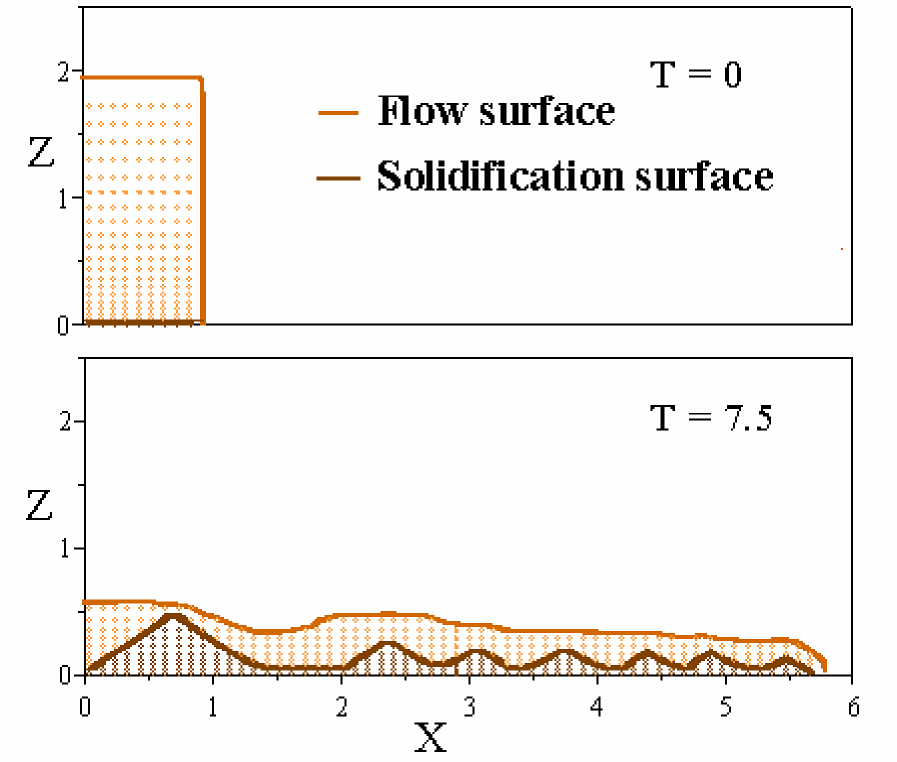
# Subaqueous sediment gravity flows undergoing progressive solidification

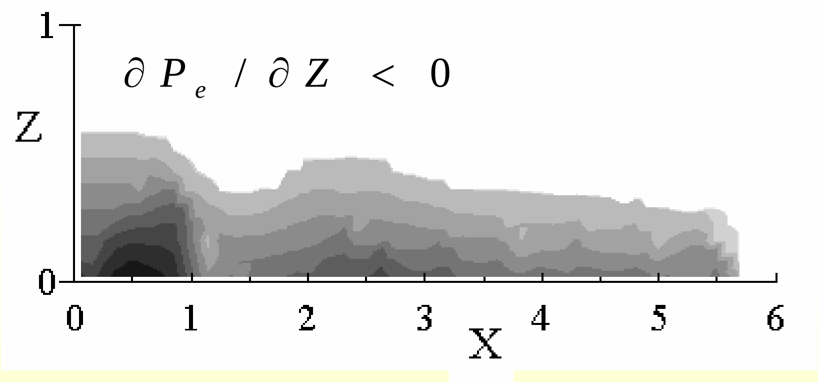
Amiruddin, SEKIGUCHI and **SASSA**

**Background:** **Salient physics of two-phase material as highlighted by a theoretical framework LIQSEDFLOW (2003)**

**Purpose of present study:** **To clarify the process of progressive solidification in hyperconcentrated sediment flows by physical modelling**




**Upward seepage flow during flowage**

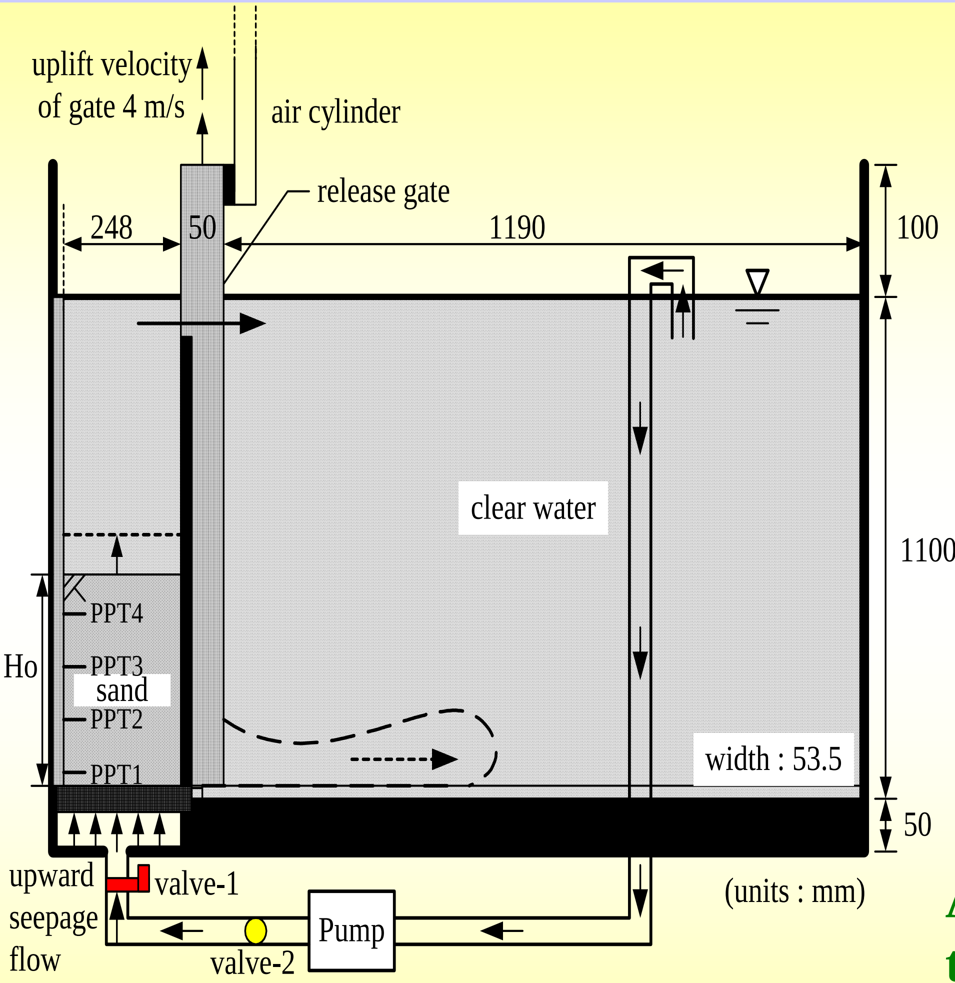


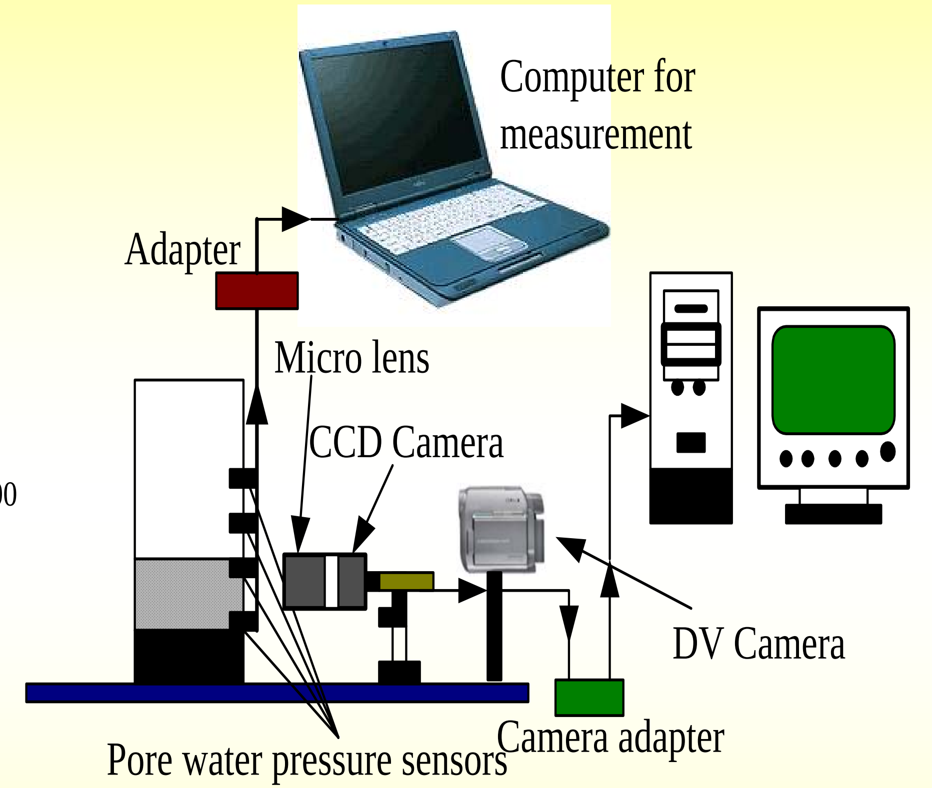

**Development of solidified zones in the course of sediment gravity flow**

x, z: Normalized coordinates

## Predictions from LIQSEDFLOW (Sassa et al., 2003)

# Experimental setup for fluidization, hindered settling and subaqueous sediment gravity flows




**Applications of high-speed CCD and PIV technique**

**Fluidization of sediment by imposing upward seepage flow**

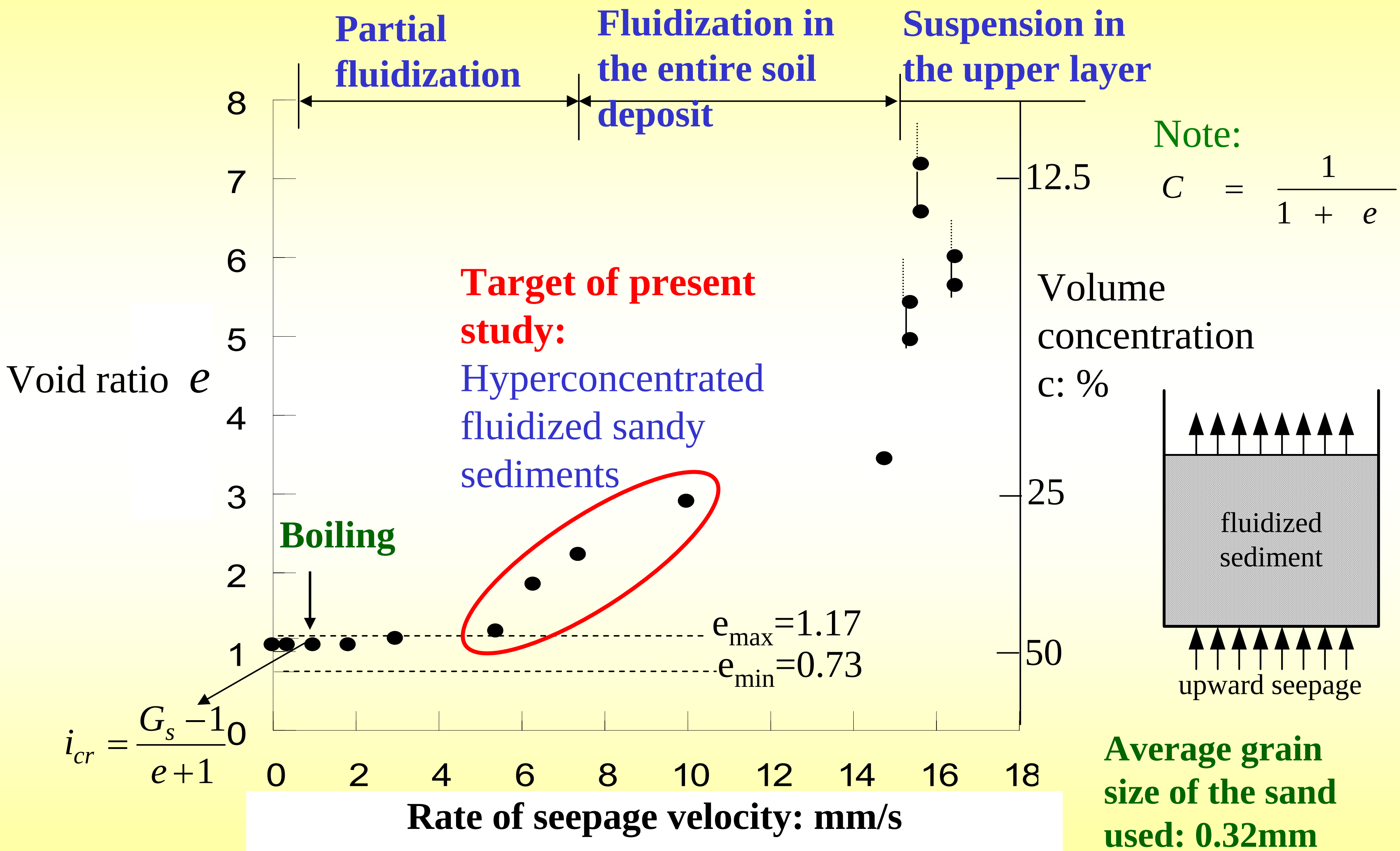
**Hindered settling**

**Subaqueous sediment gravity flows**

Release gate

**Flow-out, stop**

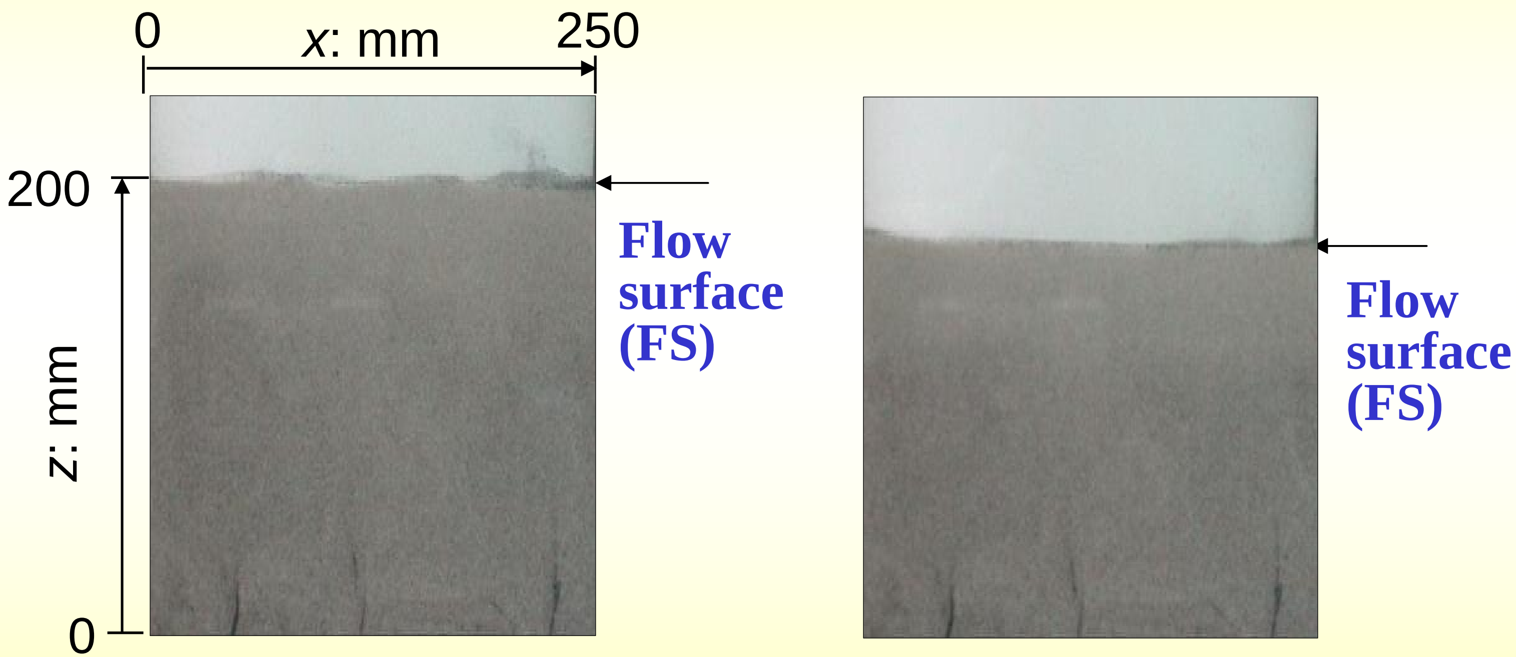
# Transformation of the state of sediment




**Average grain size of the sand used: 0.32mm**

# Results from *Hindered settling experiments*

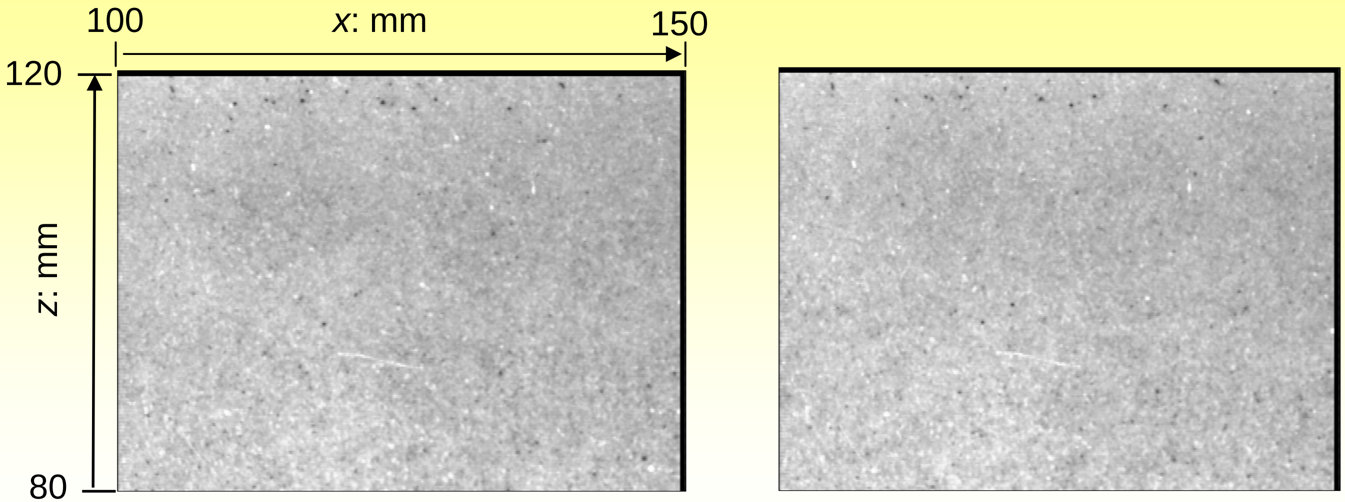
**Snapshots of hyperconcentrated sand-water mixture using a digital video camera (frame rate : 1/30 s) in test PPTCCD-1 (c = 38%)**




(a) $t$=1s (b) $t$=5s

**Identification of the downward advancement of the settling surface following the cessation of fluidization**

## Closer views from a high-speed CCD camera (test PPTCCD-1)

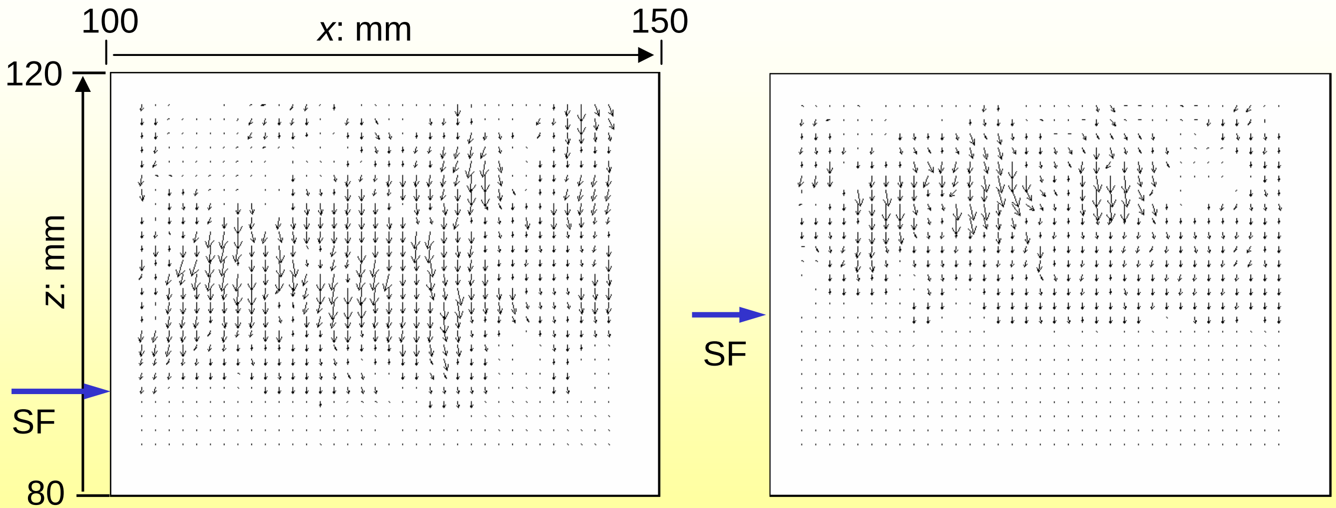



(a) $t$=1.28s

(b) $t$=5.12s

## Velocity fields obtained using PIV technique (test PPTCCD-1)

## Identification of the solidification front (SF)

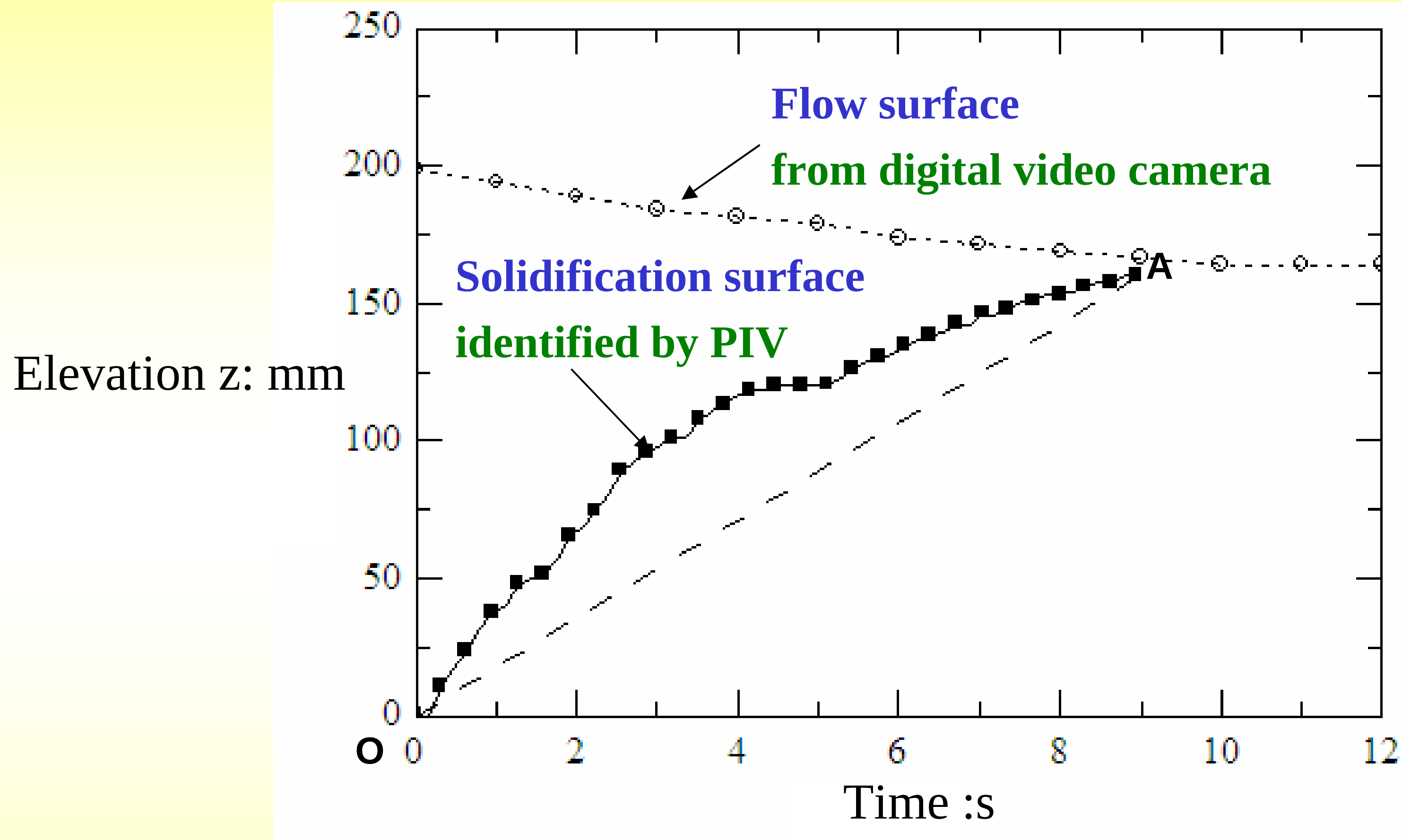



(a) $t$=1.28s

(b) $t$=5.12s

**Below SF, zero velocities**

# Evolutions of flow and solidification surfaces in test FEB05-2



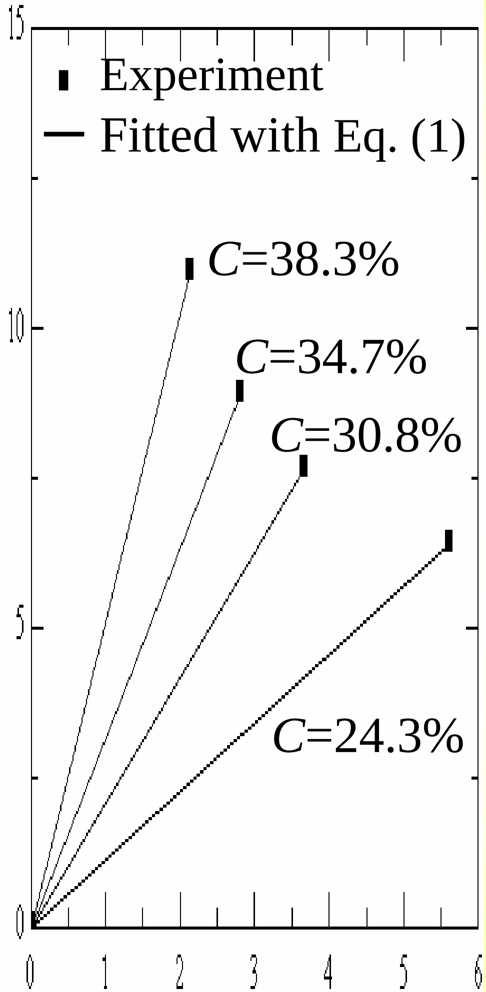

**Average downward velocity of the flow surface** $dz_{FS}/dt = \mathbf{2.6\ mm/s}$

**Average upward velocity of the solidification front** $dz_{SF}/dt = \mathbf{17.8\ mm/s}$

# Relationships between upward velocity of solidification front and settling velocity

Velocity of solidification front

$dz_{SF}/dt$ : mm/s




Settling velocity $w$: mm/s

Mass conservations for hindered settling and solidification

⇩

Velocity of solidification front

$$\frac{dz_{SF}}{dt} = \frac{C}{C_{gf} - C} \bullet w$$; Settling velocity

Eq. (1)

**$C$ : Volume concentration of fluidized sediment**

**$C_{gf}$ : Volume concentration of solidified soil**

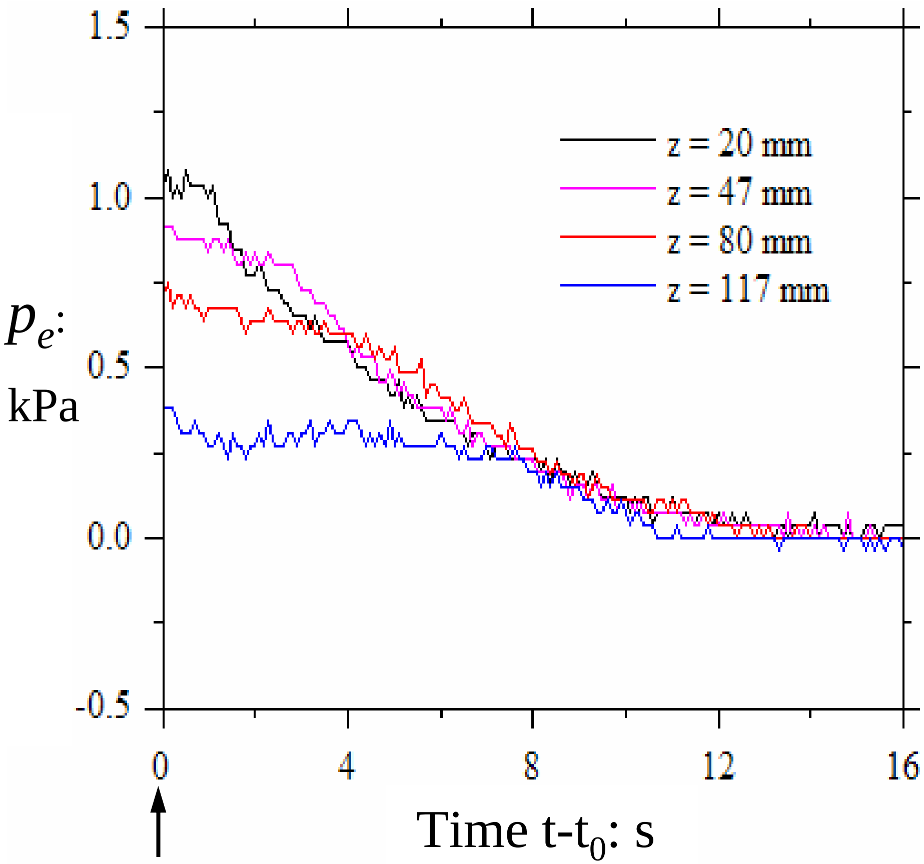
$C_{gf}$ value (best fit) = 45.9%

⇩

Corresponding to **$e_{max}$ -state** with $C_{gf}$ = 46.1%

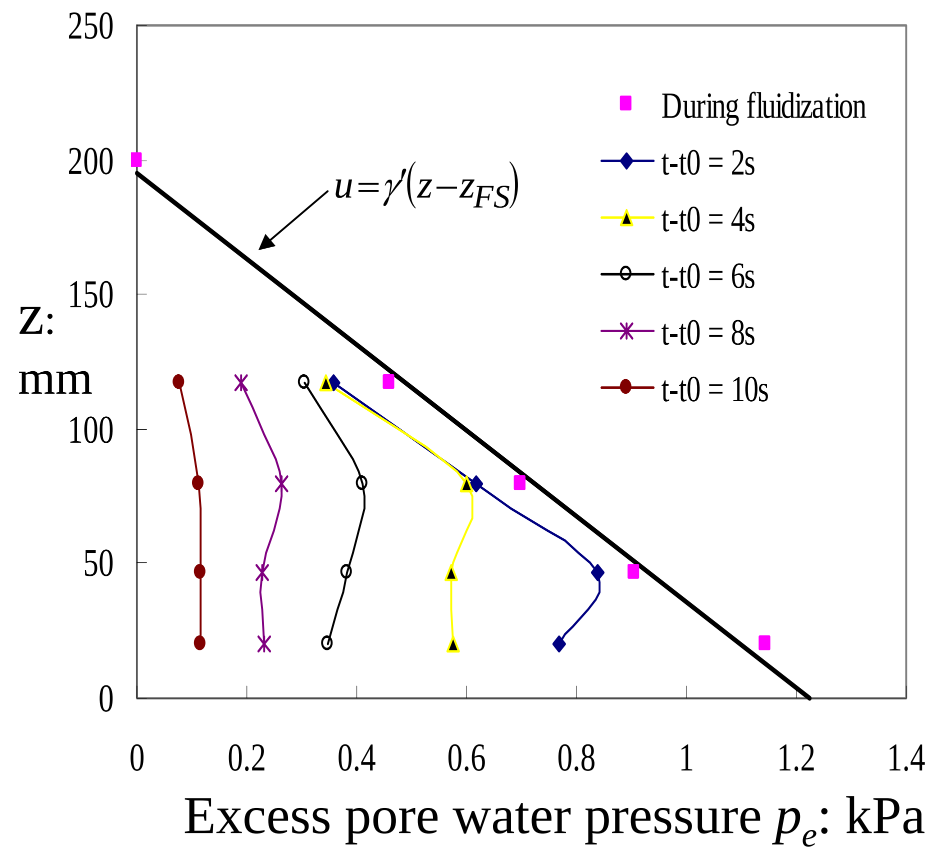
# Dissipation characteristics of excess pore pressure in the processes of hindered settling/sedimentation following fluidization

## Measured time histories of excess pore water pressure $p_e$ in test FEB05-2-3




**Start of sedimentation**
**Valve closed**

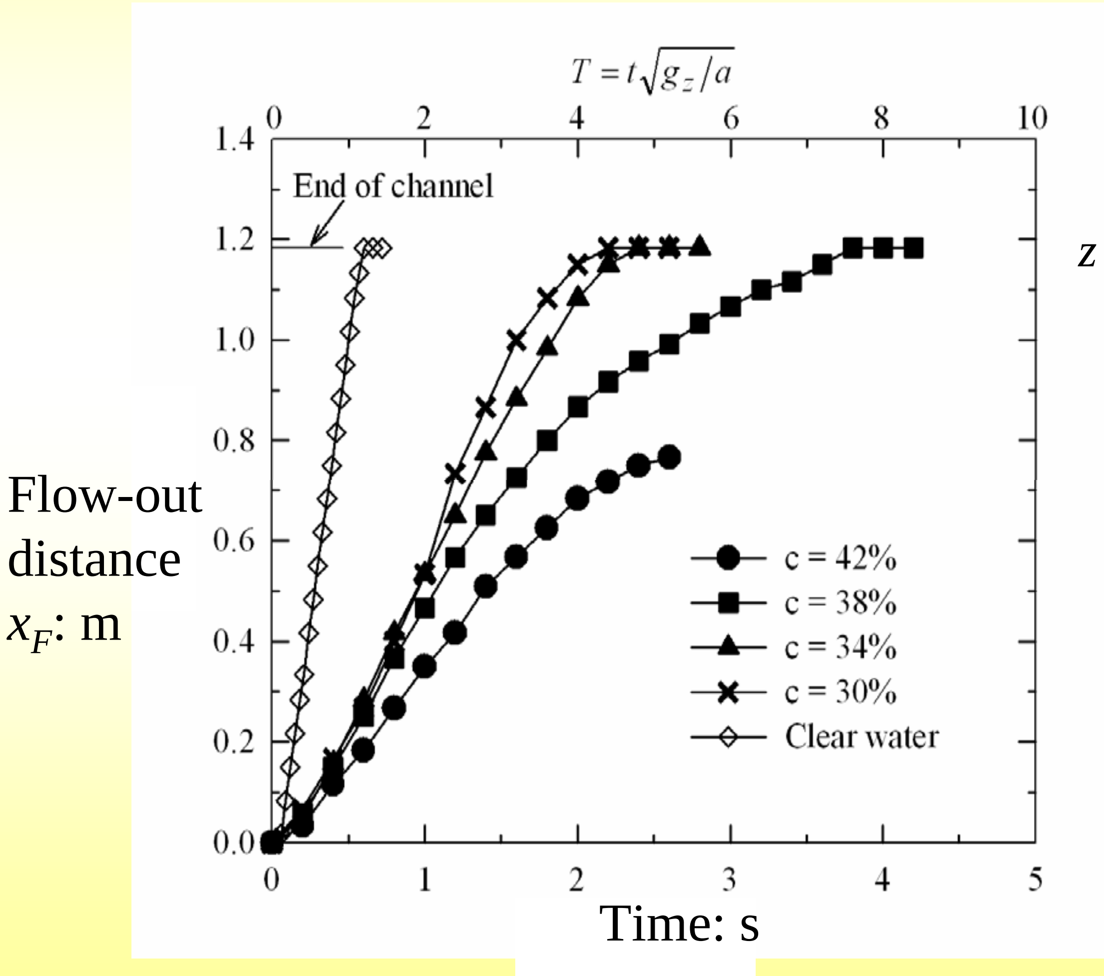
## Temporal changes in the profile of *u* against *z* for case FEB05-2-3

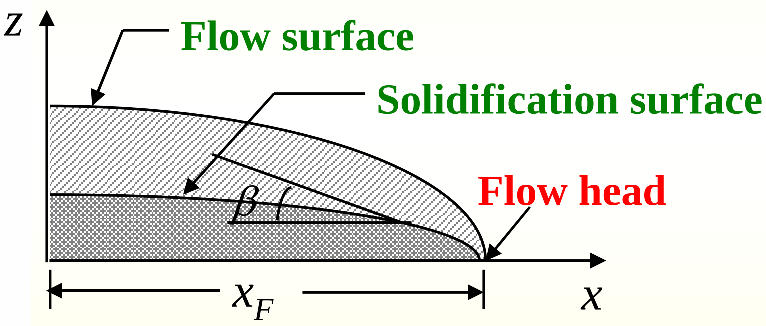



**Volumetric concentration of fluidized sand**: c = 38%

# Results from subaqueous sediment gravity flows experiment series

## Measured time histories of locations of gravity flow heads with four different solids concentrations



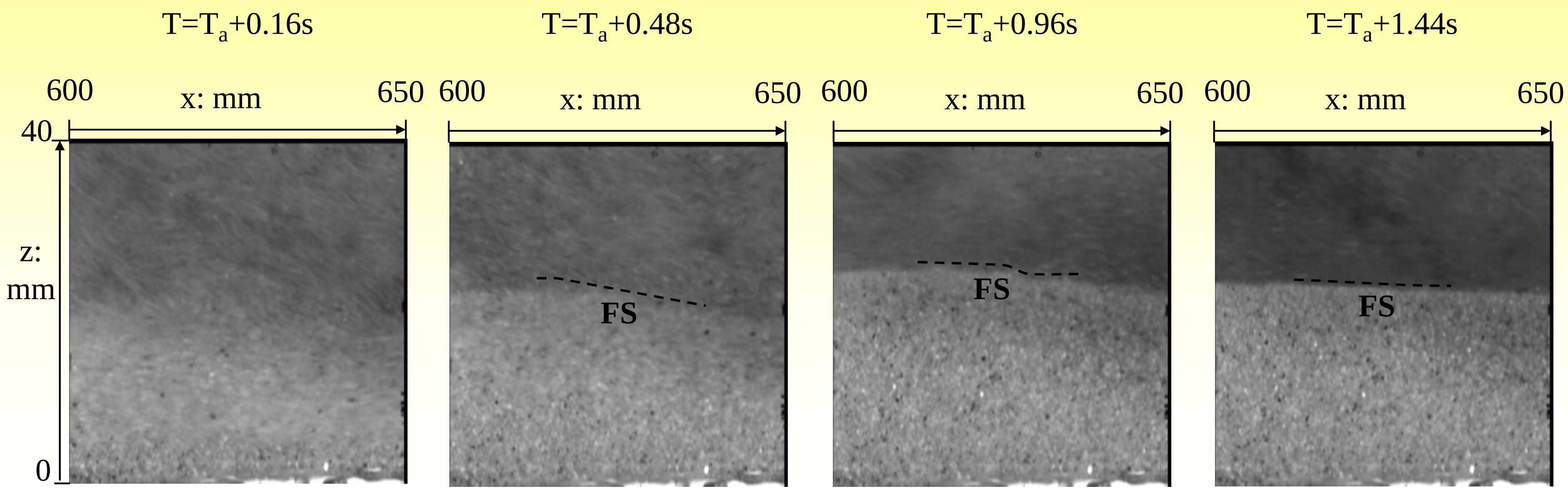




$\beta \leq \beta_{cr}$ = **critical angle in view of frictional resistance of the soil**

$x_F$ = **flow-out distance**

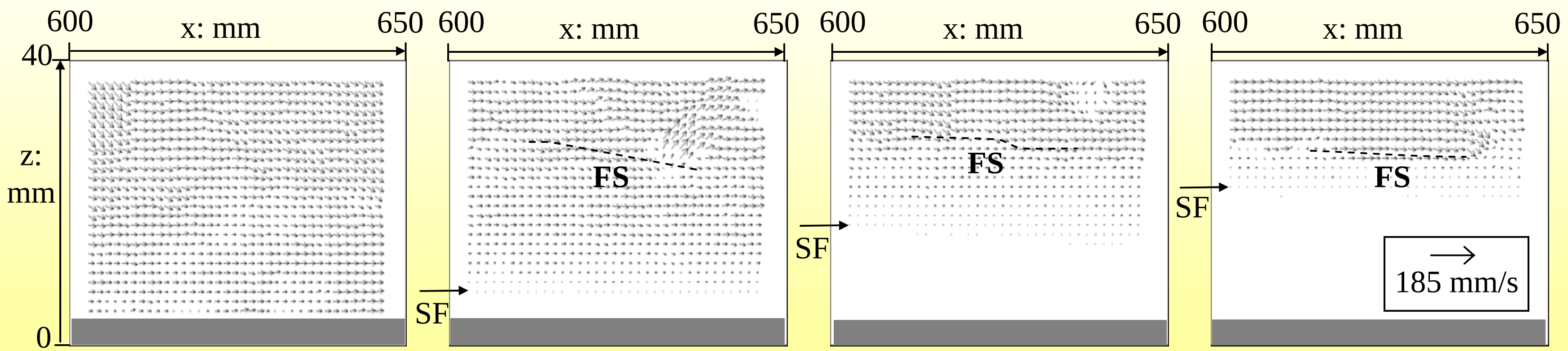
**The effect of solids concentration upon flow-out potential**

# Snapshots of fluidized sediment gravity flow (test PPTCCD-11) from a fixed station using the high-speed CCD camera



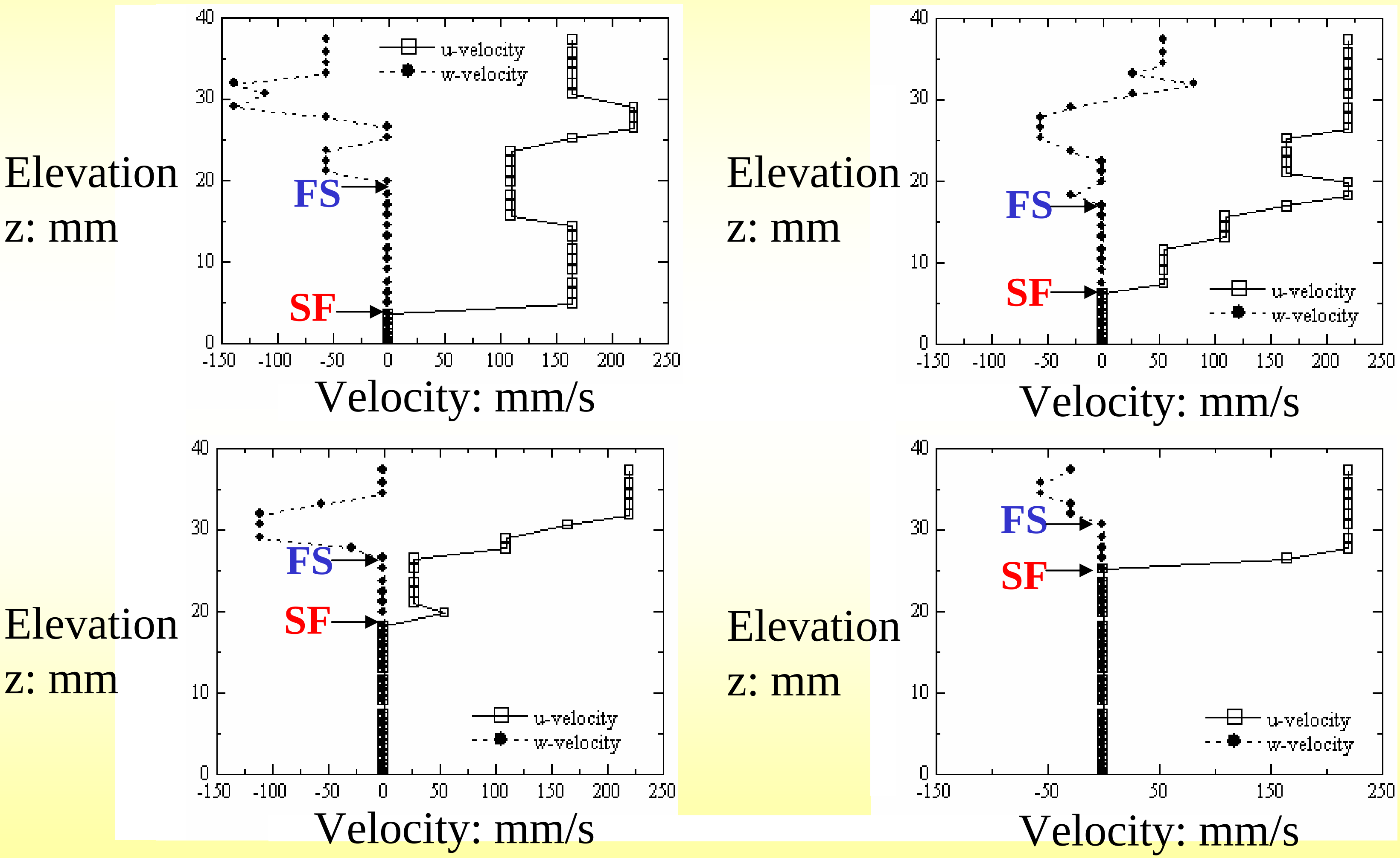

**$T_a$: Instant of time when the flow head arrived at the station of observation (x=650mm)**

# Velocity fields of sediment gravity flow in test PPTCCD-11 obtained through PIV technique, showing upward advance of solidification front



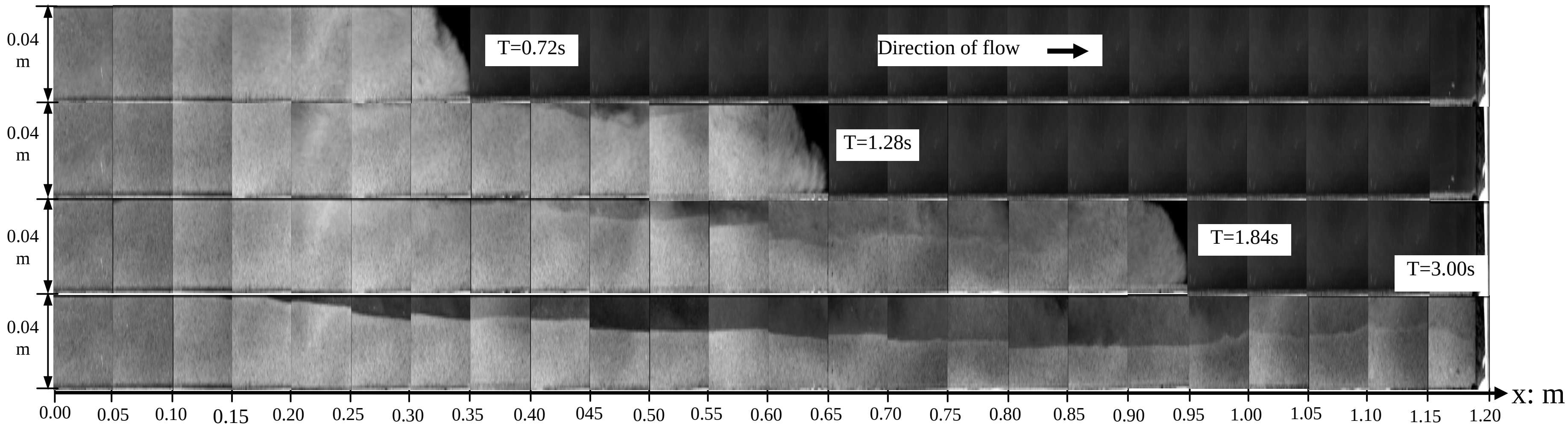

**Initially placed sand**

# Profiles of flow velocities with elevation, at x=624mm, at four different instants of time

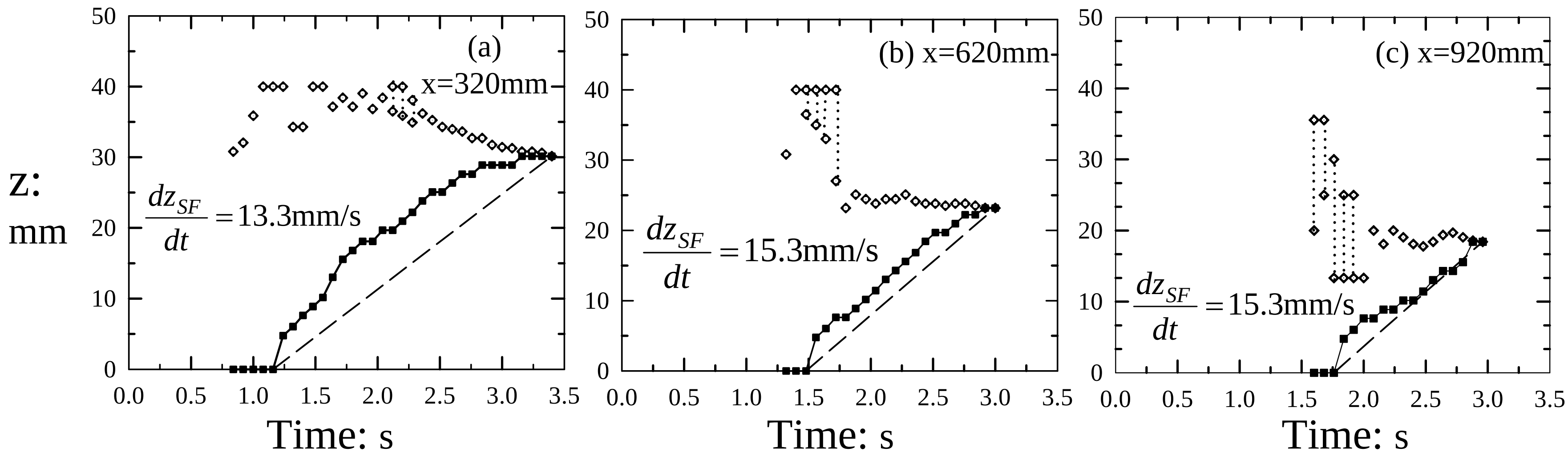



**Concurrent evolutions of flow and solidification surfaces !**

# A total of 24 pictures showing flow configurations of initially fluidized sediment with c=38% at four elapsed times indicated

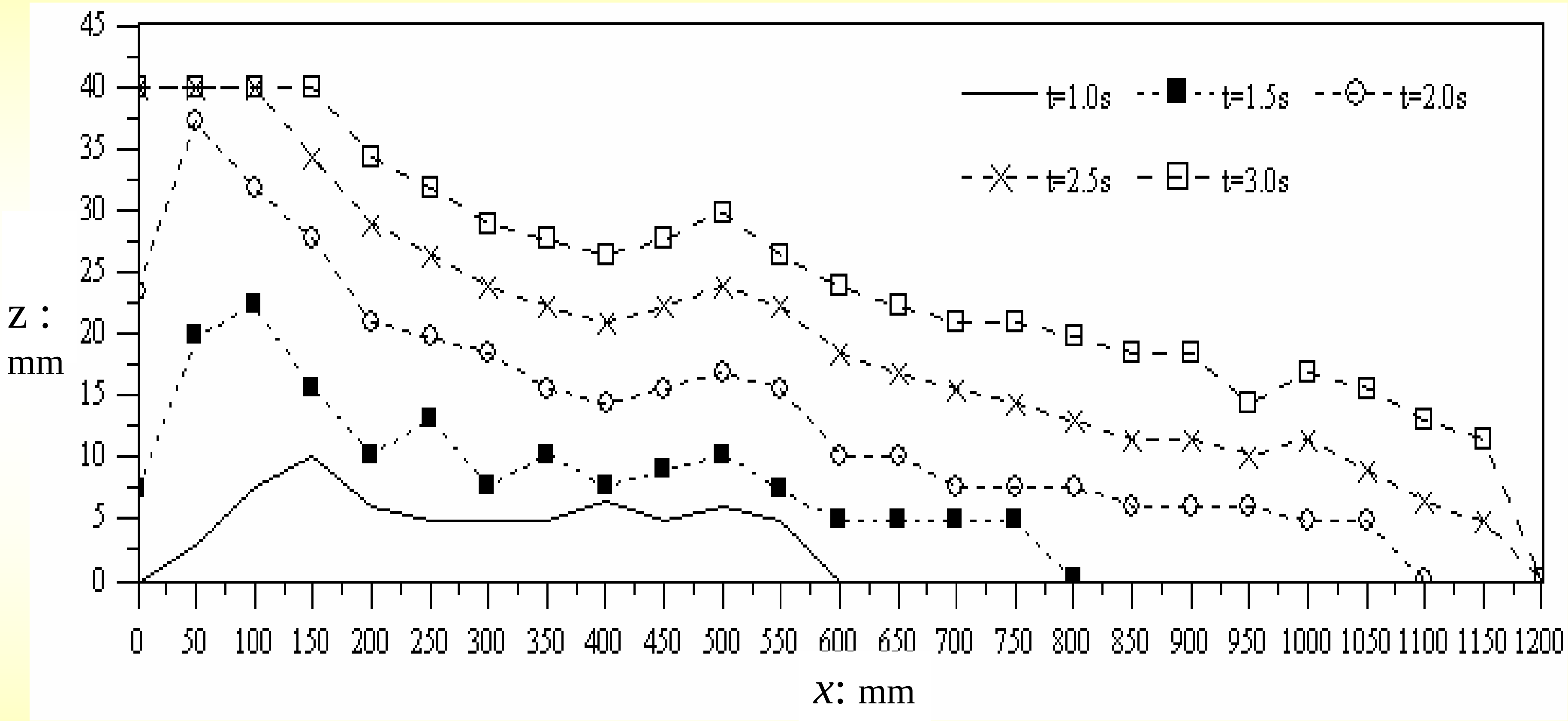



# Evolutions of flow surface and solidification front at three different stations c=38%




◇ **Flow surface location** —■— **Solidification front location** ----- **slope**

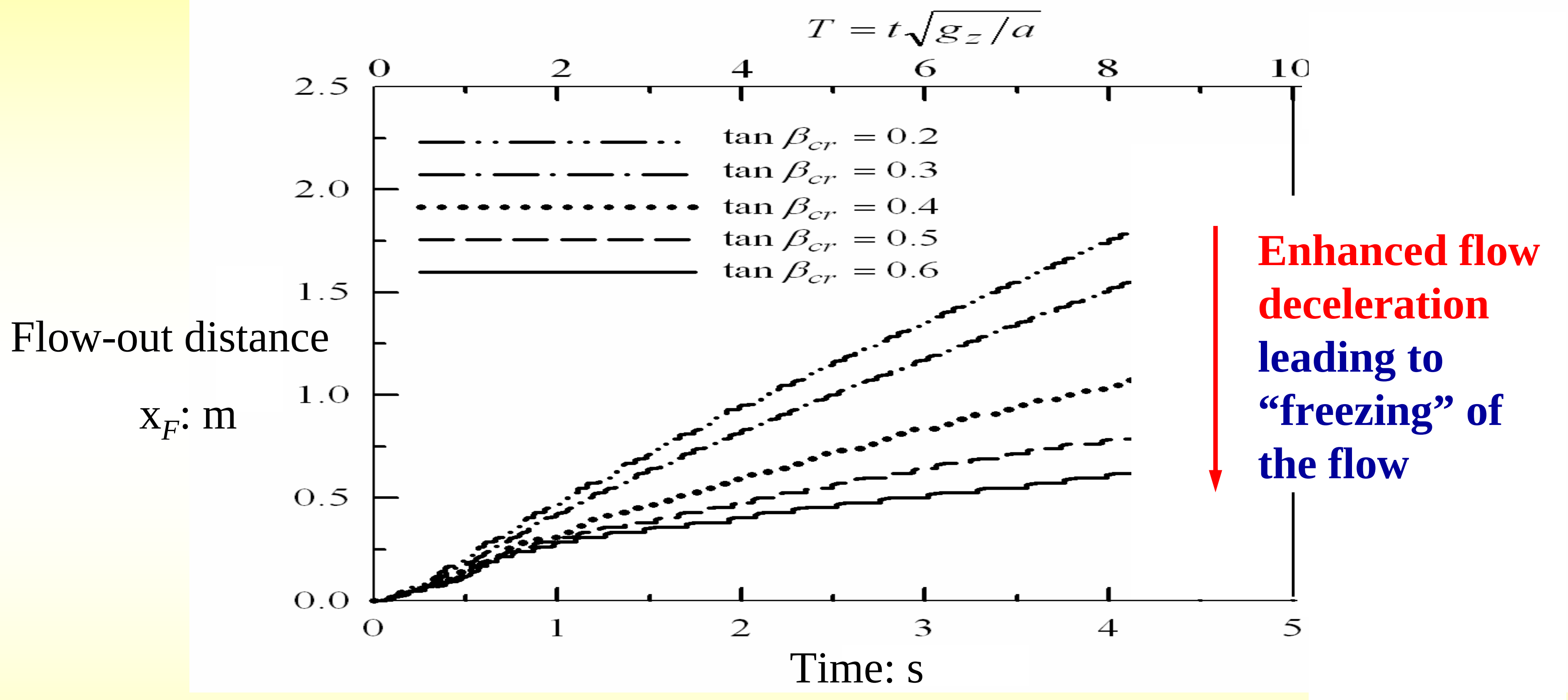
Results of 24 identical flume tests (c = 38%) obtained through PIV technique




**Verification of the 2003 predictions from LIQSEDFLOW !**

- Very mild slope
- Void ratio of redeposited sand: 1.11
- Speed of development of solidification front： 16-12mm/s

# The effect of progressive solidification upon flowage:
## Predicted results from LIQSEDFLOW




$\beta_{cr}$ : **Concentration-dependent friction angle of solidified soil**

**Predictable based on two-phase physics !**

**without introducing any artificial viscosity or yield stress**

# Summary

a. Through physical modelling of subaqueous gravity flows of hyperconcentrated fluidized sandy sediments, we were able to clarify the way in which a grain-supported framework was reestablished during flowage.

b. The observed characteristics of flow stratification/ deceleration involving progressive solidification in the fluidized sediment gravity flows generally support the theoretical framework of a computational code LIQSEDFLOW (Sassa, et al., 2003).

c. The observed complete “freezing” of the sediment gravity flow calls for more development in numerical modelling, in view of the measured effects of hindered settling upon the development of solidification during flowage.