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Numerical Investigation of Pores Statistic Distribution Influence on Porous Material Mechanical Behaviour

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The aim of the work presented in the paper was to investigate the influence of pores statistic distribution used for porous material idealistic microstructure model generation on modelled material mechanical properties. Three distribution models were used: homogenous, normal and Weibull one. The model idea was based on the observation of SEM visualisation of shale rock structure which is characterized with dual porosity. The proposed models will be useful for mechanical behaviour of such structures prediction.

Key words: dual porosity materials, statistic distribution, finite element method.

1. Introduction

Many materials, especially natural ones, are characterized by so called dual porosity. In example shale rocks have in their structures two levels of porosity [1]:

- 1st porosity level – micro and meso pores,
- 2nd porosity level – macro pores and natural fractures.

Eagle Ford shale rock structure, shown in Fig. 1, influences gas flow phenomena in this material and also can influence its mechanical properties. This kind of structure appears also in such rocks as sandstone, limestone or granite [2].

Dual porosity can be also find in human-made materials such as single-walled carbon nanotubes [3], polytetrafluoroethylene [4], etc.

In the paper the numerical research on statistically generated numerical models of dual porosity material structures was shown. The mechanical behaviour of such structures was studied and influence of the materials structure on the material strength was investigated.

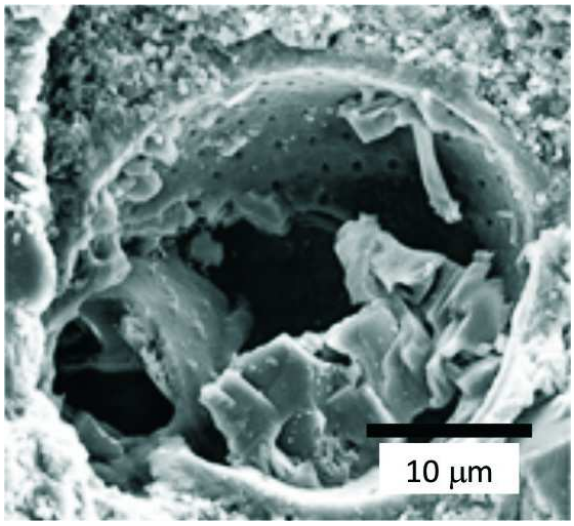

FIG. 1. SEM visualization of Eagle Ford shale rocks from Gulf Coast Basin with two levels of porosity [5].

2. Numerical model development

Methods of porosity development and different models of porous structures are known. Wide range of porous material microstructural models can be found in [6]. Other examples can be: single-porosity and dual-porosity models applied for water flow and solute transport in subsurface-drained fields investigation using effective field-scale parameters [7], dual porosity and dual permeability models formulation proposed in [8] and models considering porosity development showed in [9] and [10].

In presented work numerical model of dual porosity material structure was developed on the base of quasi-fractal porous media model proposed in [11].

The model generation method was presented in Fig. 2. In order to take account of pores having largely different sizes, a hierarchical procedure can be adopt, which yields a fractal medium. In the presented example, a 3D cube composed of cubical cells of two types: "material" (labeled 1) and "void" (labeled 0) was considered. In the porous medium of the first generation (referred to as "medium 1"), the material cells are made of solid material, while the voids may actually contain gas. In the second generation medium (referred to as "medium 2"), the material cells are cubes of the first generation; similarly, the material cells of the third generation ("medium 3") are cubes of the second generation. Thus a multitude of pore sizes is accounted for, arising from both the distribution of voids and the fractal structure. An initial porosity p_0 is chosen, and the cells are assigned values of 0 or 1 at random in such a way that

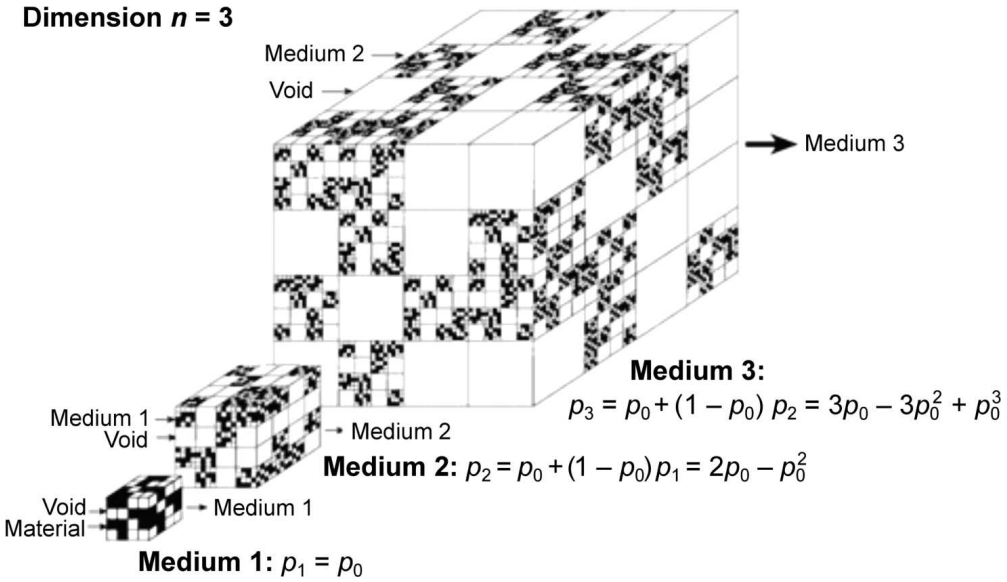

FIG. 2. Schematic representation of the hierarchical (fractal) model of a porous medium. The dimension is $n = 3$. The basic porosity is $p_0 = 0.5$ [11].

the desired porosity is attained. However, while the porosity p_1 of medium 1 is obviously $p_1 = p_0$, the actual porosity of medium 2 is

$$p_2 = p_0 + (1 - p_0)\, p_1 = 2p_0 - p_0^2 \tag{2.1}$$

and similarly for medium 3:

$$p_3 = p_0 + (1 - p_0)\, p_2 = 3p_0 - 3p_0^2 + p_0^3. \tag{2.2}$$

It can be easily shown that, generally, for a hypothetical medium n,

$$p_n = 1 - (1 - p_0)^n\,. \tag{2.3}$$

For the purpose of the presented research a series of FEM models were developed. The basic porosity p_0 was 0.3, 0.4, 0.5 and 0.6 (Fig. 3). The total porosity of the models was 0.51, 0.64, 0.75 and 0.85 respectively. Five models of each type were developed.

Three methods of random selection of localization of pores in basic porosity structure were assumed: based on homogenous, normal distribution (expectation of the distribution $\mu = 0$, variance $\sigma^2 = 0$) and Weibull distribution (scale parameter $\lambda = 1$, shape parameter $k = 2$). The charts of those distributions as well as the examples of models generated in 2D for better visualization of the method were shown in Figs. 4 and 5.

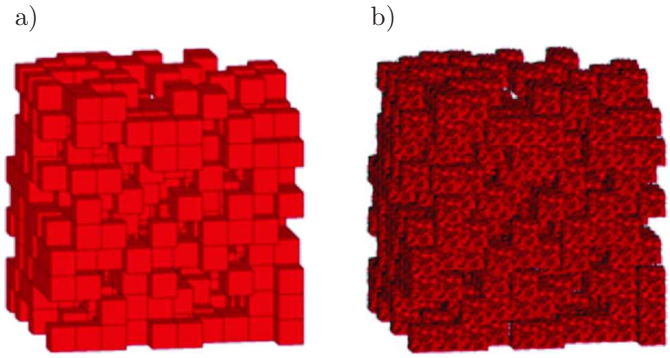

FIG. 3. Example of dual porosity numerical model used in research – model was developed with use of homogenous randomization, $p_0 = 0.6$: a) first porosity level, b) second porosity level.

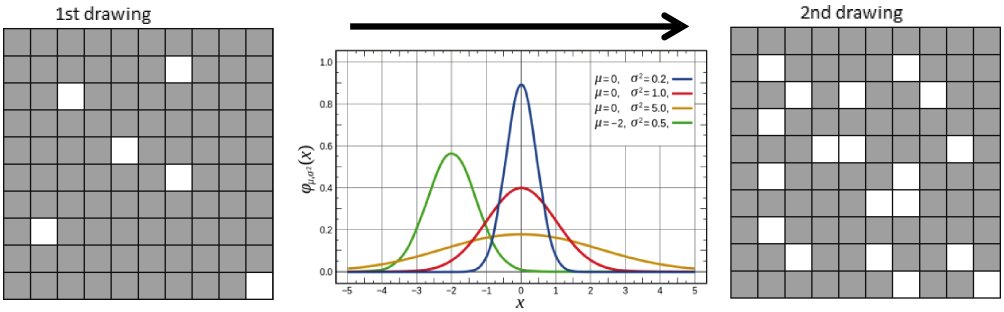

FIG. 4. Method of "porous" elements selection with the use of normal distribution.

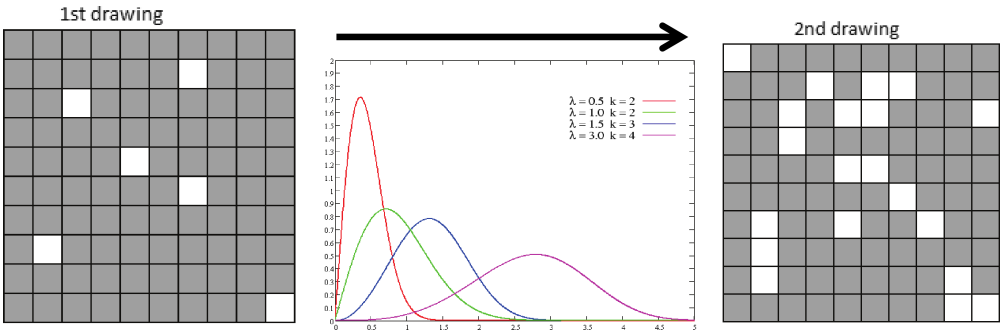

FIG. 5. Method of "porous" elements selection with the use of Weibull distribution.

The homogenous distribution was based on the Excel RAND function, which returns an evenly distributed random real number greater than or equal to 0 and less than 1. The number of pores localized randomly in finite element model was selected to achieve the assessed porosity.

The normal and Weibull models were developed on the base of two drawings: the first one was to draw 10% of assumed porosity in homogenous way, and next one was based on the mentioned distributions, where the population was described by porosity and the attribute was described as the probability of new pore appearance in the neighborhood of the previously selected "porous" element, what was schematically shown in Fig. 6. The procedure of drawing the same element was introduced.

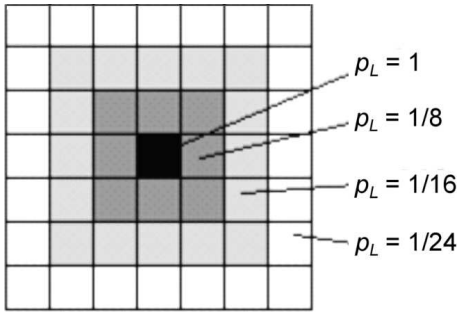

FIG. 6. Probability distribution for "porous" element location (p_L) selection for 2D model example.

3. Results and discussion

The material model for the analyzed samples was assumed as elastic – plastic one with Young's modulus of 71 GPa, Poisson's ratio of 0.33, yield stress – 0.318 GPa, compression strength – 0.488 GPa. Each model was compressed with the use of rigid plates with the friction coefficient of 0.2. The surface to surface contact with penalty function was applied. The load speed was 0.1 m/s. Each model dimension was $10 \times 10 \times 10$ mm.

The results were achieved as rigid walls force-displacement relations for each model, which were averaged for each type of numerical sample and compared. The calculations were carried out with the use of LS-Dyna computer code. All models showed typical behavior for porous material. The comparison of resulted first "peak" force was shown in Table 1.

The results of numerical calculation showed the significant influence of pores distribution on the strength behavior of the porous material. The smallest difference is for models of porosity $p_0 = 0.3$ – probably the number of pores is too low to influence the mechanical properties of material.

For models of $p_0 = 0.4$, 0.5 and 0.6 the biggest "peak" force appears when the model was based on homogenous randomization, lower force values appear for normal distribution and the lowest ones are for normal Weibull distribution.

Table 1. Comparison of first "peak" force resulted from numerical calculations.

Models of p_0	Peak force for homogenous distribution models [kN]	Peak force for normal distribution models [kN]	Peak force for Weibull distribution models [kN]
0.3	80.2	80.3	80.4
0.4	40.0	36.2	30.1
0.5	10.2	8.6	7.5
0.6	0.51	0.42	0.33

Finally, it can be concluded that the selection of model randomization can significantly influence the results of the calculation. The idealization of the researched structure, e.g. such as natural inhomogeneous shale structure, must be based on observation of real structure. The model development in such case can be based on fractal generation method coupled with stochastic randomization proposed in the paper.

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