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Concrete Infrastructure Research Group

100 years of the concrete slump test:
uncovering rheological insights via 3D reconstruction

Callum White and Janet M. Lees

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Rheology of Building Materials

COSTAIN

UKRI Engineering and Physical Sciences Research Council

Introduction

In its fresh state before setting, concrete is a complex suspension that exhibits yield stress and viscosity, i.e. it is a non-Newtonian fluid

Despite this complex behaviour, fresh-state performance is primarily assessed on-site using simple measures introduced a century ago

This work proposes a novel methodology embracing the synthesis of emerging digital technologies and the performance tests existing in current practice

Gaining improved fresh state performance insights facilitates a reduction in wastage and greater influence to implement more sustainable concrete mixes in practice

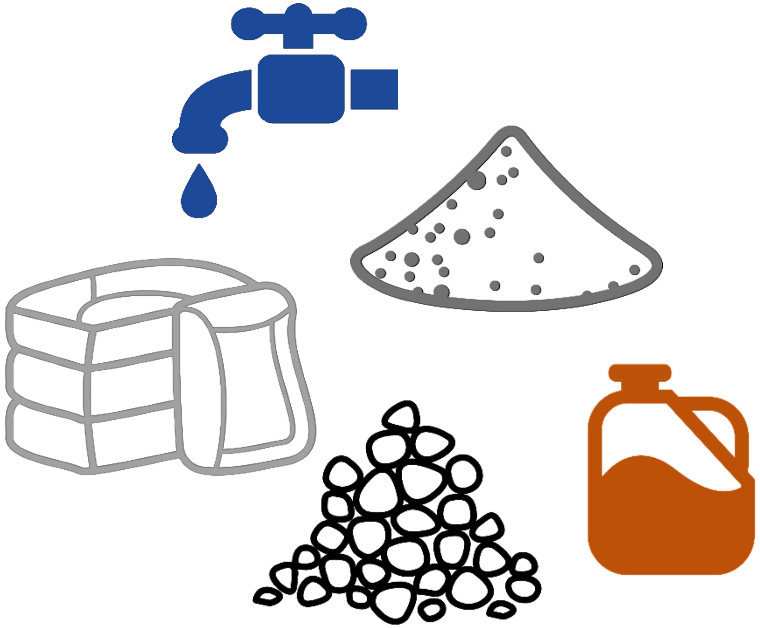
White, C., Lees, J.M.: Yield stress prediction from 3d reconstruction of fresh concrete slump. Cement and Concrete Research 174, 107331 (12 2023)
Tattersall, G. H.: Workability and Quality Control of Concrete. CRC Press (10 1991)

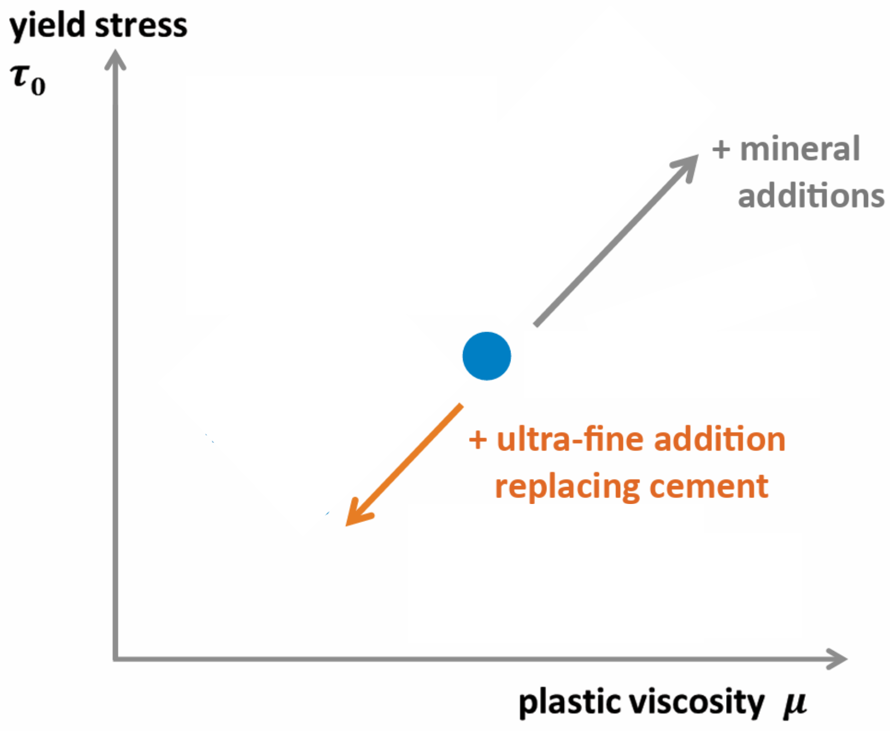
Significance

Contactors placing the concrete want a material that is easily manipulated to reduce labour requirements. There are further relationships drawn to pumping and formwork pressures

The hardened state properties such as void content, density and strength, are influenced by the fresh state properties

Fresh state concrete
Significance

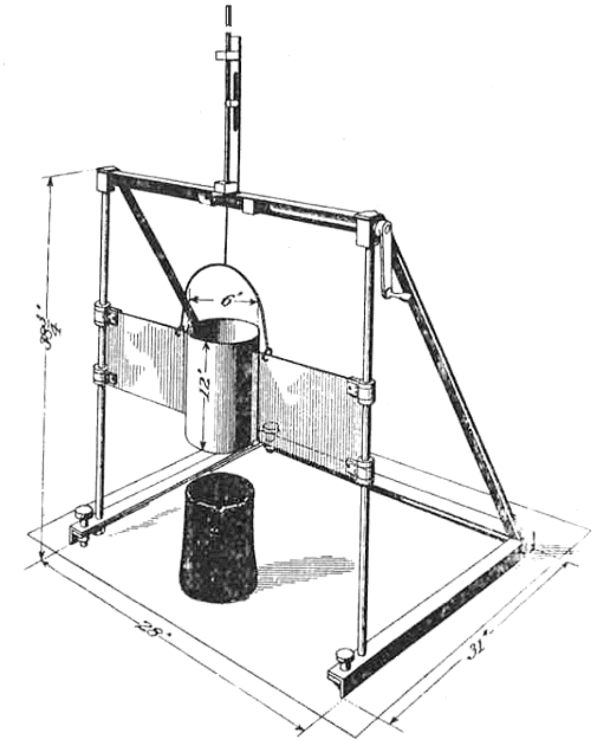


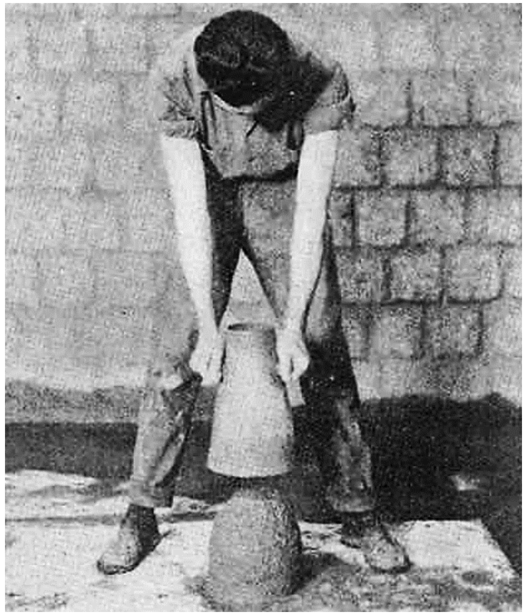


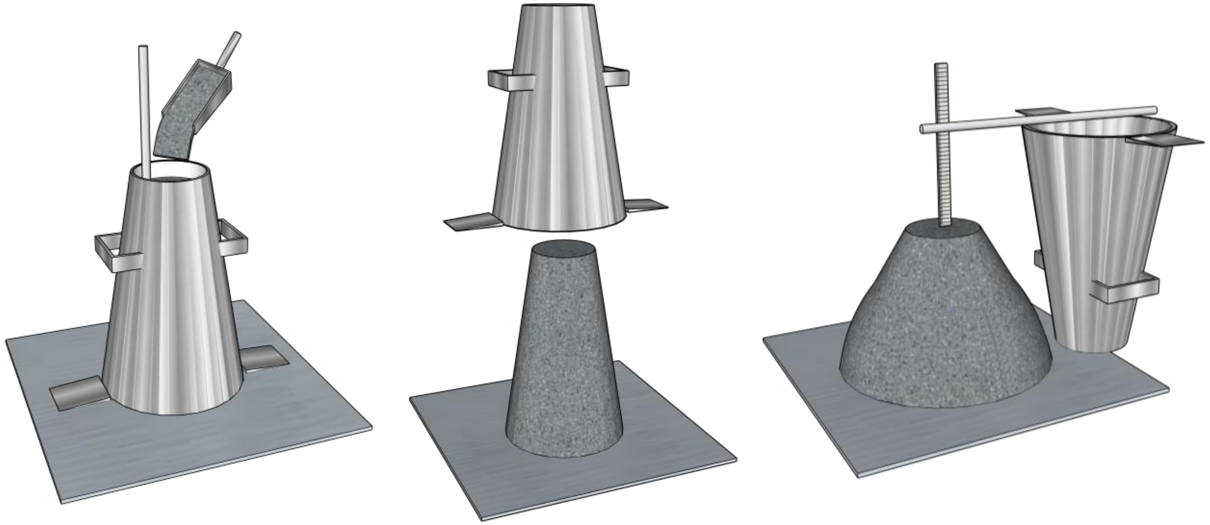
Beckhaus, K., Admiraal, B., Bell, A., Bohle, B., Boutz, M., Brown, D., Darson-Balleur, S., Faust, P., Granata, R., Harnan, C., Moore, D., Nicholson, D., & Rostert, A. (2018) Guide to Tremie Concrete for Deep Foundations

Fresh state assessment: slump test

A brief history







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Faber, O., Childe, H.L.: The Concrete Year Book 1925. 2. Concrete Series (1925)
White, C., Lees, J.M.: Yield stress prediction from 3d reconstruction of fresh concrete slump. Cement and Concrete Research 174, 107331 (12 2023)

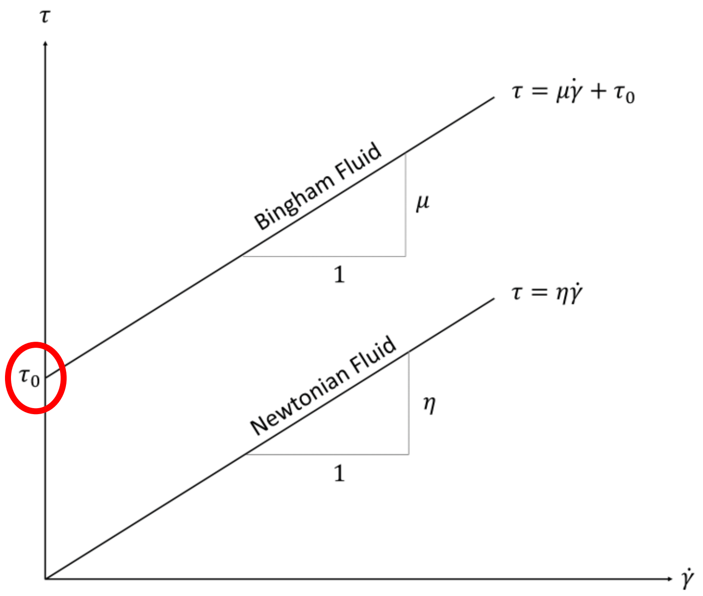
Fresh state assessment: slump test

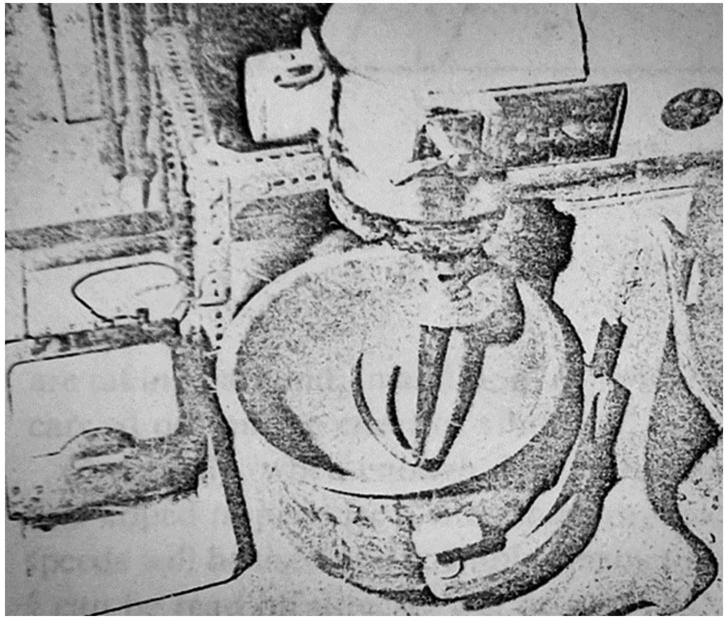
Performance specification

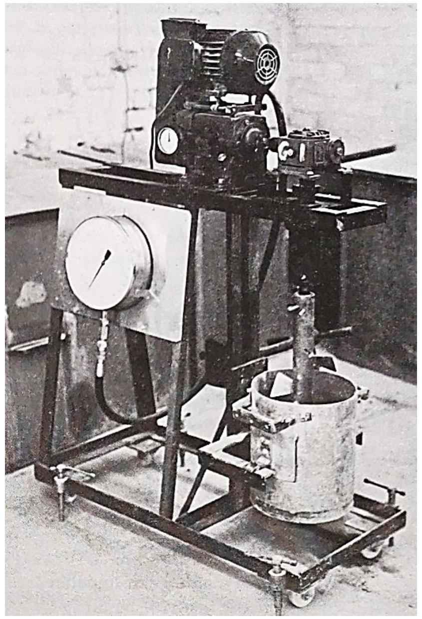
Slump Class	Not less than (mm)	Not more than (mm)
S1	0	60
S2	40	110
S3	90	170
S4	150	230
S5	210	-

Fresh state assessment: rheology

Development of assessment tools







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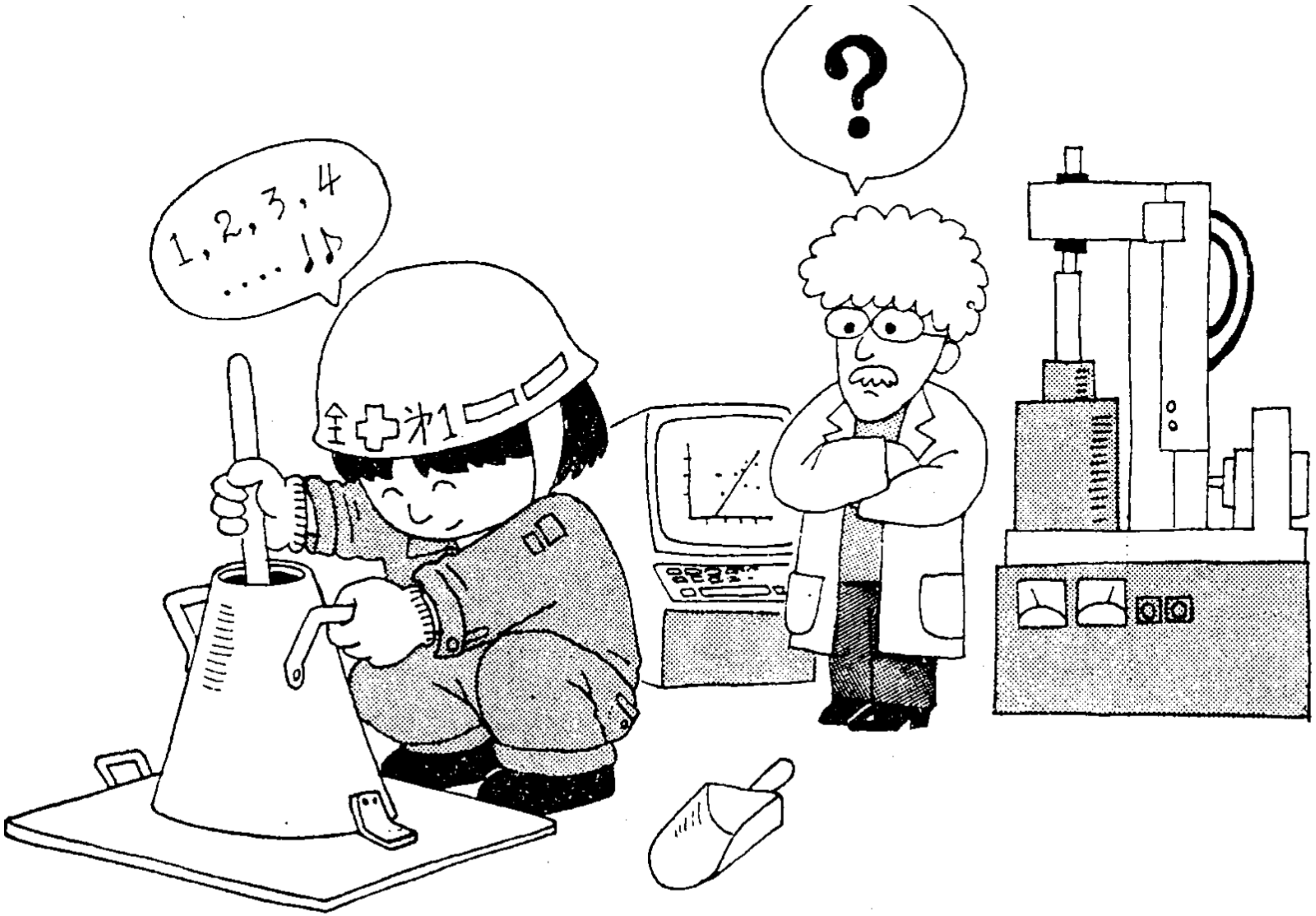
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Existing approaches

Theoretical: *Adopting the force balance deformation model, considering stress due to overlaying material*

Empirical: *Relating total slump height to yield stress via experimental means*

Simulation: *Combining the theoretical and empirical approaches utilising FE or CFD methods*

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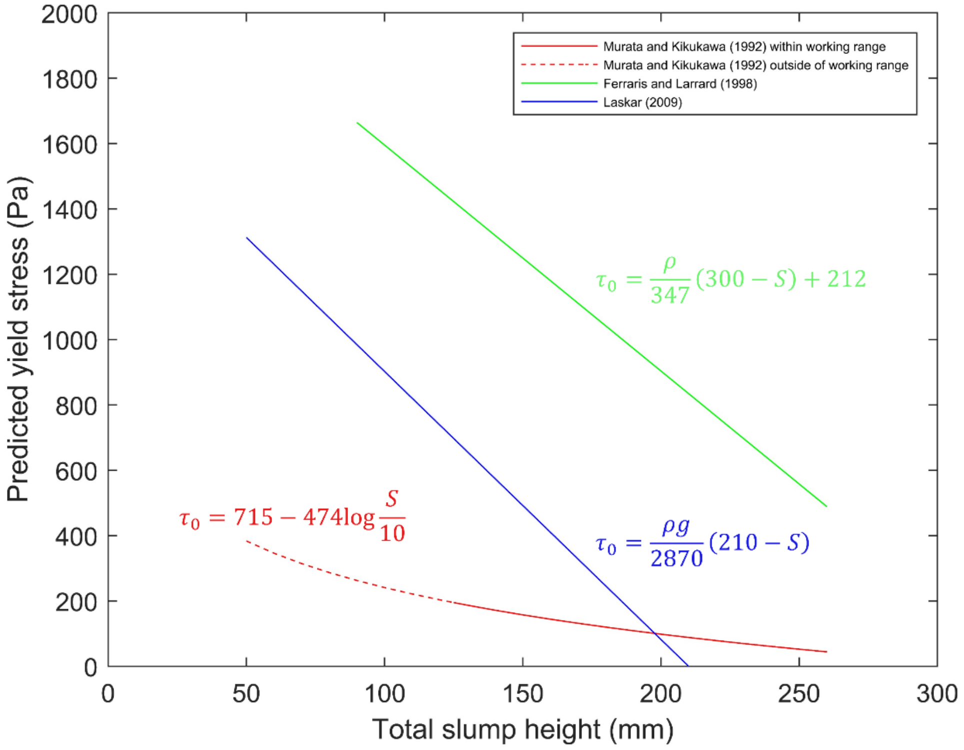
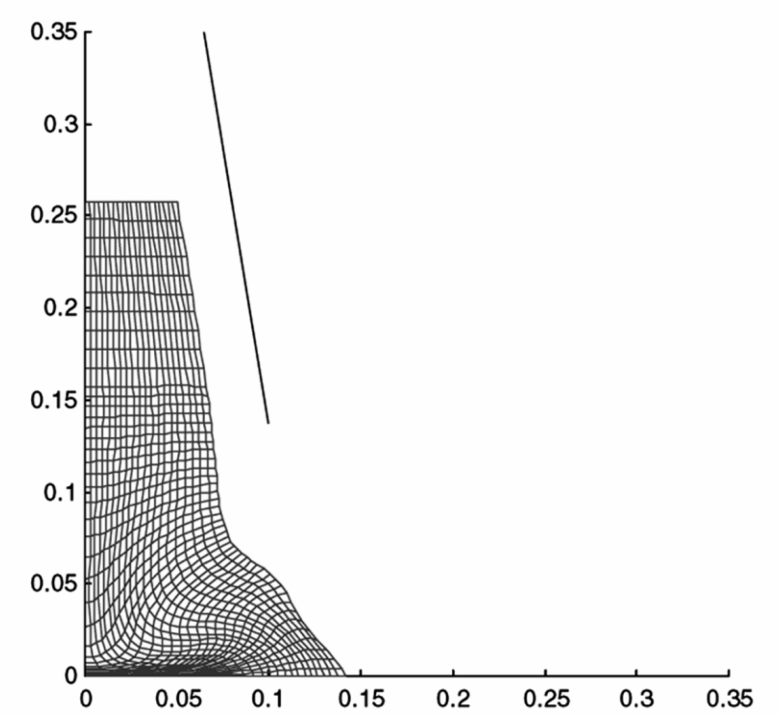
Relating slump to yield stress
Existing approaches

Empirical



Simulation



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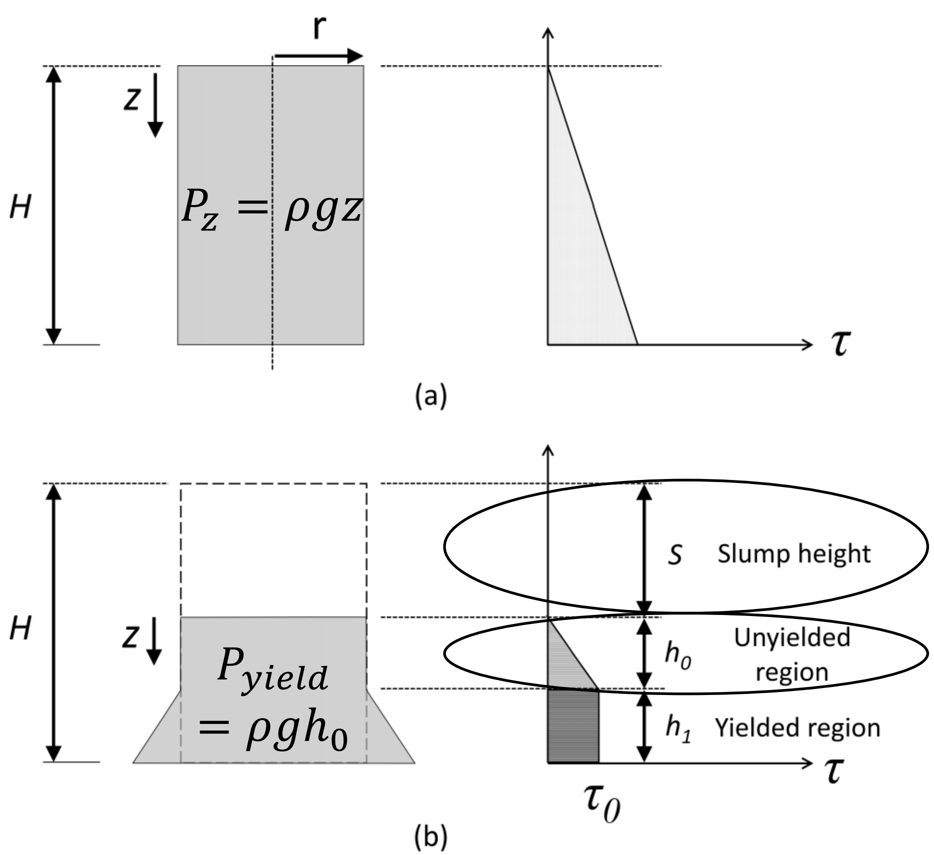
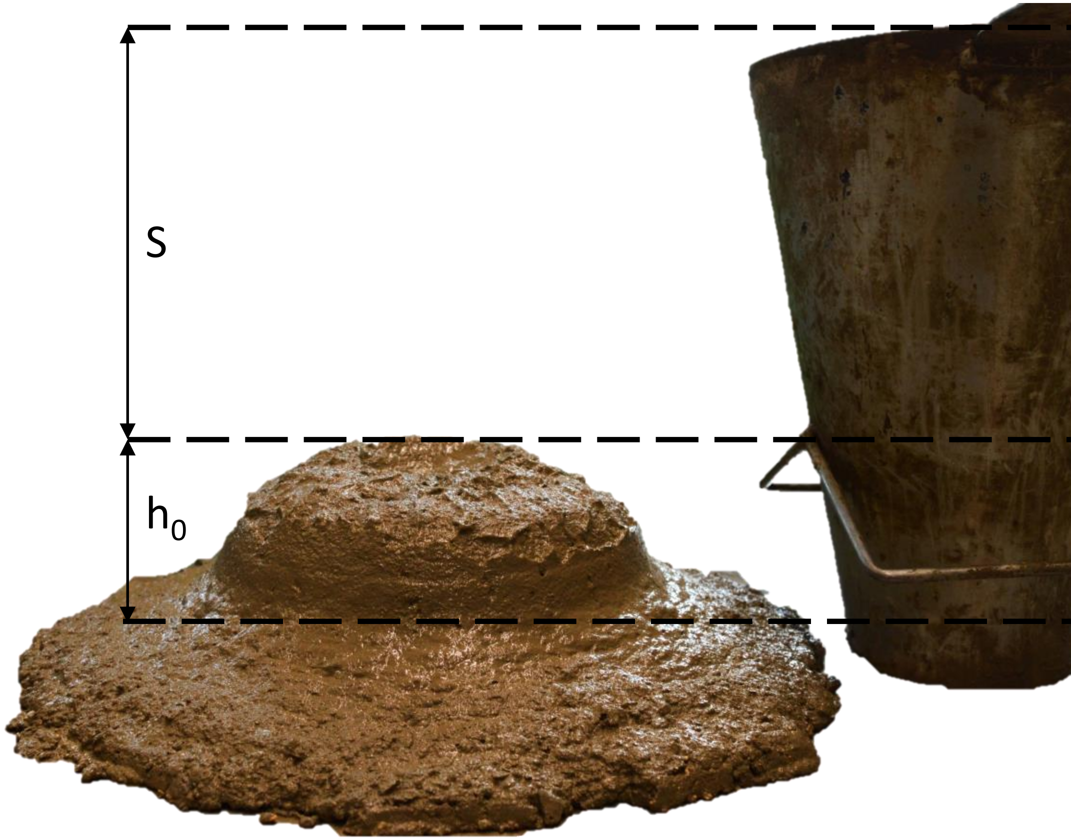
Theoretical free fall and rheology relationships

Force balance deformation approach





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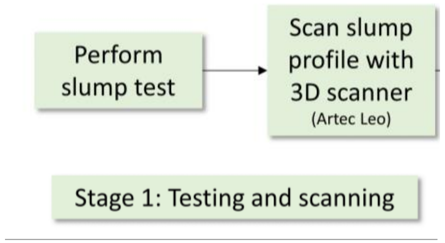
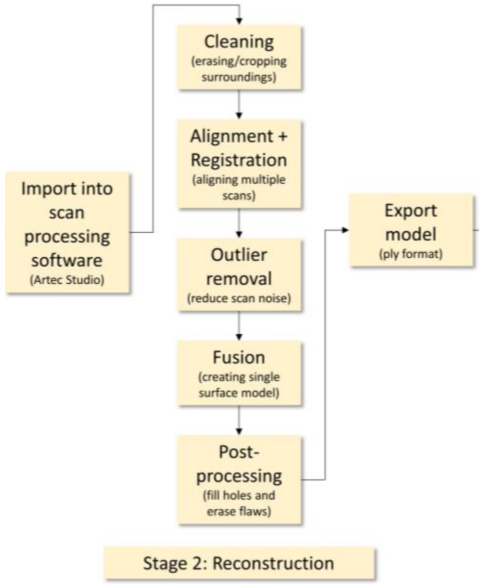
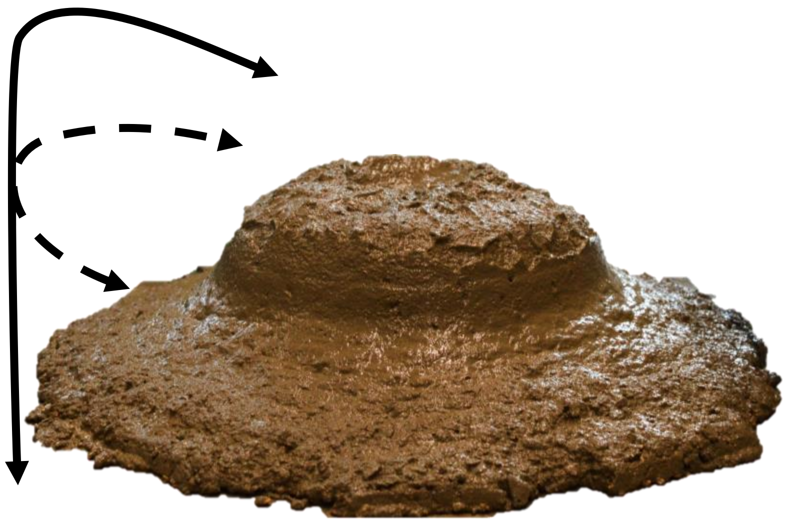
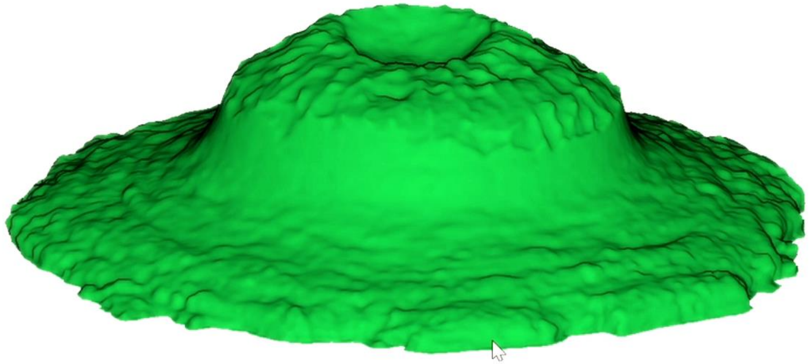
3D reconstruction
Methodology – reconstructing the slumped profile









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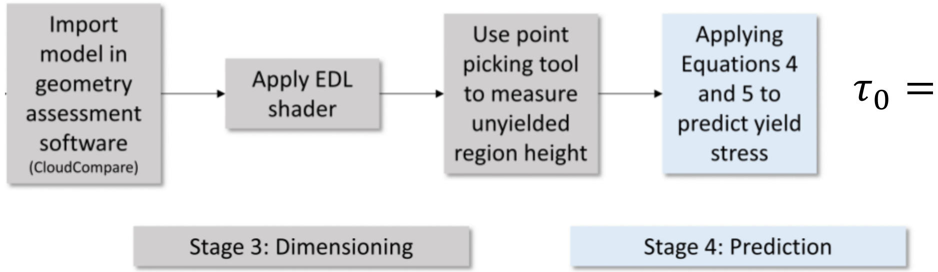
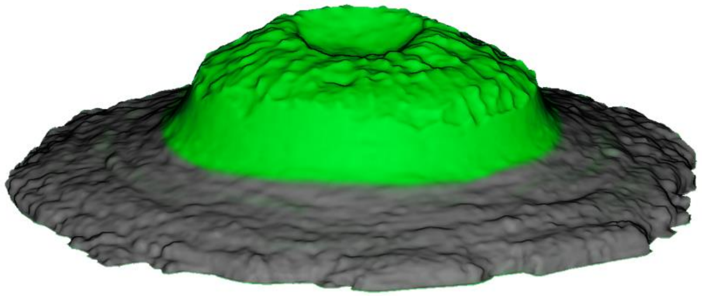
Artec, Wireless Handheld 3D Scanner. Artec3d.com (2023)

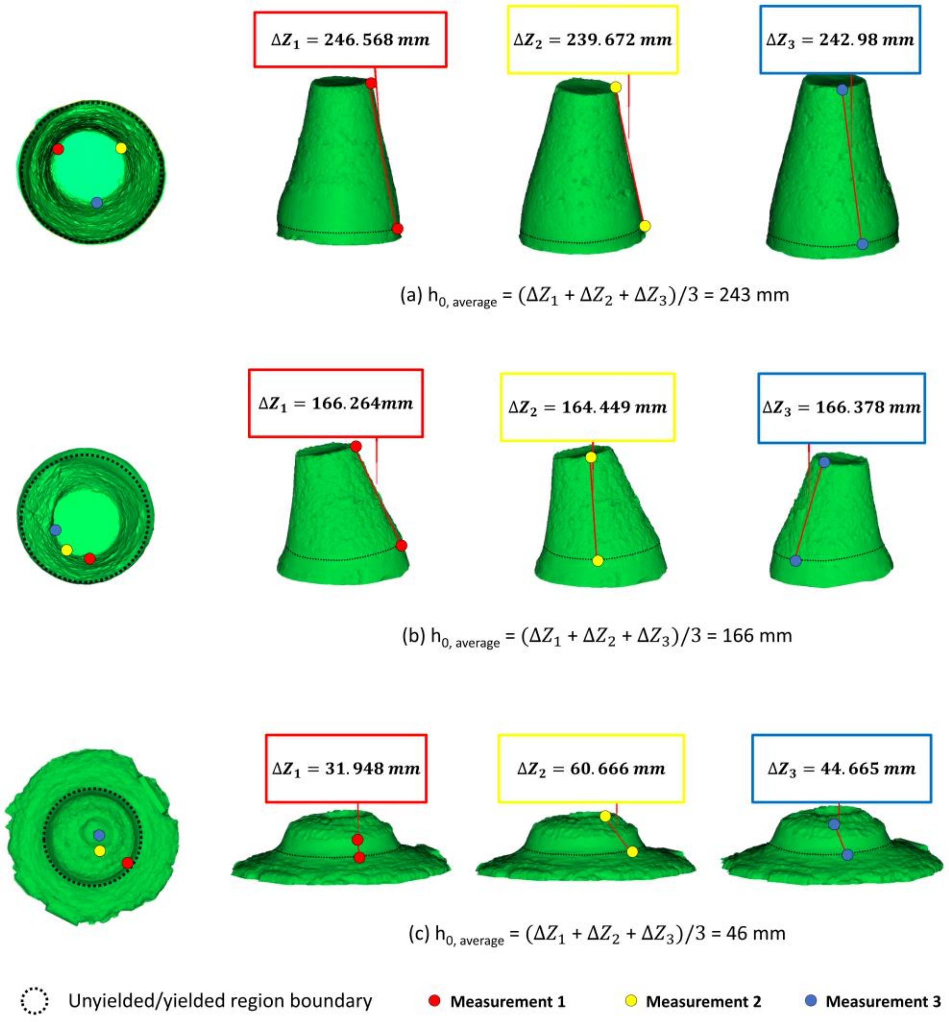
3D reconstruction

Methodology – measuring the unyielded height



$$\tau_0 = \frac{\rho g h_0}{\sqrt{3}}$$





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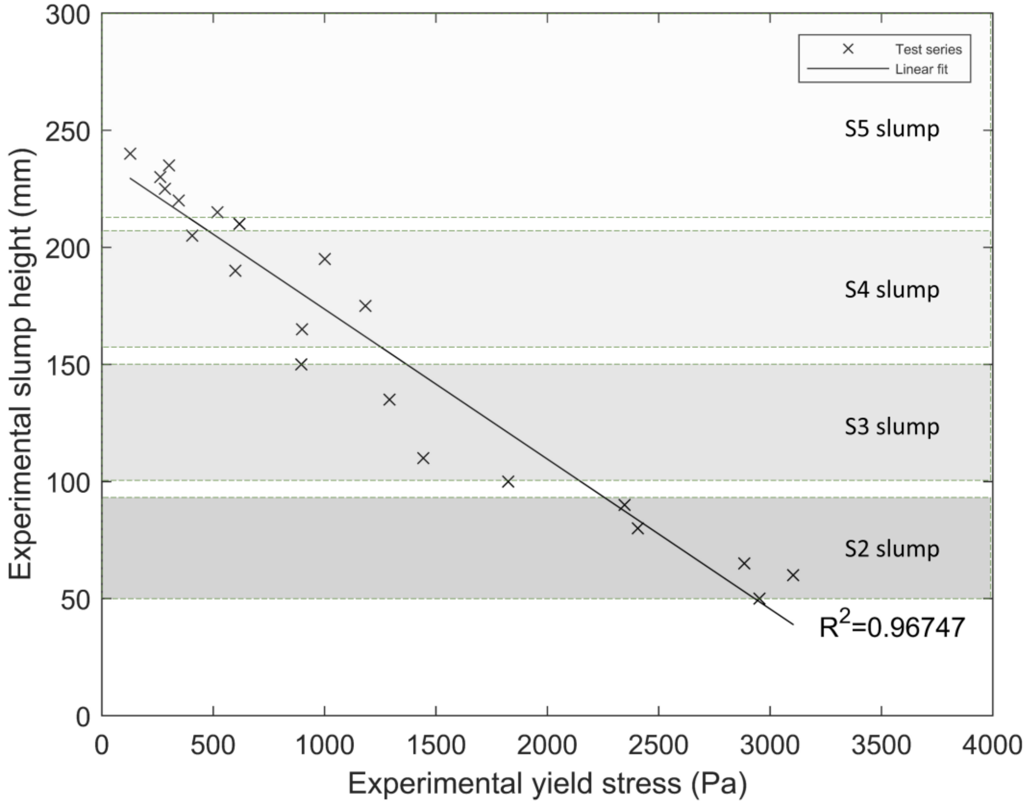
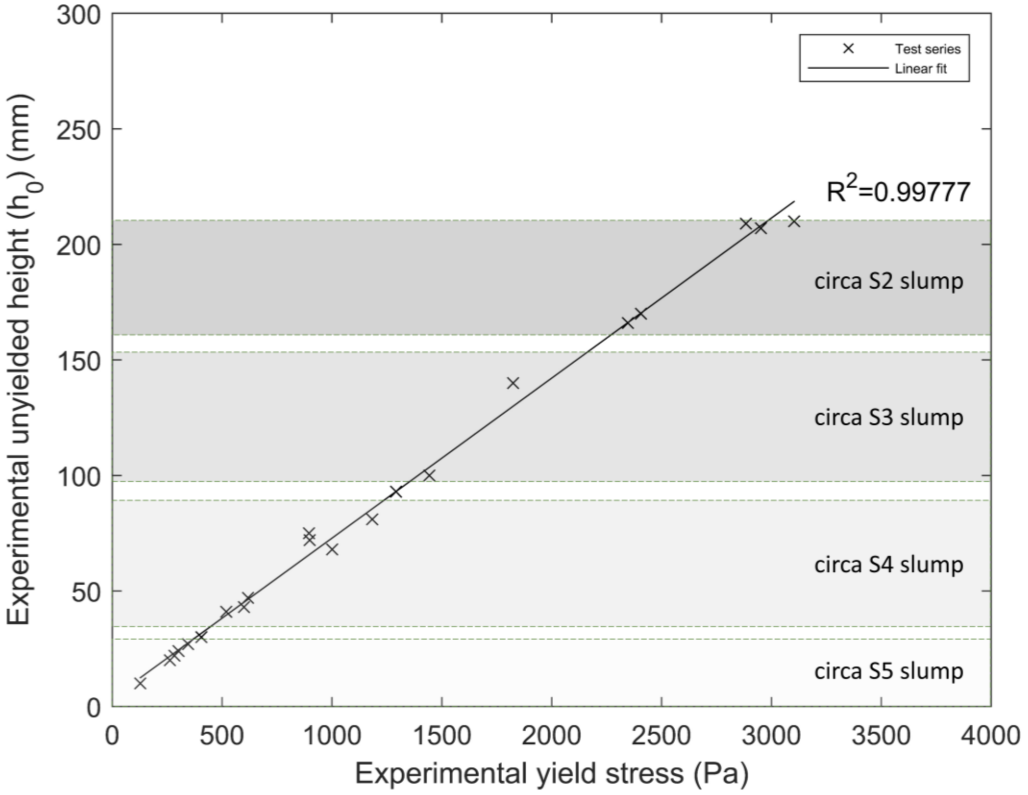
Force balance deformation approach

Total slump vs unyielded height

Total Slump Height



Unyielded height



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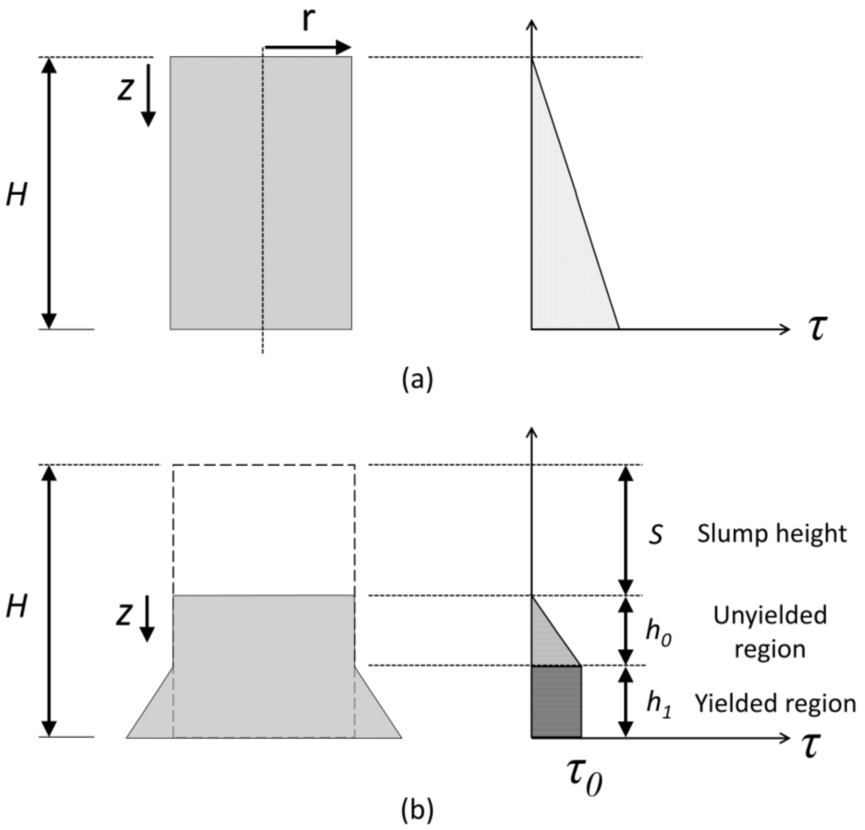
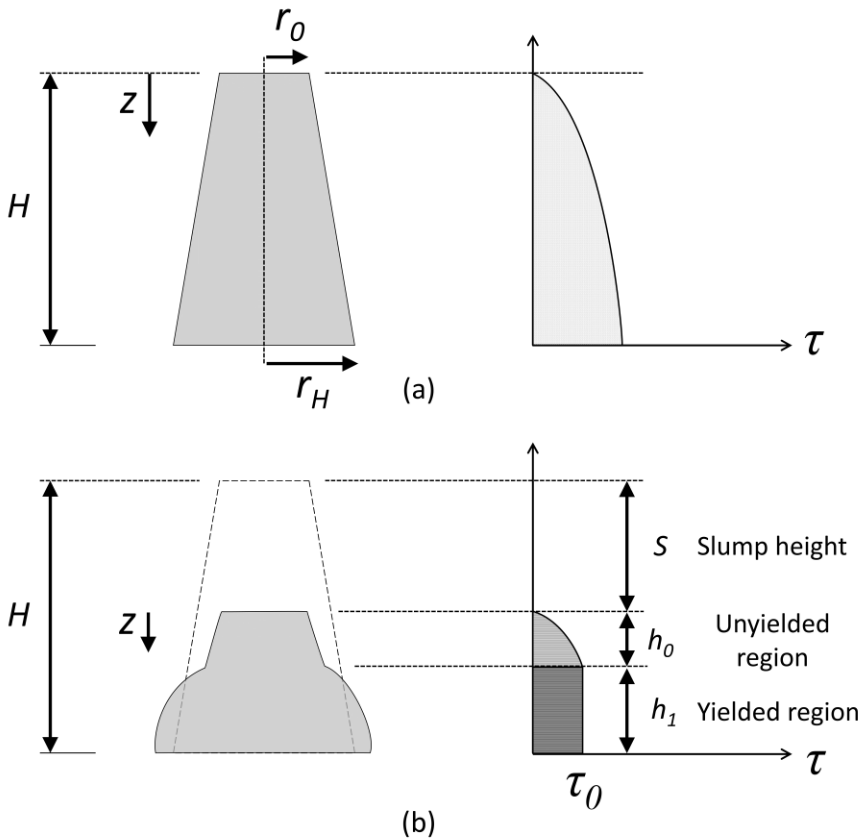
Force balance deformation approach

Assumed profile

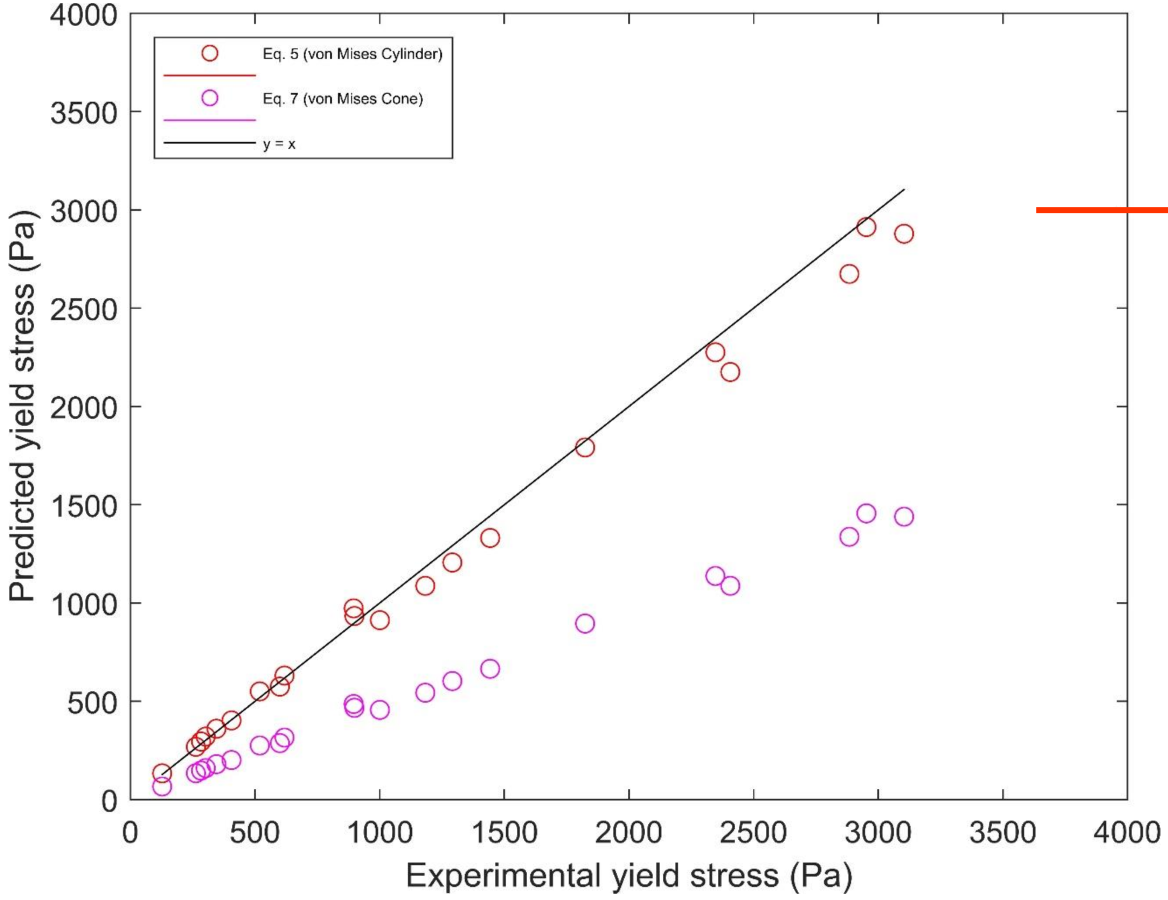


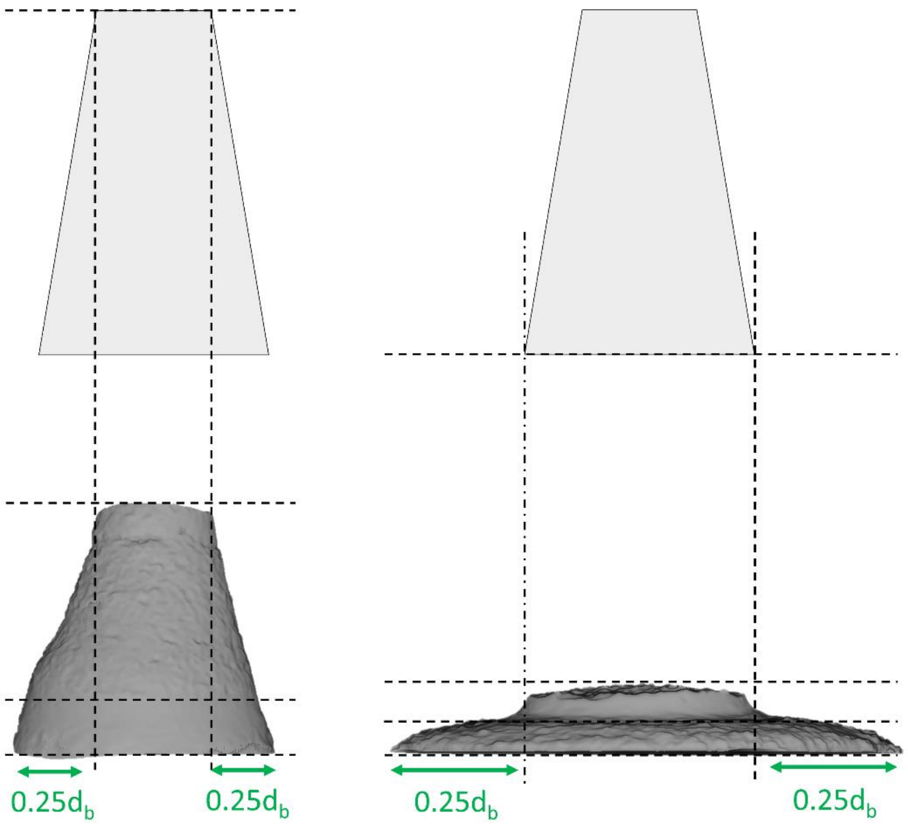


Should there be a geometrical factor?

Force balance deformation approach

Profile and yield condition performance





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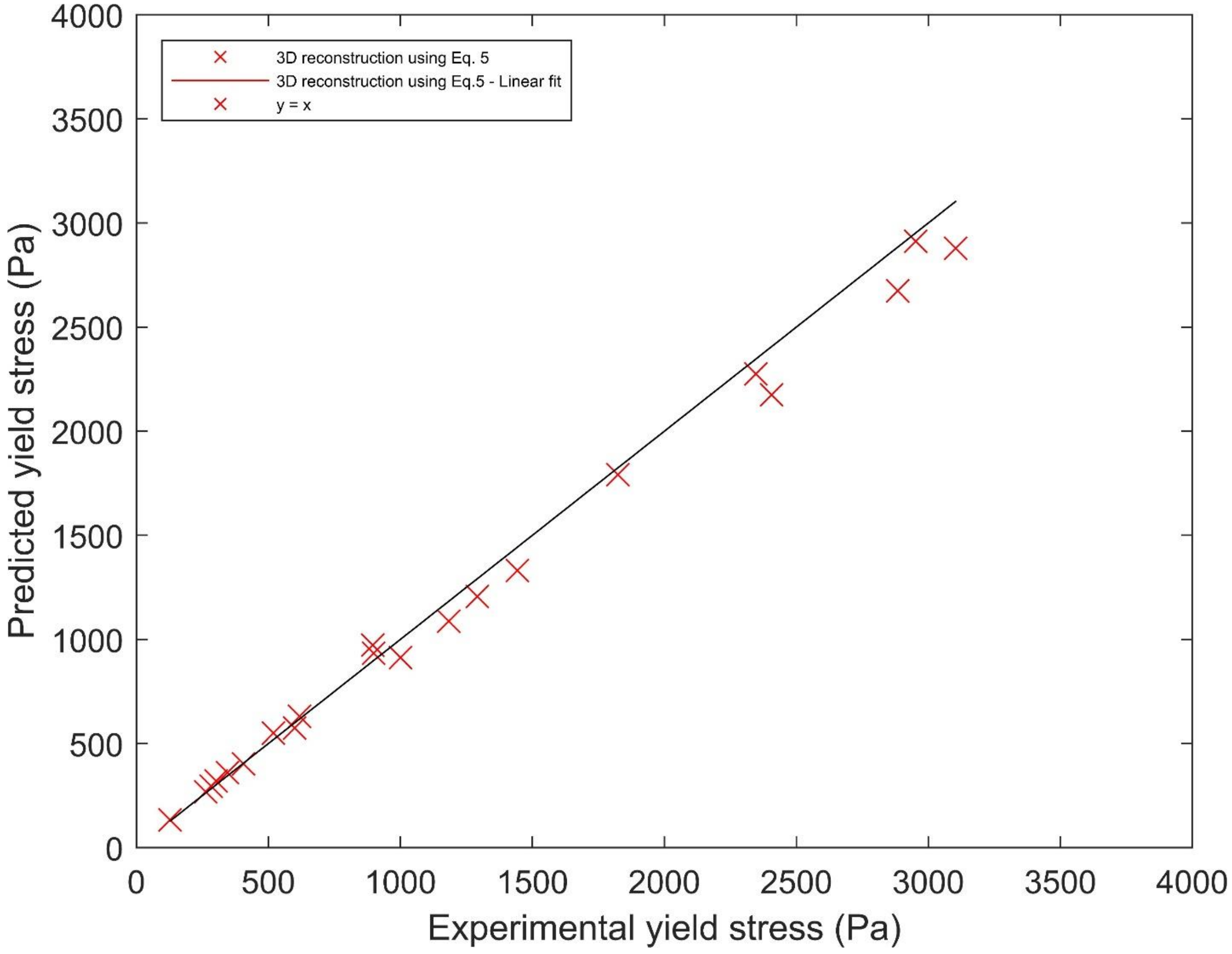
3D reconstruction

Performance assessment



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Statistical performance assessment

Model type	Reference	Mean error %	Error standard deviation %	Max error %
Theoretical	Tanigawa et al.	43	44	214
	Schowalter and Christensen	54	15	71
Empirical	Ferraris and Larrard	70	85	386
	Murata and Kikukawa	82 (80[a])	8 (9[a])	90
Simulation	Roussel	24	19	66
	Hu et al.	59	69	311
	Chidiac and Habibbeigi	56	65	295

Notes: [a] Prediction error for applicability bounds between 125-260 mm slump imposed by Murata and Kikukawa [14].

Conclusions and significance

- The unyielded height of the free fall slump test has a high correlation with yield stress – this is of increased significance to the commonly measured total slump height
- A novel method to measure the unyielded height accurately has been developed
- Using the proposed approach, the von Mises form, with a cylindrical geometrical factor, provides the most accurate predictions of yield stress

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ABSTRACT

Relating the empirical slump test to yield stress facilitates the capture of fresh state concrete performance in fundamental quantitative terms whilst avoiding the requirement for expensive rheological equipment. This paper proposes a novel method to predict yield stress from slump by directly measuring the height of the unyielded region, via a 3D reconstruction approach. The efficacy of the proposed method is assessed through an experimental series of 21 tests. The results indicate a better correlation between the height of the unyielded region and yield stress compared to total slump height and yield stress. The proposed 3D reconstruction methodology predicts yield stress with significantly increased accuracy, indicated by a mean prediction error an order of magnitude lower than the average performance of existing models. The results of this study suggest that, for the first time, a valuable fundamental rheological property can be confidently derived from a standard concrete slump test.

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