Effect of Sediment Transport on Pipeline Stability

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AUSTRALIAN OFFSHORE OIL AND GAS INDUSTRY

- Contributes > $40b/year to Australian economy (about 3% of Australian GDP)
- Australian natural gas reserves
  - 3.115 trillion cubic meters (largest in Asia Pacific region, 12th in the world)
  - More than 85% of the total gas reserves in offshore seabed
  - Most of current developments in North West Shelf of Western Australia (current projects in WA >250 billion)

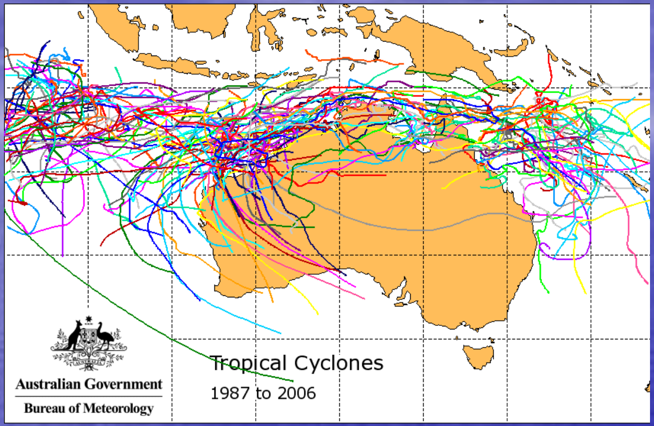
IMPORTANCE OF PIPELINES

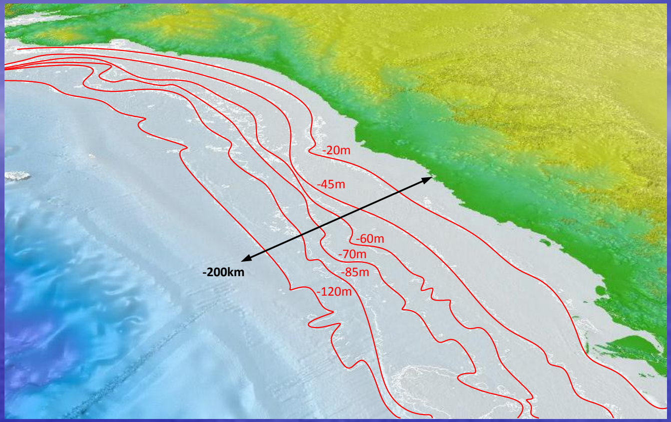
- Offshore pipelines
  - Key links between production wells and storage units
  - About 3,000 km pipelines to be built in WA in 10 years with a cost estimate of $15b
  - Stabilization cost accounts for about 30% of the total costs

DESIGN CHALLENGES

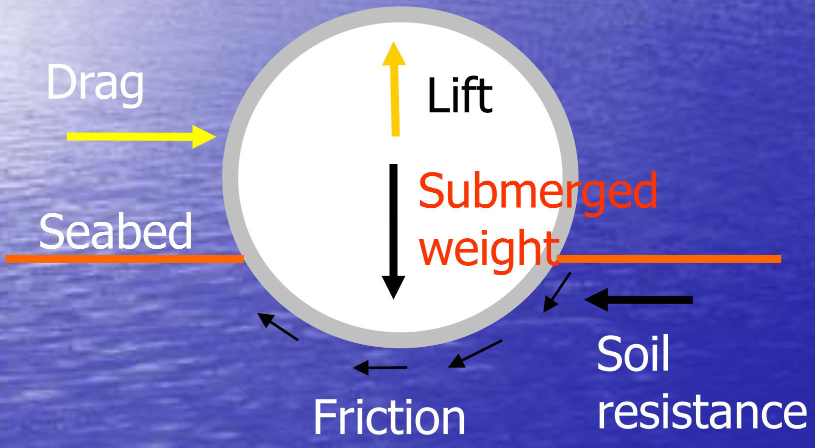
Challenges

- Cyclones
- Shallow water
- Calcareous soils
- Light gas pipelines





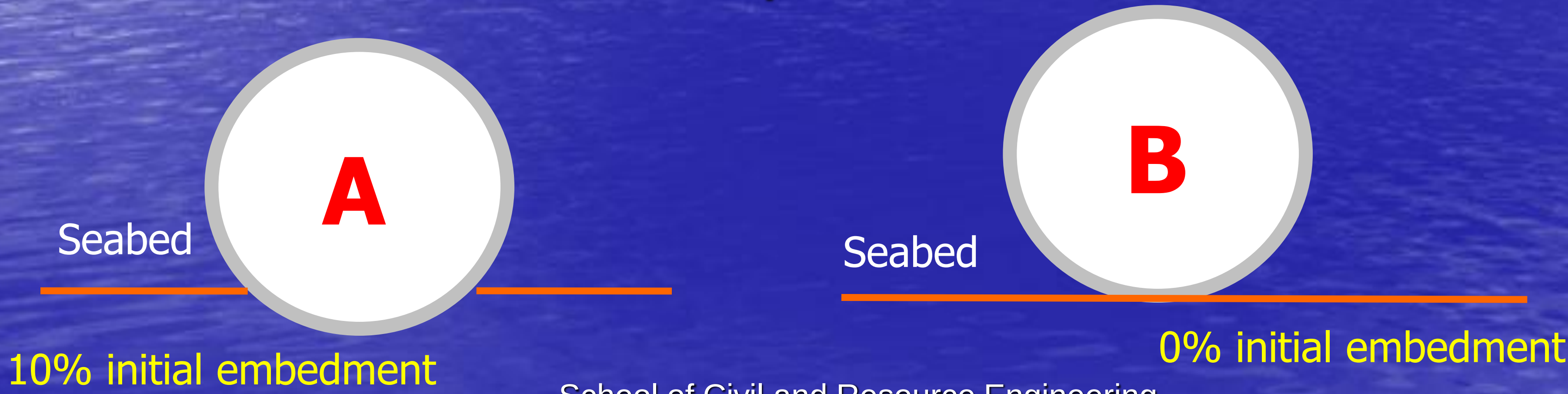
PIPELINE STABILITY DESIGN



- Ensure vertical and horizontal stability
- Recommended Practice (e.g. DNV RP F109)
  - Dynamic lateral stability analysis method
    - Time domain analysis of pipe response (loads and resistance)
  - Generalized lateral stability analysis method
    - Limit maximum allowable displacement for a design spectrum of waves
  - Absolute lateral static stability method
    - Design Wave approach

QUESTION?

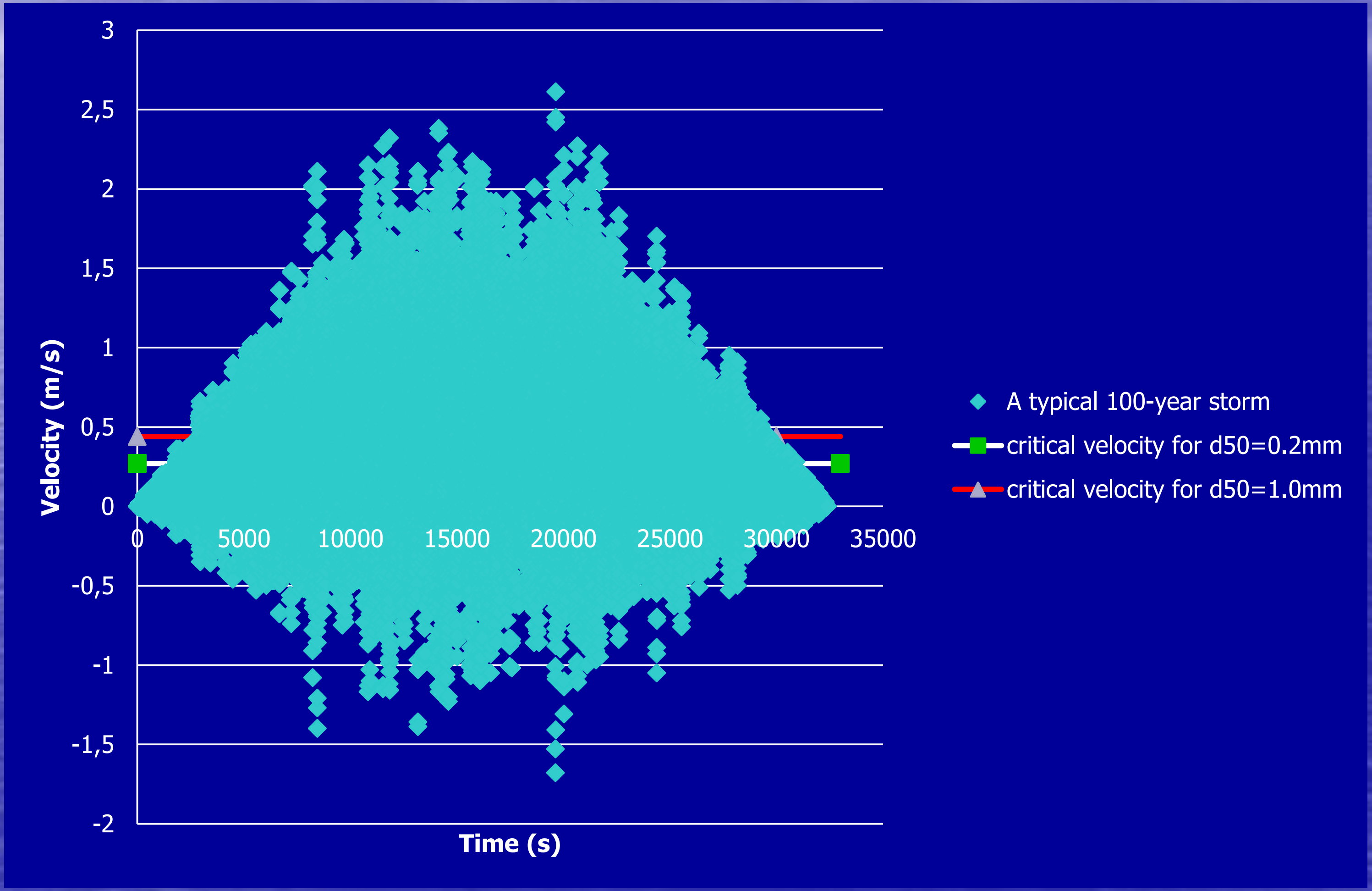
- Which of two situations below would be more stable, assuming they are subjected to identical storms with identical self-weight, seabed sediments but different initial embedment dpeths?



FLAWS IN DESIGN METHODS

- Sediment transport processes ignored
  - As-laid seabed configuration is used throughout the analysis
  - Onset of sediment transport and local scour occur earlier than storm peaks
  - Seabed profiles around the pipe significantly modified when storm peaks arrive
    - Hydrodynamic loads
    - Soil resistance
  - Overconservative or unsafe designs?

ONSET OF SEDIMENT TRANSPORT



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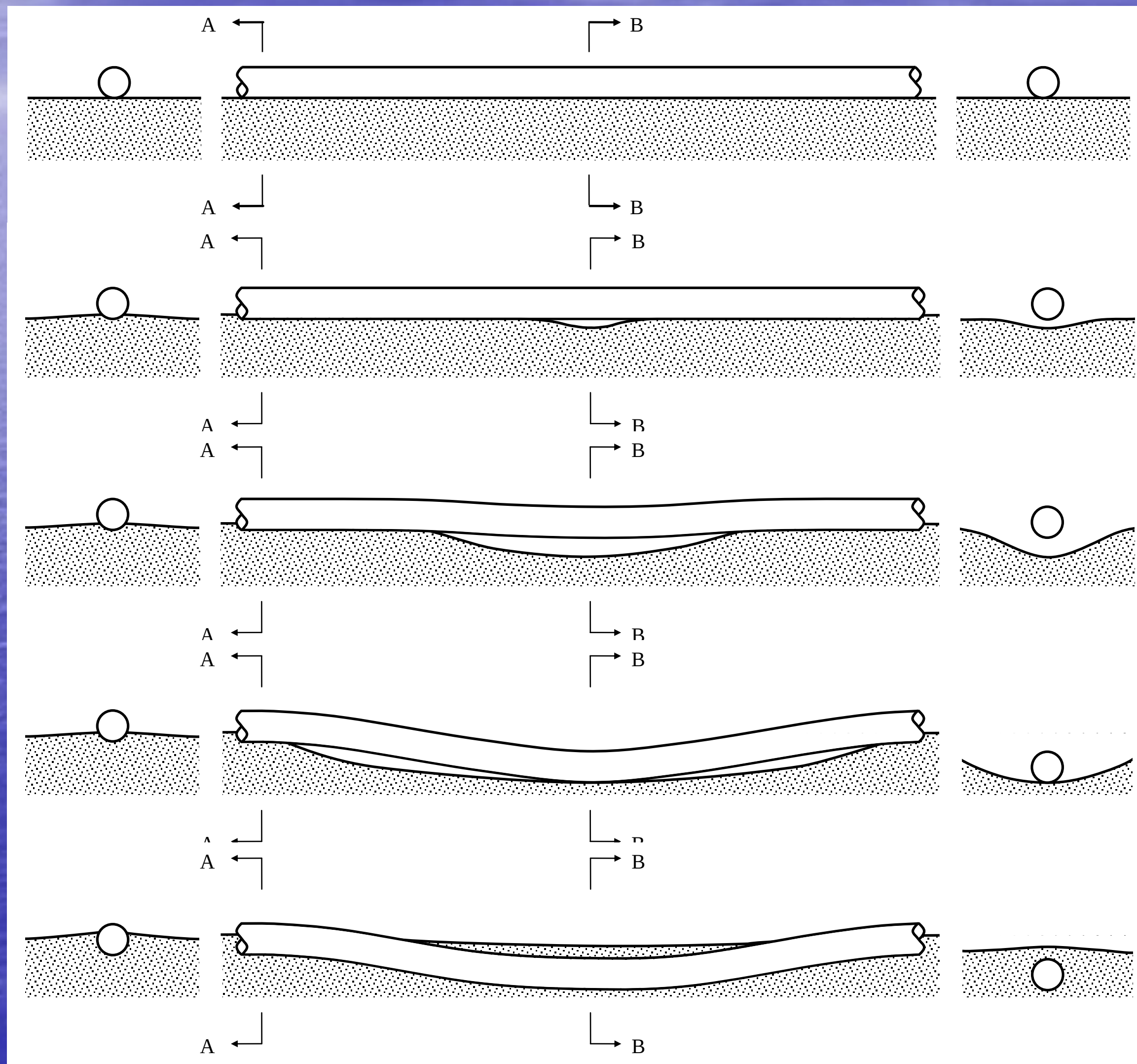
AUSTRALIAN FIELD EXPERIENCES

- Significant self-burial on sandy seabed
  - – 80%-100% burial for 60%-80% of the lengths of existing small diameter pipelines

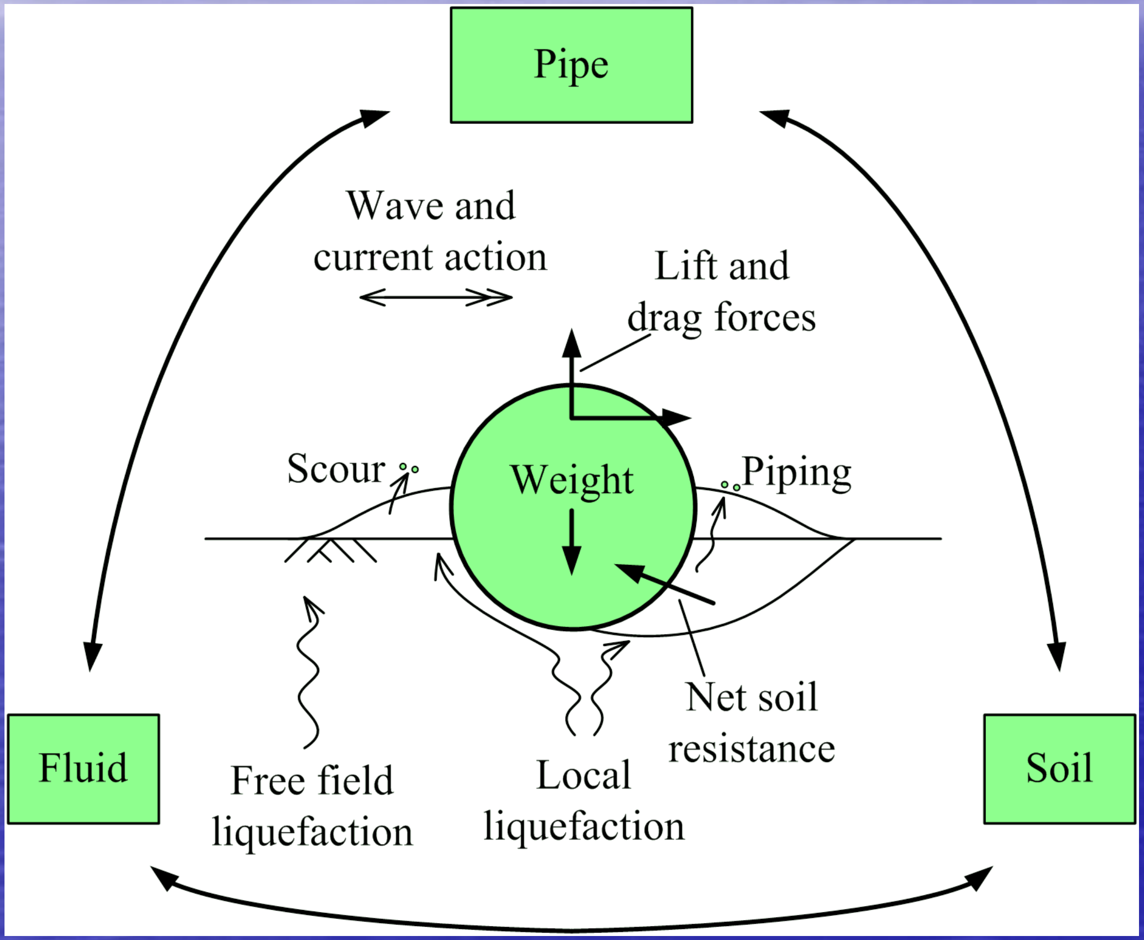
SELF-BURIAL MECHANISMS



EXISTING RESEARCH

- Individual aspects well studied
  - Hydrodynamic (fluid/pipeline)
    - Hydrodynamic forces on pipelines
  - Geotechnical (pipeline/seabed)
    - Friction factors and lateral resistance
  - Structural (fluid/pipeline)
    - VIV and buckling
- Fluid/Pipeline/seabed interactions rarely studied

NEW RESEARCH FOCUS – TRIPLET INTERACTIONS



RESEARCH CHALLENGES

- Scaling difficulties in model tests
  - Ignorance of Reynolds Criterion
    - Supercritical flow vs subcritical flow
  - Similarities in seabed profiles
    - Scaling of seabed sediments: size and erosion properties
- Control of dynamic responses of model pipe
  - Eliminations of unrealistic movements: roll, pitch and yaw
  - Control of pipe movements in response to hydrodynamic loading and soil resistance

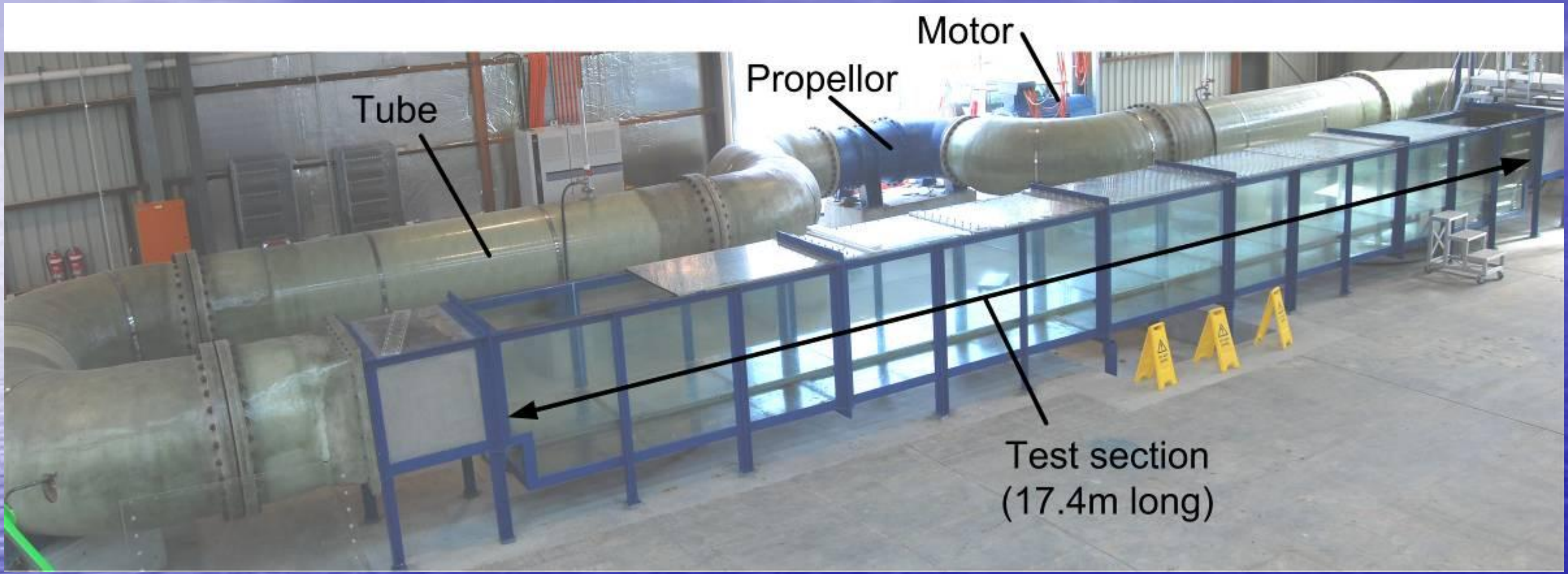
RESEARCH STRATEGIES

- Conduct pipeline stability testing at large scales to reduce scaling effects
  - Large wave + current flumes
    - Expensive and requires large amount of sediments
  - Need a unconventional facility
- Active feedback pipeline control system
  - If total force (hydrodynamic and soil resistance) on pipe > 0 – pipe movement
  - Forces changes due to pipe movements are captured and fed back to the control system

A NEW FACILITY

- Requirements
  - Conduct pipeline stability testing at large scales to reduce scaling effects;
    - 1:1 scale for small diameter pipelines (<8 inch)
    - 1:5 scale for large diameter pipelines (<40 inch)
  - Simulate flow conditions induced by cyclonic storms
    - Oscillatory flow up to 2.8 m/s with a peak period of 13 seconds
    - Steady currents up to 3.0 m/s
    - Combined random storm time series.

O-TUBE CONCEPT



- Flow is generated by controlling the rotation of impeller
  - One direction only – steady currents
  - Two directions of equal speeds – oscillatory flows
  - Two directions of different speeds – oscillatory + steady
  - Rotations from any spectra – random storms

Motor and Pump

- Motor
  - Push 60 tonnes water back and forth
  - Power: 580kw
- Pump
  - Axial flow pump
  - Nominal rated speed: 600 rpm
  - Diameter: 1 m
  - Discharge: > 3 m^3/s

WATER CIRCULATION

- Water is circulated between a water tank and O-tube
  - Capacity: 60 m^3
  - Filling and emptying time: 20 min – 30 min
  - Valves operated electronically from control room

PIPE CONTROL SYSTEMS

- Model pipe
- Mounting actuators
- Data acquisition system
- Active feedback control operations

MODEL PIPE

- D=0.2 m and L
- Internal DAQ system, communicating via Ethernet
- Up to 1 MHz, 8 channels per box
- Internally pressurised to protect DAQ system.

PIPE MOUNTING ACTUATORS

- Prevent pipe movements in unrealistic degrees of freedom
- Isolate model pipe from forces transmitted through supporting frame, for experiments where free 'natural' movement is wanted
- Allow pipe to move if the net force on pipe > 0
- Allow model pipe to be held fixed if required, whilst measuring forces acting on the model pipe
- Apply pre-determined load (e.g. self-weight) or displacements
  - e.g. for experiments to verify soil resistance in absence of hydrodynamic forces

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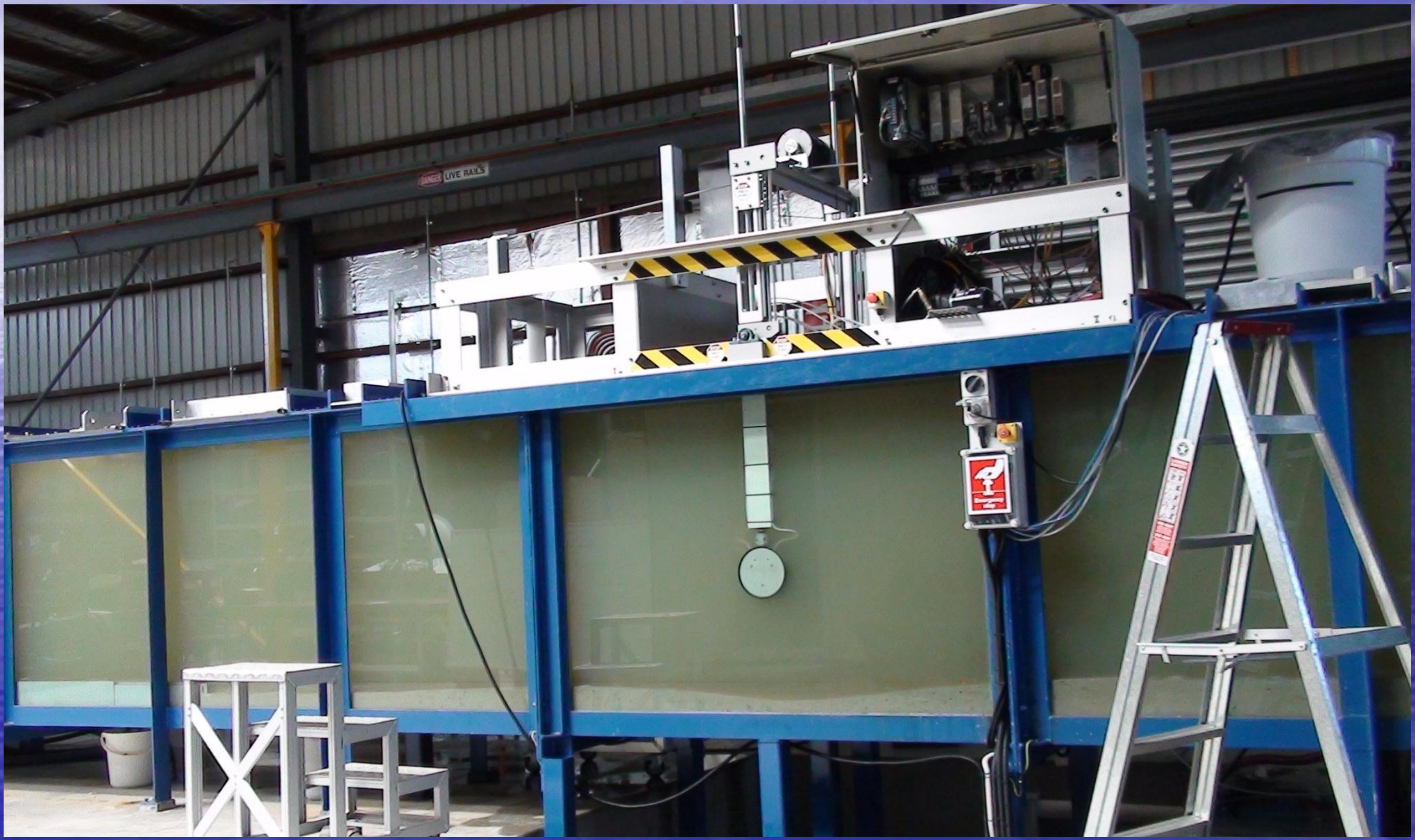
PIPE MOUNTING ACTUATORS



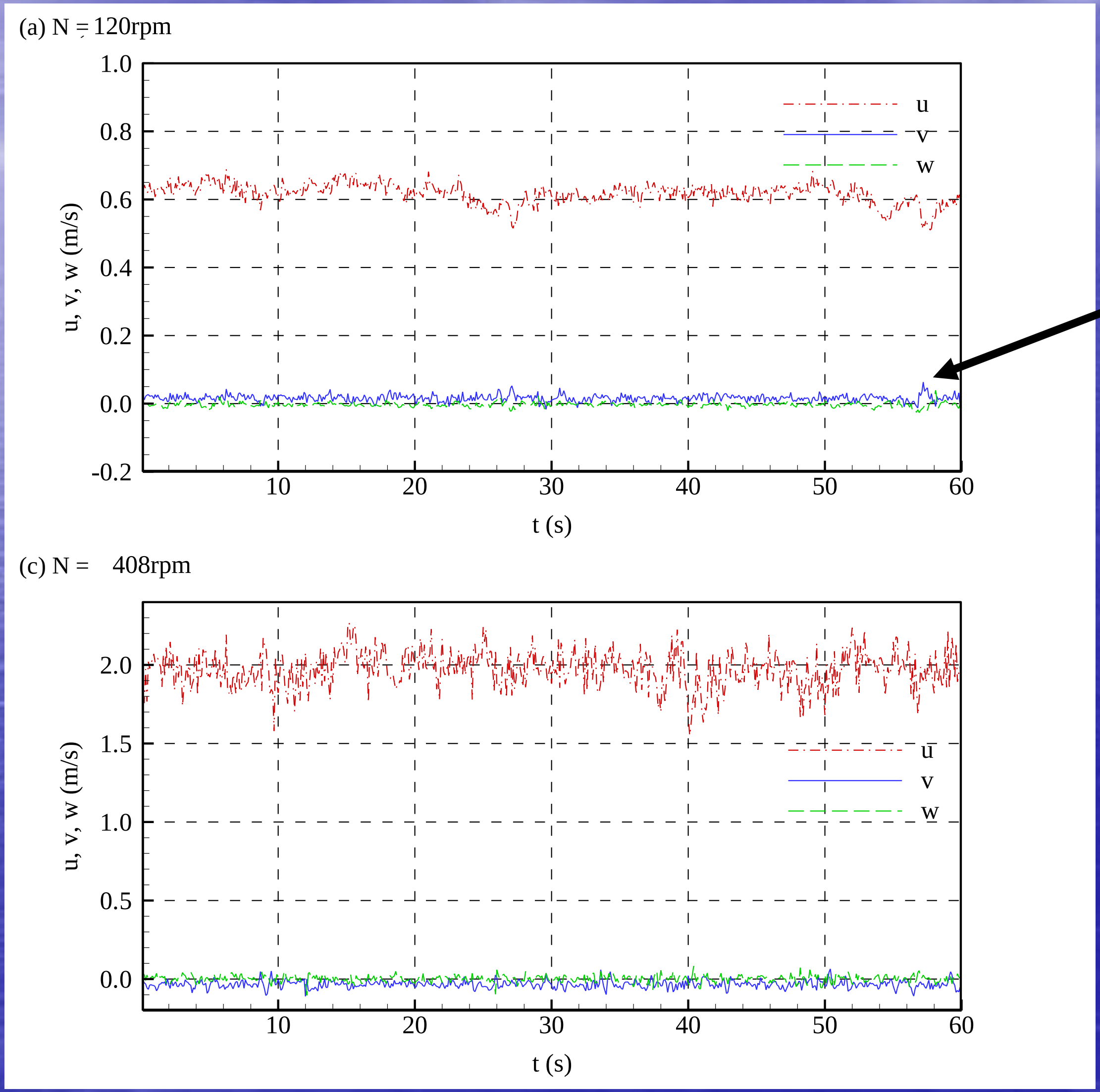
CONTROL OF O-TUBE OPERATIONS

- Fully controlled via a computer from the control room directly in front of the test section
  - Filling and emptying operations
  - Emergency stop (overpressure sensors)
  - Normal operations (start, stop, etc..)
- Control software
  - LabView – written in-house at UWA – continuously upgradeable / customisable
- Data acquisition system
  - Pressure, displacements, forces, bed profiles and velocities
  - Sensors distributed around O-tube are connected to individual 8-channel DAQ boxes, which talk to the control room via wireless network
  - Data acquisition units are UWA in-house designed

CALIBRATION TESTS

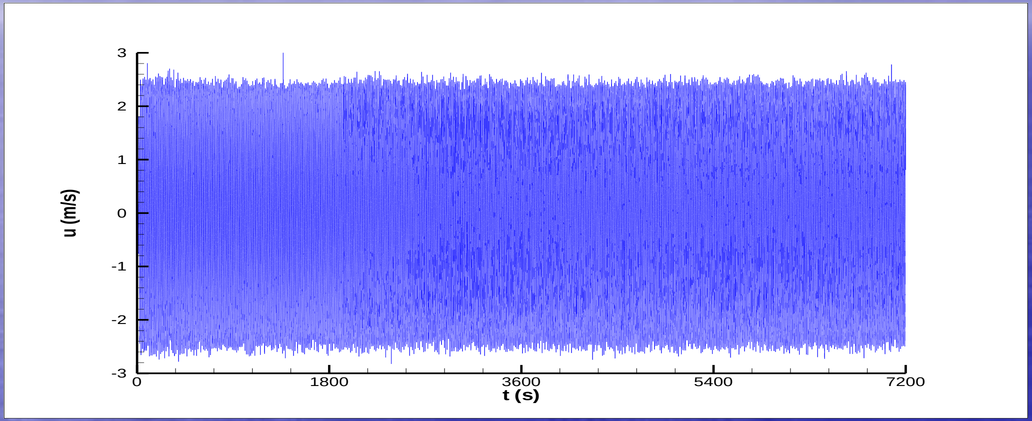
- Validation of performance against design parameters
- Determination of relationships between pump speed and flow rate in the O-tube in order to control
- Evaluation of flow characteristics in the test section

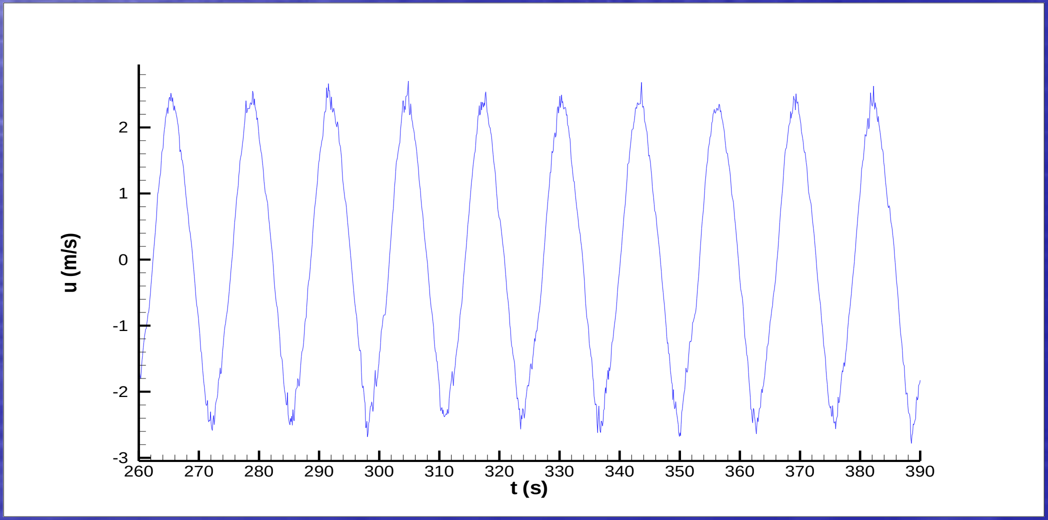
STEADY CURRENTS - EXAMPLES



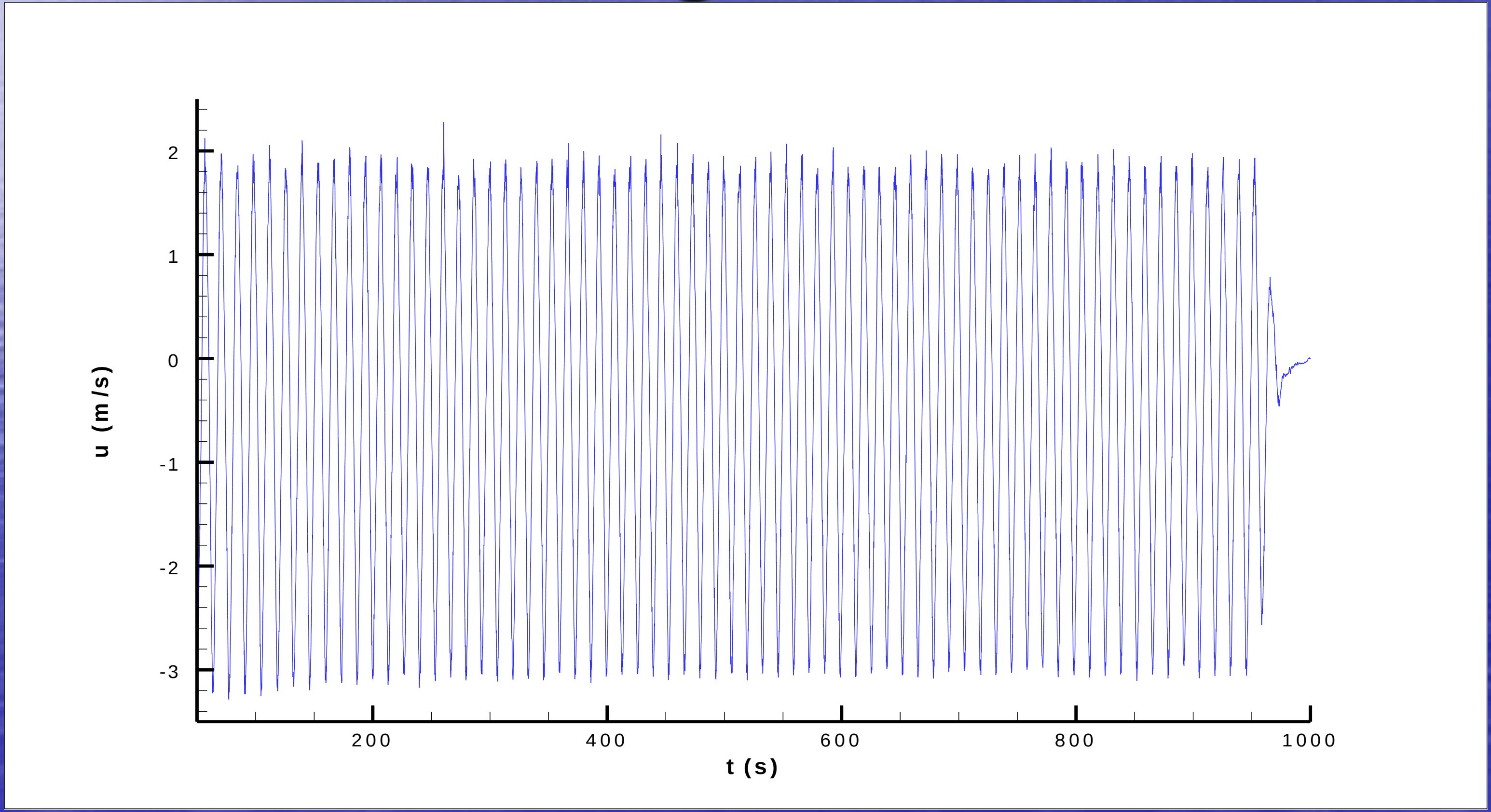
Near-zero out-of-plane flow

OSCILLATORY FLOW (U_W=2.5 M/S AND T = 13 S)

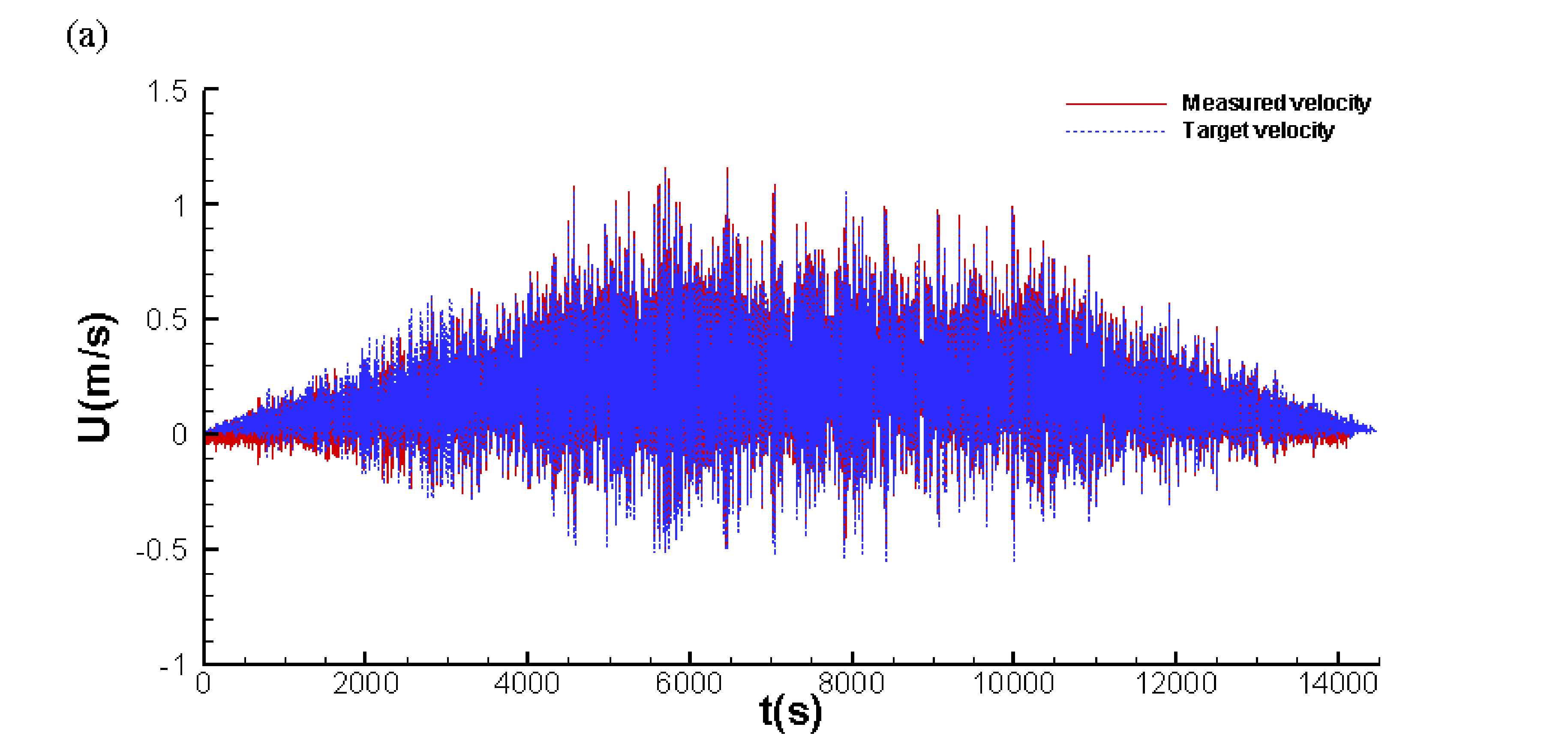




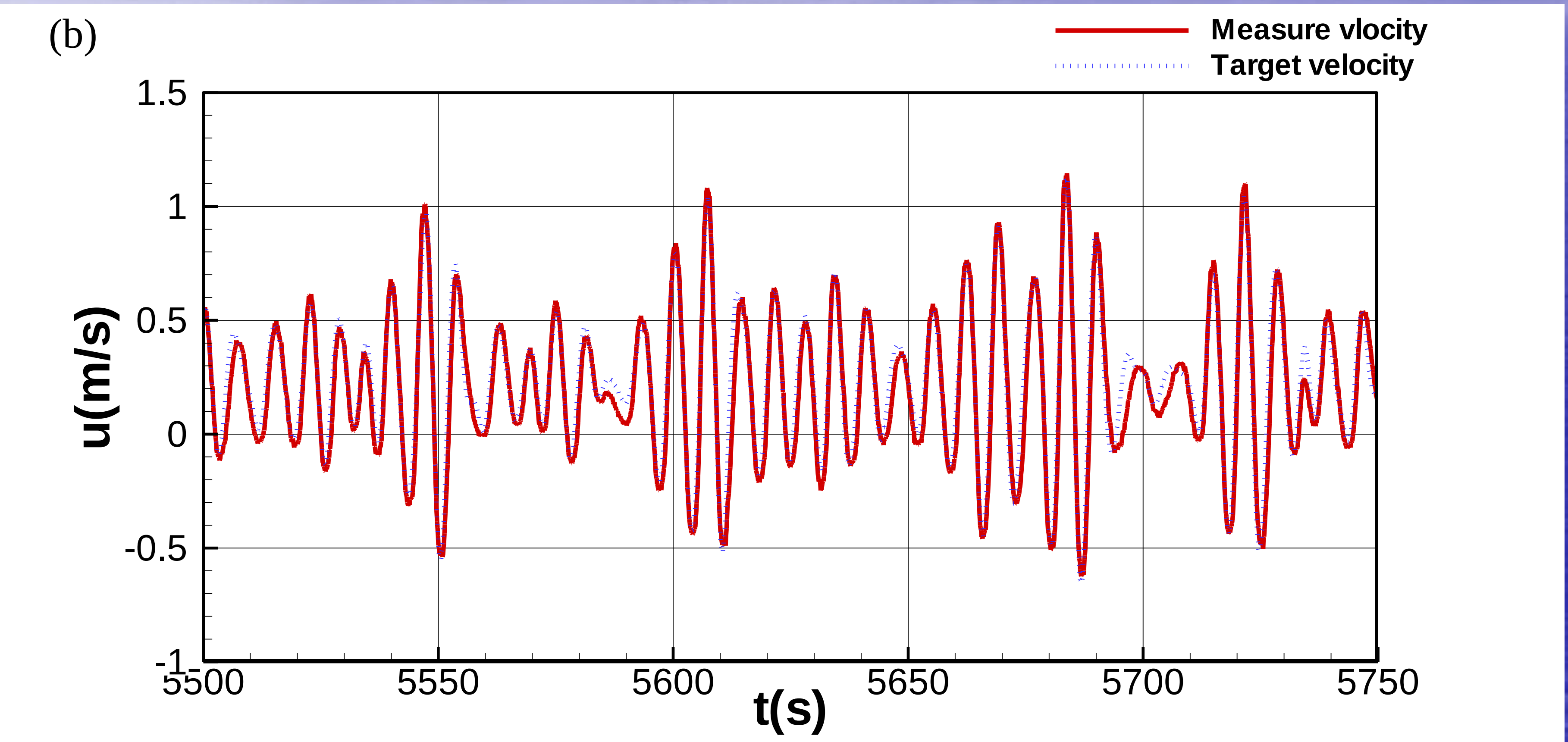
OSCILLATORY FLOW + STEADY CURRENTS (U_W=2.5 M/S, T=13S AND U_C=0.5 M/S)



RANDOM WAVES + CURRENTS



RANDOM VELOCITY TIME SERIES



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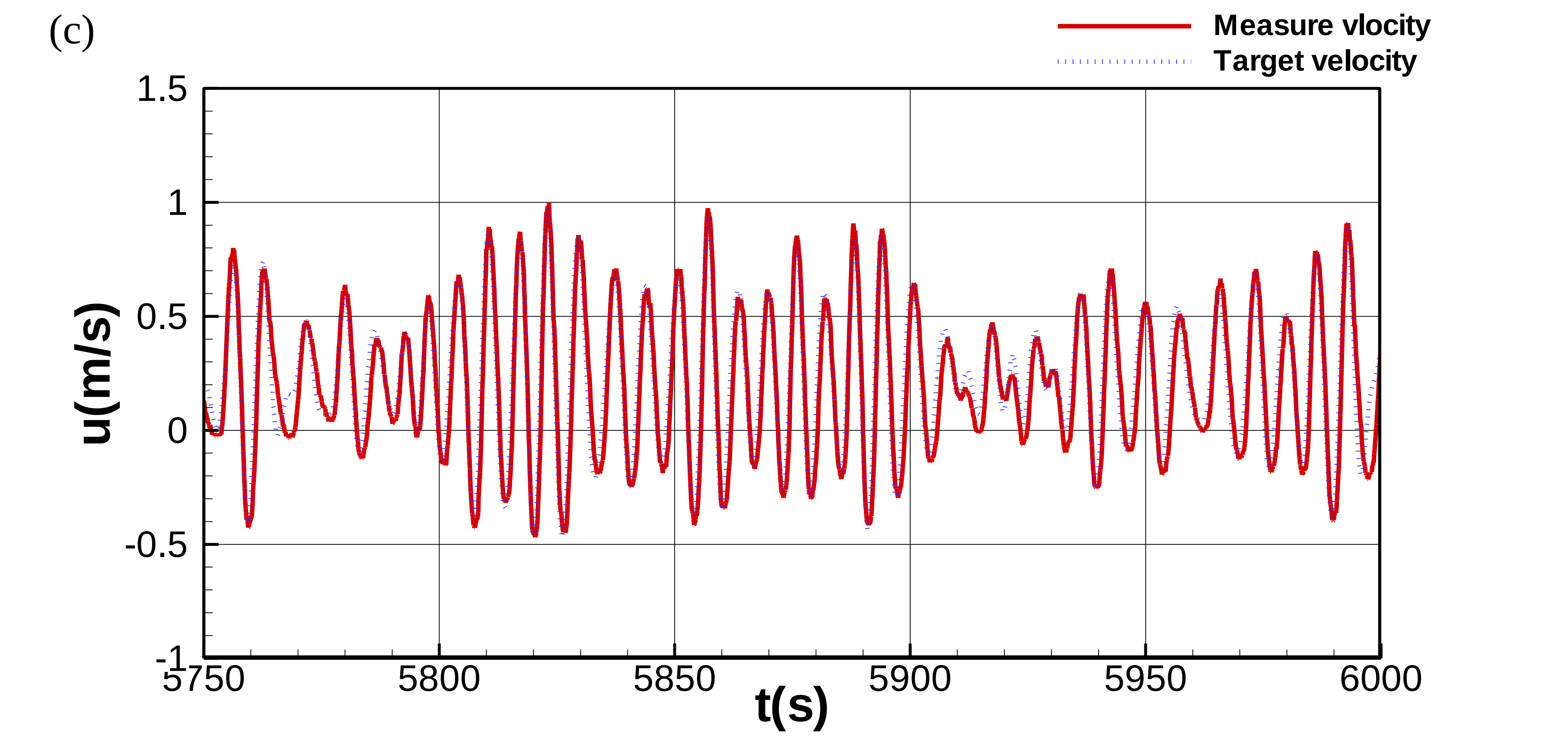
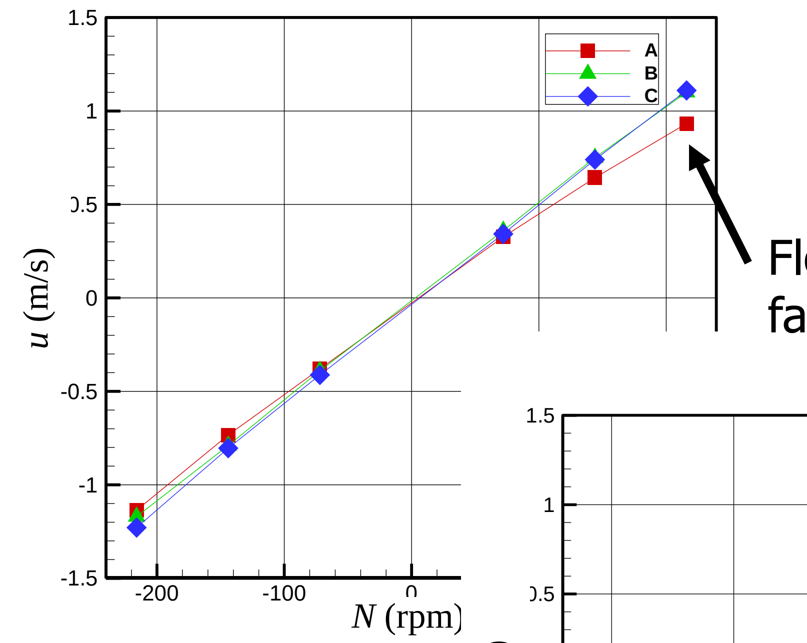
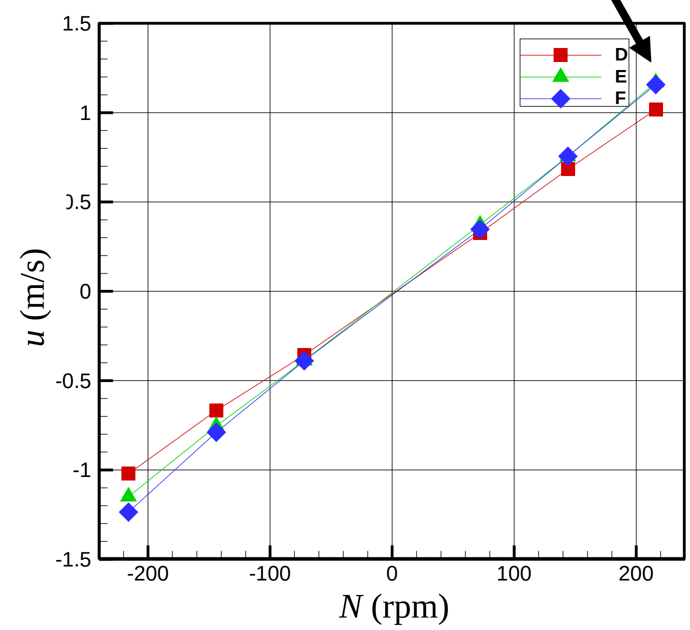
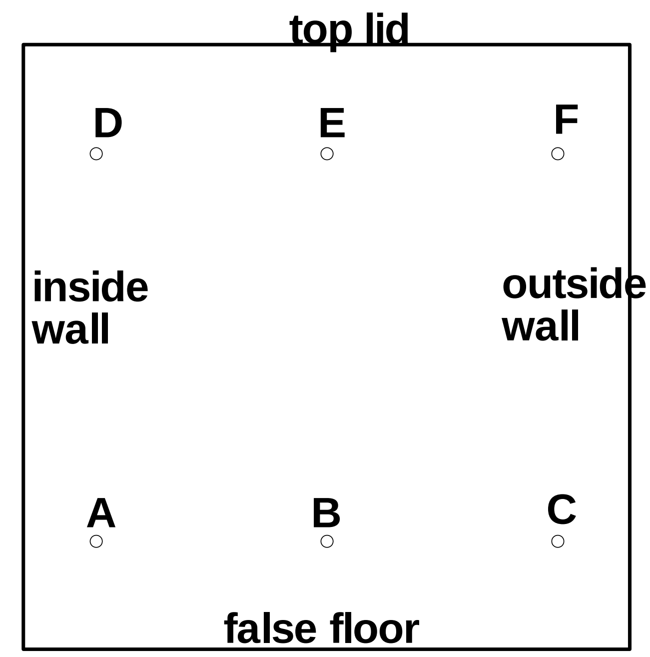


FLOW UNIFORMITY:STEADY CURRENTS



Flow is marginally faster at outside wall





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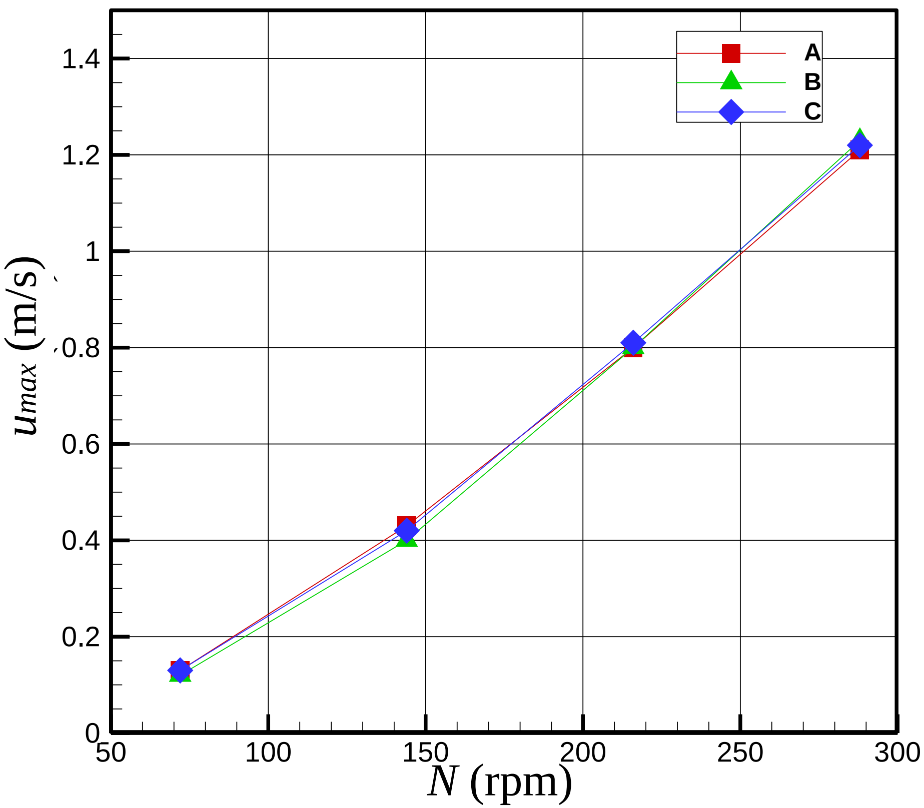
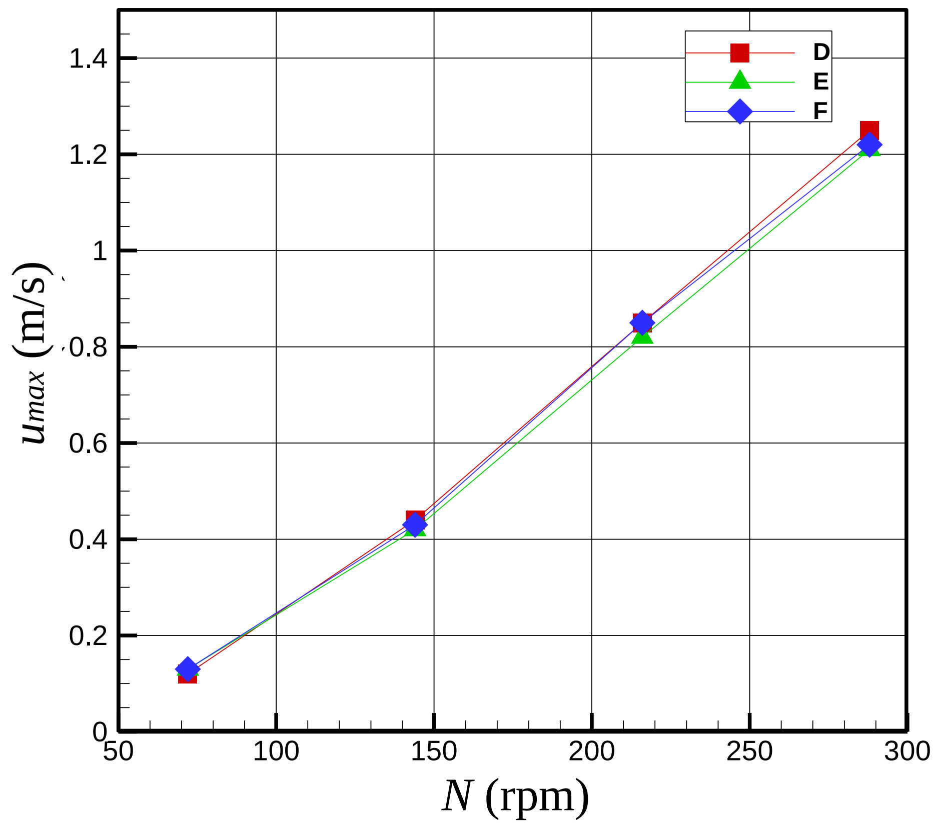
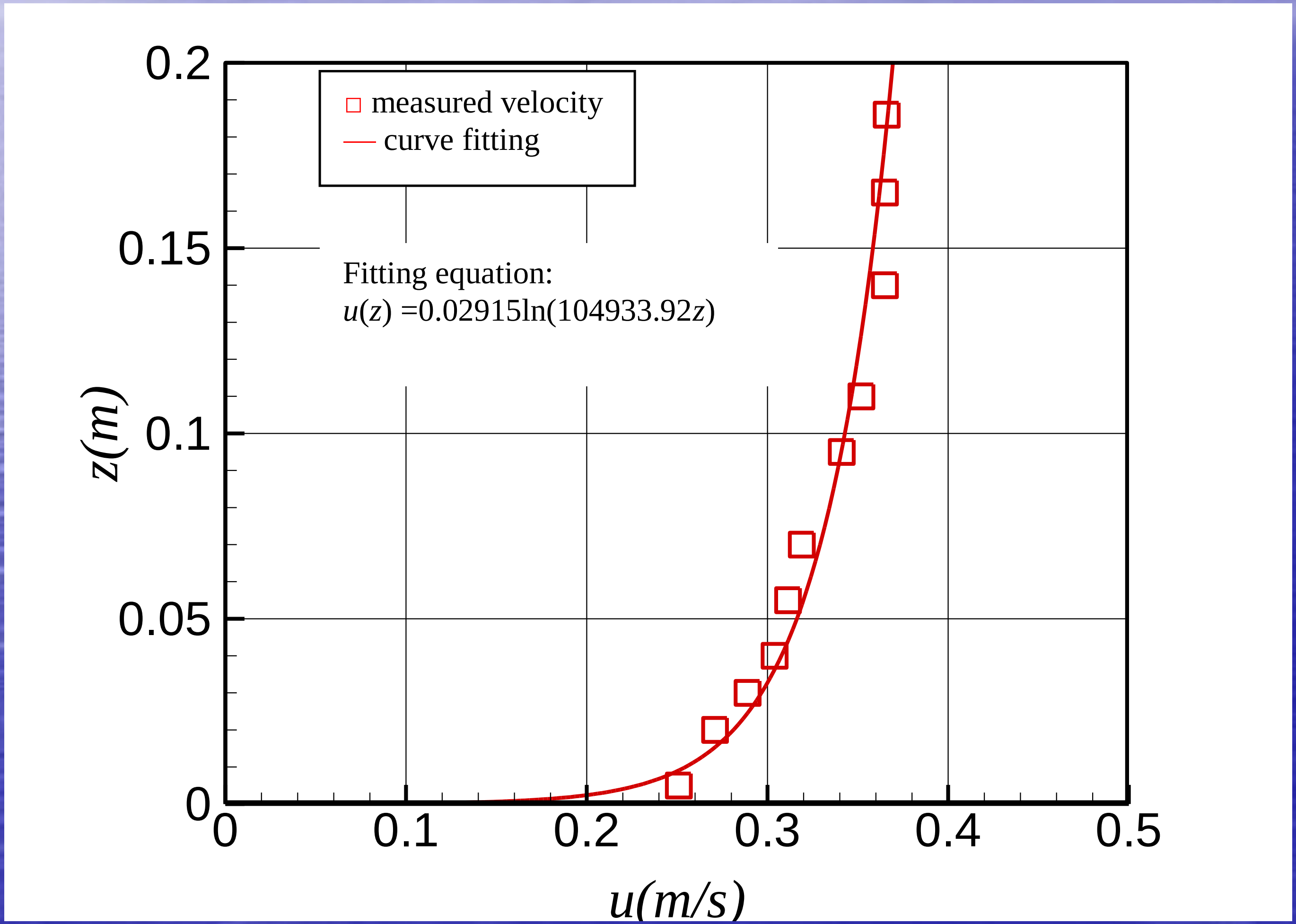
FLOW UNIFORMITY:OSCILLATORY FLOW





BOUNDARY LAYER MEASUREMENT



TEST PROGRAMS

- A number of industry sponsored physical model tests have been conducted so far
  - Effects of pipeline specific gravity, initial embedment depth, storm rump up rate and storm seed number have been investigated;
  - Results are being processed
  - More testing and research work are on-going

FINDINGS SO FAR

- Sediment transport has a significant effect on pipeline on-bottom stability
  - Scour can be beneficial to pipeline stability
- Storm build-up time and scour development time are two important competing mechanisms
  - If sufficient scour and pipe sagging occur before storm peaks arrive, pipeline **B** is more stable than pipeline **A**

AN TEST EXAMPLE: PARTIALLY BURIED PIPELINE

SEDIMENT PROPERTIES AND MODEL PIPE

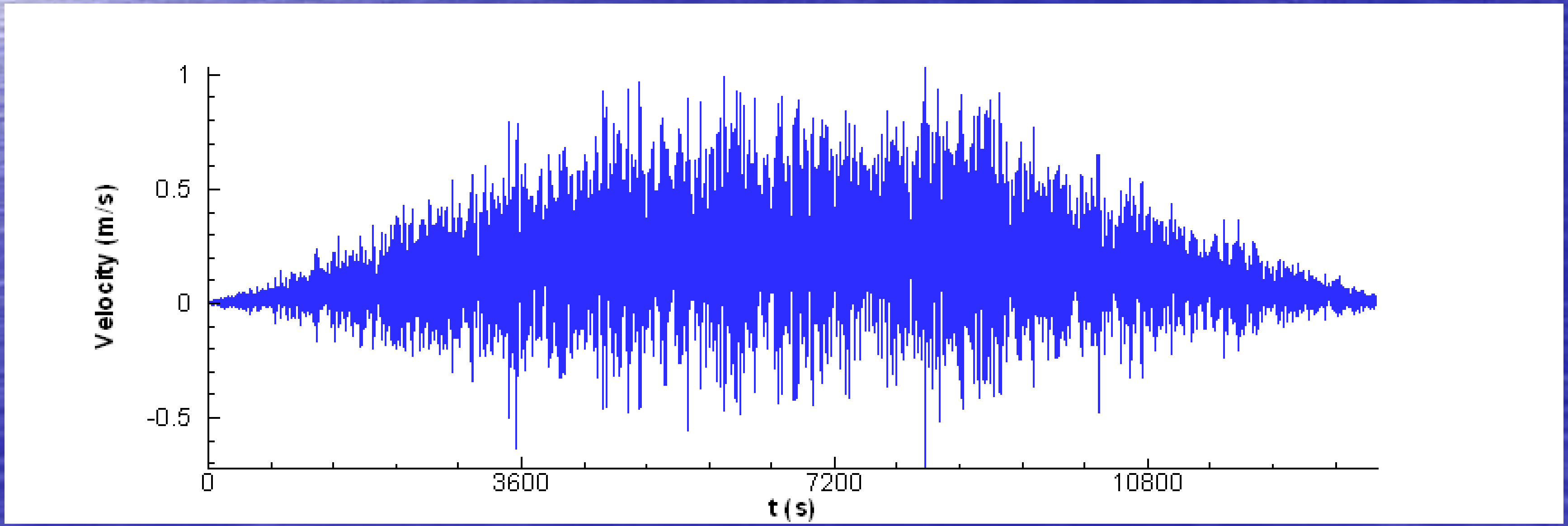
- Calcareous sands with a d_{50} of 0.2 mm and specific gravity of 2.70;
- Model pipe specific gravity of 1.2
- Initial embedment of 75%
- Model geometric factor of 5.8

STORM CONDITIONS

Velocity history: scaled 100 year RP storm of NWS of Western Australia induced velocity at seabed level:

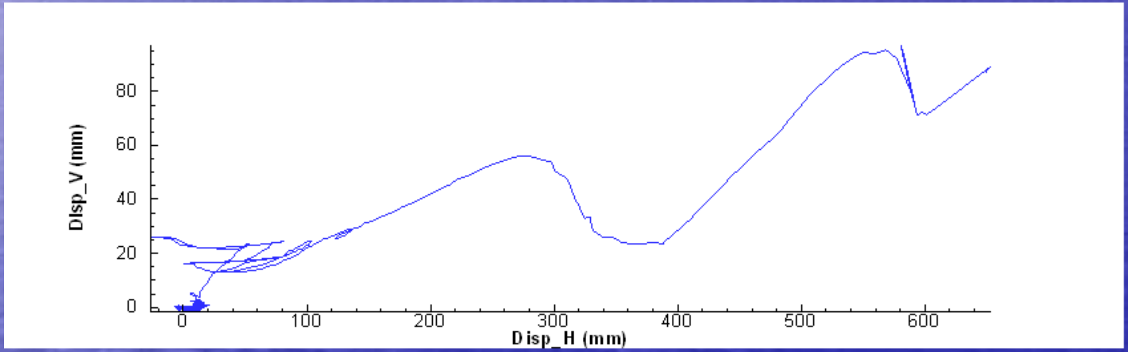
Scaled wave period: 6-7s;

Scaled peak velocity: 1.1m/s

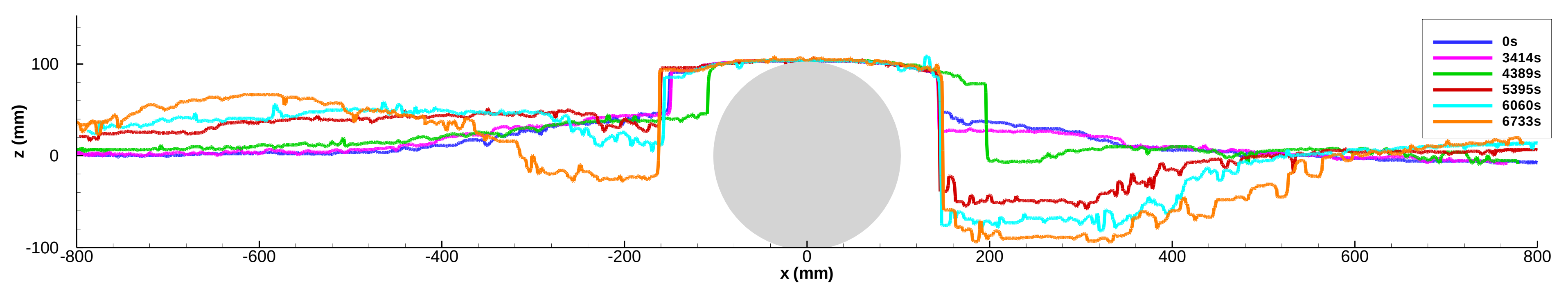


TEST RESULTS

- Pipe broke out during the storm
- Pipe trajectory

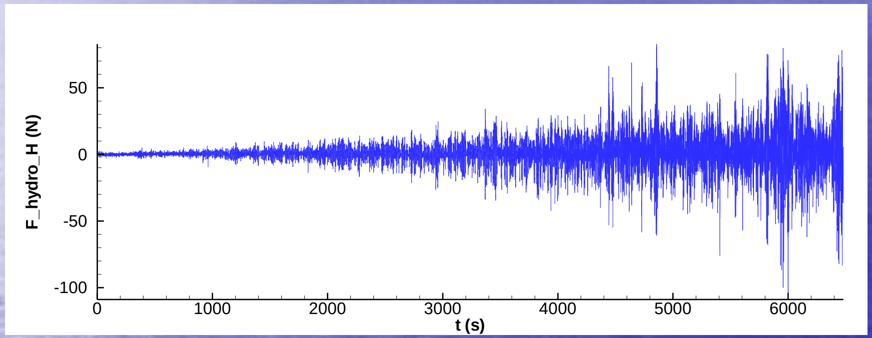


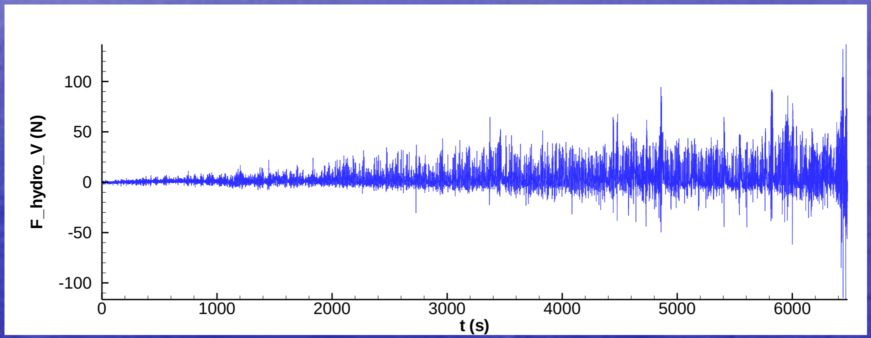
- Seabed profile (measured by acoustic sensor)



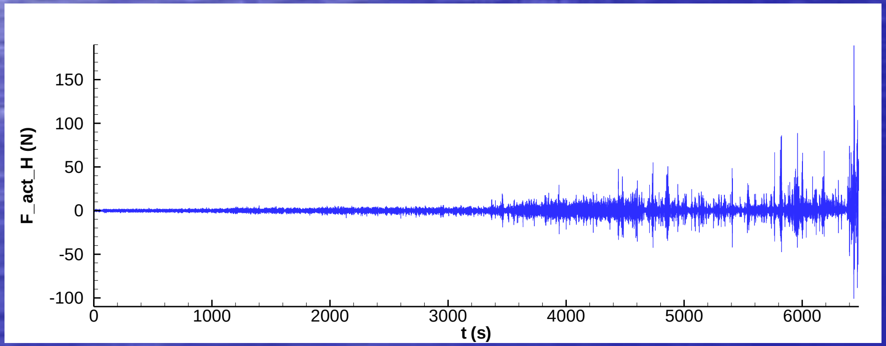
TEST RESULTS

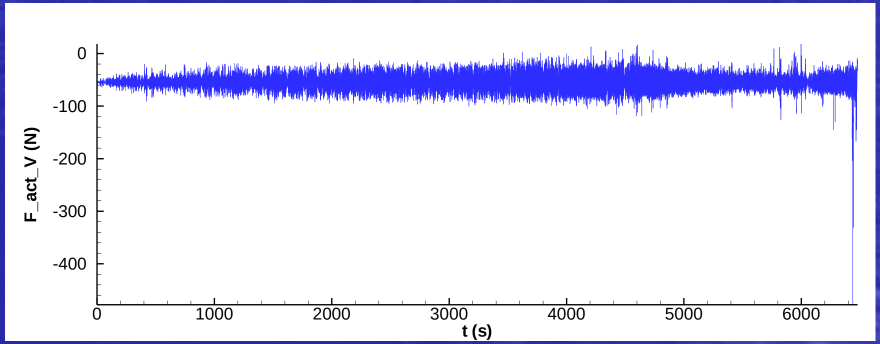
- Hydrodynamic forces (from pore pressure integration)





- Active control force





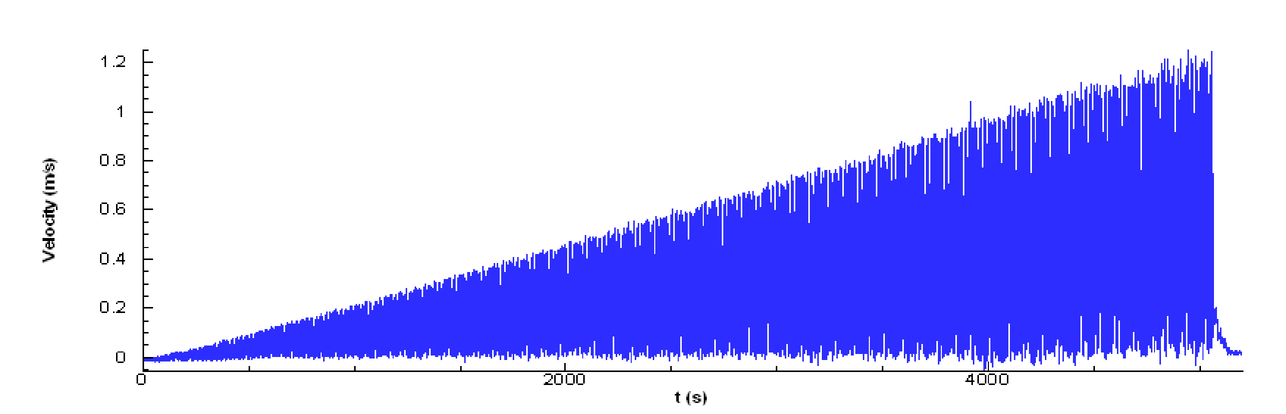
Movie -1: DURING TEST

MOVIE-2: PIPE BREAKOUT

ANOTHER EXAMPLE

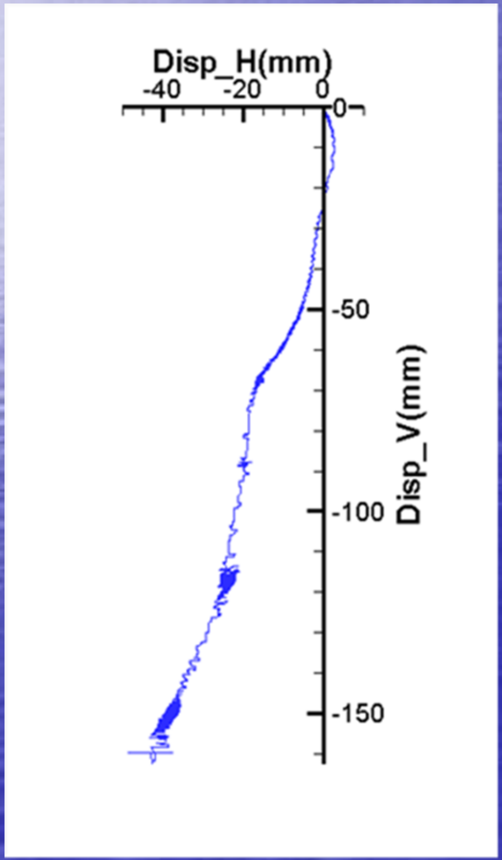
Test condition:

- Simulated pipe SG=1.5
- Initial embedment: 0-0
- Sediment: same as previous case
- Flow condition: ramping up steady current + regular oscillatory flow (T=10s)



RESULTS

Pipe trajectory



Pipe was stable for velocity amplitude up to 1.2m/s

SUMMARY

- A new testing facility (O-tube) has been established to investigate the effects of sediment transport on pipeline stability
- Ultimate aim is to develop more realistic pipeline on-bottom stability design methods
- More research efforts are needed to achieve that