# A transparent soil model for visualizing soil-structure interactions during pull-out tests of small diameter steel rods

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## 1. INTRODUCTION

The visualisation of soil-structure interactions – in general the soil displacement caused by structures which are transferring an external load into the subsoil – is of fundamental interest for understanding the soil-structure behaviour. Full field measurements in soil mechanics – commonly the three-dimensional measurements of the soil-structure interaction - are for example realisable with the help of x-ray technique Roscoe et al. (1963), computer tomography Orsi et al. (1992) and magnetic resonance Mandava et al. (1990). However, these techniques are in principle very complex and hard to handle. Mannheimer and Oswald (1993), Welker et al. (1999), Zhao (2007) and Iskander (2010) were developing a new material for full field measurements in soil mechanics, called transparent soil. A transparent soil is basically a manmade synthetic soil of an amorphous silica gel or powder which is fully saturated with a pore fluid. Both, the pore fluid and the silica gel or powder has the same refractive index Mannheimer and Oswald (1993). A laser light sheet, which is guided through a transparent soil model – before, after and during an experiment – produces specific speckle patterns (Figure 1) for each laser light sheet. The laser light sheets are photographed and the pictures of the same laser light sheet position are analysed afterwards with the digital image correlation DIC Iskander M. (2010). The change of the specific speckle pattern corresponds to the displacement of the silica gel. Nevertheless, this technology is not a real three dimensional analysis. It is a two dimensional analysis of each specific laser light sheet and gets, more or less, a three dimensional character by combining the analysis of different laser light sheet positions. This paper presents the development of a transparent soil and of testing equipment for pull-out tests of small diameter steel rods out of a transparent soil model. Finally the results – the visualisation of the soil-structure interaction caused by the pull-out tests – are shown.

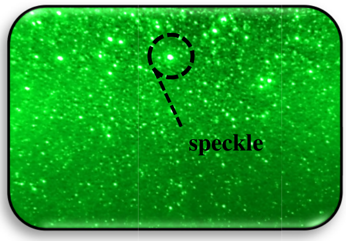


**Figure 1.** speckle

## 2. TRANSPARENT SOIL

As aforementioned, a transparent soil is synthetic handmade material of silica gel (coarse grain) or silica powder (fine grain) which is fully saturated with a pore fluid. Both, the silica gel and the pore fluid have the same refractive index $n_D$ and become therefore transparent if those materials are mixed together and if no air bubbles are in the model. Silica is an amorphous, inert, insoluble, extremely light and porous (the particles itself) product and commonly used as a desiccant Iskander (2010). In a first research step the silica gel (manufacturer: ThoMar OHG, Germany; spherically particles; grading 2 – 5mm) which was used for the pull-out tests was characterized in a soil mechanical way, Table 1 and the refractive index $n_{D,20}$ (20°C room temperature) from the silica gel was determined in an experimental way, Poprask K. (in print).

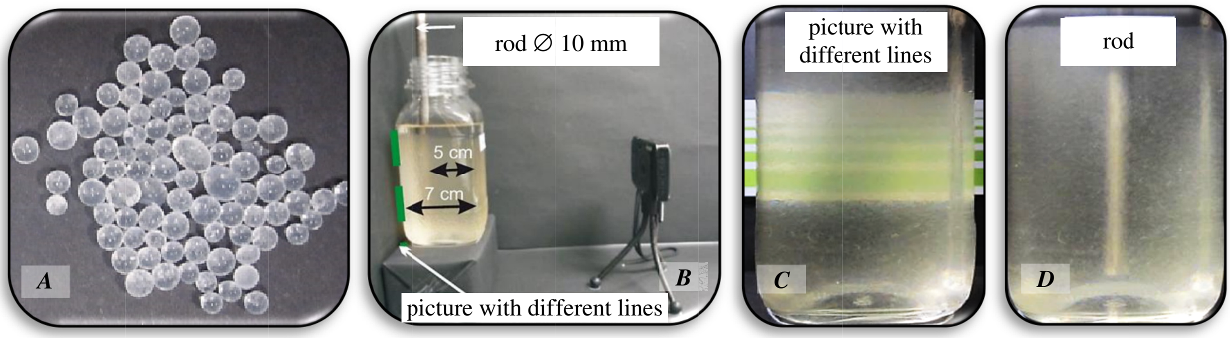


**Figure 2.** *A* silica gel (dry); *B* testing equipment: best transparent effect; *C* & *D* front view transparent effect

Finally a pore fluid which produces the best transparent effect of the transparent soil was assembled. The transparent effect was experimental tested with the help of different references inside (rod) and outside (picture with different lines) of the transparent soil model, Figure 2. The pore fluid was characterized according to the testing procedure for pore fluids of Zhao (2007), Table 2.

**Table 1.** Silica gel characteristics

| | Silica gel |
|---|---|
| True density $\rho_T$ [g/cm³] | 2.06 |
| Particle density $\rho_p$ [g/cm³] | 1.10 |
| Dry density $\rho_D$ [g/cm³] | 0.80 |
| Particle pores [-] | 0.34 |
| Total porosity [-] | 0.61 |
| Refractive index $n_{D,20}$ [-] | 1.429 |
| Friction angle $\Phi_{PEAK}$ [°] | 43 |
| Friction angle $\Phi_{RESIDUAL}$ [°] | 33 |
| Cohesion c [kPa] | ≈ 0 |
| Oedometric modulus $E_s$ [MPa] ($\sigma_1$ = 160 – 320 kPa) | 40 |
| Grading [mm] | 2 – 5 |

**Table 2.** Pore fluid[a] characteristics

| | Pore fluid | Water |
|---|---|---|
| Density ρ [g/cm³] | 0.82 | 1,00 |
| pH – Value [-] | 7 | 7 |
| Refractive index $n_{D,20}$ [-] | 1.429 | 1.330 |
| Perviousness[b] K [m²] | $8.46E^{-11}$ | $8.46E^{-11}$ |
| Surface tension Ϭ [mN/m] | 19.76 | 72.75 |
| Dyn. viscosity η [kg/s m] | 0.0011 | 0.0010 |
| Kin. viscosity ν [mm²/s] | 1.312 | 1.004 |

[a] pore fluid = 53.5 w% toluol + 46.5 w% 2-propanol
[b] through Silica gel, according to Table 1
w% . . . weight per cent
Toluol: $C_7H_8$; 2-Propanol: $C_3H_80$

## 3. TESTING EQUIPMENT & TESTING PROCEDURE

A test equipment for pull-out tests of vertical steel rods (type SAS 900/1100 FA- grade 160 FA from the company Annahuette, Germany; ∅ 15 mm; length 50 cm) out of a large transparent soil model (width / length / height = 50 / 25 / 90 cm) was constructed, Figure 3. Details can be seen in Poprask K. (2011). The transparent soil was made in advance and filled up into the test box in layers until the final height was reached Ganster K. (2012). After each layer a jogging motor which was installed benath the bottom of the traverse - Figure 3 - was activated. Finally the small diameter steel rod was screwed into the transparent soil model and pulled out stepwise with constant velocity (0.33 mm/s). A hitch was installed therefore on top of the traverse. The pull-out process was stopped after each 2 mm vertical path $u_z$ and a laser (manufacturer: Laser 2000 GmbH, Germany; type: CNI-532-3000-AC; 3.7 W; λ = 532 nm; constant wave) started to move automatically with the help of a laser-guidebar, installed below the hitch, Figure 3. A line generator which was installed on the laser source, Figure 3, generates a laser light sheet which moves through the transparent soil model while a digital camera (CCD, manufacturer: Allied Vision Technologies GmbH, Germany; type: Prosilica GX1910 (02-2404B)) takes pictures. A software was written to synchronize the laser light sheet position with the digital camera to ensure that only pictures of the same laser light sheet position are analysed with the digital image correlation DIC afterwards, Ganster D. (2012).

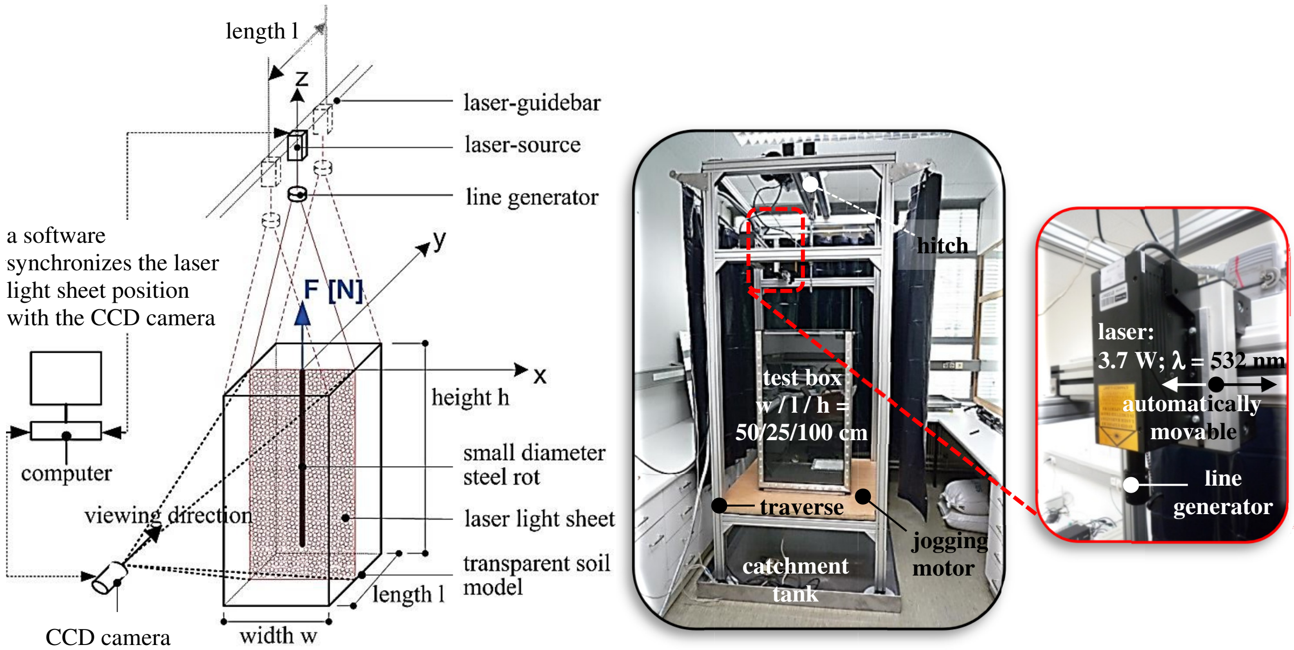


**Figure 3.** left hand side: schematic sketch of the test set up for a transparent soil experiment; right hand side: realized test set up including traverse and hitch for small diameter rod pull-out tests

## 4. RESULTS

The pull-out force – displacement diagram can be seen in Figure 4 where a softening process is recognized. The peak value ($F_{max}$ = 320N) was reached after 7 mm vertical displacement $u_z$. Pictures of different laser sheet positions (0.2; 4; 8 and 11 cm behind the front window from the test box, Figure 3) have been analysed with the digital image correlation DIC after a vertical displacement $u_z$ of 6 mm. Details of this method are described for instance in Raffel et al. (2007) and Iskander (2010). A clear failure body is visualized in Figure 4 which is caused by the soil-structure interaction. Poprask K. (in print).

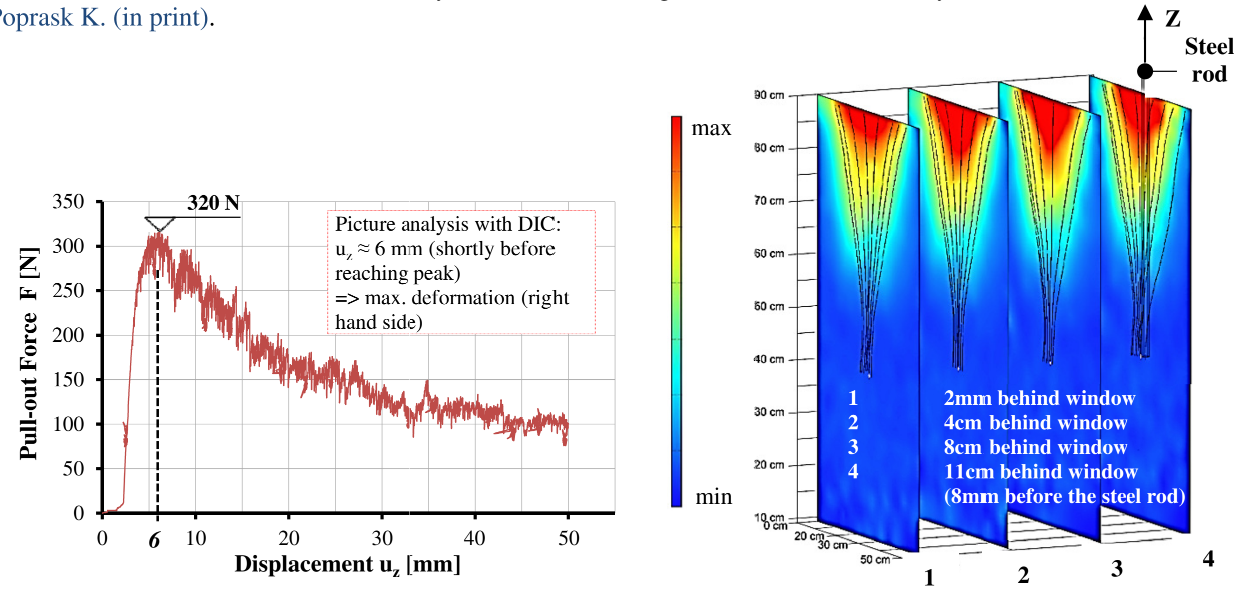


**Figure 4.** left hand side: pull-out test diagram; right hand side: total displacement analysis with digital image correlation of different laser light sheet positions (1- 4) (for $u_z \approx 6$ mm => max. displacement, ≈ 0 mm => min. displacement)

## 5. CONCLUSION

- A transparent soil model which behaves almost like a real soil was successfully conducted
- The pore fluid was tested according to the testing procedure of Zhao (2007)
- A large test equipment for pull-out tests of small diameter steel rods out of a transparent soil model was assembled
- Pull-out tests were conducted and a failure body, caused by the soil-structure interaction was three-dimensional visualized
- The pull-out test diagram shows a clear softening process
- The peak-value of the pull-out test diagram is already reached after 7mm vertical displacement

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