

# **DEVELOPMENT OF A MATHEMATICAL MODEL FOR DESIGNING OF NEEDLE PUNCHED GEOTEXTILES IN HYDRAULIC APPLICATION**

*by*

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*Thesis submitted  
in fulfilment of the requirements  
for the degree of*

**DOCTOR OF PHILOSOPHY**

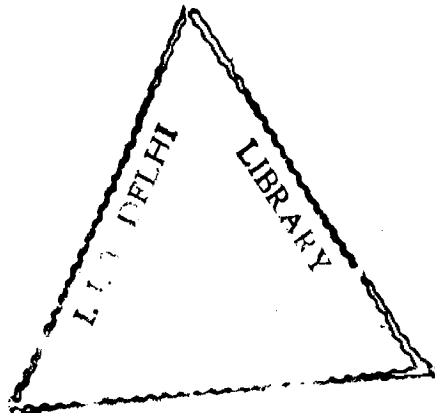


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## CERTIFICATE

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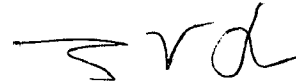
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## ABSTRACT

In the field of geotechnical engineering, permeable textile material known as geotextiles have firmly established itself as a viable substitute for the conventional raw materials. The current world wide consumption of geotextiles is being more than 1000 million square meter per annum. In any application a geotextile requires to perform either one or combinations of few basic functions like reinforcement, separation, filtration, drainage, etc. However, due to the wide diversity in the nature of these basic functions no single class of geotextile can perform all the functions satisfactorily. Presently for a wide spectrum of application problem, civil engineers are constrained to select from the limited range of geotextiles available in the market. Hence, for proper cost effective and reliable engineering solution of a geotechnical problem, systematic application oriented designing of geotextiles become imperative. A function oriented designing of geotextile is only possible when the relationships between different raw material properties, process variables, relevant fabrics properties and the end use requirements are clearly defined.

Thus the main purpose or aim of this thesis is -

- 1) To identify the different factors governing the needle punched fabric properties and using these as input variables an experimental plan was formulated.
- 2) To evaluate the properties of the samples prepared in relation to drainage and filtration.
- 3) To establish empirical relationship between input variables and geotextile properties using multi variable regression analysis.

- 4) To develop an optimization programme for locating the right combination of raw material properties, process and machine parameters corresponding to a set of desirable index properties.

Based on the information available through published literature five raw material, and process related variables, viz., fibre fineness, fibre length, batt areal density, needle depth of penetration, and punch density, expected to have considerable influence on needle punched geotextile properties were identified.

An orthogonal, rotatable, central composite experimental design (CCD) of second order was used for sampling plan. Employing a full factorial design, 59 fabric samples from polyester fibres and using a half factorial design, 36 fabric samples from PP fibres were developed on a Asselin needle punching machine. According to the recommendation of different experts available through literature a comprehensive list of fabric properties having direct and indirect bearings with hydraulic applications were prepared. An elaborate testing programme comprising of the test methods recommend by either ASTM or by reputed organisations like EDANA or Franzius Institute were planned for evaluating the fabrics performance in hydraulic applications.

The tests for the study are broadly classified in three groups -

1. Test related to dimensional properties of geotextiles.
2. Test related to the sustaining ability of geotextiles against constructional hazards i.e. survivability properties.
3. Tests related to the evaluation of geotextile properties related to their hydraulic behaviour.

Twenty eight different fabric properties were studied and about 40,000 data points were generated. Alongwith the other properties related to hydraulic applications pore size distribution of the needle punched geotextiles were estimated

by using mercury intrusion method. In order to get an insight about pores larger than 200 microns, a modification has been incorporated in the design of the porosimeter used for this study.

Various statistical techniques were employed with different data sets to provide a compact shape and mathematical form to this large volume of test data.

Test data obtained for each fabric property were used for developing statistical models. Fifty six such models (one for each property), free from 'lack of fit' and proved to be excellent representative of test data were developed.

In addition to the regression models pertaining to each fabric properties, some more statistical models were worked out viz.,

- Thickness at different normal pressure both during loading and unloading sequence, i.e. during compression and recovery phases with the applied pressure were excellently fitted with a logarithmic and a power series curve respectively by using the least square technique.
- Regression analysis was carried out to find out the relationships among different survivability properties. Cross machine direction strength was found to be most closely related with other survivability properties.
- In-plane and cross-plane flow data at different normal pressure and hydraulic head were fitted with a modified hyperbolic model with three parameters. These parameters are good indicator of the geotextile flow behaviour and can be used for characterising the flow behaviour of geotextile.
- To quantify the pore size distribution curve obtained through the mercury porosimetry test, a standard distribution involving one parameter (Rayleigh distribution) was successfully fitted with the porosimetry data. The

model parameter was used for characterisation of the flow behaviour of geotextile.

- An intensive correlation analysis among various geotextile properties related to pore size and flow properties revealed that an excellent degree of association (correlation) exists between all flow properties and pore size distribution parameter obtained through mercury porosimetry data.

An intensive analysis of the regression models relating the individual fabric properties with fabric production parameters leads to the following conclusions;

- For satisfactory hydraulic function, a needle punched geotextile should exhibit a degree of structural mobility which is negatively correlated with the survivability properties of geotextile.
- Higher fibre denier consistently improves flow properties whereas higher fibre length and batt areal density improves survivability properties and reduced compressibility and recovery.
- Two surfaces of needle punched geotextiles are not identical; hence surface-dependent properties such as bursting strength, and puncture resistance show a bias.

The difference between polypropylene and polyester fibres with respect to the effects of the five selected input variables on various properties are primarily due to greater thickness, higher bending rigidity and higher cohesive drag of polypropylene fibre.

In order to predict a set of input fabric design variables corresponding to a set of desired geotextiles properties related to hydraulic application, an optimisation model was developed. Based on the statistical relationships (regression models)

developed earlier for each fabric property, the model used a sequential quadratic programming method with only bound constraint for solving the problem. A rigorous validation exercise pertaining to the model's performance testified the model's excellent ability to predict the set of fabric design parameters (input variables) corresponding to a set of desired fabric properties. This observation regarding the model's performance was further justified by a set of test results obtained from fabrics produced with the design data generated through the optimisation programme. From the validation results one may conclude that the model is reasonably accurate (in most of instances, error of estimation is  $\leq 10\%$ ) and hence would form a useful tool in the hand of geotextile manufactures for designing tailor made fabrics.

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