Scopus

Documents

Ahmad, M.[a b] , Al-Zubi, M.A.[c] , Kubińska-Jabcoń, E.[d] , Majdi, A.[e] , Al-Mansob, R.A.[a] , Sabri, M.M.S.[f] , Ali, E.[g] , Naji, J.A.[h] , Elnaggar, A.Y.[i] , Zamin, B.[j]

Predicting California bearing ratio of HARHA-treated expansive soils using Gaussian process regression
(2023) *Scientific Reports*, 13 (1), art. no. 13593, .

DOI: 10.1038/s41598-023-40903-1

[a] Department of Civil Engineering, Faculty of Engineering, International Islamic University Malaysia, Selangor, Jalan Gombak, 50728, Malaysia
[b] Department of Civil Engineering, University of Engineering and Technology Peshawar (Bannu Campus), Bannu, 28100, Pakistan
[c] Department of Mechanical Engineering, Hijjawai Faculty for Engineering, Yarmouk University, Irbid, 21163, Jordan
[d] Faculty of Management, AGH University of Science and Technology, Krakow, 30-067, Poland
[e] Department of Building and Construction Techniques Engineering, Al-Mustaqbal University College, Hilla, 51001, Iraq
[f] Peter the Great St. Petersburg Polytechnic University, St. Petersburg, 195251, Russian Federation
[g] Faculty of Engineering and Technology, Future University in Egypt, New Cairo, 11835, Egypt
[h] Department of Civil Engineering, Al-Baha University, P. O. Box 1988, Al-Baha, 65527, Saudi Arabia
[i] Department of Food Nutrition Science, College of Science, Taif University, P. O. Box 11099, Taif, 21944, Saudi Arabia
[j] Department of Civil Engineering, CECOS University of IT and Emerging Sciences, Peshawar, 25000, Pakistan

Abstract
The California bearing ratio (CBR) is one of the basic subgrade strength characterization properties in road pavement design for evaluating the bearing capacity of pavement subgrade materials. In this research, a new model based on the Gaussian process regression (GPR) computing technique was trained and developed to predict CBR value of hydrated lime-activated rice husk ash (HARHA) treated soil. An experimental database containing 121 data points have been used. The dataset contains input parameters namely HARHA—a hybrid geometrical binder, liquid limit, plastic limit, plastic index, optimum moisture content, activity and maximum dry density while the output parameter for the model is CBR. The performance of the GPR model is assessed using statistical parameters, including the coefficient of determination (R2), mean absolute error (MAE), root mean square error (RMSE), Relative Root Mean Square Error (RRMSE), and performance indicator (ρ). The obtained results through GPR model yield higher accuracy as compare to recently establish artificial neural network (ANN) and gene expression programming (GEP) models in the literature. The analysis of the R2 together with MAE, RMSE, RRMSE, and ρ values for the CBR demonstrates that the GPR achieved a better prediction performance in training phase with (R2 = 0.9999, MAE = 0.0920, RMSE = 0.13907, RRMSE = 0.0078 and ρ = 0.00391) succeeded by the ANN model with (R2 = 0.9998, MAE = 0.0962, RMSE = 4.98, RRMSE = 0.20, and ρ = 0.100) and GEP model with (R2 = 0.9972, MAE = 0.5, RMSE = 4.94, RRMSE = 0.202, and ρ = 0.101). Furthermore, the sensitivity analysis result shows that HARHA was the key parameter affecting the CBR.

References

- Haupt, F., Netterberg, F.
  Prediction of California bearing ratio and compaction characteristics of Transvaal soils from indicator properties
  (2021) *J. S. Afr. Inst. Civ. Eng.*, 63 (2), pp. 47-56.
- Katte, V.Y.
  Correlation of California bearing ratio (CBR) value with soil properties of road subgrade soil
  (2019) *Geotech. Geol. Eng.*, 37, pp. 217-234.
- Nagaraju, T.V., Prasad, C.D., Raju, M.J.
  Prediction of California bearing ratio using particle swarm optimization
  (2019) *Soft Computing for Problem Solving: SocProS 2018*, 1, pp. 795-803.
  Springer
- Mendoza, C., Caicedo, B.
  Elastoplastic framework of relationships between CBR and Young's modulus for granular material

(2018) *Road Mater. Pavement Des.*, 19 (8), pp. 1796-1815.
COI: 1:CAS:528:DC%2BC2sXhtFOju73E

- Brown, S.
Soil mechanics in pavement engineering
(1996) *Géotechnique*, 46 (3), pp. 383-426.

- Mousavi, F., Abdi, E., Rahimi, H.
Effect of polymer stabilizer on swelling potential and CBR of forest road material
(2014) *KSCE J. Civ. Eng.*, 18, pp. 2064-2071.

- Kumar, P., Chandra, S., Vishal, R.
Comparative study of different subbase materials
(2006) *J. Mater. Civ. Eng.*, 18 (4), pp. 576-580.
COI: 1:CAS:528:DC%2BD28XmvFCjsbk%3D

- Moghal, A.A.B., Chittoori, B.C., Basha, B.M.
Effect of fibre reinforcement on CBR behaviour of lime-blended expansive soils: Reliability approach
(2018) *Road Mater. Pavement Des.*, 19 (3), pp. 690-709.
COI: 1:CAS:528:DC%2BC2sXpsVKmtQ%3D%3D

- Sivapullaiah, P., Moghal, A.
CBR and strength behavior of class F fly ashes stabilized with lime and gypsum
(2011) *Int. J. Geotech. Eng.*, 5 (2), pp. 121-130.
COI: 1:CAS:528:DC%2BC3MXnslKrurc%3D

- Daraei, A.
Stabilization of problematic soil by utilizing cementitious materials
(2019) *Innov. Infrastruct. Solut.*, 4, pp. 1-11.

- Blayi, R.A.
Strength improvement of expansive soil by utilizing waste glass powder
(2020) *Case Stud. Constr. Mater.*, 13.

- Zulkifley, M.T.M.
A review of the stabilization of tropical lowland peats
(2014) *Bull. Eng. Geol. Environ.*, 73, pp. 733-746.
COI: 1:CAS:528:DC%2BC2cXhtlWmsL7P

- Neopaney, M.
Stabilization of soil by using plastic wastes
(2012) *Int. J. Emerg. Trends Eng. Dev.*, 2 (2), pp. 461-466.

- Rehman, Z.
Prediction of CBR value from index properties of different soils
(2017) *Tech. J.*, 22 (2), pp. 18-26.

- Wang, G., Ma, J.
A hybrid ensemble approach for enterprise credit risk assessment based on support vector machine
(2012) *Expert Syst. Appl.*, 39 (5), pp. 5325-5331.

- Zeng, J.
Prediction of peak particle velocity caused by blasting through the combinations of boosted-CHAID and SVM models with various kernels
(2021) *Appl. Sci.*, 11 (8), p. 3705.
COI: 1:CAS:528:DC%2BB3MXhs1ymt7jE

- Asteris, P.G.
Predicting concrete compressive strength using hybrid ensembling of surrogate

machine learning models
(2021) *Cem. Concr. Res.*, 145.
COI: 1:CAS:528:DC%2BB3MXovF2kt7g%3D

- Noori, A.M.
Feasibility of intelligent models for prediction of utilization factor of TBM
(2020) *Geotech. Geol. Eng.*, 38 (3), pp. 3125-3143.

- Dormishi, A.
Evaluation of gang saws' performance in the carbonate rock cutting process using feasibility of intelligent approaches
(2019) *Eng. Sci. Technol. Int. J.*, 22 (3), pp. 990-1000.

- Mikaeil, R., Haghshenas, S.S., Hoseinie, S.H.
Rock penetrability classification using artificial bee colony (ABC) algorithm and self-organizing map
(2018) *Geotech. Geol. Eng.*, 36 (2), pp. 1309-1318.

- Mikaeil, R.
Performance evaluation of adaptive neuro-fuzzy inference system and group method of data handling-type neural network for estimating wear rate of diamond wire saw
(2018) *Geotech. Geol. Eng.*, 36 (6), pp. 3779-3791.

- Momeni, E.
Prediction of pile bearing capacity using a hybrid genetic algorithm-based ANN
(2014) *Measurement*, 57, pp. 122-131.

- Xie, C.
Optimized functional linked neural network for predicting diaphragm wall deflection induced by braced excavations in clays
(2022) *Geosci. Front.*, 13 (2).

- Armaghani, D.J.
Development of hybrid intelligent models for predicting TBM penetration rate in hard rock condition
(2017) *Tunn. Undergr. Space Technol.*, 63, pp. 29-43.

- Guido, G.
Development of a binary classification model to assess safety in transportation systems using GMDH-type neural network algorithm
(2020) *Sustainability*, 12 (17), p. 6735.

- Morosini, A.F.
Sensitivity analysis for performance evaluation of a real water distribution system by a pressure driven analysis approach and artificial intelligence method
(2021) *Water*, 13 (8), p. 1116.

- Asteris, P.G.
Revealing the nature of metakaolin-based concrete materials using artificial intelligence techniques
(2022) *Constr. Build. Mater.*, 322.
COI: 1:CAS:528:DC%2BB38XkvVarur8%3D

- Hajihassani, M.
Prediction of airblast-overpressure induced by blasting using a hybrid artificial neural network and particle swarm optimization
(2014) *Appl. Acoust.*, 80, pp. 57-67.

- Onyelowe, K.C.
Application of 3-algorithm ANN programming to predict the strength performance of

hydrated-lime activated rice husk ash treated soil
(2021) *Multisc. Multidiscipl. Model. Exp. Des.*, 4 (4), pp. 259-274.

- Onyelowe, K.C.
Application of gene expression programming to evaluate strength characteristics of hydrated-lime-activated rice husk ash-treated expansive soil
(2021) *Appl. Comput. Intell. Soft Comput.*, 2021, pp. 1-17.

- Ahmad, M.
Prediction of ultimate bearing capacity of shallow foundations on cohesionless soils: A Gaussian process regression approach
(2021) *Appl. Sci.*, 11 (21), p. 10317.
COI: 1:CAS:528:DC%2BB3MXisVygtLvO

- Ahmad, M.
Prediction of liquefaction-induced lateral displacements using Gaussian process regression
(2022) *Appl. Sci.*, 12 (4), p. 1977.
COI: 1:CAS:528:DC%2BB38XltVamt78%3D

- Ahmad, M.
Novel approach to predicting soil permeability coefficient using Gaussian process regression
(2022) *Sustainability*, 14 (14), p. 8781.

- Ahmad, M.
Predicting subgrade resistance value of hydrated lime-activated rice husk ash-treated expansive soil: A comparison between M5P, support vector machine, and Gaussian process regression algorithms
(2022) *Mathematics*, 10 (19), p. 3432.

- Mahmoodzadeh, A.
Tunnel geomechanical parameters prediction using Gaussian process regression
(2021) *Mach. Learn. Appl.*, 3.

- Kumar, M., Samui, P.
Reliability analysis of settlement of pile group in clay using LSSVM, GMDH, GPR
(2020) *Geotech. Geol. Eng.*, 38, pp. 6717-6730.

- Samui, P.
Reliability analysis of slope safety factor by using GPR and GP
(2019) *Geotech. Geol. Eng.*, 37, pp. 2245-2254.

- Samui, P.
Determination of friction capacity of driven pile in clay using Gaussian process regression (GPR), and minimax probability machine regression (MPMR)
(2019) *Geotech. Geol. Eng.*, 37, pp. 4643-4647.

- Naik, S.P.
Geological and structural control on localized ground effects within the Heunghae Basin during the Pohang Earthquake (MW 5.4, 15th November 2017), South Korea
(2019) *Geosciences*, 9 (4), p. 173.

- Deo, R.C., Samui, P.
Forecasting evaporative loss by least-square support-vector regression and evaluation with genetic programming, Gaussian process, and minimax probability machine regression: case study of Brisbane City
(2017) *J. Hydrol. Eng.*, 22 (6), p. 05017003.

- Samui, P., Jagan, J.
Determination of effective stress parameter of unsaturated soils: A Gaussian

process regression approach
(2013) *Front. Struct. Civ. Eng.*, 7, pp. 133-136.

- Onyelowe, K.
Oxides of carbon entrapment for environmental friendly geomaterials ash derivation
(2019) *International Congress and Exhibition Sustainable Civil Infrastructures*,
Springer

- Benesty, J.
Pearson correlation coefficient
(2009) *Noise Reduction in Speech Processing*, pp. 1-4.
Springer

- (2018) *Modeling of Transport demand–analyzing, Calculating, and Forecasting Transport Demand*, p. 472.
by VA Profillidis and GN Botzoris, Amsterdam, Elsevier, 125 (paperback and ebook), eBook, (Taylor & Francis, 2020)

- Zhou, J.
Random forests and cubist algorithms for predicting shear strengths of rockfill materials
(2019) *Appl. Sci.*, 9 (8), p. 1621.

- Rasmussen, C., Williams, C.
(2006) *Gaussian Processes for Machine Learning*, 38, pp. 715-719.
The MIT Press

- Kuss, M.
(2006) *Gaussian Process Models for Robust Regression, Classification, and Reinforcement Learning*,
Echnische Universität Darmstadt

- Asteris, P.G.
Prediction of cement-based mortars compressive strength using machine learning techniques
(2021) *Neural Comput. Appl.*, 33 (19), pp. 13089-13121.

- Ly, H.-B.
Estimation of axial load-carrying capacity of concrete-filled steel tubes using surrogate models
(2021) *Neural Comput. Appl.*, 33 (8), pp. 3437-3458.

- Asteris, P.G.
Soft computing techniques for the prediction of concrete compressive strength using non-destructive tests
(2021) *Constr. Build. Mater.*, 303.

- Asteris, P.G.
Evaluation of the ultimate eccentric load of rectangular CFSTs using advanced neural network modeling
(2021) *Eng. Struct.*, 248.

- Arora, H.C.
Axial capacity of FRP-reinforced concrete columns: Computational intelligence-based prognosis for sustainable structures
(2022) *Buildings*, 12 (12), p. 2137.

- Gandomi, A.H.
Novel approach to strength modeling of concrete under triaxial compression
(2012) *J. Mater. Civ. Eng.*, 24 (9), pp. 1132-1143.

- Bui, X.-N.
Prediction of slope failure in open-pit mines using a novel hybrid artificial intelligence model based on decision tree and evolution algorithm
(2020) *Sci. Rep.*, 10 (1), pp. 1-17.

- Manouchehrian, A., Gholamnejad, J., Sharifzadeh, M.
Development of a model for analysis of slope stability for circular mode failure using genetic algorithm
(2014) *Environ. Earth Sci.*, 71, pp. 1267-1277.

- Suman, S.
Slope stability analysis using artificial intelligence techniques
(2016) *Nat. Hazards*, 84, pp. 727-748.

- Armstrong, J., Collopy, F.
The selection of error measures for generaliz-ing about forecasting methods: Empirical comparisons
(1992) *Int. J. Forecast.*, 8 (1), pp. 69-80.

- Gandomi, A.H., Roke, D.A.
Assessment of artificial neural network and genetic programming as predictive tools
(2015) *Adv. Eng. Softw.*, 88, pp. 63-72.

- Wu, X., Kumar, V.
(2009) *The Top Ten Algorithms in Data Mining*,
CRC Press

- Momeni, E.
Prediction of uniaxial compressive strength of rock samples using hybrid particle swarm optimization-based artificial neural networks
(2015) *Measurement*, 60, pp. 50-63.

- Ahmad, M.
Evaluating seismic soil liquefaction potential using bayesian belief network and C4.5 decision tree approaches
(2019) *Appl. Sci.*, 9 (20), p. 4226.

- Ahmad, M.
Development of prediction models for shear strength of rockfill material using machine learning techniques
(2021) *Appl. Sci.*, 11 (13), p. 6167.
COI: 1:CAS:528:DC%2BB3MXit1GqsLnL

Correspondence Address
Ahmad M.; Department of Civil Engineering, Selangor, Malaysia; email: ahmadm@iium.edu.my

Publisher: Nature Research

ISSN: 20452322
PubMed ID: 37604957
Language of Original Document: English
Abbreviated Source Title: Sci. Rep.
2-s2.0-85168452264
Document Type: Article
Publication Stage: Final
Source: Scopus