**Geomechanics and Engineering**, *Vol. 9, No. 2 (2015) 261-273*
DOI: http://dx.doi.org/10.12989/gae.2015.9.2.261


# Compaction and unconfined compressive strength of sand modified by class F fly ash

Ashis K. Bera* and Sourav Chakraborty [a]

*Department of Civil Engineering, IIEST, Shibpur, Howrah-711 103, India*

(*Received October 12, 2014, Revised March 23, 2015, Accepted April 09, 2015*)

**Abstract.** In the present investigation, a series of laboratory compaction and unconfined compressive strength laboratory tests has been performed. To determine the effect of compaction energy, type of sand, and fly ash content, compaction tests have been performed with varying compaction energy (2700 kJ/m$^3$-300 kJ/m$^3$), types of sand, and fly ash content (0% to 40%) respectively. From the experimental results, it has been found that the optimum value of unconfined compressive strength obtained for a sand-fly ash mixture comprised of 65% sand and 35% fly ash. Based on the data obtained in the present investigation, a linear mathematical model has been developed to predict the OMC of sand-fly ash mixture.

**Keywords:** compaction; sand; UCS; fly ash; OMC; MDD

## 1. Introduction

A fly ash is a by-product from thermal power plants and can be considered as solid waste. Every year in the world from different thermal power plants a huge amount of residue, commonly called fly ash, is being produced. Disposal of this needs thousands of hectares of precious land, and also it is causing severe health and environmental hazards. Fly ash has the potential applications in different areas like cement manufacturer, brick making, soil stabilization as well as a fill material etc. Utilization of fly ash as structural fill and also road construction from thermal power plants, spatially distributed all over the world, not only helps to consume bulk quantities of fly ash solving its disposal problems to a certain extent; but also satisfies the construction requirements. Ahmaruzzaman (2010) reported that the use of fly ash in road construction works reduce road construction cost by about 10-20%. A number of literatures already documented by the different researchers on effective utilization of fly ash alone or mixed with clay and lime/ cement/lime stone dust/calcium carbide residue in the field of civil engineering application of fly ash (Athanasopoulou 2014, Pal and Ghosh 2014, Manskinen *et al*. 2012, Horpibulsuk *et al*. 2012, Sivapullaiah and Moghal 2011, Brooks *et al*. 2011, Tastan *et al*. 2011, Jongpradist *et al*. 2010, Prabakar *et al*. 2004, Kaniraj and Havanagi 1999). But study on potential use of sand fly ash mixture to strengthen road subgrade as well as structural fill are scarce. Chauhan *et al*. (2008) studied on performance evaluation of silty sand subgrade reinforced with fly ash and fibre.

*Corresponding author, Associate Professor, E-mail: ashis@civil.iiests.ac.in
[a] M.E., E-mail: sourav0403@gmail.com


http://www.techno-press.org/?journal=gae&subpage=7 ISSN: 2005-307X (Print), 2092-6219 (Online)

Table 1 Chemical composition of the fly ash sample

| Constituents | Values (%) |
|---|---|
| $SiO_2$ | 56.55 |
| $MgO$ | 0.79 |
| $SO_3$ | 1.97 |
| $Na_2O$ | 0.012 |
| $Fe_2O_3$ | 2.41 |
| $CaO$ | 2.23 |
| $K_2O$ | 0.0005 |
| $Na_2O$ | 0.012 |
| $Al_2O_3$ | 31.45 |
| LOI (Loss on Ignition) | 3.46 |

Table 2 Physical property of the fly ash sample

| Properties of sample | Value |
|---|---|
| Specific gravity | 2.183 |
| Gravel size (%) | 0.00 |
| Sand size (%) | 23.84 |
| Fines (%) | 76.16 |
| Uniformity coefficient ($C_u$) | 5.07 |
| Coefficient of curvature ($C_c$) | 1.01 |
| Group symbol | ML |
| Plasticity | Non Plastic |
| Permeability (cm/s) | $6.454 \times 10^{-5}$ |

In the present investigation a series of laboratory compaction test and also unconfined compression test has been performed on sand and fly ash mixture to determine the optimum percentage of fly ash content in sand fly ash mixture for construction of road subgrade as well as structural fill. An attempt has been made to develop mathematical model to predict the *OMC* of sand fly ash mixture in terms of fly ash content (FC), optimum moisture content of sand ($OMC_{sand}$), and specific gravity of sand fly ash mixture ($G_{mix}$). An attempt has also been made to develop an empirical equation to predict the specific gravity of sand fly ash mixture ($G_{mix}$) in terms of specific gravity of sand ($G_{sand}$), specific gravity of fly ash ($G_{flyash}$), and fly ash content (FC).

## 2. Materials

In the present investigation one type of fly ash and also three different types of sand have been used.

### 2.1 Fly ash

In the present paper fly ash has been procured from the thermal power plant at Budge Budge,

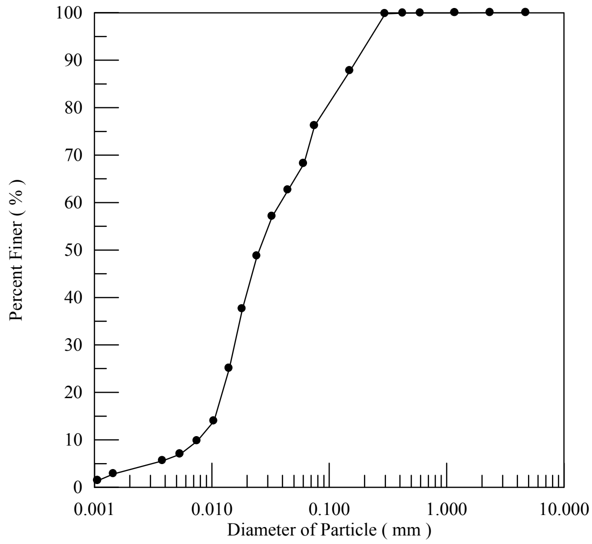


Fig. 1 Grain size distribution curve for fly ash

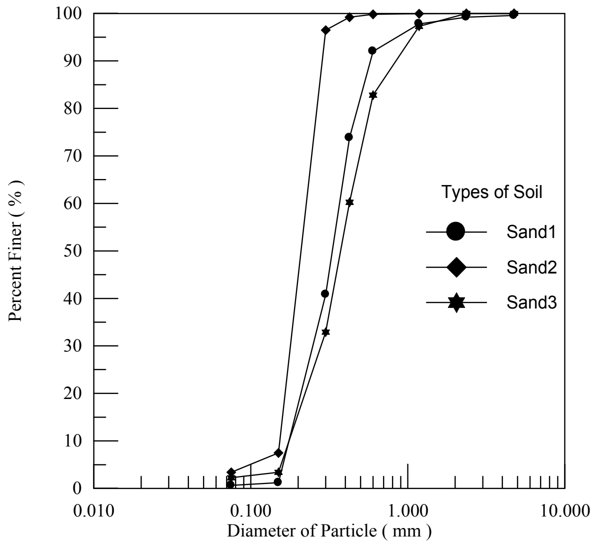


Fig. 2 Grain size distribution curve for sands tested

Kolkata, West Bengal, India. The chemical composition of fly ash has been tested in accordance with IS 3812 (Part-I): 2003. Table 1 presents the different chemical composition of the fly ash. In accordance with ASTM C618, the above fly ash may be classified as a Class F Fly Ash. Basic engineering properties of fly ash such as grain size distribution, specific gravity, and permeability have been determined in the geotechnical engineering laboratory, IIEST, Shibpur. Fig. 1 shows the grain size distribution curve for fly ash sample. Table 2 presents the different engineering properties of fly ash sample. According to USCS the above fly ash sample may be classified as ML.

### 2.2 Sand

In the present study sand samples have been collected from the river bed Ganga near Diamond harbor at Kolkata, Botanical Garden, Howrah and also from Hoogly district in West Bengal. The above three types of sand may be designated as sand1, sand2, and sand3. The engineering properties of sand samples such as grain size distribution, specific gravity, permeability has been performed in the geotechnical engineering laboratory, IIEST, Shibpur. Fig. 2 shows the grain size distribution curve for three sand samples. Table 3 presents the values of different parameters of three different sand samples. In accordance with USCS the sand samples such as sand1, sand2, and sand3 may be classified as SP, SP, and SP respectively.

### 2.3 Specific gravity of sand fly ash mixture

Specific gravity of the sand fly ash mixture has been determined in accordance with ASTM D854. Fig. 3 shows the plots of specific gravity of sand fly ash mixture ($G_{mix}$) versus fly ash content curve. From the curves (Fig. 3) it is found that with increase in fly ash content in the sand fly ash mixture, the values of specific gravity of sand fly ash mixture decreases irrespective of the types of sand. It may be due to low specific gravity of fly ash (2.18) resulting in decrease in specific gravity of the sand fly ash mixture. Mir and Sridharan (2013) also found the similar trend in case of clay soil fly ash mixture.

Based on the present experimental data a linear model has been developed to predict the specific gravity of sand fly ash mixture ($G_{mix}$) in terms of specific gravity of sand ($G_{sand}$), Specific gravity of Fly ash ($G_{flyash}$), and fly ash content (FC, in percentage) as follows

$$G_{mix} = 2.3994 \times G_{sand} - 0.0047 \times FC - 1.6940 \times G_{flyash} \tag{1}$$

To test the effectiveness of the model, the values of coefficient of determination ($R^2$) and

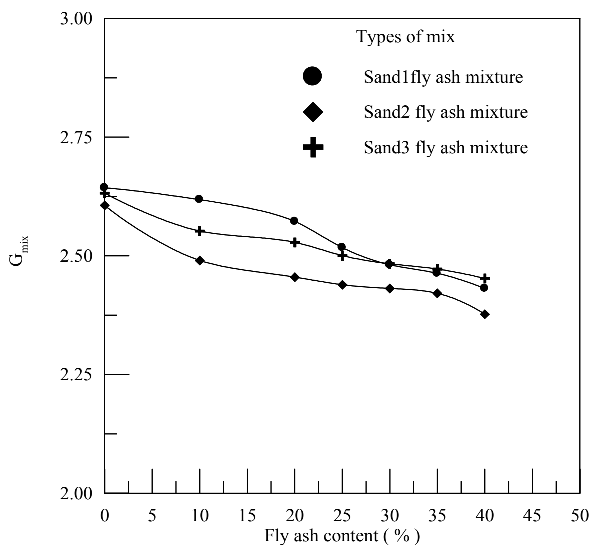


Fig. 3 $G_{mix}$ versus fly ash content curve

Table 4 Values of $t$-statistics and $F$-statistics for different parameter of Eq. (1)

| Parameters | Values of the coefficient of the parameter | Standard error | $t_{\text{statistics}}$ | $t_{\text{critical}} = t_{(0.975,10)}$ | $F_{\text{statistics}}$ | $F_{\text{critical}} = t_{(0.975,3,10)}$ |
|---|---|---|---|---|---|---|
| $G_{\text{sand}}$ | + 2.3994 | 0.316854 | + 7.57272 | | | |
| FC | − 0.0047 | 0.000482 | + 9.65251 | 2.228 | 80961 | 3.71 |
| $G_{\text{flyash}}$ | − 1.6940 | 0.380885 | − 4.44757 | | | |

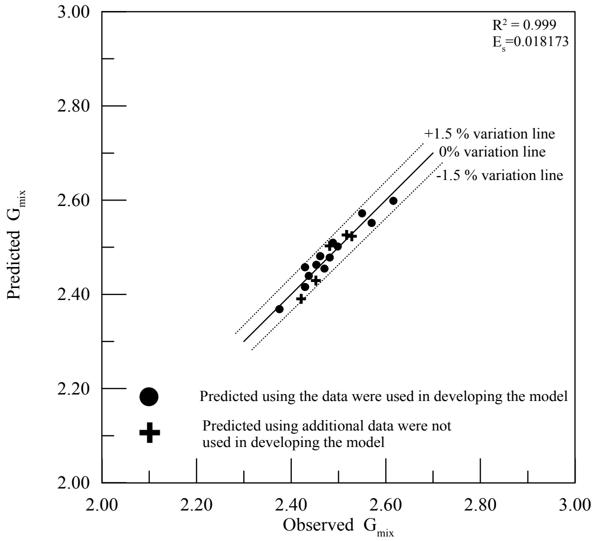


Fig. 4 Predicted $G_{\text{mix}}$ versus observed $G_{\text{mix}}$

estimated standard error ($E_S$) of the model (Eq. (1)) have been determined and corresponding values are 0.99 and 0.018173 respectively. The significance of the regression coefficients as a whole and also partial regression coefficient of the equation (Eq. (1)) has been tested by using '$F$' statistics and '$t$' statistics respectively. Table 4 shows the summary of the '$t$' statistic and '$F$' statistics. From Table 4 it is observed that the coefficients of the equation (Eq. (1)) have significant contribution to the model. Fig. 4 shows the plots of observed $G_{\text{mix}}$ versus predicted $G_{\text{mix}}$. From Fig. 4 it is found that the predicted $G_{\text{mix}}$ based on data used in developing the model and also the predicted $G_{\text{mix}}$ based on the data not used in developing the model are within ± 1.5% error. The above model has been developed based on the present investigation with varying FC, $G_{\text{sand,}}$ within the range of 10-40%, 2.643-2.606 and also one type of fly ash. The authors suggest that beyond this range the model be further refined by at least one series of experimental data.

## 3. Compaction tests

To determine the compaction characteristics of sand modified with fly ash, compaction tests have been performed in two different series (Series A and series B) as shown in Table 5. In the series A, compaction tests have been performed to determine the effect of fly ash content on sand fly ash mixture. To determine the effect of compaction energy on compaction characteristics of sand modified with fly ash, series B has been performed. Standard compaction tests and modified compaction tests have been performed in accordance with ASTM D698 and ASTM D1557. Reduced proctor tests has been performed similar to standard proctor tests except that the compaction energy kept as 300 kJ/m$^3$ by applying number of blows in consecutive three layers 12-,13-, and 12 number respectively.

### *3.1 Results and discussion*

Fig. 5 shows the dry unit weight versus moisture content curve for fly ash sample. Dry unit weight versus moisture content for sand fly ash mixture samples are plotted in Fig. 6. Figs. 7-8 shows the plots of MDD versus fly ash content for sand fly ash mixture sample with varying types of sand samples and also types of compaction. Figs. 9-10 shows the plots of OMC versus fly ash content curves with varying compaction energy and also sand sample respectively. Based on the experimental results discussions are made as follows:

#### *3.1.1 Influence of fly ash content on the Maximum Dry Density (MDD) of sand-fly ash mixtures*

Fig. 7 shows the plots of MDD versus fly ash content for sand fly ash mixture with varying types of sand samples. From the curve it is found that with increase in fly ash content the values of

Table 5 Plan of compaction test

| Series | Type of compaction test | Compaction energy (kJ/m$^3$) | Sand samples | Fly ash content (%) |
|---|---|---|---|---|
| A | Standard proctor tests | 593.9 | Sand1, Sand2,Sand3 | 0,10,20,25,30,35,40 |
| B | Modified proctor tests | 2700.0 | Sand1 | 0,10,20,25,30,35,40 |
| | Reduced proctors | 300.0 | Sand1 | 0,10,20,25,30,35,40 |

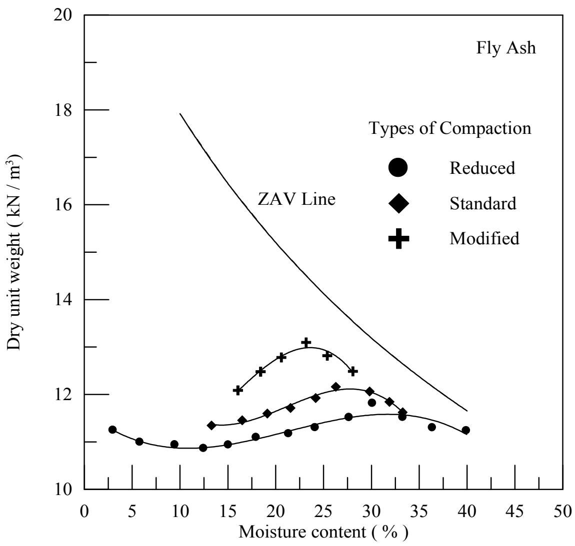


Fig. 5 Dry unit weight versus water content curve for fly ash sample

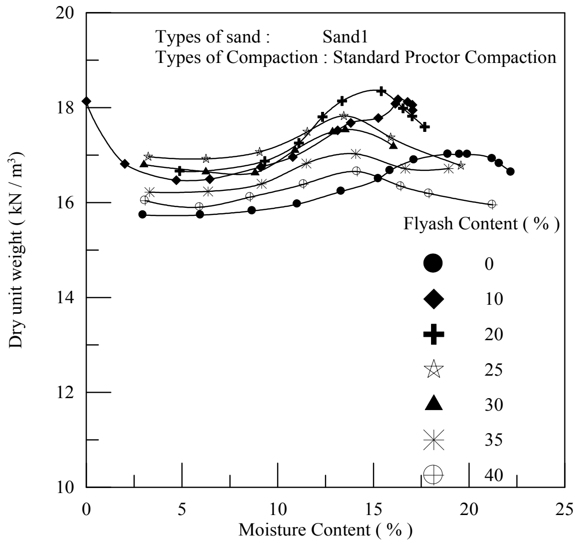


Fig. 6 Dry unit weight versus moisture content for sand fly ash mixture sample

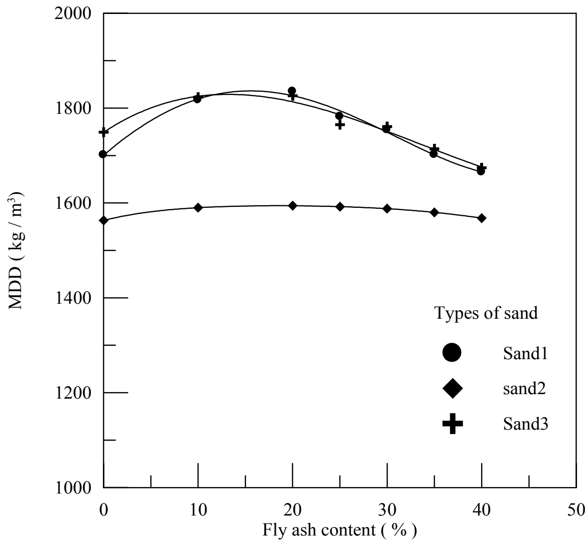


Fig. 7 MDD versus fly ash content curve for sand fly ash mixture sample (Varying types of sand)

MDD increases around up to 15% fly ash content after that it is decreases. Similar trend is observed in Fig. 8. This occurs due to the reason that the void spaces between the sand particles are occupied by the fly ash particles up to 15% by weight of Fly ash and thereafter the extra fly ash content tends to reduce the density. Sharma (2012) found the similar types of results in case of sandy clay fly ash mixture. From Fig. 8 it is also found that with increase in compaction energy (varying compaction types from reduced proctor compaction to modified proctor compaction) dry density of each sand fly mixture increases. It may be due to the fact that with increase in compaction energy result in closer packing of sand fly ash mixture and hence there is a higher dry density.

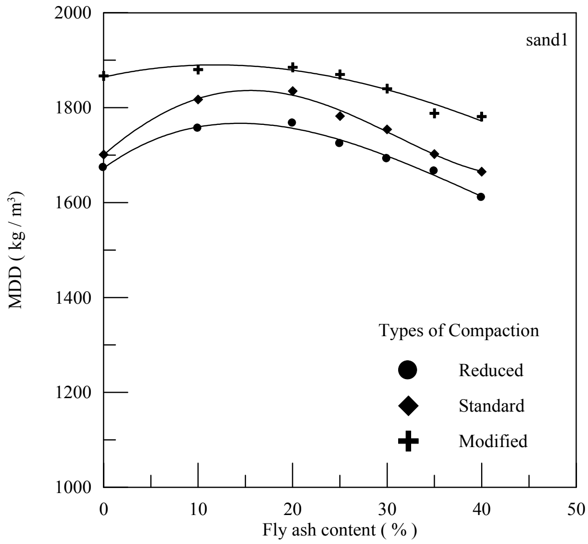


Fig. 8 MDD versus fly ash content curve for sand fly ash mixture sample (Varying types of compaction)

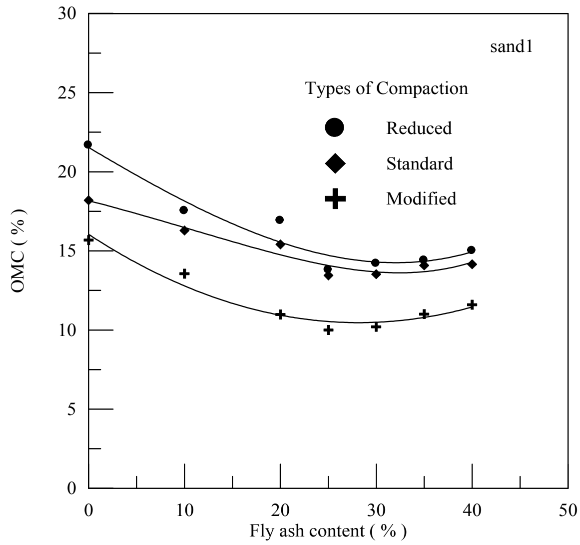


Fig. 9 Optimum moisture content versus fly ash content for sand fly ash mixture sample

### *3.1.2 Influence of fly ash content on the Optimum Moisture Content (OMC) of sand-fly ash mixtures*

Optimum moisture content is one of the important controlling factors for any compaction. Figs. 9-10 shows the plots of OMC versus fly ash content curve with varying compaction energy and also with varying types of sand. From both the curve it is found that with increase in fly ash content the values of optimum moisture content decreases at certain value (around 30%-35%) after that it is remain more or less constant. Chauhan *et al*. (2008) also reported similar type's results in case of sand fly ash mixture.

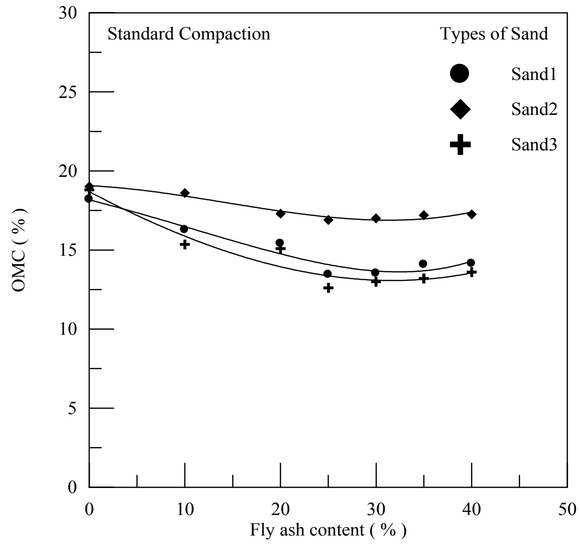


Fig. 10 Optimum moisture content versus fly ash content for sand fly ash mixture sample

Table 6 Testing programme for UCS test

| Series | Sand samples | Fly ash content (%) | Dry density | Water content (%) | Type of compaction test |
|---|---|---|---|---|---|
| 1 | Sand1, Sand2, Sand3 | 0,10,20,25,30,35,40 | MDD of the respective mixture | OMC of the respective mixture | Standard proctor tests |
| 2 | Sand1 | 0,10,20,25,30,35,40 | MDD of the respective mixture | OMC of the respective mixture | Modified proctor tests |
| | | 0,10,20,25,30,35,40 | MDD of the respective mixture | OMC of the respective mixture | Reduced proctors |

## 4. Unconfined compression tests

Based on the OMC and MDD obtained in the different compaction tests for sand fly ash mixture a series of unconfined compressive strength (UCS) tests have been performed. Table 6 presents the testing programme of unconfined compressive strength tests on sand fly ash mixture. Samples were prepared for two series (1 & 2) of UCS tests. The tests under series 1 have been performed with varying fly ash contents for three different sands. In this series dry density and moisture content have been selected from the respective MDD and OMC of respective sand fly ash mixture based on standard Proctor compaction tests. Series 2 have been performed with varying fly ash content for sand1. In this series dry density and moisture content has been selected from the respective MDD and OMC of respective sand fly ash mixture based on modified Proctor compaction tests and reduced Proctor compaction tests. For preparing the UCS test sample of sand fly ash mixture, the required quantity (respective proportion) of dry fly ash has been mixed with dry sand and then water corresponding to the required moisture content (respective OMC of sand fly ash mixture) was spread over the sand fly ash mixture. Then mixing has been done thoroughly.

For preparation of the samples of size 76 mm × 38 mm, the split mould of internal dimension of 38 mm diameter and 76 mm height has been used. Samples have been prepared with uniform tamping. The weights of the prepared samples have been considered against the required respective MDD and OMC of sand fly ash mixture. The UCS test has been performed in accordance with ASTM D 2166.

### *4.1 Results and discussion*

Fig. 11 shows the UCS versus fly ash content for sand1 fly ash mixture samples with varying

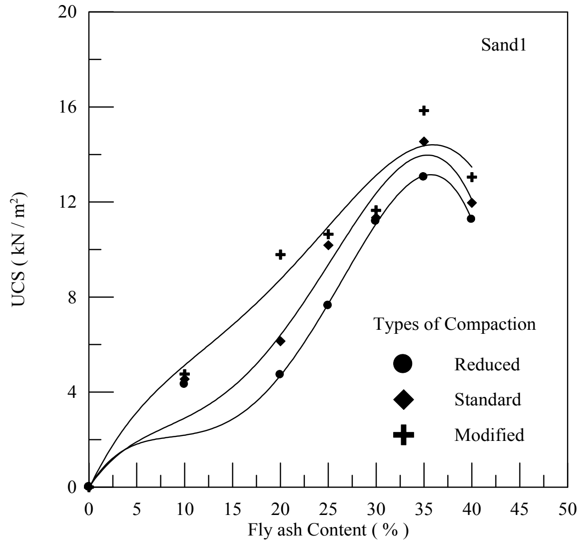


Fig. 11 UCS versus fly ash content for sand fly ash mixture sample

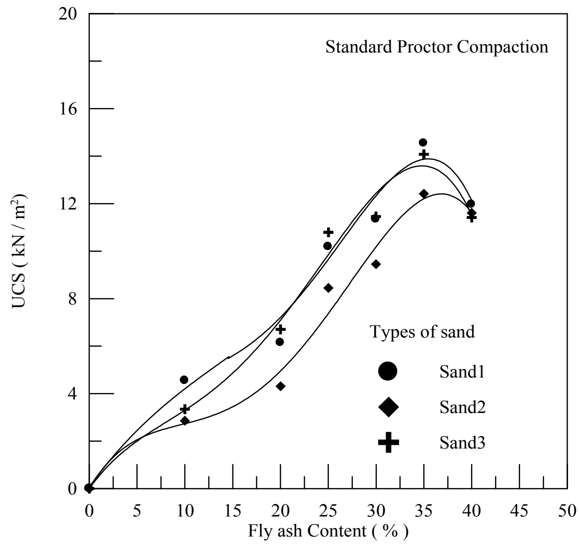


Fig. 12 UCS versus fly ash content for sand fly ash mixture sample

MDD and OMC obtained from the respective compaction methods. UCS versus fly ash content for sand fly ash mixture samples with varying types of sand fly ash mixture at OMC and MDD obtained from the standard proctor tests is plotted in the Fig. 12. From both the figures (Figs. 11-12) it is found that with increase in fly ash content the values of UCS increases and reaches a peak value after that it is slightly decreases. From both the figures (Figs. 11-12) it is also observed that the maximum values of unconfined compressive strength obtained at 35% of fly ash and 65% of sand mixture irrespective of types of sand and compaction energy. Similar types results also found by Chauhan *et al*. (2008) in case of silty-sand fly ash mixture. The maximum values of UCS obtained in this combination (35% FA and 65% sand) of sand fly ash mixture because at this combination of fly ash sand mixture OMC values reaches the optimum value as a result of maximum quantity of cementitious compounds formation between the sand sample and the pozzolans present in the fly ash.

## 5. Numerical model for OMC

Optimum moisture content is an important parameter for any mixture for obtaining the maximum strength. In practice for getting the preliminary idea on OMC, a mathematical model may be necessary to developed in terms of fly ash content. Ferguson (1993) opined that OMC for maximum compressive strength of a fly ash treated material must be defined for each fly ash contents. A number of mathematical models have already proposed by the different researcher to predict OMC in terms of different governing parameters. Bera (2014) proposed linear mathematical model to predict OMC for fine grained soil and rice husk ash mixture. Bera and Ghosh (2011) presented the linear mathematical model to predict OMC for fine grained soil only. In the present investigation, based on the present experimental data point and by using multiple regression analysis, a linear mathematical model has been developed as follows

$$\widehat{OMC}_{\text{mix}} = 74.38 - 0.2063 \times FC + 0.751533 \times OMC_{\text{sand}} - 27.2504 \times G_{\text{mix}} \quad (2)$$

Where,

$\widehat{OMC}_{\text{mix}}$ = predicted value of optimum moisture content of sand and fly ash mixture,
FC = Fly ash content (%),
$OMC_{\text{sand}}$ = Optimum moisture content for sand,
$G_{\text{mix}}$ = Specific gravity of sand fly ash mixture.

The values of coefficient of determination ($R^2$) and estimated standard error ($E_S$) of the model are 0.88 and 1.12% respectively. The significance of the regression coefficients as a whole and also partial regression coefficient of the equation (Eq. (2)) has been tested by using '$F$' statistics and '$t$' statistics respectively. Table 7 presents the values of $F_{\text{statistics}}$ and $t_{\text{statistics}}$. From Table 7 it is found that all the variables of the equation (Eq. (2)) have significant contribution to the equation. Fig. 13 shows the Predicted OMC versus observed OMC for sand fly ash mixture sample. From the figure (Fig. 13), it is found that predicted OMC using the data used in developing the model were within ± 10% error and also the predicted OMC using the data not used in developing the model were within ± 20% error. The proposed model is very much useful to the field engineers because one has to conduct the compaction tests which take into consideration of types of sand and compaction energy in addition to the specific gravity of sand fly ash mixture ($G_{\text{mix}}$) which can be determined from equation (Eq. (1)) developed in the present investigation. The above model (Eq.

(2)) has been developed based on the present data with varying FC up to 10% to 40%, $G_{mix}$ of 2.38-2.62 and $OMC_{sand}$ of 15.68%-21.67% . However, the above model may be useful within range of FC, $G_{mix}$, and $OMC_{sand}$ are 10% to 40%, 2.38-2.62 and 15.68%-21.67% respectively. The proposed model has been developed based on a specific type of fly ash (class F). For different types of fly ash and also for values beyond the given range of the predictors, the result from the equations (Eq. (2)) should be checked for at least one series of compaction test results.

## 6. Conclusions

On the basis of the results and discussions made in the previous section the following conclusions may be drawn:

- With the increase in fly ash content in the sand fly ash mixture, the values of maximum dry density of sand fly ash mixture initially increases at certain percentage of fly ash content (up to 15%) after which decreases.
- With increase in fly ash content of sand fly ash mixture the values of optimum moisture content decreases up to 30%-35% after which it remains more or less constant.
- With increase in fly ash content on fly ash sand mixture the values of UCS of fly ash sand mixture increases and reaches a peak value at a certain fly ash content (35%) irrespective of types of sand and compaction method.
- The values of specific gravity of sand fly ash mixture decreases with increase in fly ash content, irrespective of types of sand.
- Based on the experimental data obtained in the present investigation a linear empirical model has been developed to predict $G_{mix}$ in terms of $G_{sand}$, $G_{flyash}$, and FC.
- The first model (Eq. (1)) to predict the specific gravity of sand fly ash (class F) mixture ($G_{mix}$) is applicable with varying FC, $G_{sand,}$ within the range of 10-40%, 2.643-2.606 respectively.
- Based on the present data point a linear empirical model has been developed to predict $OMC_{mix}$ in terms of FC, $G_{mix}$, and $OMC_{sand}$.
- The second model (Eq. (2)) may be useful in practice to predict the optimum moisture content ($OMC_{mix}$) of sand and specific types of fly ash (class F) mixture having the values of FC, $G_{mix}$, and $OMC_{sand}$ are in the range of 10% to 40%, 2.38-2.62 and 15.68%-21.67% respectively. Beyond the ranges of values of the predictors, the results from the equation (Eq. (2)) should be checked for at least on series of compaction test results.

## References

ASTM C618 (2008), Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete, PA, USA.

ASTM D698 (1992), Standard test method for laboratory compaction characteristics of soil using standard effort, PA, USA.

ASTM D854 (1992), Standard test method for specific gravity of soil, PA, USA.

ASTM D 1557 (1992), Standard test method for laboratory compaction characteristics of soil using modified effort (2,700 kJ/m$^3$), PA, USA.

ASTM D 2166 (2000), Standard Test Method for Unconfined compression Strength of Cohesive Soil, PA,

USA.
Ahmaruzzaman, M. (2010), "A review on the utilization of fly ash", *J. Prog. Energy Combus. Sci.*, **36**(3), 327-363.
Athanasopoulou, A. (2014), "Addition of lime and fly ash to improve highway subgrade soils", *J. Mater. Civil Eng., ASCE*, **26**(4), 773-775.
Bera, A.K. (2014), "Compaction characteristics of fine grained soil and rise husk mixture", *Int. J. Geotech. Eng.*, **8**(2), 121-129.
Bera, A.K. and Ghosh, A. (2011), "Regression model for prediction of optimum moisture content and maximum dry unit weight of fine grained soil", *Int. J. Geotech. Eng.*, **5**(3), 297-305.
Brooks, R., Udoevo, F.F. and Keerthi, T.V. (2011), "Geotechnical properties of problem soils stabilized with fly ash and limestone dust in Philadelphia", *J. Mater. Civil Eng.*, **23**(5), 711-716.
Chauhan, M.S., Mittal, S. and Mohanty, B. (2008), "Performance evaluation of silty sand subgrade reinforced with fly ash and fibre", *Geotext. Geomembr.*, **26**(5), 429-435.
Ferguson, G. (1993), *Use of a Self Cementing Fly Ashes as Soil Stabilization Agent*, ASCE Geotechnical Special Publication No. 36, New York, NY, USA.
Horpibulsuk, S., Phetchuay, C. and Chinkulkijniwat, A. (2012), "Soil stabilization by calcium carbide residue and fly ash", *J. Mater. Civil Eng.*, **24**(2), 184-193.
IS 3812 (Part-I) (2003), Pulverized Fuel Ash-Specification; New Delhi, India.
Jongpradist, P., Jumlongrach, N. and Chucheepsakul, S. (2010), "Influence of fly ash on unconfined compressive strength of cement-admixed clay at high water content", *J. Mater. Civil Eng.*, **22**(1), 49-58.
Kaniraj, S.R. and Havanagi, V.G. (1999), "Compressive strength of cement stabilized fly ash-soil mixtures", *J. Cement Concrete Res.*, **29**(5), 673-677.
Manskinen, K., Nurmesniemi, H. and Pöykiö, R. (2012), "Occupational risk evaluation of using bottom ash and fly ash as a construction material", *J. Hazard. Toxic Radioact. Waste*, **16**(1), 79-87.
Mir, B.A. and Sridharan, A. (2013), "Physical and compaction behavior of clay soil- fly ash mixture", *J. Geol. Geotech. Eng.*, **31**(1), 1059-1072.
Pal, S.K. and Ghosh, A. (2014), "Volume change behavior of fly ash-Montmorillonite clay mixtures", *Int. J. Geomech.*, **14**(1), 59-68.
Prabakar, J., Dendorkar, N. and Morchhale, R.K. (2004), "Influence of fly ash on strength behavior of typical soils", *Constr. Build. Mater.*, **18**(4), 263-267.
Sivapullaiah, P. and Moghal, A. (2011), "Role of gypsum in the strength development of fly ash with lime", *J. Mater. Civil Eng.*, **23**(2), 197-206.
Sharma, N.K. (2012), "Subgrade characteristics of locally available soil mixed with fly ash and randomly distributed fibers", *Proceedings of International Conference on Chemical, Ecology and Environmental Sciences* (*ICEES*), Bangkok, Thailand, March.
Tastan, E.O., Edil, T.B., Benson, C.H. and Avdilek, A.H. (2011), "Stabilization of organic soils with fly ash". *J. Geotech. Geoenvir. Eng.*, **137**(9), 819-833.

*CC*