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# STRENGTH BEHAVIOUR OF RANDOMLY DISTRIBUTED FIBRE REINFORCED NATURAL SAND

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**Abstract**— The need for improvement of ground is ever increasing due to rapid growth in infrastructure development. The randomly distributed fibre reinforced sand is one of the popular ground improvement techniques. The need for selection of a suitable fibre material is an important aspect. A constitutive model for prediction of sand reinforced with any fibre will help in proper selection of the fibre material. Efforts were made in this study to conduct a series of triaxial compression tests and based on the test results, efforts were made to constitute a statistical model. To achieve the objective, a series of tri-axial tests were conducted on Aleru River Sand in its Natural grain size form reinforced with four different fibre materials viz., Nylon, Steel, Plastic coated copper wire and coir. These fibres are mixed in 1%, 3%, 4% and 5% duly varying the Aspect Ratios at 25 and 85. The results indicated an improvement in strength behaviour of Sand Reinforced with fibre in randomly distributed form. The investigations showed an improvement in Strength Ratio upto 4.06 and Bearing Capacity Ratio upto 5.58 when 5% of steel fibre with Aspect ratio 25 is used. Based on the results, a statistical constitutive model was developed to predict the primary variable viz., the Deviatoric Stress at failure. The regression equations obtained showed $R^2$ values in the range of 0.947 indicating good agreement. To sum up, this provided a tool to predict the BCR for Natural sand reinforced with fibres, based on fibre characteristics.

**Index Terms**— All FOUR fibres, Aspect ratio, coir, constitutive model, fibre content, Fibre reinforced Natural sand, Nylon, Plastic coated copper wire, Ramdomly distributed, Steel, Strength behaviour,Triaxial test validated.



## 1 INTRODUCTION

IMPROVEMENT of ground is an important challenge before Geotechnical Engineers world over. Geo-reinforcement is a very promising area in improvement of bearing capacity of soil. Concept involving the reinforcement of soil using fibres has been used since ancient times. For example, early civilizations added straws and plants roots to soil bricks to improve their properties, while building the Great Wall of China the clay soil was mixed with tamarisk branches, although the reinforcing mechanism may have not been fully understood. While reinforcement in fabric form is widely adopted in field applications, there is need for though understanding of behaviour of fibre reinforced soil. Efforts were made to formulate a constitutive model to predict the behaviour of Randomly Distributed Fibre Reinforced Soil . There is need for development of more generalized, universally applicable constitutive model that can predict the improvement in bearing capacity of Natural Sand reinforced with any type of reinforcement material with any aspect ratio mixed in any proportion. Efforts were made in the current research, to develop such a model for predicting of strength behaviour of Randomly Distributed Fibre Reinforced Sand.

## 2 REVIEW OF LITERATURE

The literature on strength characteristics of randomly distributed fibre reinforced sand is reviewed in this section. Schlosser and Long (1970), conducted extensive research on samples of sand reinforced with horizontal thin aluminum plates. Gray (1970) observed that the presence of plant roots is beneficial to the strength of the soils and the stability of natural slopes. Subsequently more detailed studies on soils reinforced with various kinds of reinforcements were conducted. Subsequently by Broms (1977), Saran et al (1978), Verma and Char (1978), Talwar and Saran (1983), Gray and Ohashi (1983), Gray and Al-Refeai (1986), Venkatappa Rao et al (1987), Fukushuima et al (1988), Venkatappa Rao et al (1989), Shewbridge and Sitar (1989), Shamsher (1992) and Haeri et al (2000) and others have conducted extensive research on soils in which various kinds of reinforcing material (primarily geosynthetics) were oriented in particular directions and successfully demonstrated their efficacy in ground improvement.

Venkatappa Rao et al (1987) based on their investigations on the triaxial behaviour of geotextile reinforced sand, reported the applicability of Hausmann's model with a difference that no geotextile rupture occurred even at high confining pressures. Venkatappa Rao et al (1989) conducted the drained triaxial tests on sand reinforced with disks of woven and non-woven geotextiles. The results of this study show that the reinforcement induced confining stress varies hyperbolically with the applied confining pressure for both the type of reinforcement. Shamsher (1992) performed drained triaxial tests on three different types of sand reinforced with oriented geotextiles.

Lee et al (1973) performed triaxial tests on medium sand reinforced with random distributed wood shavings 0.2 mm wide with length varying between 25 mm and 27 mm. However, failure tends to occur at a slightly higher axial strain in the reinforced specimens.

Shamsher (1992) performed drained triaxial tests on three different types of coarse grained soil reinforced with randomly distributed geogrid micromesh (GMM) of size 30 mm x 30 mm and 50 mm x 50 mm.

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# 3 METHODOLOGY

The methodology include characterization of the Natural sand and the four types of fibres used as reinforcement materials. Later, the preparation of the specimen and the test procedure are described.

### 3.1 Characterisation of Natural Sand

| Physical Properties of Aleru River Sand | | | | | | | Relative Density of Sands | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $D_{10}$ | $D_{30}$ | $D_{50}$ | $D_{60}$ | $C_u$ | $C_c$ | Classification (IS: 1498 – 1970) | $G_s$ | $\gamma_{max.}$ g/cc | $\gamma_{min.}$ g/cc | $\gamma_o$ g/cc | $e_{max}$ | $e_{min}$ | $e_o$ | $I_d$ |
| 0.45 | 0.72 | 0.96 | 1.25 | 2.78 | 0.92 | Uniformily graded (SP) | 2.60 | 1.664 | 1.539 | 1.55 | 0.689 | 0.559 | 0.677 | 9.23 |

### 3.2 Characterisation of fibres

| Sl. No. | Type of Material | Specific Gravity (Gs) | Diameter (mm) d | Adopted aspect ratio (l/d) | Adopted % fibre ($f_b$) | Coefficient of surface friction ($f_s$) | Youngs modulus E (kPa) |
|---|---|---|---|---|---|---|---|
| 1. | Nylon | 0.86 | 0.30<br>1.00 | 85<br>25 | 1, 3, 4 & 5 | 0.50 | $2x\ 10^8$ |
| 2. | Steel wire | 7.50 | 1.0 | 25 | 1, 3, 4 & 5 | 0.50 | $2x\ 10^8$ |
| 3. | Plastic Coated Copper Wire (PCCW) | 4.13 | 1.0 | 25 | 1, 3, 4 & 5 | 0.40 | $5x\ 10^6$ |
| 4. | Coir | 0.80 | 0.30 | 85 | 1, 3, 4 & 5 | 0.66 | $2x\ 10^6$ |

### 3.3 Mix Proportioning

It is proposed to conduct conventional triaxial tests on dry sand along with fibre reinforcement. Hence, to maintain the percentage by weight of fibres in a given volume of the specimen requires some computation. These are presented in this section. The Aspect ratios of fibres adopted are 25 and 85. The percentages of fibres used were 1 %, 3 %, 4 %, and 5 % by weight of the sand of the test specimen mould. The percentage of fibres and sand has take into consideration of volume and specific- gravity of materials. Using the percentage of fibres used the volume content of sand is adjusted.

According to the required void ratio ($e_o$) and fibre concentration by volume ($\rho$), the corresponding fibre concentration by weight ($\rho_w$) was calculated as

$$\rho_W = \frac{(1+e)G_s\ \rho}{(1+e)(G_r - G_s)\rho\ + G_s}$$

where, $G_s$ and $G_r$ = specific gravity of the sand and fibres, respectively.

The weight of the dry sand ($W_s$) and the fibres ($W_r$) was then calculated from

$$W_s = \frac{V}{(1+e)}\ \frac{(1-\rho_w)G_s\ G_r}{(1-\rho_w)G_r\ +\ \rho_w G_s}\ \gamma_w$$

and

$$W_r = \frac{V}{(1+e)}\ \frac{\rho_w\ G_s\ G_r}{(1-\rho_w)G_r\ +\ \rho_w G_s}\ \gamma_w$$

Where, V = required volume of the mixture (volume of the specimen); and $\gamma_w$ = unit weight of water.

Thus the densities of the specimens prepared will be different.

However the density of sand is maintained at the required level, to enable effective comparison. The same methodology is adopted in the Steel, PCCW, Nylon, and Coir.

### 3.4 Test procedure

The Natural Sand used in this study has been reinforced using FOUR different fibre materials namedly Nylon fibre, Steel wire, Plastic Coated Copper wire (PCCW) and Coir. In each of these the percentage of fibre Aspect ratio ($A_s$) has been changed from 1%, 3%, 4% and 5%. The As 25 is maintained for Nylon fibre, Steel wire and PCCW fibre materials and As 85 for Nylon fibre and coir fibre. Total **63 number** of test samples have been tested including unreinforced Natural Sand.. The UU Triaxial compression tests with control on confining pressure are performed as per the scheme of experiments.

# 4 EXPERIMENTAL RESULTS

The experimental results are presented in the following Table 1 and Table 2.

### 4.1 Strength behaviour of Natural sand

The stress-strain behaviour of Natural Sand is generally seen that the strength of the sand increases with confining pressure. Hyperbolic stress-strain relationships is observed to be linear. From this it is evident that there is a general agreement of the test data with hyperbolic predictions within a range of 10 %. For further comparisons, the predicted values of $(\sigma_1\text{-}\sigma_3)_f$ viz., $(\sigma_1\text{-}\sigma_3)_{f,pred.}$ are made use of. The values of c' and $\phi$' are computed from the plots of $(\sigma_1\text{-}\sigma_3)/2$ Vs $(\sigma_1\text{+}\sigma_3)/2$. The sand exhibits a $\phi$' value of $37.40^0$ and no effective cohesion intercept.

### 4.2 Strength Behaviour of Natural Sand Reinforced with Different Fibres

This section presents the results of Natural Sand with the four types of reinforcing fibres.

It is generally seen that increasing the percentage of fibre has improved the overall stress-strain behaviour, i.e., there is an increase in the peak strength and modulus with increase in reinforcement content. Similar behaviour is observed at all the three confining pressures.

The confining pressure 50 kPa for 1% reinforcement it is observed that the maximum improvement is for Steel Wire $A_s$ = 25 followed by Plastic Coated Copper Wire (PCCW) $A_s$ = 25, Nylon fibre $A_s$ = 85, Coir $A_s$ = 85, and Nylon fibre $A_s$ = 25, with the best being for Steel. Similar behaviour is observed for confining pressures of 100 kPa and 150 kPa. On the whole the behaviour observed is very similar with increasing percentage of reinforcement showing a better behaviour. The best improvement was found for 5% steel fibres at the confining pressure of 150 kPa.

In general the relationship is found to be linear from the results obtained by hyperbolic plots. Similar to unreinforced sand, and reinforced Natural sand the predictions from hyperbolic plots also indicate the percentage agreement with measured $(\sigma_1 - \sigma_3)_f$ is found to be generally in the range of 5 % to 10 %, with a few exceptions to these. On the whole the agreement is best for Nylon $A_s$ = 25 and Coir and poor for PCCW and Steel fibres.

The variation of Deviatoric stress with axial strain for Natural Sand (without reinforcement) is shoewn in Fig. 1 and Natural sand for different reinforcing fibres with 5% fibre content under 50, 100 & 150 kPa confining pressure is Fig. 6(a), 6(b) & 6(c) respectively.

Similar plots were obtained for all other test conditions.

The variation of Deviatric Stress Vs % of fibre for Natural Sand is shown in Fig. 2

## 5 OBSERVATIONS

From the laboratory model studies conducted on Natural Sand (possessing c'= 0 and $\phi$'= $37.40^0$ ) reinforced with various fibres, the following major conclusions are drawn.

1) With Nylon fibre As = 25, for increasing percentage of fibre reinforcement, the average value of $\phi$' is $33.76^0$ (Range $32.89^0$ to $34.92^0$), the value of c' increases gradually up to 49.70 kPa.
2) With PCCW (Plastic Coated Copper Wire), As = 25, the average value $\phi$' is $36.03^0$ (Range $34.50^0$ to $37.64^0$) the value of c' increases gradually with percentage reinforcement upto 115.70 kPa.
3) With Steel fibre, As = 25, the average value of $\phi$' is $36.70^0$ (range $34.95^0$ to $39.54^0$) and the value of c' increases gradually with percentage reinforcement up to 120.70 kPa.
4) With Nylon fibre, As = 85, the average value of $\phi$' is 35.370 (range $33.96^0$ to $36.75^0$) and the value of c' increases gradually with percentage reinforcement up to 107.60 kPa.
5) With Coir fibre, As = 85, the average value of $\phi$' is $34.74^0$ (range $33.16^0$ to $35.94^0$) and the value of c' increases gradually with percentage reinforcement up to 73.00 kPa.

By a further comparison, it is evident that the maximum c' and $\phi$' were for Steel Fibre and the least for Nylon As = 25. Steel fibre is followed by PCCW, Nylon 85 and coir. The reason behind this may be the fact that, Comparing the fibres with As = 25, Steel fibre has the best values of c' and $\phi$', followed by PCCW and Nylon (As = 25). From the above it is evident that, the maximum improvement in strength ratio of 4.06 is achieved when 5% of steel fibre with aspect ratio of 25 is mixed with the natural sand.

On the whole this study indicates that a definite imprudent in Strength behaviour of Sand is observed when it is reinforced with RDFS. Hence using RDFS the thickness of sand layer can be economized and thus depletion of sand can be minimized.

## 6 DEVELOPMENT OF MODEL

Mathematical regression models are formulated based on the experimental test data from the triaxial tests conducted on the reinforced sand. The experimental data obtained from 63 Tiaxial tests Natural sand of Aleru River near Hyderabad.

### 6.1 Parameters Considered

The mathematical model developed to predict the improvement factor for ‘σd’ deviatoric stress has the general form

Y = Bo +B1 X1 +B2 X2 +B3 X3 +B4 X4 +B5 X5 +B6 X6 +B7 X7+B8 X8 (5.3)

where,

Y is dependent variable,

Bo, B1, ….. B8 are the coefficients of the regression equation for each input or independent variable and,

X1, X2, …. X8 are the input or the independent variables.

All the variables in the regression model are dimensionless.

The dependent variable for the developed model is the value of ‘$\sigma_d$’ Deviatoric stress improvement factor.

$\sigma_d = f(A_s, f_b, \gamma_b, \sigma_3, D_{60}, D_{10}, f_s, E)$

The independent variables are

$A_s$ = Aspect ratio ($A_s$ = l/d), $f_b$ = % of fibre, $\gamma_b$ = Bulk density (kN/m$^3$), $\sigma_3$ = Confining pressure (kPa)

$D_{60}$ = $D_{60}$ of sand, $D_{10}$ = $D_{10}$ of sand, $f_s$ = Coefficient of Surface friction of fibre

E = Young’s modulus or Elastic constant of fibre (kPa)

The linear Regression equation for estimation of the deviatoric stess at failure for the Natural sand is obtained as shown below :

$$\sigma_d = -1625.642 + 1.630 A_s + 66.657 f_b + 106.964 \gamma_b + 2.807 \sigma_3 - 258.229 f_s - 1.20 x 10^{-7} E \quad (1)$$

With the high values of $R^2$ 0.947in each of these equations, the analysis is encouraging.

### 6.2 Validation of the model for individual sands

Fig. 3 depict the plots of predicted Vs measured value of $\sigma_d$, which conforms to the above observations made.

Obviously, as already indicated by the high value of $R^2$, the predictions are quite satisfactory.

As such the regression equations can be of great use in field application, for sands and fibres of same/similar type. Even with limited data of fibre and sand, the equations could be very useful in predictions, from which we can obtain the values of c' and $\phi$' and subsequently compute the improved bearing capacity.

## 7 CONCLUSIONS

On the whole, the thesis has attempted to provide an insight in to the behaviour of randomly distributed fibre reinforced sand. Based on the investigations made in this research, the following conclusions are made:

1) In general, there is a considerable improvement in strength of Sand reinforced with any type of fibre material. The maximum improvement in strength ratio was found to be 4.06 (Fig. 4).
2) The value of B.C.R also increases with increase in Aspect Ratio of reinforcing fibre. The maximum improvement in B.C.R. was found to be 5.58 (Fig. 5).
3) For Natural sand, the improvement in strength ratio is proportionately increasing as the percentage of fibre is increasing.
4) For Natural sand and reinforced with any type of fibre, the improvement in strength ratio is taking proportionately as the aspect ratio is increasing.
5) For a given Sand-fibre combination, the strength ratio is found to be more when the confining pressure is at 50 kPa.

The multiple regression analysis yielded mathematical models with $R^2$ 0.947. This enables the designer to estimate the behaviour of Fibre reinforced sand of given combination, even without conducting the laboratory tests.

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TABLE -1
SUMMARY OF B. C. R. FOR NATURAL SAND

| % fibre | Nylon As = 25 | PCCW As = 25 | Steel Wire As = 25 | Nylon As = 85 | Coir As = 85 |
|---|---|---|---|---|---|
| 1 | 1.04 | 1.44 | 1.62 | 1.31 | 1.14 |
| 3 | 1.44 | 2.70 | 3.24 | 2.09 | 1.74 |
| 4 | 1.71 | 3.90 | 4.87 | 2.97 | 2.25 |
| 5 | 1.87 | 4.78 | 5.58 | 4.06 | 2.82 |

TABLE - 2
SUMMARY OF SHEAR RATIO FOR NATURAL SAND

| % fibre | Confining Pressure $\sigma_3$ (kPa) | Nylon As = 25 | PCCW As = 25 | Steel Wire As = 25 | Nylon As = 85 | Coir As = 85 |
|---|---|---|---|---|---|---|
| 1 | 50 | 1.25 | 1.50 | 1.61 | 1.43 | 1.33 |
| | 100 | 1.01 | 1.17 | 1.24 | 1.12 | 1.05 |
| | 150 | 1.01 | 1.06 | 1.12 | 1.05 | 1.04 |
| 3 | 50 | 1.56 | 2.28 | 2.52 | 1.96 | 1.75 |
| | 100 | 1.19 | 1.60 | 1.74 | 1.43 | 1.32 |
| | 150 | 1.06 | 1.38 | 1.48 | 1.25 | 1.17 |
| 4 | 50 | 1.73 | 2.80 | 3.17 | 2.40 | 2.02 |
| | 100 | 1.30 | 1.91 | 2.12 | 1.68 | 1.47 |
| | 150 | 1.15 | 1.61 | 1.77 | 1.44 | 1.29 |
| 5 | 50 | 1.98 | 3.84 | 4.06 | 3.57 | 2.66 |
| | 100 | 1.39 | 2.38 | 2.51 | 2.23 | 1.76 |
| | 150 | 1.19 | 1.89 | 1.99 | 1.78 | 1.46 |

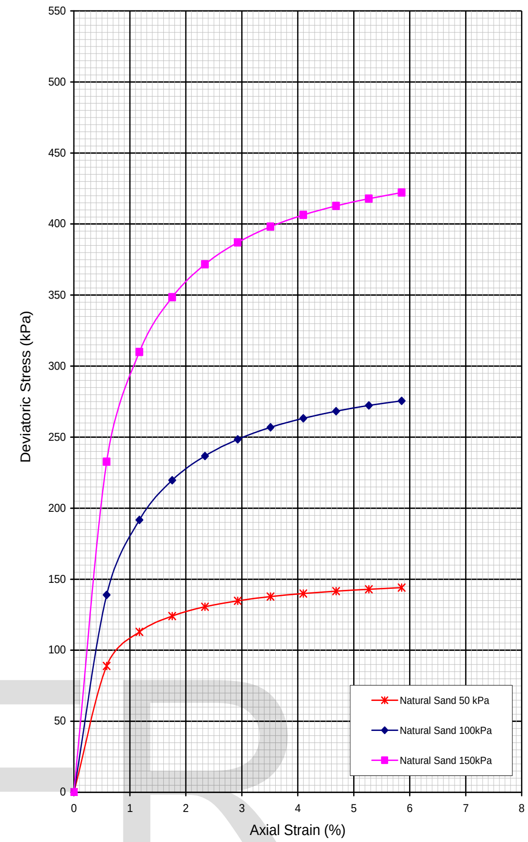


Fig. 1 Stress-Strain Curves for Natural Sand

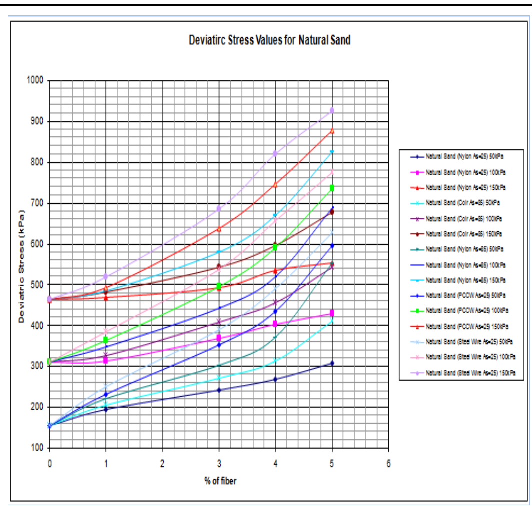


Fig. 2 Deviatric Stress Vs % of fibre for Natual Sand for As 25 & 85 for 1, 3, 4, 5% and 50, 100, 150 kPa/m$^3$

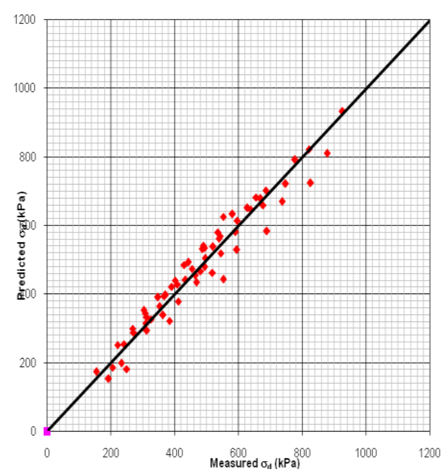


Fig.3. Comparision of measured and predicted values of $\sigma_d$ using Eqauation 1

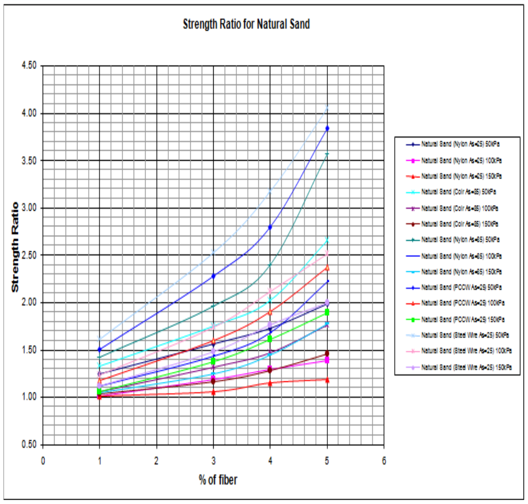


Fig. 4. Strength Ratio Vs. % of fibre for Natural Sand

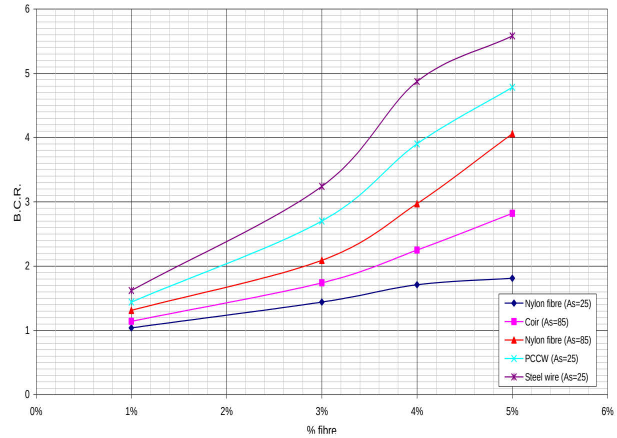


Fig. 5. B.C.R. for Natural Sand for different fibres with Aspect Ratios (25, 85) fand different percentage of inclusion (1%, 3%, 4% and 5%)

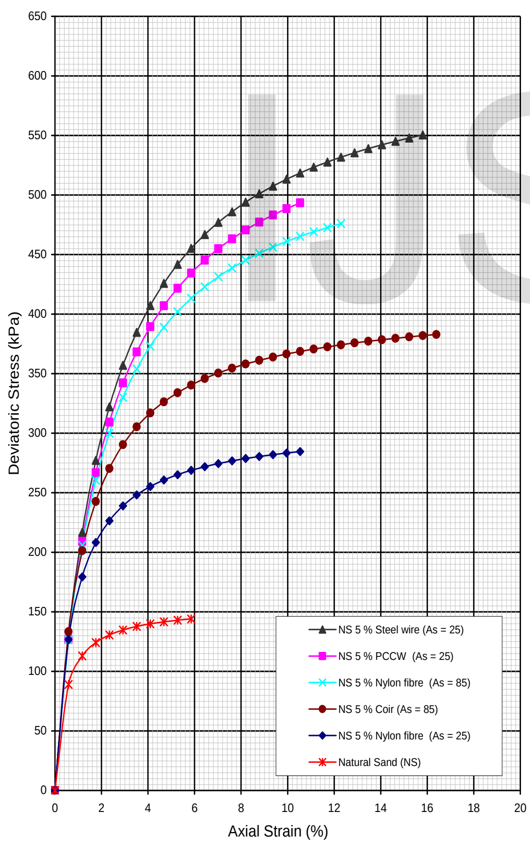


Fig. 6(a) Stress-Strain Curves of Natural Sand for different reinforcing fibres with 5% fibre content at $\sigma_3$ = 50 kPa

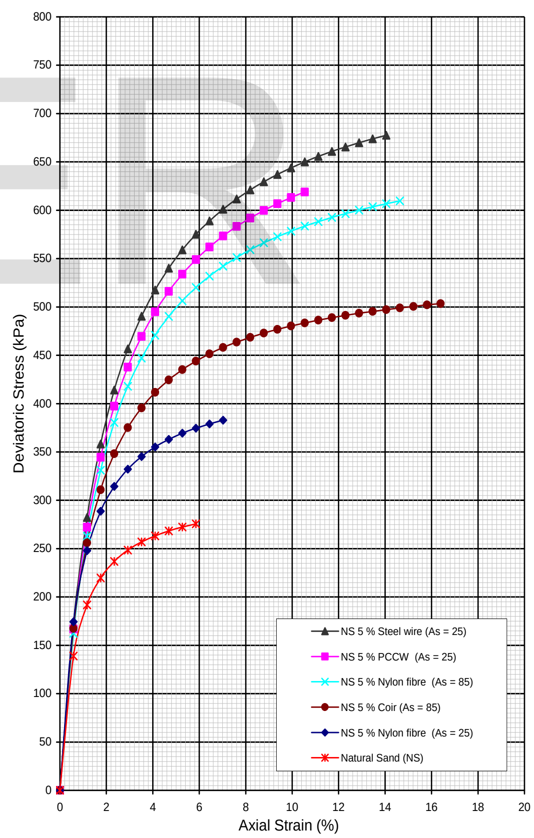


Fig. 6(b) Stress-Strain Curves of Natural Sand for different reinforcing fibres with 5% fibre content at $\sigma_3$ = 100 kPa

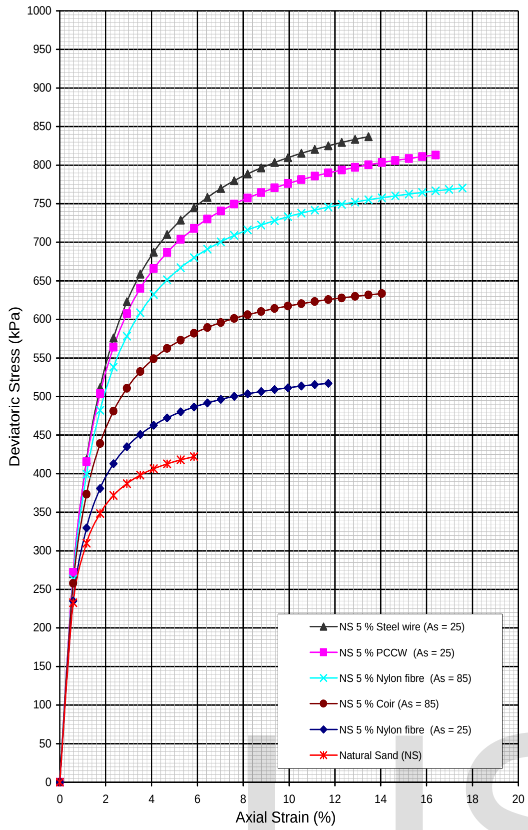


Fig. 6(c) Stress-Strain Curves of Natural Sand for different reinforcing fibres with 5% fibre content at $\sigma_3$ = 150 kPa



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