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Offshore pipeline performance evaluation by different artificial neural networks approaches

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A B S T R A C T

This paper investigates the upheaval buckling behaviour of offshore pipeline buried in clay soil considering the possible variability in soil, operating condition and pipe properties. A 2-D finite element model of the pipeline–soil system was developed in OpenSEES software to model the upheaval buckling. Further, the uncertainty in the controlling variables was modelled using the optimized Latin Hyper Cube (LHC) sampling technique to draw the samples from appropriate probability distribution. Finally, six different models based on artificial neural networks (ANNs) were developed to predict the performance of offshore pipeline using the simulated upheaval buckling displacement. A total number of 500 data were collected from simulation, randomly divided into 350, 75 and 75 datasets, and were used for training, validating and testing the proposed models, respectively. Comparison between results showed that all models are capable to deliver displacement values very close to the simulated ones. To determine the best performance model, several controlling methods were used and finally one of the models was suggested as the best one. An additional analysis was performed for displacements above 30 mm where the number of achieved data is limited and scattering in data is observed. Analysis of the results illustrated that the models are reliable for predicting displacement values in upper band (above 30 mm) as well.

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1. Introduction

Offshore pipelines are major transportation system for oil and gas and operate at elevated temperatures and pressures. It will try to expand longitudinally due to rise in temperature; however, the expansion is resisted by soil friction that will set up the axial compressive force in the pipe wall. The compressive forces are frequently large enough to induce either lateral buckling in as-laid pipe or upheaval buckling in buried pipe. Although these two buckling modes are not essentially failure modes, they can precipitate failure through excessive bending that may lead to fracture, fatigue or propagation buckling [1].

In order to insure the safety of the pipeline, it is important to understand the controlling parameters and its effect on the buckling behaviour. Due to the uncertainty in the behaviour of seabed and cover soils, operating condition and pipe material, the prediction of upheaval buckling resistance of buried pipelines has been a challenge [16]. The studies reported in Maltby and Calladine [9] are the early analytical work to understand the upheaval buckling behaviour in buried pipelines. Also, several experimental works were reported in the past [2,4,6,18]. However, most of the experimental works on uplift resistance were carried out in granular soils and very limited

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experimental studies were reported in clayey backfill [3,16]. However, the effect of uncertainty in soil resistance and operating conditions in upheaval buckling of pipeline and the safety has not been studied to full depth [14].

Therefore, this paper investigates the upheaval buckling behaviour of offshore pipeline buried in clayey soil considering the possible variability in soil, operating condition and pipe properties. A 2-D finite element model of the pipeline–soil system was developed in OpenSEES software to model the upheaval buckling displacement. Further, the uncertainty in the controlling variables was modelled using the optimized Latin Hyper Cube (LHC) sampling technique to draw the samples from appropriate probability distribution. Finally, six different models based on artificial neural networks (ANNs) were developed to predict the performance of offshore pipeline using the simulated upheaval buckling displacement.

ANNs are widely used in civil engineering problems in both materials and structural applications. These types of modelling can be considered as one of the most important methods for finding a relationship between a target parameter through a series of input parameters. Target parameter is a property of an engineering problem (such as compressive strength, buckling and displacement) to the corresponding independent parameter which directly affect that property. This relationship through utilizing ANNs is established by giving appropriate weights to the input parameter to achieve the highest accuracy. Application of ANNs in structural section of civil engineering incorporates many field such as soil mechanics [15], earthquake engineering [8], structural health monitoring [10] and pipeline engineering [11].

Application of ANNs in pipeline engineering problems has been widely reported in the literature. Najafi and Kulandaivel [11] applied ANNs to for predicting the condition of sewer pipes based on the historic condition assessment data. The aim of their paper was to find the distressed segments of the overall sewer pipeline network. However, because of the lack of available data, some noises were appeared in their modelling in spite of reasonable findings achieved. Geem et al. [7] used ANNs to assess the water pipe condition without excavating. Analyzing of the results showed that the problem can be solved more appropriately than multiple regression models. Tran et al. [17] predicted the structural condition of storm-water pipes with ANNs. Storm-water pipe networks in Australia are designed to convey water from rainfall and surface runoff and because of the environmental conditions their structural deterioration is progressive with aging and will eventually cause pipe collapse with consequences of service interruption. Therefore, prediction of their performance due to environmental conditions is of importance. El-Abbasy et al. [5] employed ANNs to predict the condition of offshore oil and gas pipelines based on several factors besides corrosion based on historical inspection data collected from three existing offshore oil and gas pipelines in Qatar. They achieved accuracy more than 97% in validating datasets which can be considered as a reasonable performance criterion for their proposed model. This short survey shows the ability of ANNs for predicting different problems dealing with pipeline engineering and hence ANNs are used in this work to solve the problem provided in the next section.

2. Definition of the problem

The problem of this paper is same as that presented in the authors' previous paper [12]. In that paper, we modelled the upheaval buckling values by genetic programming (GP). Although the results obtained by GP were accurate, the results of this paper will show that ANNs model is a better tool to evaluate the problem of this paper. As it has been provided in the previous paper [12], the steel offshore pipeline of 500 m is considered for the analysis by a 2D finite element model in OpenSEES software. The pipe was modelled with elastic beam element while the seabed and cover soils were modelled with elastic zero-length spring element. Properties of the materials used and the schematic diagram of the buried pipeline have been given in the previous paper [12].

3. Probabilistic modelling of pipe and soil properties and operational conditions

The elastic modulus of backfill soil (E_s), pipe wall thickness (t), pipe elastic modulus (E_p), operational temperature (T) and pressure (P), product density (γ_p) are considered as uncertain variables. Respective mean values and corresponding coefficient of variation (CoV) of the parameters together with assigned probability distribution are same as those reported in the previous papers [14,12]. The response of pipeline is affected by the uncertainties associated in soil and pipe properties and operational conditions. The uncertainty in the response of pipeline can be derived using several methods such as computationally intensive Monte Carlo simulation with random sampling. However, the uncertainty in the response can be efficiently quantified using Optimized Latin Hypercube Sampling (OLHS). OLHS provides a stratified sampling scheme rather than the purely random sampling, as it provides more efficient means of covering the probability space.

4. Modelling procedure by artificial neural networks

A total number of 500 datasets were obtained by simulation process and were used for modelling by ANNs. Statistical features of these datasets have been given in the previous paper [12]. t, E_P, E_S, T, P and ρ were six independent input parameters and displacement was the output parameter. Datasets were randomly divided into 500, 75 and 75 groups and were used for training, validating and testing the results respectively.

In the present paper, six ANN model were developed. In all ANN models, one hidden layer was used. The difference between the models was in their number of neurons in the hidden layer and randomly selected datasets for training, validating and testing phases. Schematic illustration of the network used in this study for ANN models has been illustrated in Fig. 1. The input, output and hidden layers were completely interconnected by weights.

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