IDK 2020
INTERDISCIPLINARY
DOCTORAL
CONFERENCE

9th Interdisciplinary Doctoral Conference

CONFERENCE BOOK

IX. Interdiszciplináris Doktorandusz Konferencia

TANULMÁNYKÖTET

27-28th of November 2020
2020. november 27-28.

IX. INTERDISZCIPLINÁRIS DOKTORANDUSZ KONFERENCIA 2020 TANULMÁNYKÖTET

9th INTERDISCIPLINARY DOCTORAL CONFERENCE 2020 CONFERENCE BOOK

2020
Pécs

Felelős kiadó / Publisher

Pécsi Tudományegyetem Doktorandusz Önkormányzat
Doctoral Student Association of the University of Pécs

Borító / Cover Page
Járfás Vivien

Pécs, 2020. december 28.

ISBN 978-963-429-583-9

Tartalomjegyzék / Table of contents

Prediction of Failure of Ferritic Steel Using Artificial Neural Network

Yassine Chahboub, *University of Miskolc, Miskolc, Hungary*
Dr. Szavai Szabolcs, Bay Zoltán *nonprofit ltd. for applied research, Miskolc, Hungary*

The Gurson–Tvergaard–Needleman (GTN) model is a micromechanical model used to predict equipment failure based on lab specimens.
The direct method to determine the GTN parameters is finding the correct combination between the experimental and Finite Element modeling results. The process is to repeat the simulations until getting the same results as in the experiment.
This paper aims to find the GTN parameters for the Compact tension (CT) specimen based on the Notch tensile test using the Artificial Neural Network (ANN) approach.
The results that we got from this work prove that ANN is a great tool to determine the GTN parameters quickly.

Keywords: GTN; ANN; simulation

I. Introduction

Ensuring that the Nuclear power plants work at high performance means ensuring that all the parts are well maintained and in good condition.
Moreover, one of these parts is the pipeline, the leakage problem in the pipelines is one of the main critical issues that's might affect the performance of the Nuclear Power Plants, and the ferritic steel is the primary type of material from which the pipelines usually constructed.
Ductile fracture is the primary mode of fracture in ferritic steels; the ductile fracture's physical process involves three steps: the nucleation, growth, and coalescence of microvoids
The cracks are always present in the pipelines, but with different degrees; by using the GTN model, we can predict the crack initiation and propagation,
The GTN model is already implemented in Finite Element Modelling software products as MSC Marc Mentat.
The Compact tension specimen is a good representative for the pipeline; for this reason, we decided to predict the CT specimen's failure to prove the ANN approach's utility in pipelines.
The studies show that it is time-consuming (one hundred and forty hours) to find the parameters using the direct method (Y., Chahboub; Szávai, Szabolcs; H., Aguir 2019), so to accelerate the process of finding GTN parameters, the introduction of ANN was necessary.

I.1. GTN model

Gurson, Tvergaard, and Needleman's damage model (Gurson, Arthur L 1975) is an analytical model that predicts ductile fracture based on nucleation, growth and, a coalescence of voids in materials

The model defined as:

$$\phi = \frac{\sigma_e^2}{\sigma_M^2} + 2q_1 f^* \cosh\left[\frac{tr\sigma}{2\sigma_M}\right] - \left(1 + q_1{}^2 f^{*2}\right) \tag{1}$$

In which ϕ is the Gurson plastic potential, q_1 is the material constant, $tr\sigma$ is the sum of principal stresses, σ_M is the equivalent flow stress, σ_e is the effective stress. Furthermore, f* is the ratio of voids effective volume to the material volume ratio defined as follows:

$$f^*(f) = f_c \ \text{ If } f \le f_c \tag{2}$$

$$f^*(f) = f_c + \frac{(1/q_1) - f_c}{f_f - f_c}(f - f_c) \ \text{ If } f \ge f_c \tag{3}$$

Where f is the voids volume ratio, f_c is the voids volume ratio at the beginning of nucleation, and f_f is the voids volume ratio when the fracture occurs.
σ_M obtained from the following work hardening rel

$$\sigma_M\left(\varepsilon_M^{pl}\right) = \sigma_y\left(\frac{\varepsilon_M^{pl}}{\varepsilon_y} + 1\right)^n \tag{4}$$

In which *n* is the strain-hardening exponent and ε_M^{pl} is the equivalent plastic strain. The voids growth rate is the sum of existing voids growth f_g and the new voids nucleation f_n, and the following equation presents it:

$$\dot{f} = \dot{f}_n + \dot{f}_g \tag{5}$$

Where the components formulated as follows

$$(\dot{f}_g) = (1-f)tr\,\dot{\varepsilon} \quad (6)$$

$$\dot{f}_n = \frac{f_n}{S_n\sqrt{2\pi}}\exp\left[-1/2\left(\frac{\varepsilon_M^{pl}-\varepsilon_N}{S_N}\right)\right]\dot{\varepsilon}_M^{pl} \quad (7)$$

In which $tr\dot{\varepsilon}^{pl}$ Is the volume plastic strain rate, S_N is the voids nucleation mean quantity, fn is the volume ratio of the second phase particles (responsible for the voids nucleation), and ε_M is mean strain at the time of voids nucleation.

So, eight parameters must be defined:

$$\phi = \phi(q_1, q_2, f_0, f_c, f_n, f_f, \varepsilon_N, S_N) \quad (8)$$

In this work, we will determine the values of 6 parameters using Marc MSC Mentat software because the GTN model is included in the software, so we will not need to write a script for our GTN model order to include it in the program.
According to the literature (Table1), q_1 and q_2 values are almost fixed values: q_1=1.5 and q_2=1.

Table 1. Gurson parameters according to literature

References	q_1	q_2	E_N	S_N	f_0	f_c	f_n	f_f	Material
Bauvineau, Burlet, H., Eripret, C., & Pineau,. (1996)	1.5	1	-	-	0.002	0.004	-	-	CMn Steel
Decamp K., Bauvineau, L., Besson, J., Pineau, A.(1997)	1.5	1	-	-	0.0023	0.004	-	0.225	CMn Steel
Schmitt W., Sun, D.Z., Blauel, J.G.(1997)	1.5	1	0.3	0.1	0	0.06	0.002	0.212	Ferritic base Steel
Skallerud and Zhang . (1997)	1.25	1	0.3	0.1	0.0003	0.026	0.006	0.15	CMn Steel
Benseddiq and Imad . (2008)	1.5	1	0.3	0.1	0	0.004-0.06	0.002-0.02	~0.2	

I.2. Artificial Neural Network Method

An Artificial Neural network (ANN) is a mathematical model that simulates the computational model like the biological neural networks. It consists of interconnected artificial neurons and

processes information using a connectionist approach. Its system adaptivity to the change of external or internal information that flows through the network during the learning process. Another aspect of the artificial neural network is that different architectures require different algorithms, but a neural network is relatively simple if handled intelligently compared to other complex systems.
One of the ANN's advantages is the backpropagation of error, by which the network can be trained to minimize the error up to an acceptable accuracy.
A neural network's schema depends on the network topology and two more parameters: the transfer function and learning algorithm.
The network's training procedure can be selected to fit the purpose of supervised and unsupervised training types.
ANN's benefits are that the network's output for the selective number of points can be used to determine the outcome for any other new position using the same parameters.
The ANN model's architecture comprises three layers: the input layer, hidden layer, and output layer.
Each neuron receives total outputs from all of the neurons, as clarified in the figure shown below for the hidden layer.
We took advantage of the nnstart tool in Matlab 2018 in order to train our Neural network using a database of sixty simulations done using notch tensile test as shown in figure 1,

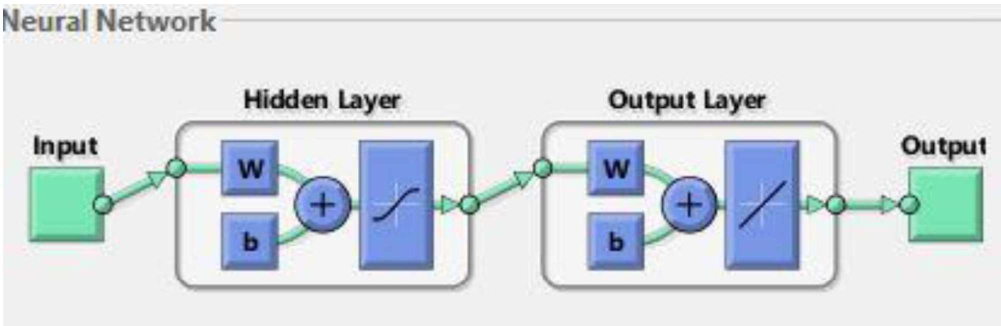

Figure 1. The architecture of ANN Matlab [2018]

Where the parameters w and b referred to all the weights and biases in the network,

II. Methodology and Results

To predict the ferritic steel's ductile failure in our case, we will use the CT specimen as it is a good representative of the pipelines.
The determination of the GTN parameters is done by following the steps below:

- Perform the small scale tests (CT, NT) In order to provide the Experimental data
- Make the Finite Element Simulations to make the Database for the neural network
- Determination of the GTN parameters by using Artificial Neural Network

II.1. NT specimen modeling

To determine the GTN parameters for the CT specimen Figure 2, we used the notch tensile test results as a database to train our Neural network Figure 3, because the computing time is not very big, from one to 5 minutes.
We took advantage of the symmetry, and we make the 2D FEM model just for the quarter of the NT specimen; as shown in Figure 3, the FEM model contains a total of 4604 nodes and 4640 elements.

The mesh size has to be very fine near the crack tip because it is the most sensitive place in the specimen; unlike the upper part of the specimen, which saves a little more of computing time, the mesh size in the front of the pre-crack tip is 0.125 mm × 0.0625 mm. The mesh is composed of axisymmetric quadratic elements with eight nodes.

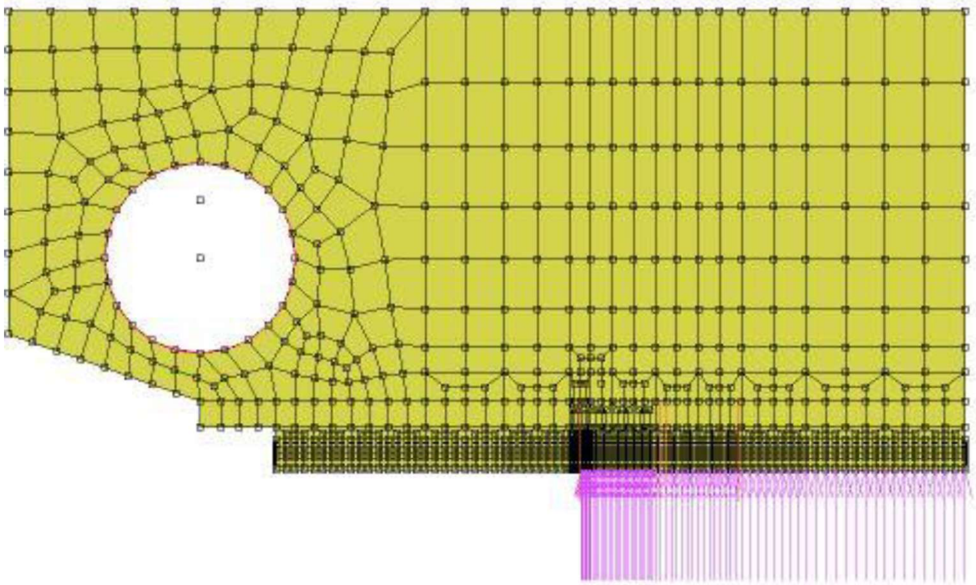

Figure 2 CT specimen

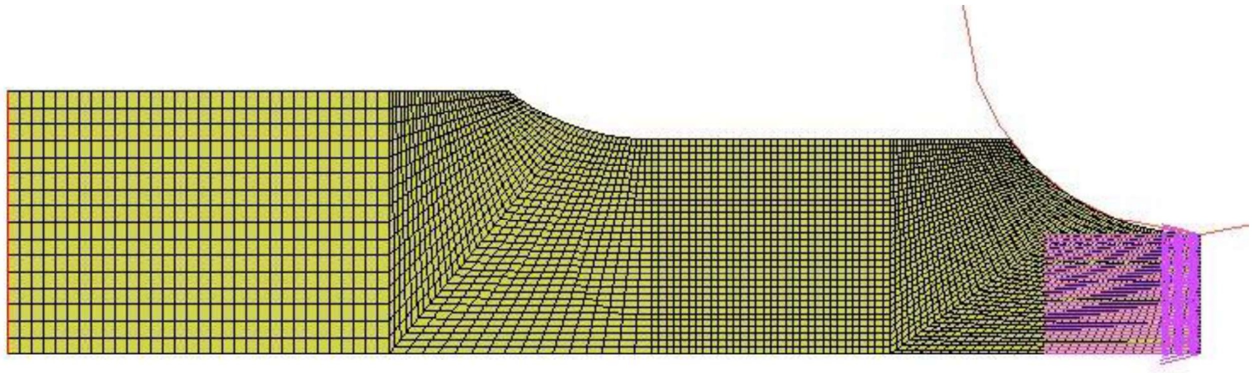

Figure 3 NT specimen

II.2. ANN and Database creation

To train the ANN, sixty simulations were done for the NT specimen with different sets of GTN parameters.
For the NT test, the trained ANN model consists of four hundred and one in the input layer, twenty neurons in the hidden layer, and six neurons in the output layer (401-20-6**.** The neurons of the input layer represent the displacements of a reference point chosen in the boundary of the specimen corresponding to the given values of the reaction force F, and the neurons of the output layer are the six GTN parameters to be identified (f_0, f_c, f_f, S_n, ε_n, and f_n).
After training the Neural Network, we could determine the six parameters, and it did not take much time as if we did it by using the direct method, which is the combination between the

Experimental data and finite element data, as the simulation of notch specimen took just one to two minutes

The GTN parameters determined by using the ANN are f_0=0.0028, f_c=0.0520, S_n= 0.0043, ε_n= 0.5631, f_f=0.3316, and f_n= 0.2851.

II. 2.1. Prediction of Crack propagation for CT SPECIMEN

The prediction of crack propagation for CT specimen is done using the same GTN parameters found using NT Simulations,

We will use the axisymmetry during the NT simulation and make the 3D model just for half of the specimen, and the FEM model contains 58,103 nodes 51,512 elements.

The mesh size in the front of the pre-crack tip is the same as in the NT specimen to avoid the mesh sensitivity effects on the results (0.125 mm × 0.0625 mm).

After making just one simulation with the GTN parameters that we got from the ANN, the results show that the simulation curve fits the experimental curve, and they are in a good agreement in Figure 4.

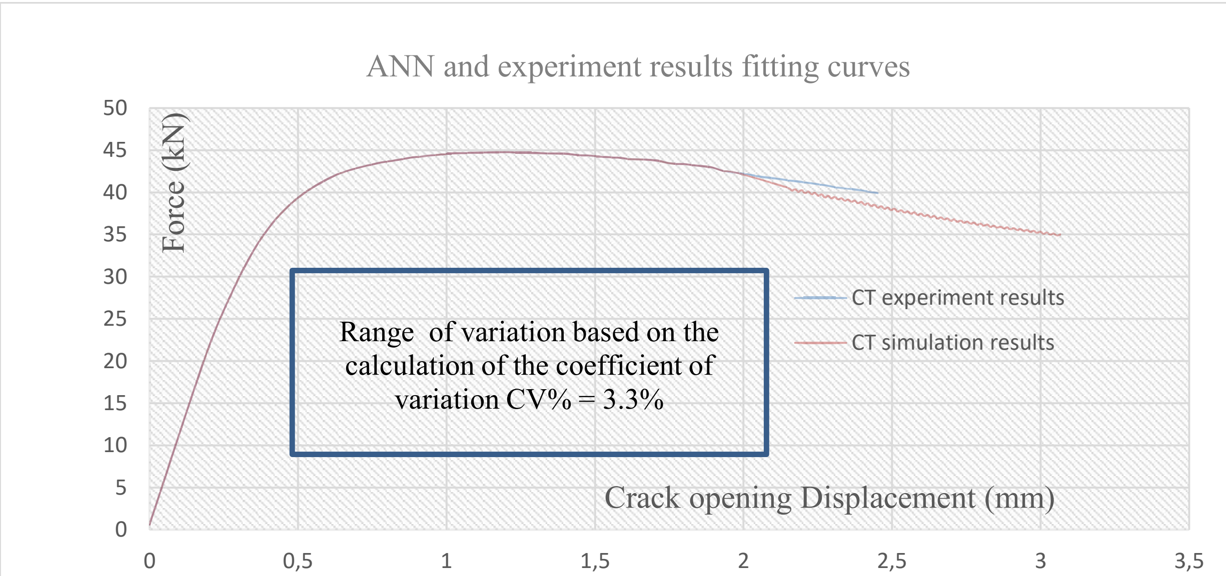

Figure 4 ANN and experiment results in fitting curves

III. Conclusion

The GTN model is an advanced mechanical model used to predict the crack initiation and propagation in the material to avoid failure.

The determination of GTN parameters required much time and simulations using the direct method.

This paper proved that ANN could be combined with the direct method to quickly determine the GTN parameters, two hours instead of one hundred and forty hours.

The ANN approach's implementation needs more detailed studies to develop a proper script used directly in the research and industrial areas.

References

Y., Chahboub; Szávai, Szabolcs; H., Aguir Determination of GTN parameters using artificial neural network for ductile failure In Szita Tóthné, Klára; Jármai, Károly; Voith, Katalin (eds.) Solutions for Sustainable Development: Proceedings of the 1st International Conference on Engineering Solutions for Sustainable Development, (ICESSD 2019) London, the United Kingdom / England: CRC Press, (2019) pp. 25-32. , 8 p.)

Gurson, Arthur L.: Plastic Flow and Fracture Behavior of Ductile Materials Incorporating Void Nucleation, Growth, and Interaction. Ph.D. Thesis, Brown University, Providence, RI, USA, pp. 464. 1975

Bauvineau, L., Burlet, H., Eripret, C., & Pineau, A.L., 1996. Modeling ductile stable crack growth in a C-Mn steel with local approaches. Journal de Physique IV – Proceedings 06 (C6), C6-33–C6-42.

Benseddiq, N., Imad, A., 2008. A ductile fracture analysis using a local damage model. International Journal of Pressure Vessels and Piping 85 (4), 219–227.

Decamp, K., Bauvineau, L., Besson, J., Pineau, A., 1997. Size and geometry effects on ductile rupture of notched bars in a C-Mn steel: experiments and modeling. International Journal of Fracture 88 (1), 1–18

Schmitt, W., Sun, D.Z., Blauel, J.G., 1997. Damage mechanics analysis (Gurson model) and experimental verification of the behaviour of a crack in a weld-cladded component. Nuclear Engineering and Design 174 (3), 237–246.

Skallerud, B., Zhang, Z.L., 1997. A 3D numerical study of ductile tearing and fatigue crack growth under nominal cyclic plasticity. International Journal of Solids and Structures 34 (24), 3141–3161.

Chahboub Yassine, scientific degree (doctoral student)
Institution: the University of Miskolc, Faculty of Mechanics and informatics, Institute of products and machine design, Sályi István Doctoral School
e-mail: chahboubyassine@gmail.com

Tutor: Dr.Szavai Szabolcs, Ph.D., Institute of products and machine design
Reviewer: Dr. El mahjoub Chakir, Professor, Faculty of Science

PÉCSI TUDOMÁNYEGYETEM
UNIVERSITY OF PÉCS

Pécsi Tudományegyetem
Doktorandusz Önkormányzat

PTE ÁJK