as an approximation of actual non-linear behaviour using a passive linear approximation. In other words, a non-linear behaviour is replaced by a series of elastic response. For each piece the material parameters such as E and μ or (K and G) are evaluated by making stress as function of the state of stress.

The tangent modulus is defined as slope between two computed points as-

$$ET=\frac{\sigma_i-\sigma_{i-1}}{\varepsilon_i-\varepsilon_{i-1}} \quad \text{--------- (1)}$$

The constitutive equation can be derived in incremental form as

$$d\sigma_y=Kd\varepsilon_{nn^{\delta}ij}+2G(d\varepsilon_{ij}-\frac{1}{3}d\varepsilon_{nn}\delta_{ij}) \quad \text{--------- (2)}$$

$$(d\sigma)^m=(D_t)^m(d_t)^m \quad \text{--------- (3)}$$

Where m denotes the mth increment of stress $(d\sigma)$ and strain $(d\varepsilon)$ and $(D_t)^m$denotes the tangent constitutive matrix corresponding to the mth load increment. The stress-strain curve which is used for the analysis has been shown in Fig.3. The multi linear model is useful for respective non-linear elastic nature of soil.

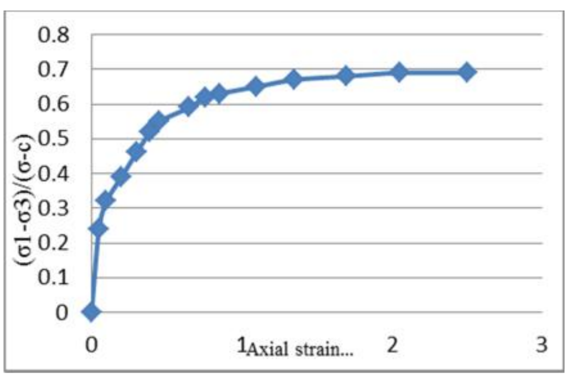

Figure3. *Stress-strain curve from triaxial test on Kawasaki normally consolidates clay*

3. Result and Discussion

3.1. Interactive Analysis

It can observe more settlement below centre and edge of strip footing and gradually, reducing along depth of the soil mass. Most of settlement with depth, below centre and edge of strip footing in the soil is shown in Fig.4. The vertical settlement more below the centre of footing than edge of the footing are shown in Fig. 4(a) and Fig. 4(b).

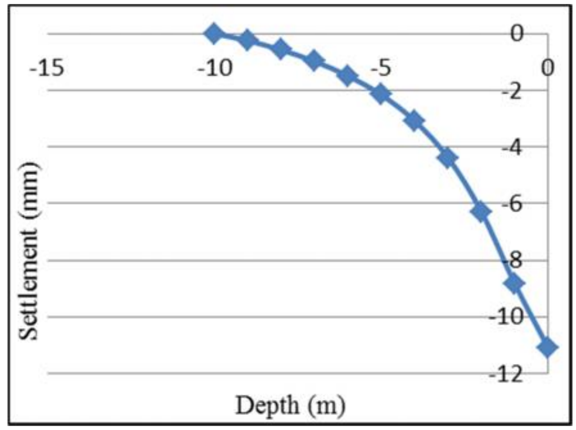

***Figure 4(a)**. Below center of strip footing*

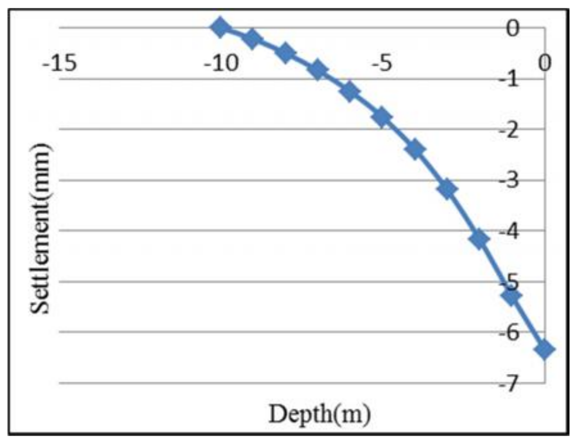

***Figure 4(b).** Below edge of strip footing*

Figure 4. *Variation of settlement with depth, below center and edge of strip footing in soil*

3.2. Vertical stress distribution in the soil mass:

Fig.5. shows variation of vertical stress with depth obtained in a soil system due to strip footing pressure. Vertical stress is maximum below the center of footing up to 6m depth and gradually reduces after 6m is shown in Fig (a). Vertical stress below the edge of footing is half of the vertical stress obtained below the center of footing is shown in the Fig (b). At 4m, 6m away from the center of footing, vertical stress is not observed, hence there is no effect of footing of strip footing pressure to soil is shown in Fig. 5(c) and Fig. 5(d).

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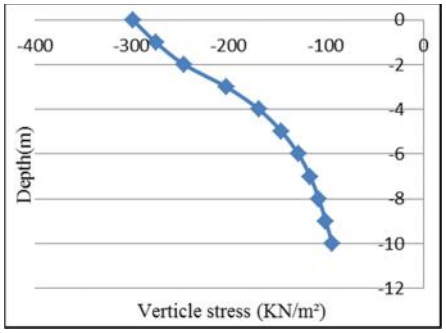

Figure 5(a). *Variation of vertical stress with depth below center of footing*

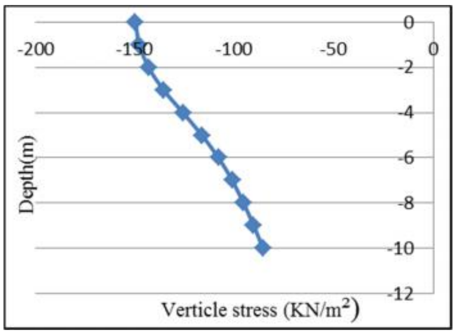

Figure 5(b).*Variation of vertical stress with below depth, below edge of footing*

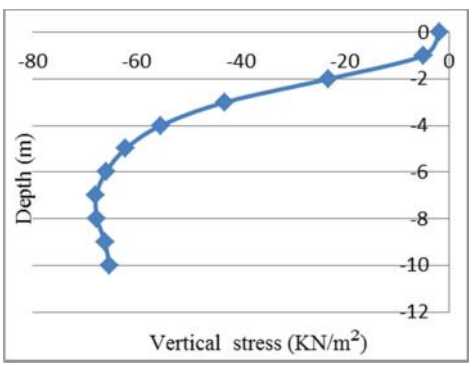

Figure 5(c). *Variation of vertical stress with depth at 4m away from center of footing*

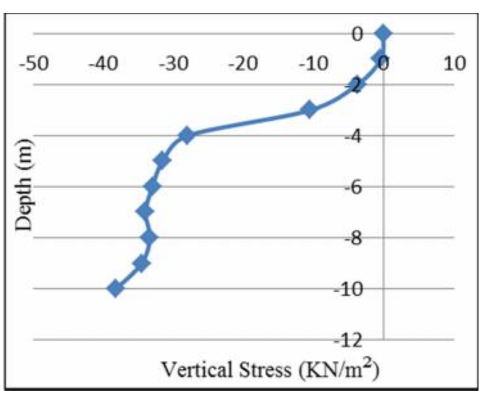

Figure 5(d).*Variation of vertical stress with depth, at 6m from center of footing*

Figure 5*.shows variation of vertical stress with depth obtained in a soil system due to strip footing pressure*

3.3 Comparison of vertical stress from ANSYS and Boussinesq's equation

Using Boussinesq's equation, we can calculate the vertical stress in the soil due to strip footing pressure. The vertical stresses values in the soil are compared with ANSYS and Boussinesq's equation. The variation of vertical stress with depth is shown in fig.6. up to 6m depth, the vertical stress values are compares well in both ANSYS and Boussinesq's results. After 6m depth the vertical stresses values are not comparing more in both ANSYS and Boussinesq's results which is shown in Fig.6.

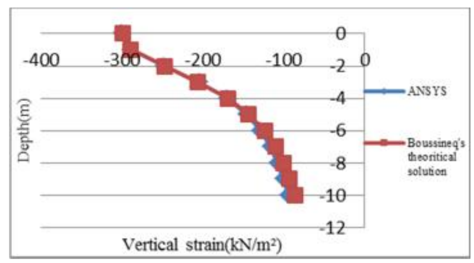

Figure 6(a). *Variation of vertical stress with depth below center of footing*

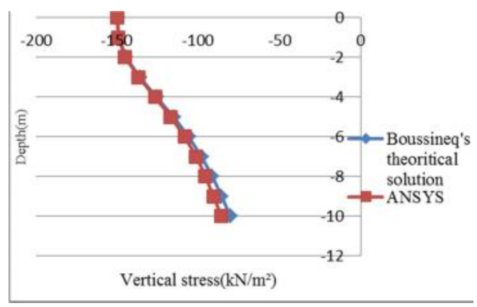

Figure 6(b). *Variation of vertical stress with depth below edge of footing*

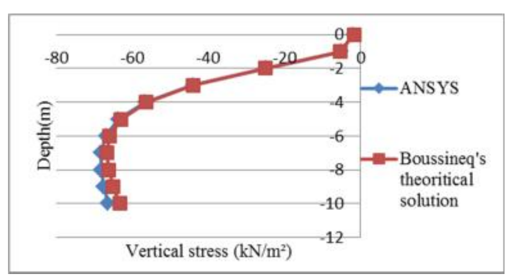

Figure 6(c). *Variation of vertical stress with depth at 4m away from center of footing*

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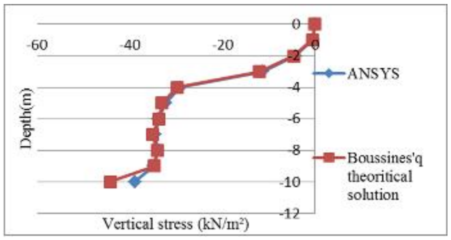

Figure 6(d). *Variation of vertical stress with depth at 6m away from center of footing*

Figure.6*.Comparison of vertical stress using ANSYS and Boussinesq Equation.*

3.4. Comparison of vertical stress from linear and Non-linear analysis

The vertical stresses values in the soil are compared with linear and Non-linear, The variation of vertical stress with depth is shown in fig 7. Up to 6m depth, the vertical stress values are compares well in both linear and Non-linear analysis. After 6m depth the vertical stresses values are not comparing more in both linear and Non-linear analysis which is shown in Fig 7.

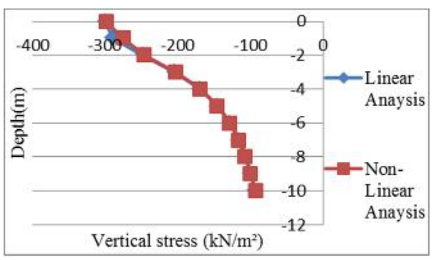

Figure 7(a). *Variation of vertical stress with depth below center of footing*

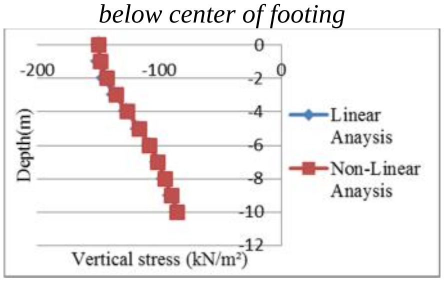

Figure 7(b). *Variation of vertical stress with depth below edge of footing*

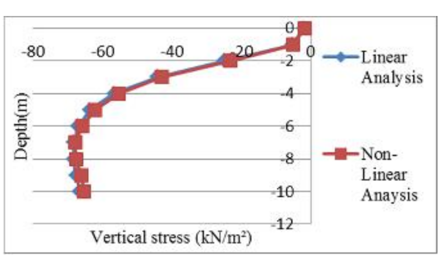

Figure 7(c). *Variation of vertical stress with depth at 4m away from center of footing*

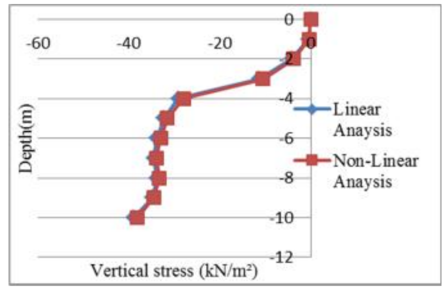

Figure 7(d). *Variation of vertical stress with depth at 6m away from center of footing*

Figure 7*.Comparison of vertical stress using Linear and Non-Linear Analysis*

4. Conclusion

The present work is concerned with the study of linear and Non-linear soil structure interaction of strip footing pressure by considering them as single integral compatible unit using finite element analysis. Based on the limited parametric study carried out, the following conclusions have been drawn.

1) Vertical settlement more below the centre of footing than the edges of footing.
2) Vertical stress below the edges of footing is half of the vertical stress obtained below the centre of footing.
3) Vertical stress obtained from finite element analysis due to strip footing pressure for single layer of soil is compares well with Boussinesq's results.
4) Vertical stress values are compare will in both linear and Non-linear analysis.
5) Finally concluded that linear interaction analysis is sufficient for strip footing pressure analysis.

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