NUMERICAL MODELING OF CONCRETE FLOW IN DRILLED SHAFT

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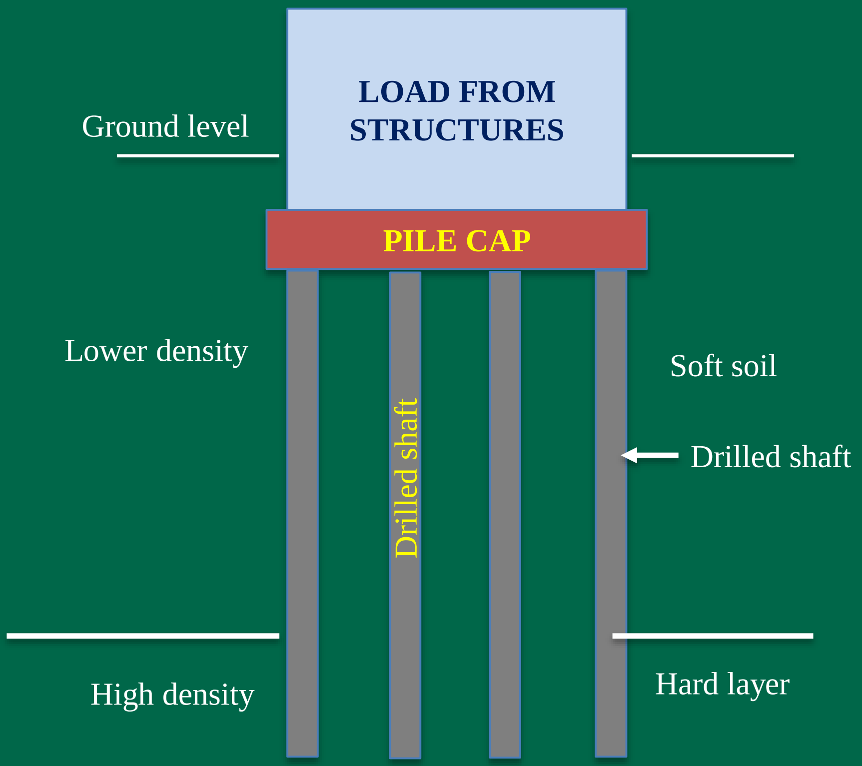
DRILLED SHAFT

- Deep foundation element
- Cylindrical in shape and cast at site with concrete
- Transfers load from super-structure to hard soil strata.
- Size: 2 feet to 5 feet diameter common and 10 feet max.
- depth: 50 feet to 100 feet common and 250 feet max.



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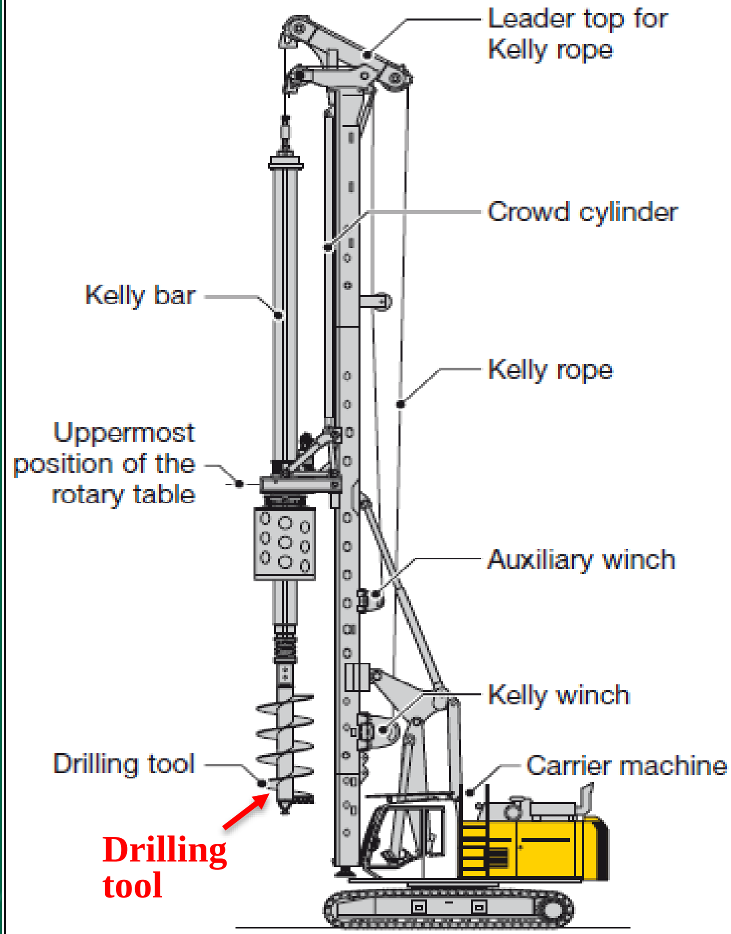
CONSTRUCTION OF DRILLED SHAFT

The drilled shaft construction involves:

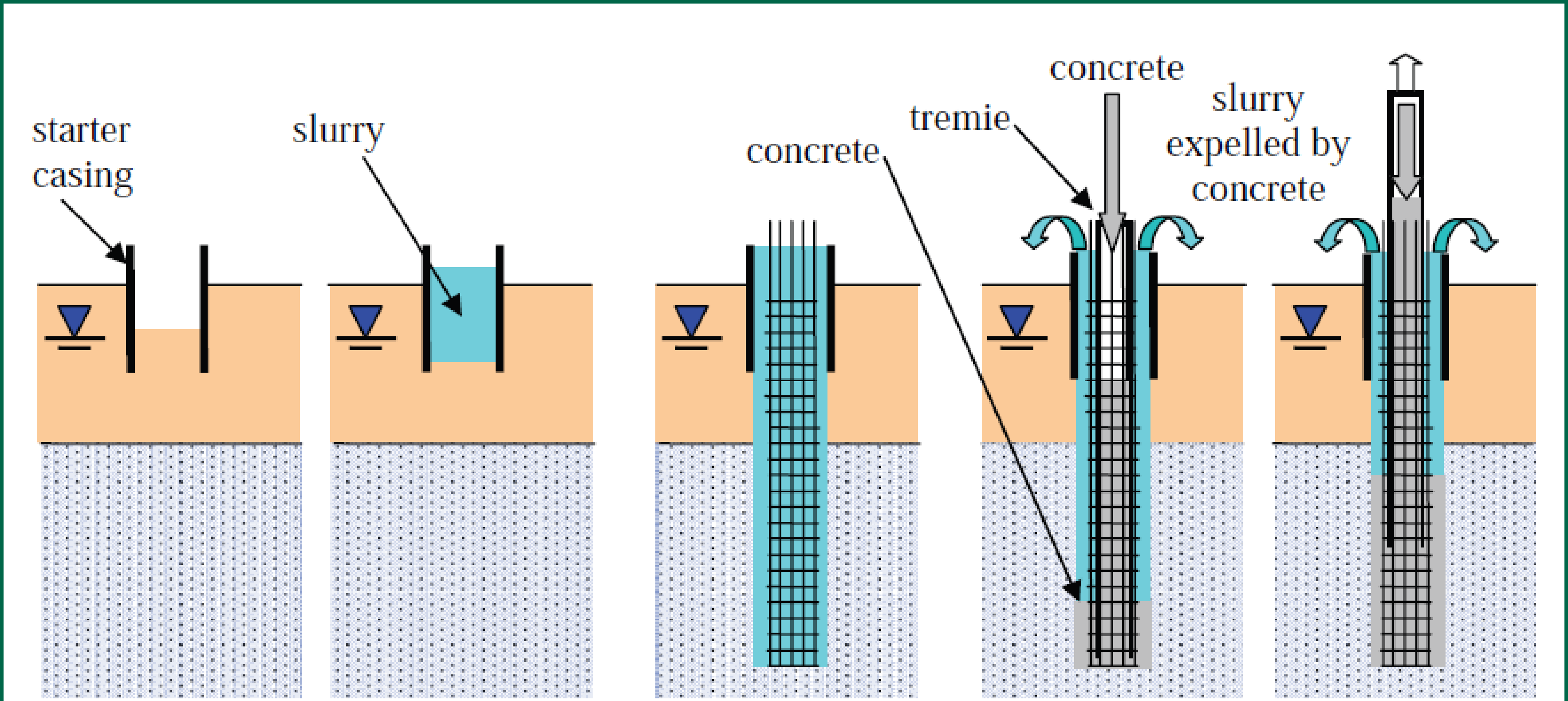
- Drilling equipment,
  (Bauer, Casagrande, Soilmec)
- Excavation
- Placing of rebar
- Concreting



crawler mounted rotary piling rig

CONSTRUCTION OF DRILLED SHAFT

Drilling and concreting process



a) set starter casing

b) fill with slurry

c) complete drilling and set rebar cage

d) place concrete through tremie

e) pull tremie while adding concrete

slurry

concrete

CONSTRUCTION OF DRILLED SHAFT

Drilled shaft construction - stages


Drilling excavation


Placing rebar


Concreting

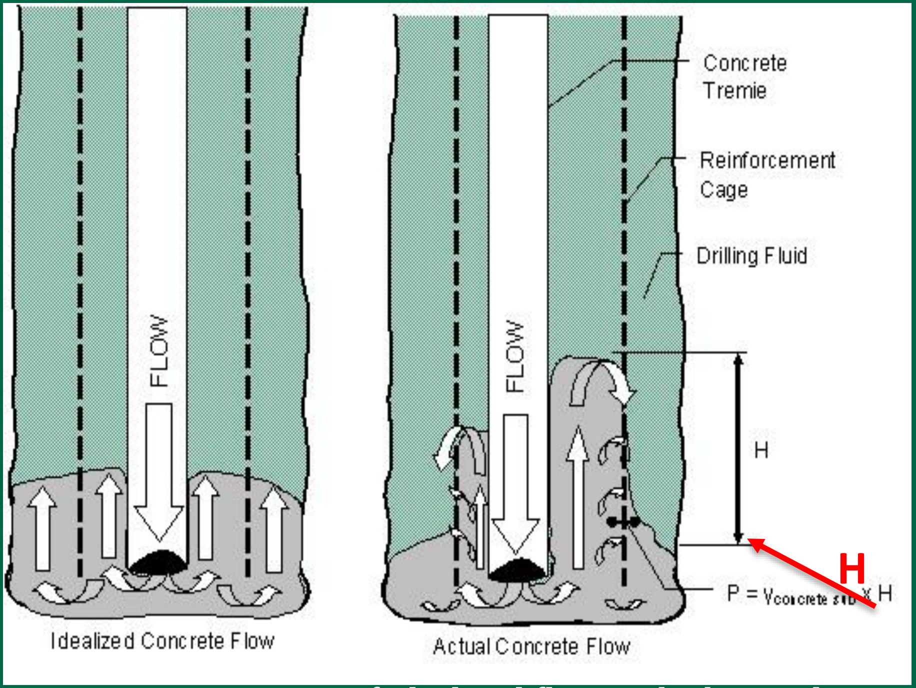
The main factors in concreting:

- Under water placement via tremie pipe.
- Single point tremie discharge into large diameter excavation
- Concrete has to pass through rebar cage

FLOW OF CONCRETE IN DRILLED SHAFT

The flow of concrete in drilled shaft:

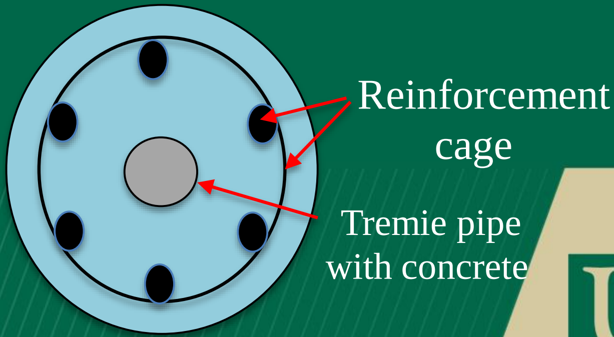
- Idealized as rising fluid and displaces the lighter slurry.
- The rising concrete is affected by rebar cage.
- Head differential in concrete



Comparison of idealized flow with observed (G Mullins 2005)

The differential head “ H” is related to:

- spacing of rebar in terms of cage spacing to maximum aggregate diameter ratio (CSD)
- Flow rate (upward) of the concrete



Cross section of drilled shaft excavation

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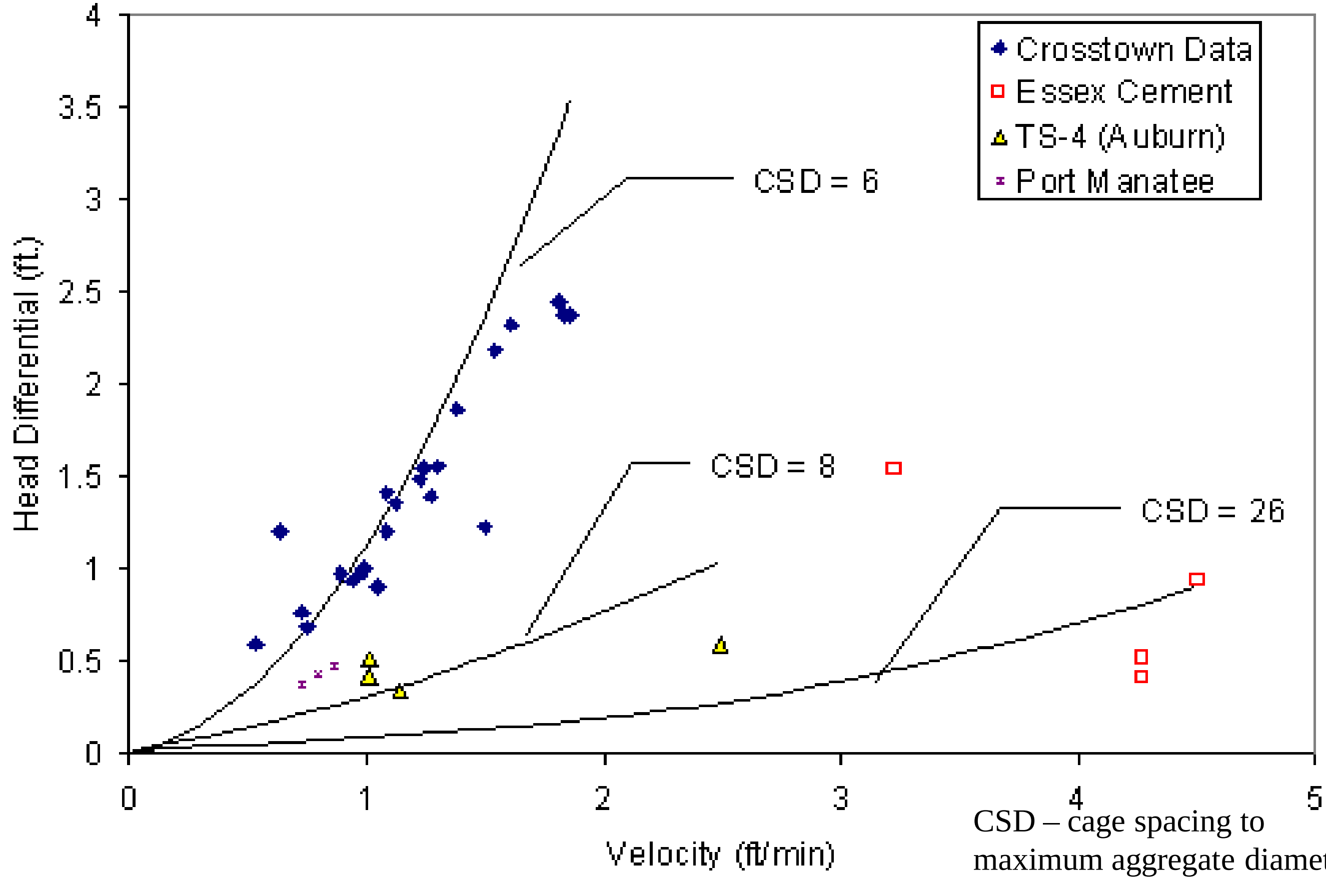
CONSTRUCTION OF SELF DRILLED SHAFT

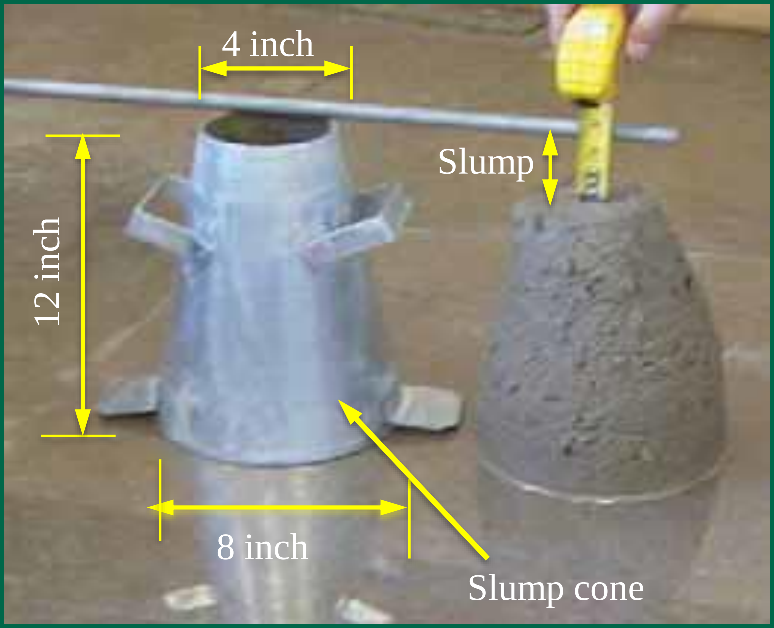


CSD – cage spacing to maximum aggregate diameter

inside – outside cage differential head vs upward concrete velocity

CONSTRUCTION OF DRILLED SHAFT

Quality assurance test for drilled shaft concrete currently used.



Slump test

Description	Value - Range
Maximum aggregate size	¾ inch
Slump	4 - 6 inch - for dry uncased permanent casing
	6 - 8 inch - for temporary casing
	7 - 9 inch - slurry displacement

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EMPIRICAL WORKABILITY TEST FOR SCC

Workability tests for SCC

Slump flow test

Common range : 20 to 30 inch

EMPIRICAL WORKABILITY TEST FOR SCC

Slump tests are well established one and is used over long time.
It is purely empirical one.

In spite of specification for fresh concrete and for drilling fluid there are anomalies in drilled shaft concrete in the form of :

- Soil inclusion
- Concrete segregation
- Reduction in cross section area
- Exposure of reinforcements

ANOMALIES IN DRILLED SHAFT

Shaft exhumed -poor concrete flow performance

The anomalies in the drilled shaft is attributed to the kinematics of flowing concrete inside a borehole containing reinforcing steel.

EXPERIMENTAL STUDY OF CONCRETE FLOW IN DRILLED SHAFT USING SCC

USF Research study, G Mullins, 2013

- Objective: Upper viscosity limit for bentonite and polymer slurry.
- Cast shafts 24 No. 42 in. dia. 2 feet height.
- Shafts were cast under bentonite slurry, polymer slurry with different viscosities and under water.
- Flow patterns through the rebar cage were studied.

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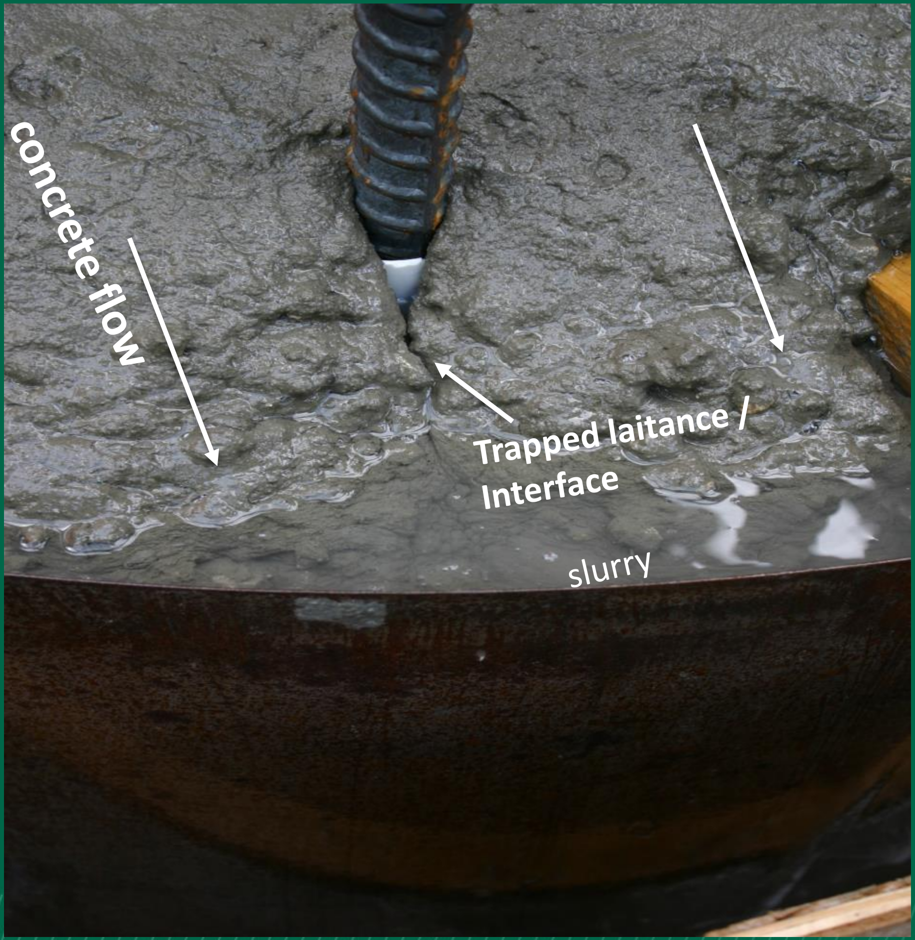
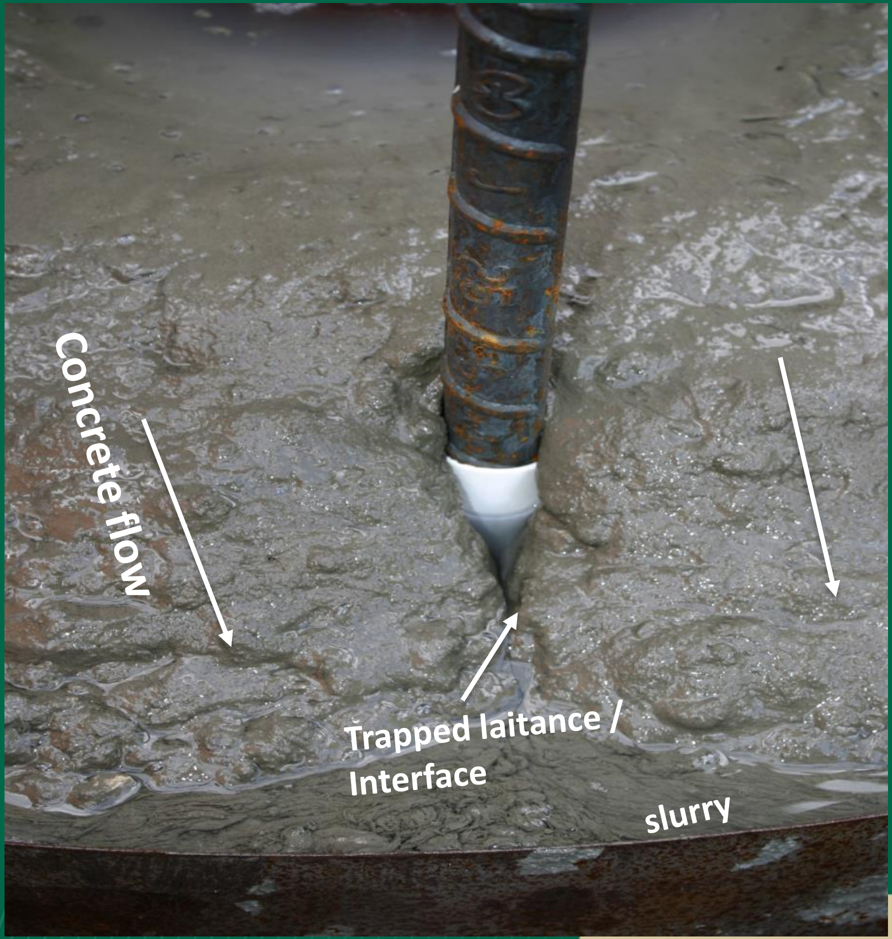
FLOW OF CONCRETE IN DRILLED SHAFT





Radial flow and formation of interfaces around the reinforcement

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CASE STUDIES OF DRILLED SHAFT USING SCC

USF Research study – shafts cast under mineral slurry

cast under mineral slurry, 40 sec/qt.

cast under mineral slurry 50 sec/qt.

USF RESEARCH STUDY

Creases in the concrete

standard 4ksi shaft mix in bentonite slurry 40sec/qt.

SCC concrete shaft cast in bentonite environment viscosity 40sec/qt.

- Creases in the concrete coincided with the pattern of reinforcement arrangement.
- Coring revealed trapped bentonite slurry in the creases

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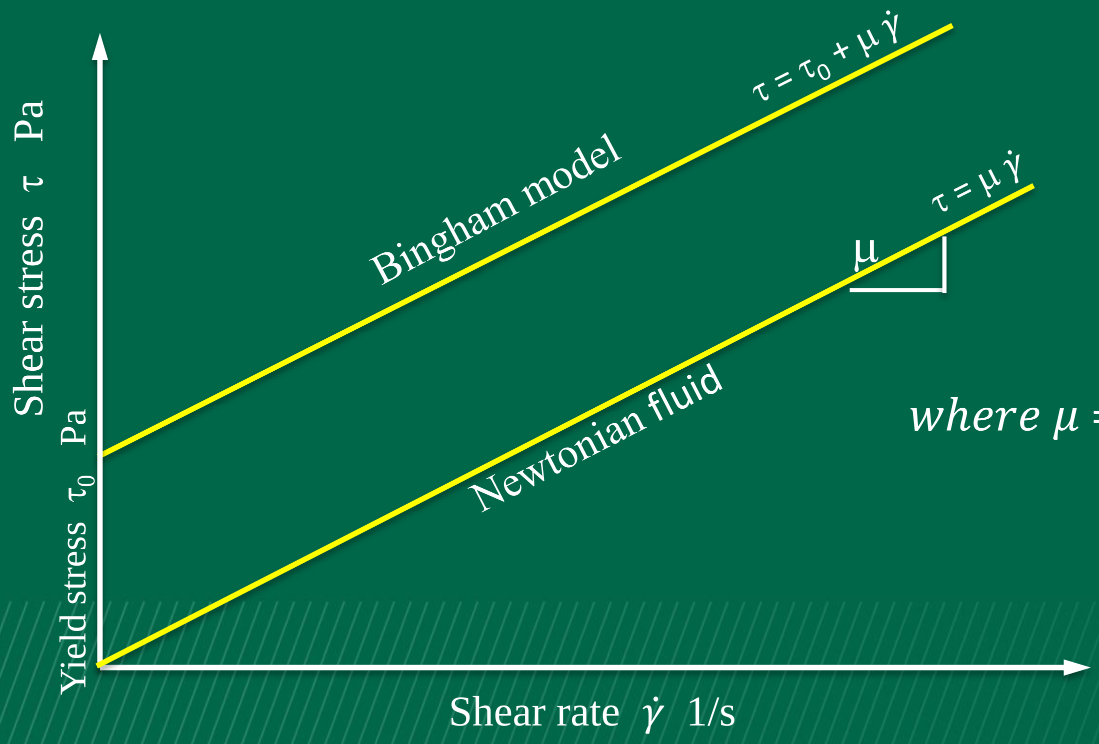
CONCRETE FLOW IN DRILLED SHAFT

NUMERICAL MODELING OF CONCRETE FLOW IN DRILLED SHAFT

- In drilled shaft, the quality control is based on empirical type workability tests.
- No rheological evaluation of concrete is done for drilled shaft.
- Drilled shaft size, rebar size and rebar arrangement are not considered.
- This research program covers:
  - Numerical modeling and simulation of concrete flow in drilled shaft taking into account the rheological properties of concrete, drilled shaft size, lay out of rebar and concrete flow through tremie pipe.
  - Influence of the size of drilled shaft, size of reinforcement, arrangement of rebar on the concrete flow pattern.

RHEOLOGY OF LIQUID

- Rheology of liquid is relation between shear stress and shear rate of liquid flow under applied force.
- Viscosity and yield stress are the important rheological parameters.



where $\mu = \tau/\dot{\gamma}$ is viscosity

CONCRETE FLOW MODEL

1.0 Bingham model

$\tau = \tau_0 + \mu * \dot{\gamma}$

Concrete and SCC in fresh state can be assumed to behave as Bingham fluid

2.0 Hershel-Bulkley model

$\tau = \tau_0 + \mu * \dot{\gamma}^{\mathbf{n}}$

For n >1, the model describes shear thickening and for n < 1, shear thinning is described.

If n is 1, the Bingham model is described.

RHEOLOGY OF CONCRETE

3.0 Carreau - Yasuda model (CY model)

The equation of CY model is:

$\mu_{eff}(\dot{\gamma}) = \mu_{inf} + (\mu_0 - \mu_{inf})(1+ (\lambda\dot{\gamma})^a)^{(n-1)/a}$

and $\tau = \mu_{eff}\,\dot{\gamma}$,

where ,

μ_0 = viscosity at zero shear rate (Pa s)

μ_{inf} = viscosity at infinite shear rate (Pa s)

λ = relaxation time (s)

a = shape index

n = power index

It describes the variation of viscosity with shear rate.

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SIMULATION OF CONCRETE FLOW IN DRILLED SHAFT CONCRETING

- COMSOL Multiphysics software is used for the modeling and simulation.
- Modeling involves multiple layers: Excavation, tremie pipe, rebar
- Two phase flow solution: drilling fluid, concrete
- To start with basic 2D modeling is carried out.
- Carreau –Yasuda model is considered for the analysis.
- Using Level set method for capturing the interface: Adopts capturing technique to determine the moving interface.

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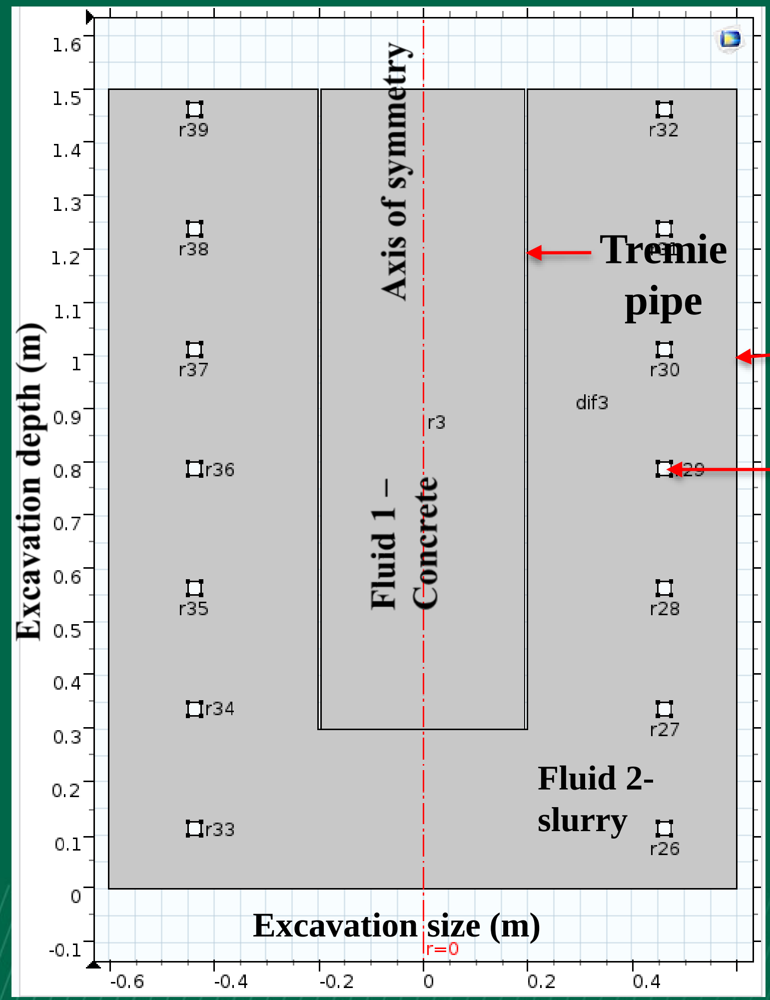
MODELING OF CONCRETE FLOW IN DRILLED SHAFT

- Two phase flow solution



Drilled shaft excavation

Modeled as Rebar

2 D Model geometry

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MODELING OF CONCRETE FLOW IN DRILLED SHAFT

Parameters used for the analysis:

Fluid 1 – concrete :

density - 2200 kg/m^3 to 2400 kg/m^3 (137 lb/ft^3 to 150 lb/ft^3)

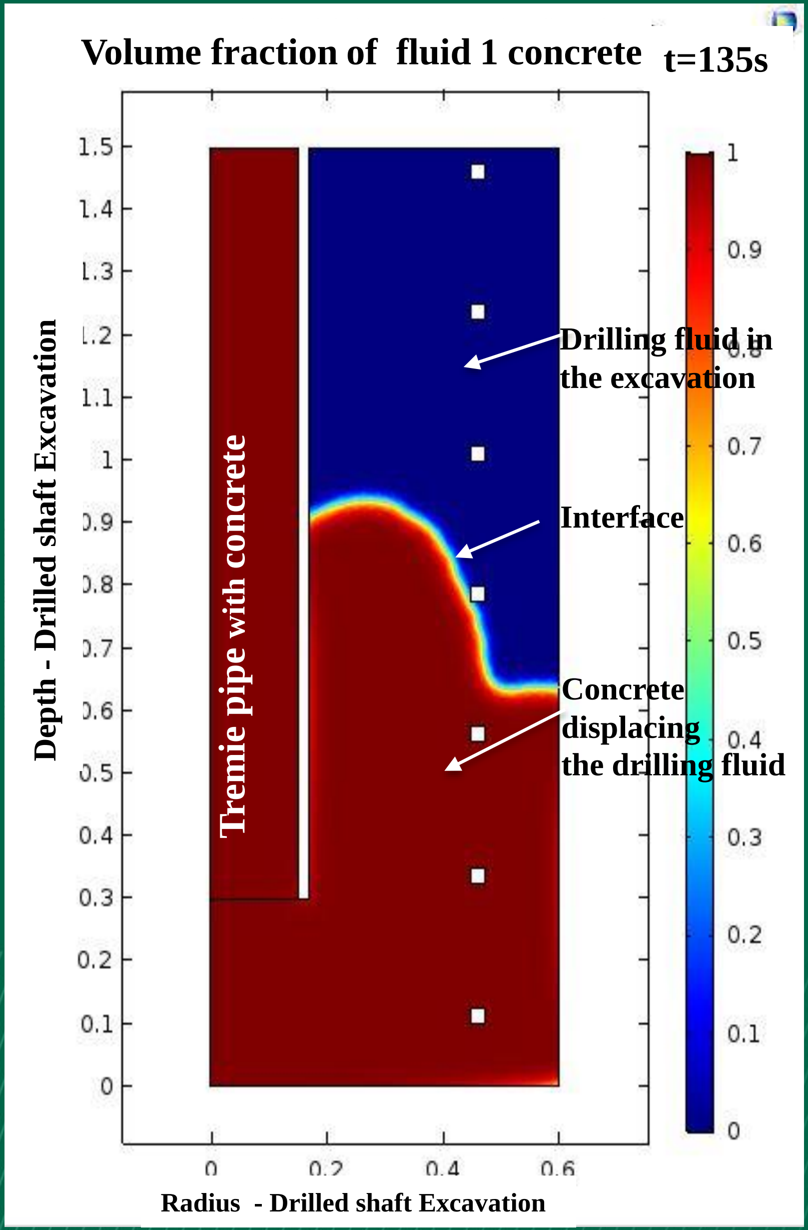
viscosity -10 - 25 Pa .s

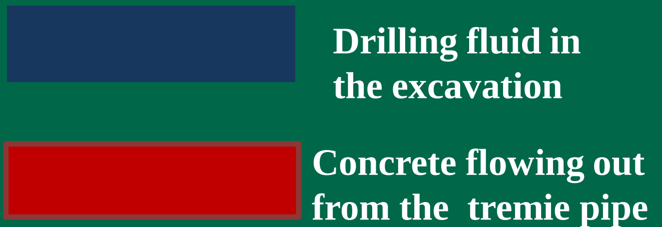
Fluid 2 – drilling fluid:

density - 1025 kg/m^3 to 1150 kg/m^3 (64 lb/ft^3 to 72 lb/ft^3)

viscosity - 28 - 50 s (per quart)

ANALYSIS RESULTS: NON-NEWTONIAN MODEL
PLOT: VOLUME FRACTION OF FLUID 1 CONCRETE





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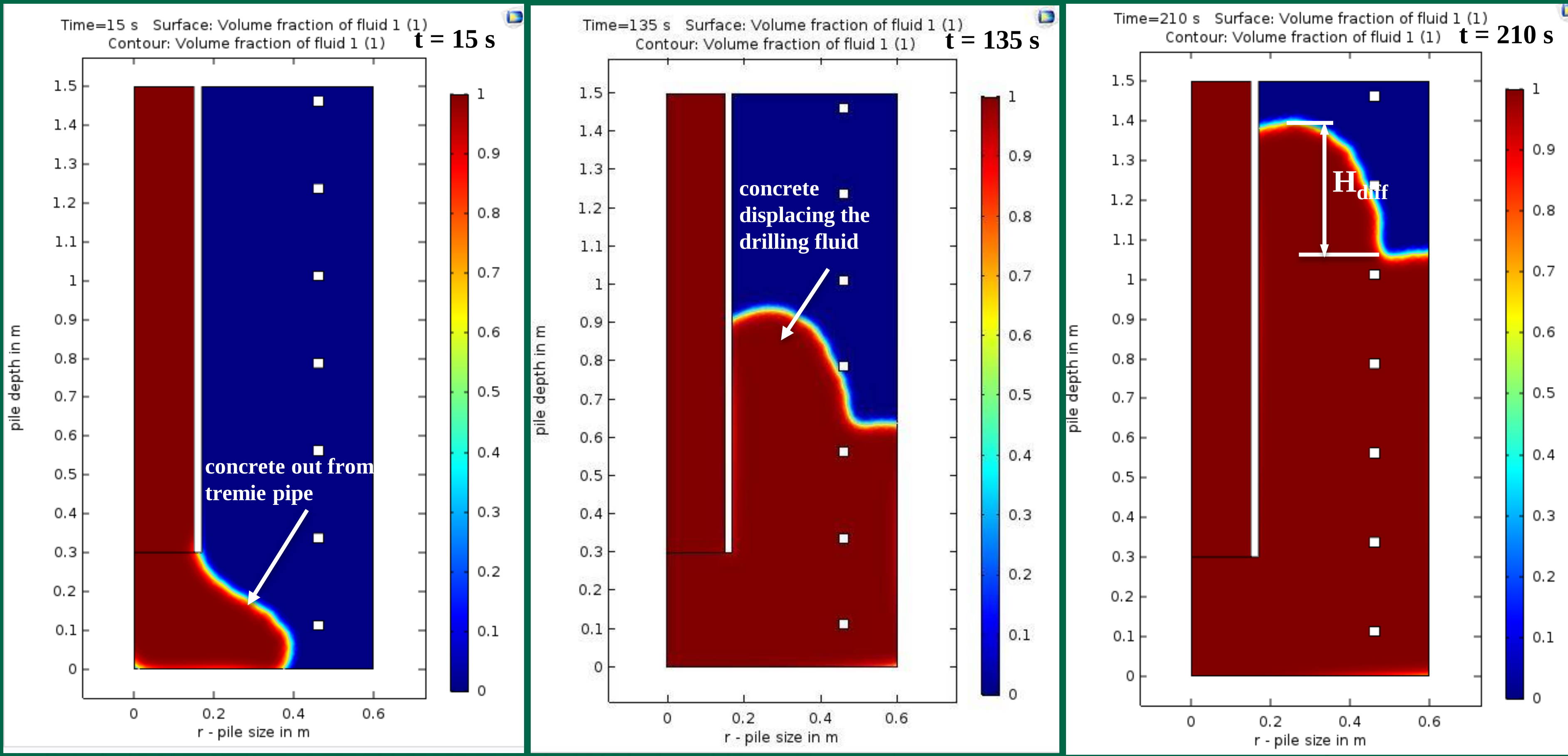
ANALYSIS RESULTS: NON-NEWTONIAN
PLOT: VOLUME FRACTION OF FLUID 1 CONCRETE



Drilling fluid in the excavation

Concrete flowing out from the tremie pipe

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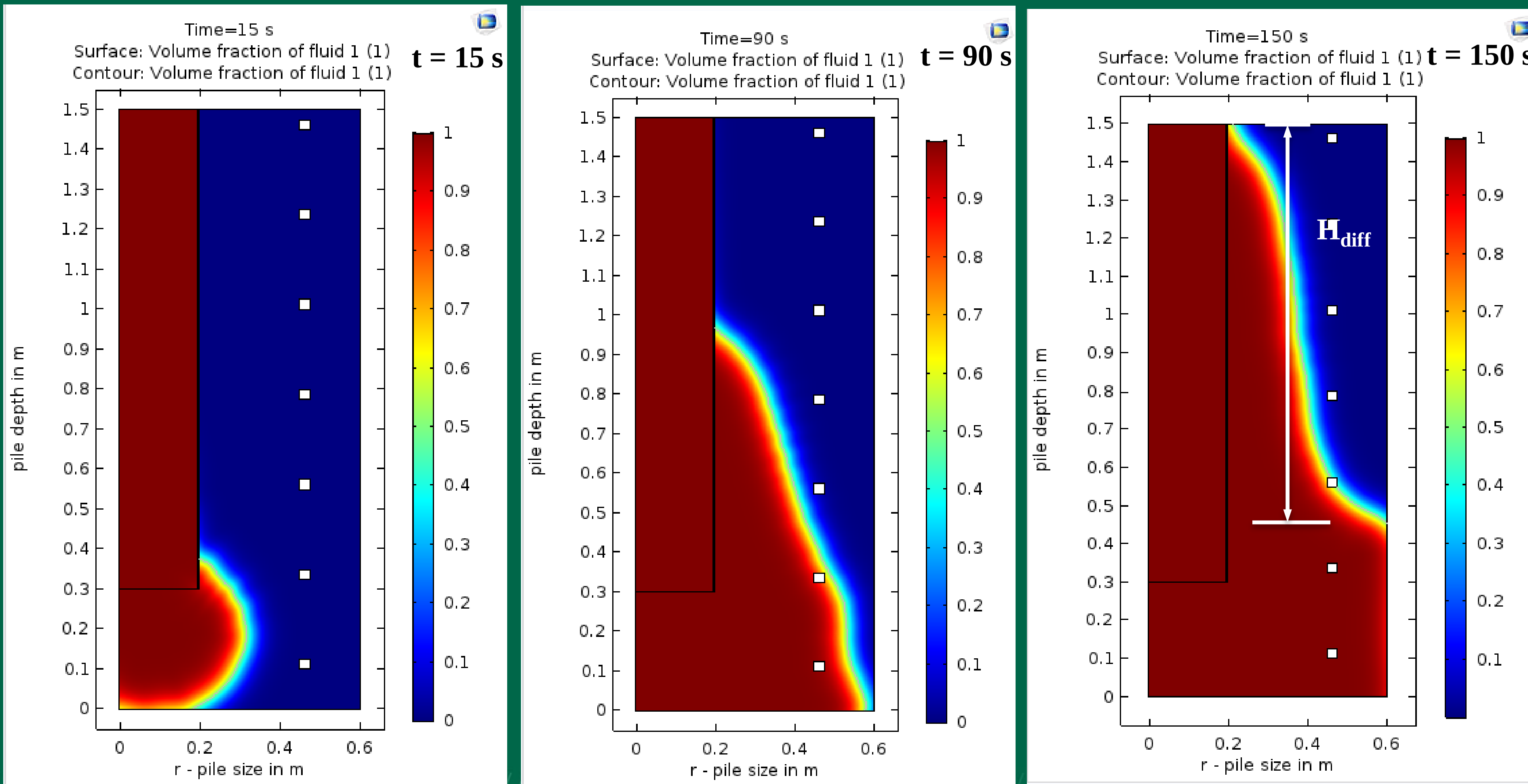
ANALYSIS RESULTS: NEWTONIAN
PLOT: VOLUME FRACTION OF FLUID 1 CONCRETE



Drilling fluid in the excavation

Concrete flowing out from the tremie pipe

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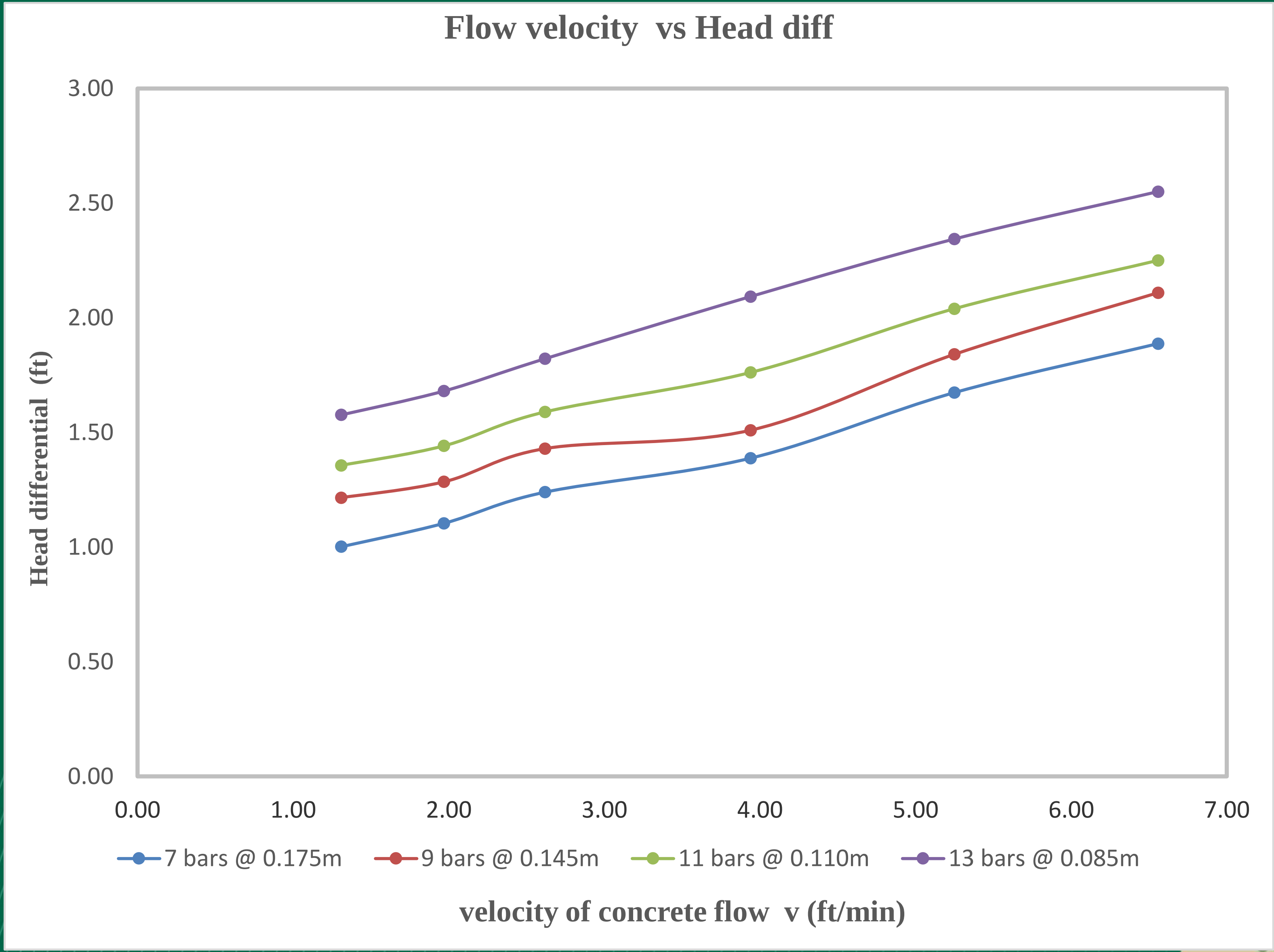
FLOW VELOCITY VS HEAD DIFFERENTIAL



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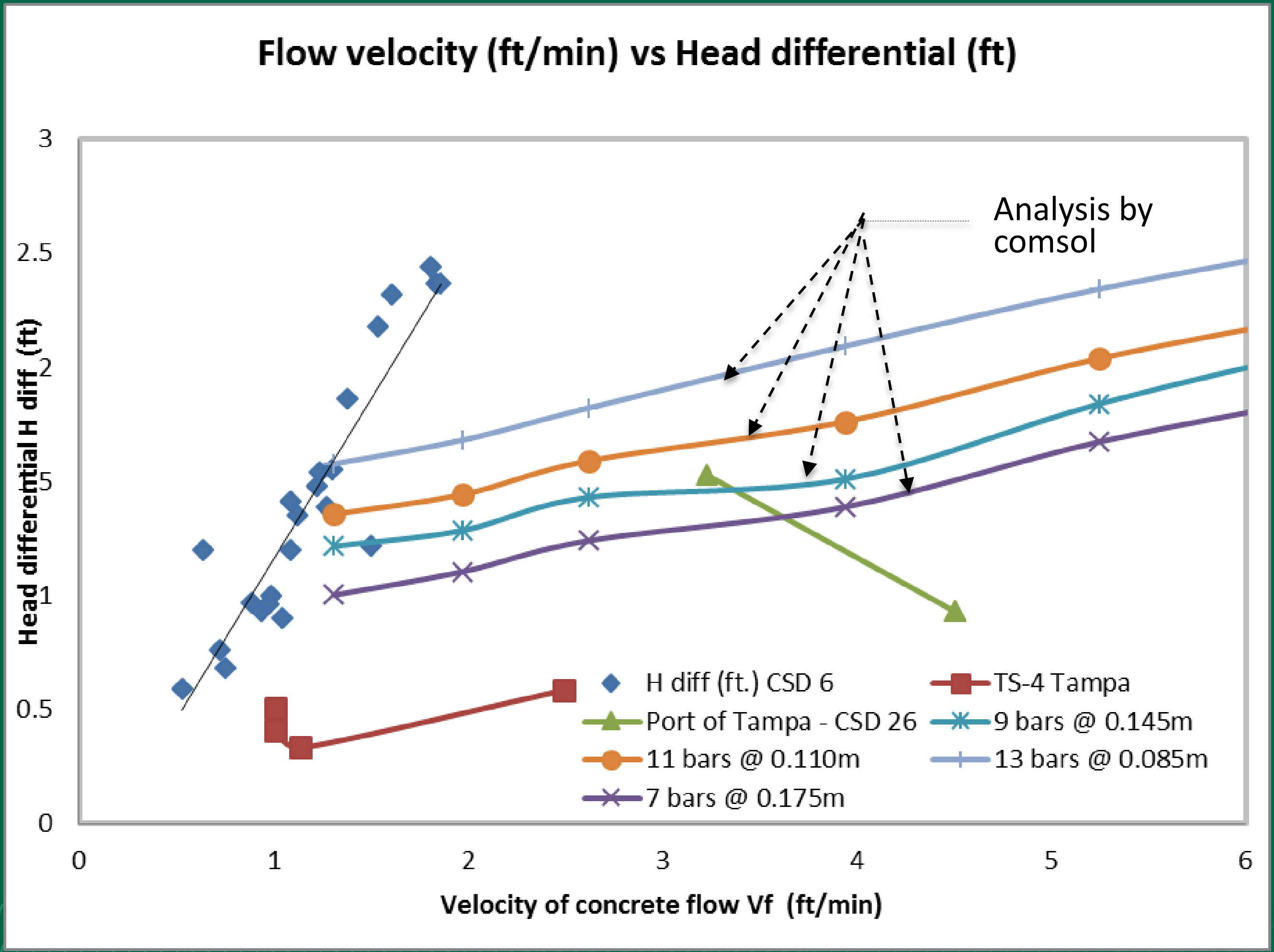
FLOW VELOCITY VS HEAD DIFFERENTIAL



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CONCLUSION

- A 2-D model and simulation of concrete flow in drilled shaft using COMSOL Multiphysics® is presented.
- The results from the simulation show the similar pattern of concrete flow observed in laboratory experiments.
- The concrete head differential between inside and outside rebar cage increases, when the velocity of concrete flow increases. Also, the head differential increases, when the clear spacing of rebar reduces.
- It is observed that for the concrete flow computations, Non-Newtonian fluid model is more appropriate than the Newtonian fluid model.

CONCLUSION

- The model will be extended to 3-D.
- The simulation should allow engineers to specify the realistic workability for concrete so that proper drilled shaft concreting is achieved.

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Thank you