6th International Workshop on Rock Physics

13-17 June 2022, A Coruña, Spain

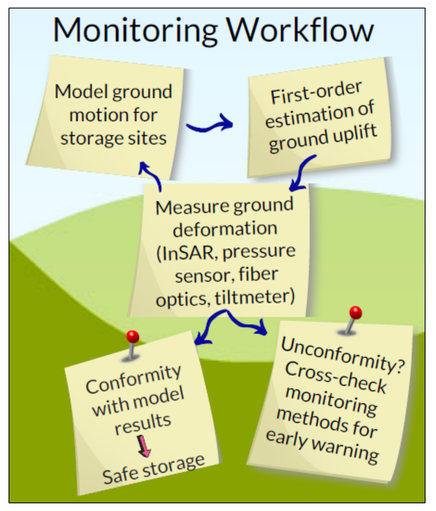
Discrimination of fluid pressure and saturation changes during geological CO_2 storage based on surface deformation data

Héctor Marín-Moreno, Jean-Rémi Dujardin, and Joonsang Park

Norwegian Geotechnical Institute (NGI), Sognsveien 72, 0806 Oslo, Norway Country

Motivation

During **geological CO_2 storage, fluid pressure** can build up (depending on e.g. injection rate, the reservoir permeability, the presence of pressure barriers) and this can create **uplift** of the materials above. The magnitude of uplift also depends on the **bulk modulus of the sediment** which is indeed affected by the pore fluids. Subsurface uplift is then affected by both **fluid saturation and pressure changes** and **discriminating** their contribution may provide early-warning of undesired pressure pattern anomalies.



This work is part of the ACT project SENSE, *Assuring integrity of CO_2 storage sites through ground surface monitoring* (*https://sense-act.eu/*).

Concept

Discrimination of fluid pressure and saturation changes from surface uplift by combining an analytical solution for pressure-induced deformation of a multilayered seabed, machine learning, analytical rock physics modelling, and a capillary pressure model.

Solution of the inverse problem via machine learning using training data obtained from our modified Geertsma's solution

Data: Seabed vertical displacements

P_e, G_e, ν_e

Module 1

$$K_e = \frac{2G_e(1+\nu_e)}{3(1-2\nu_e)} \qquad \nu_m = \frac{3K_m - 2G_m}{2(3K_m + G_m)}$$

$$P_0 = H \cdot g \cdot \rho_{w0}$$
$$K_{f1} = f1(P_0 + Pe, T)$$
$$K_{f2} = f2(P_0 + Pe, T)$$

$$G_d = G_e$$
$$K_d = G_d \frac{5(2+\nu_m)}{3(2+3a-\nu_m(1+3a))} \qquad \nu_d = \frac{2-2a+\nu_m(2a-1)}{2(4+a-\nu_m(2+a))}$$

$$K_{fe} = G_d \frac{\varphi(K_e - K_d)}{\left(1-\frac{K_d}{K_m}\right)^2 - (K_e - K_d)\left(\frac{1-\varphi}{K_m} - \frac{K_d}{K_m{}^2}\right)}$$

Parameters
$H, g, \rho_{w0}, \varphi, K_m, G_m, T, b, a$

$$if\left(\nu_d < \nu_e - Tol_\nu \,\&\, K_{fe} < K_{f1} - Tol_{K_{f1}} \,\&\, K_{fe} > K_{f2} + Tol_{K_{f2}}\right)$$

$$S_{f2} = 1 - \left(\frac{K_{fe} - K_{f2}}{K_{f1} - K_{f2}}\right)^{1/b} \qquad S_{f1} = 1 - S_{f2}$$

$$S_{f2} = \frac{K_{f2}(K_{f1} - K_{fe})}{K_{fe}(K_{f1} - K_{f2})} \qquad S_{f1} = 1 - S_{f2}$$

Module 2

$$P_e = P_{f1} + w * (P_{f2} - P_{f1}) - P_0$$

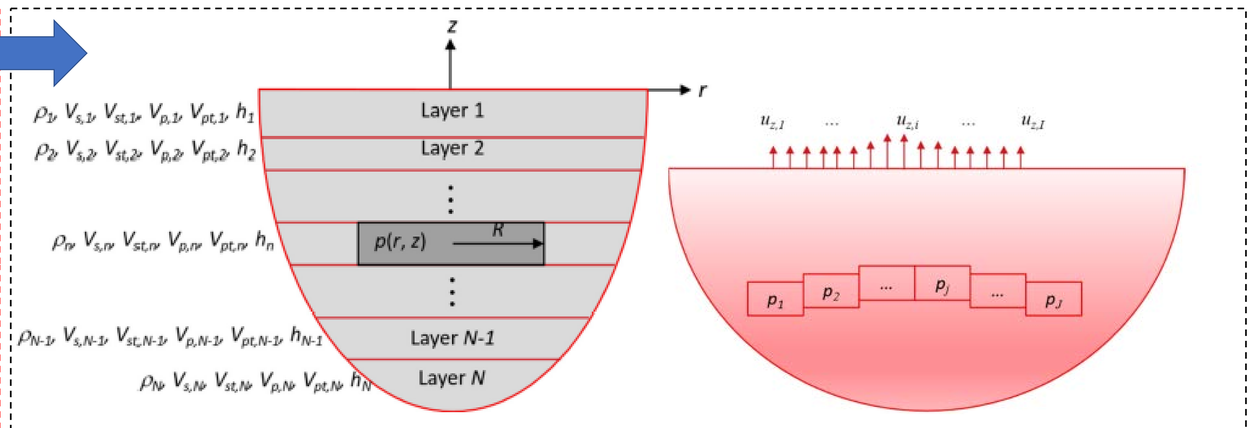
$$P_{f2} - P_{f1} = P^*\left(S^{*-1/n} - 1\right)^{1-n}$$

$$S^* = \frac{S_{f1} - S_{f1i}}{S_{f1max} - S_{f1i}}$$

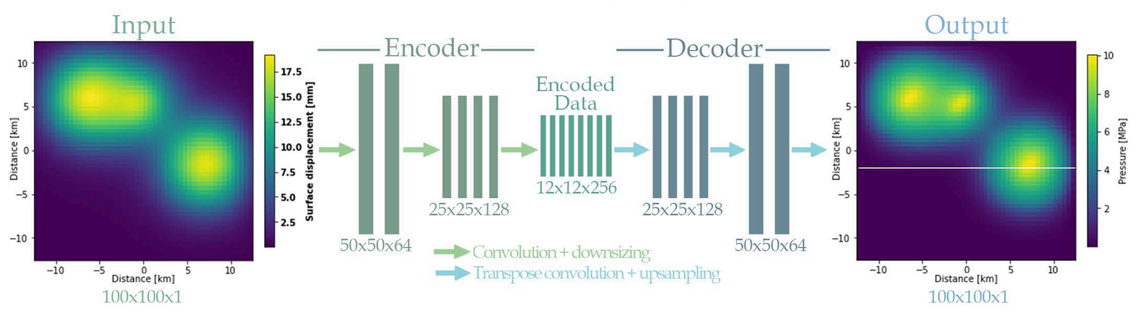
- Gassmann model
- Hertz-Mindlin contact model
- Brie's effective fluid expression
- Reuss effective fluid expression
- Van Genuchten capillary pressure model
- Effective pressure increment model

P_{f1} ; P_{f2}

Module 3



Generalized Geertsma solution for anistropic layered seabed (*Park et al., 2021*)

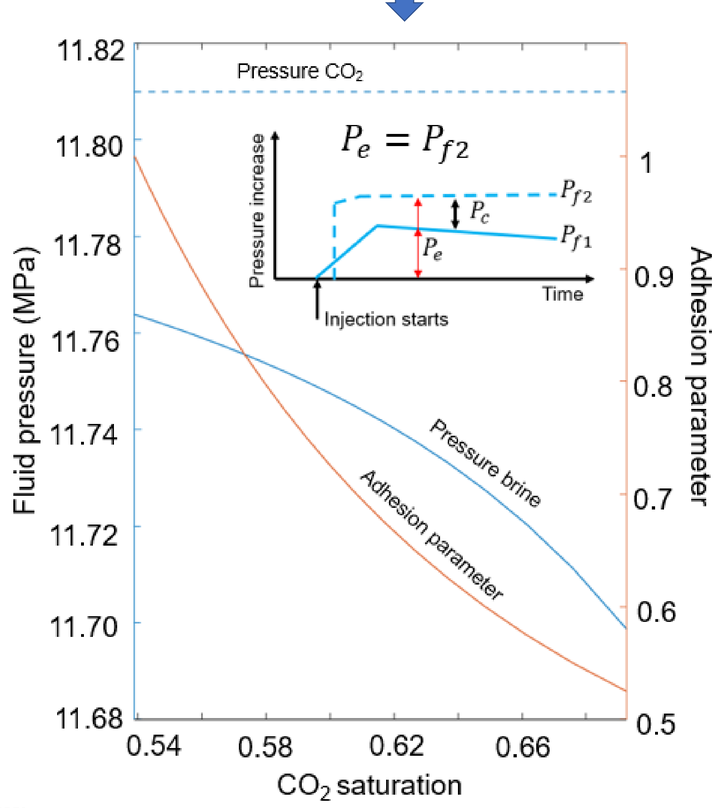


Convolutional neural network (CNN) with an encoder-decoder architecture

Synthetic study

Input seabed deformation → Module 1 → Reservoir properties: P_e = 2 MPa, K_e = 1.6 GPa, G_e = 1 GPa

Modules 2 & 3



This concept is applicable to any fluid injection problem where surface deformation data is detectable

Acknowledgments

This work is financially supported by SENSE, through ACT (EC Project no. 691712) and subsidized by Gassnova, Norway, United Kingdom Department for Business, Energy and Industrial Strategy, Forschungszentrum Jülich GMBH, Projektträger Jülich, Germany, The French Agency for the Environment and Energy Management, The United States Department of Energy, State Research Agency, Spain, with additional support from Equinor and Quad Ge-ometrics.

References:

Park J., Bjørnarå T.I., Bohloli B (2021) An Analytical Solution for Pressure-Induced Deformation of Anisotropic Multilayered Subsurface. Geosciences, 11, 180. DOI: 10.3390/geosciences11040180)