# RISK-BASED ANALYSIS OF BRIDGE SCOUR PREDICTION

## Fourth year workout

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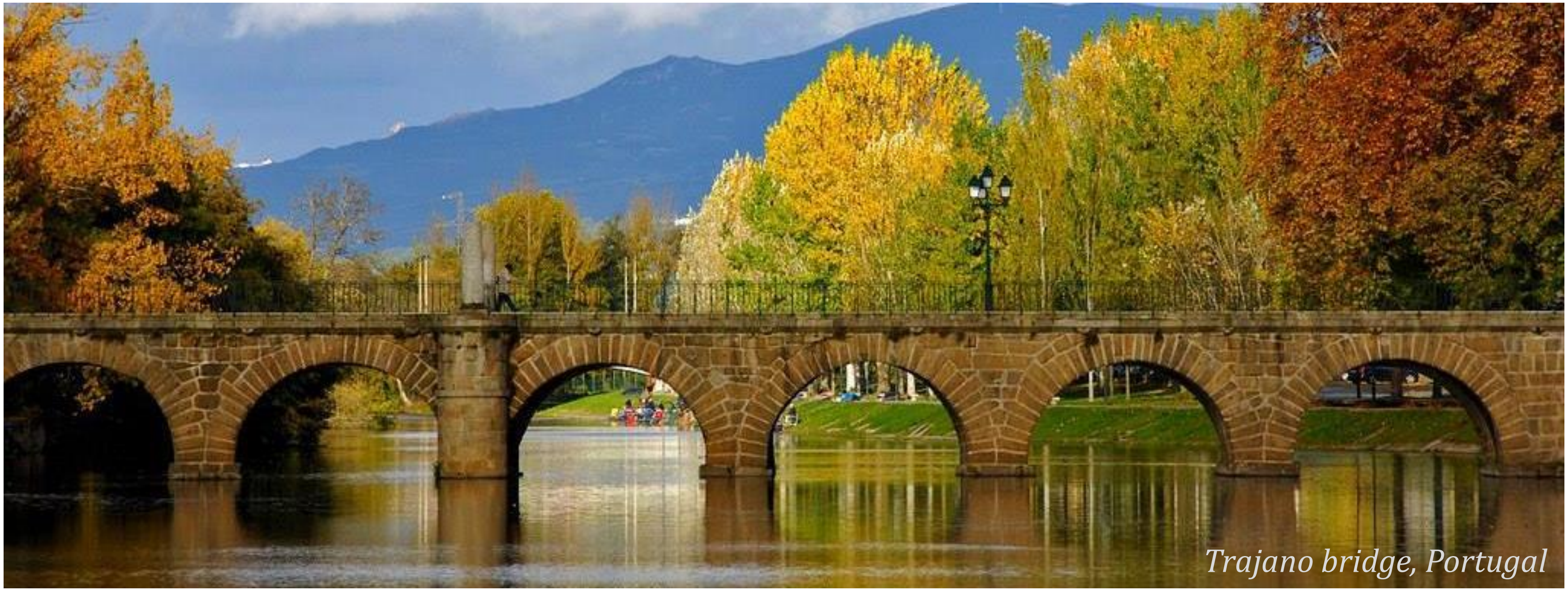
Supervisors: Dr. Teresa Viseu (LNEC), Dr. Lúcia Couto (LNEC) & Dr. João Pedro Pêgo (FEUP)



*Trajano bridge, Portugal*

# Outline

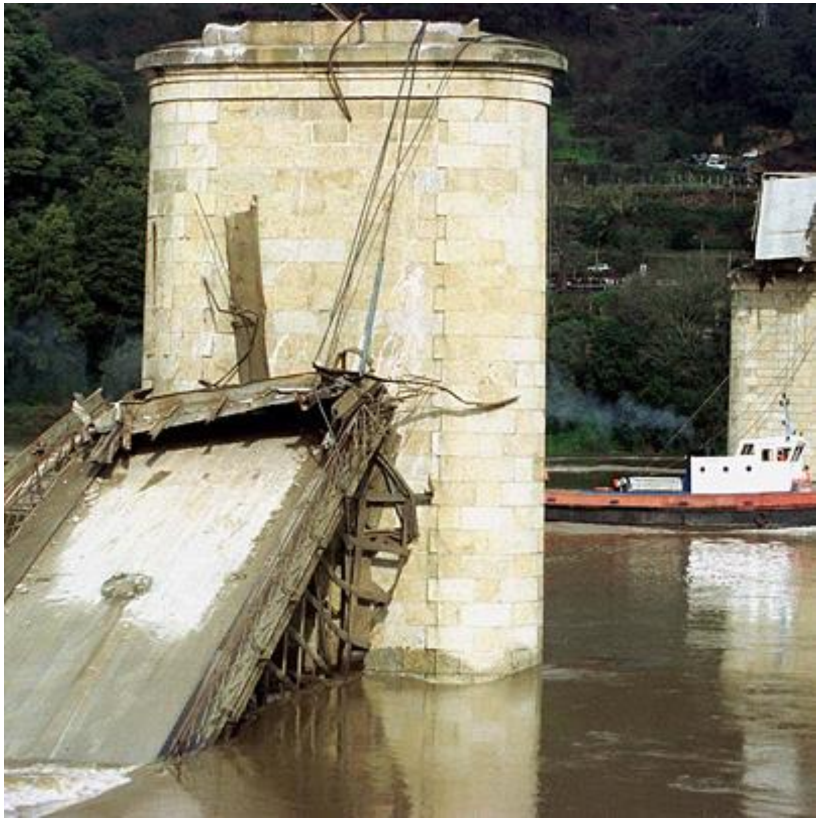
1. Motivation
2. Objective and Approaches
3. Risk-based Analysis
4. Experimental Work
5. Numerical Modelling
6. Conclusions and Future Works

# Outline

# Motivation

**Bridge scour** is widely identified as a major cause of bridge collapses. Over a period of **30 years more than 1000 bridges** have **collapsed** in USA, **60%** of which as **result of scour at the bridge foundation level.**

*Schoharie Creek bridge, NY, USA, 1987*



*Hintze Ribeiro bridge, Portugal, 2001*

# Outline

1. Motivation
2. **Objective and Approaches**
3. Risk-based Analysis
4. Experimental Work
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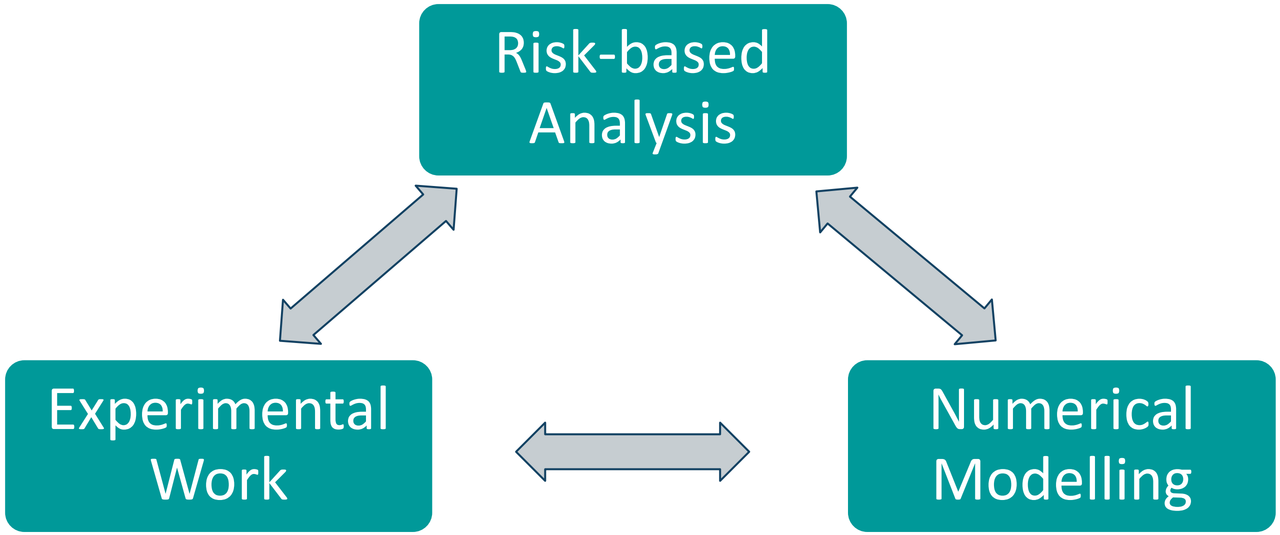
# Objective and Approaches

**Develop** a new and pragmatic **risk-based methodology to evaluate the risks** associated with **scour at bridge foundations** under **clear water and live bed** flow conditions



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3. **Risk-based Analysis**
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# Risk-based Analysis (1/7)

*Proposed methodology for bridge scouring risk*

- Data reliability analysis (hypothesis tests)
- Hydrological modelling (probabilistic approach)
- Maximum discharges for different return periods

**Assessing extreme hydrological events**

**Modelling river behaviour**

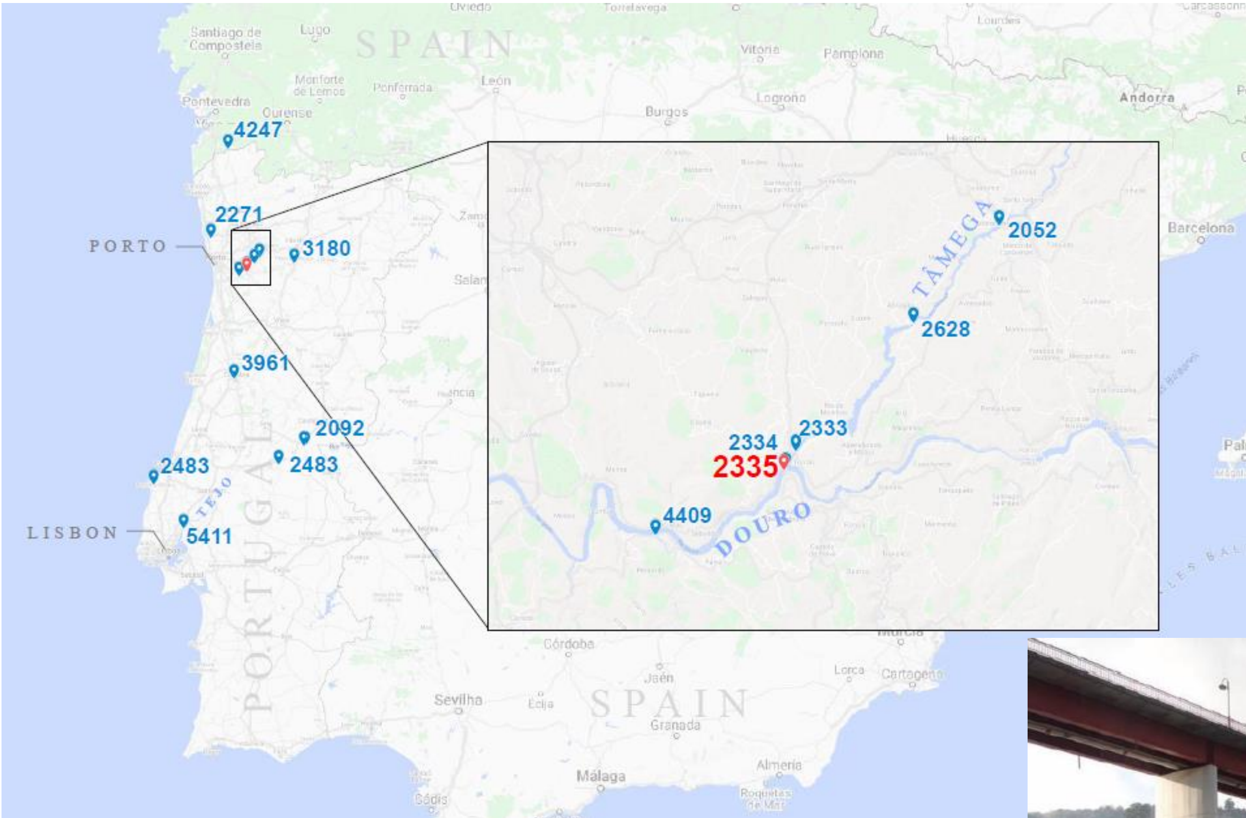
- Design floods, Digital Elevation Model (DEM) and riverbed material
- Hydraulic modelling and Bridge scour analysis (HEC-RAS + empirical equations)
- Water levels, flow velocities and scour depths

- Foundation depth and bridge vulnerability rating (priority factor)
- Scour risk rating (qualitative assessment)
- Scour depth to foundation depth ratio and susceptibility to scour

**Assessing bridge scour risk**

# Risk-based Analysis (2/7)

*Case study bridge selection*

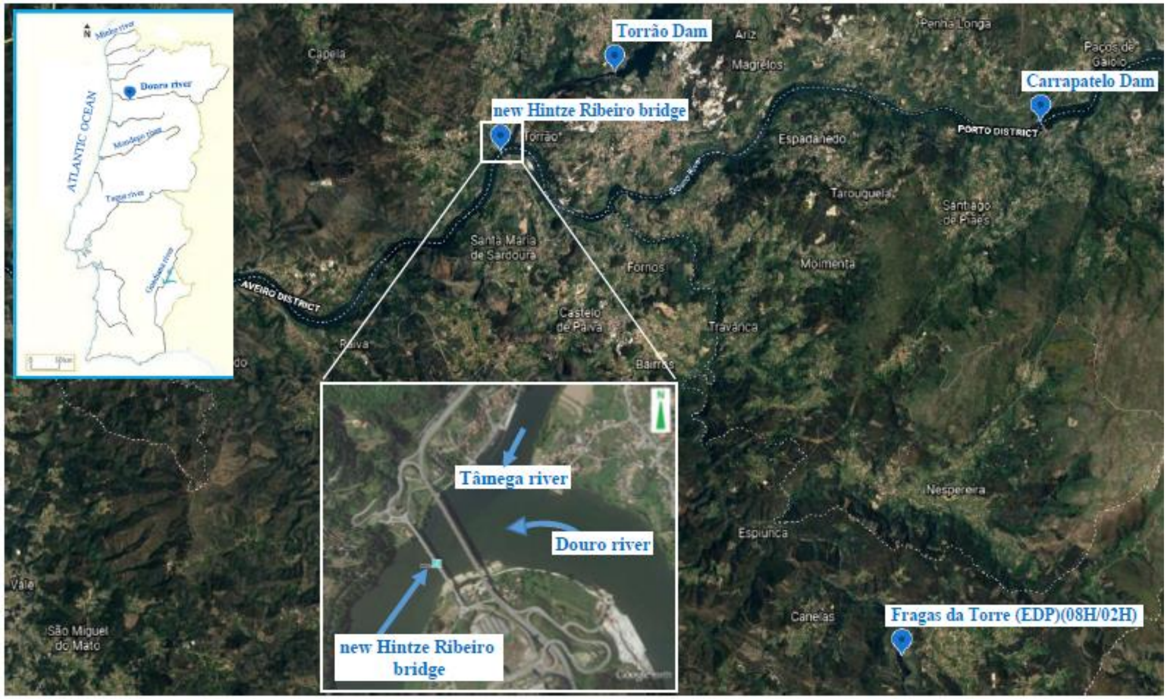



*Portuguese bridges referenced by Infraestruturas de Portugal (Google Maps, n.d.)*


*new Hintze Ribeiro bridge, Portugal*

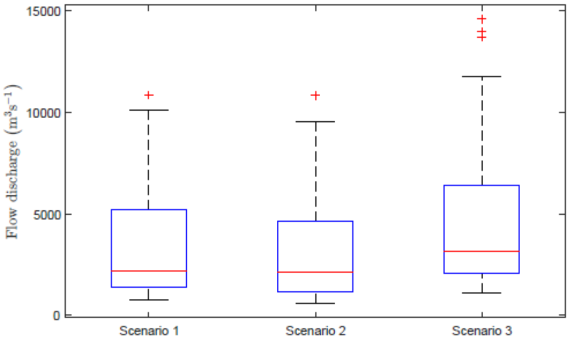
# Risk-based Analysis (3/7)

## *Assessing extreme hydrological events*




*Location of the case study, the new Hintze Ribeiro bridge, over the Douro river (Google Earth, n.d.)*

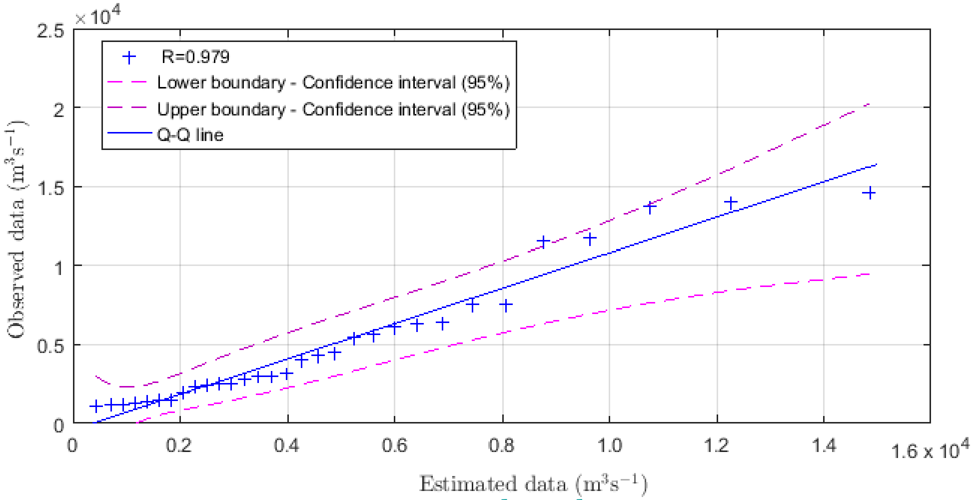
| Database | Description | Scenarios |
|---|---|---|
| Mean daily | Sum of the design floods obtained independently for each gauging station | 0 |
| | Sum of the maximum annual discharges of the three gauging stations | 1 |
| | Sum of the discharges from the three gauging stations and calculation of the maximum annual values | 2 |
| Instantaneous | Sum of the maximum annual discharges of the three gauging stations | 3 |



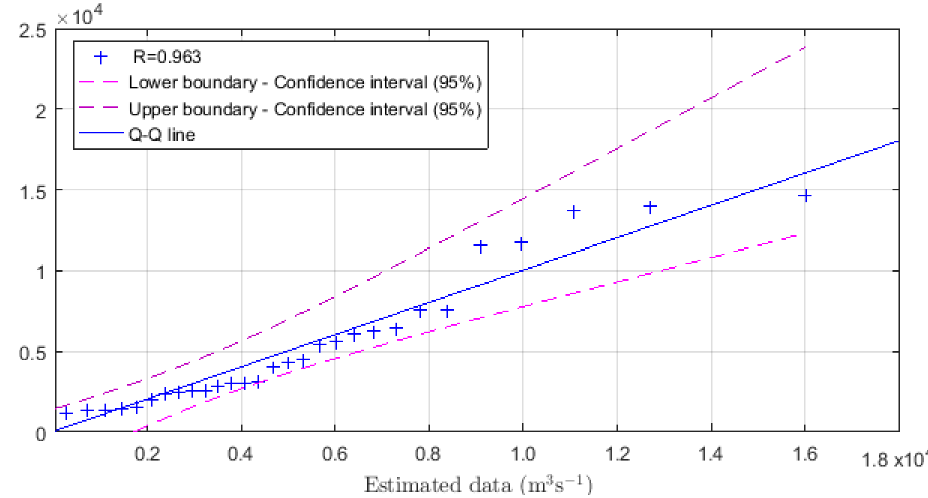

*Hydrological scenarios considered for $Q_{HR}$ estimation and corresponding box-plot graph*

# Risk-based Analysis (4/7)

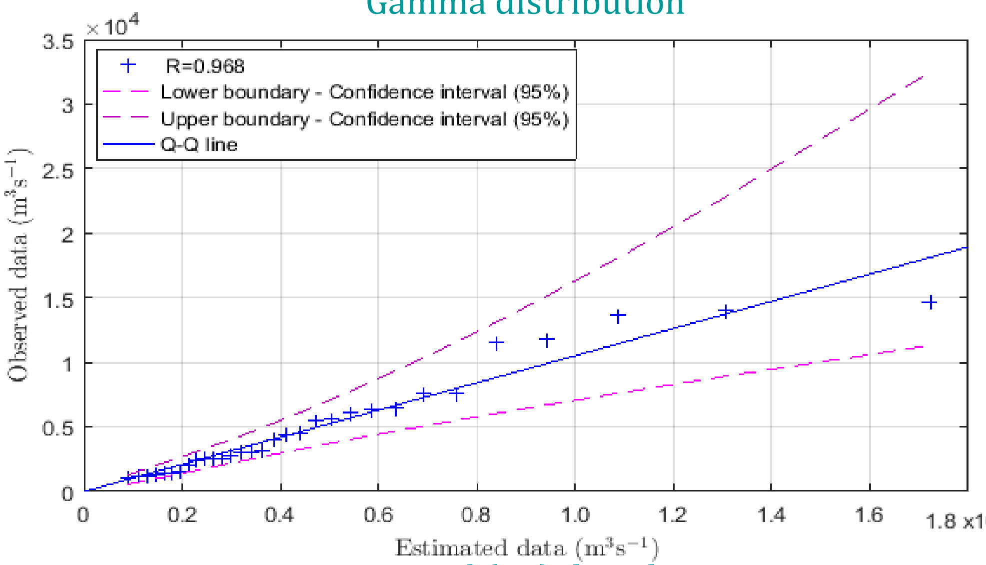
*Assessing extreme hydrological events*



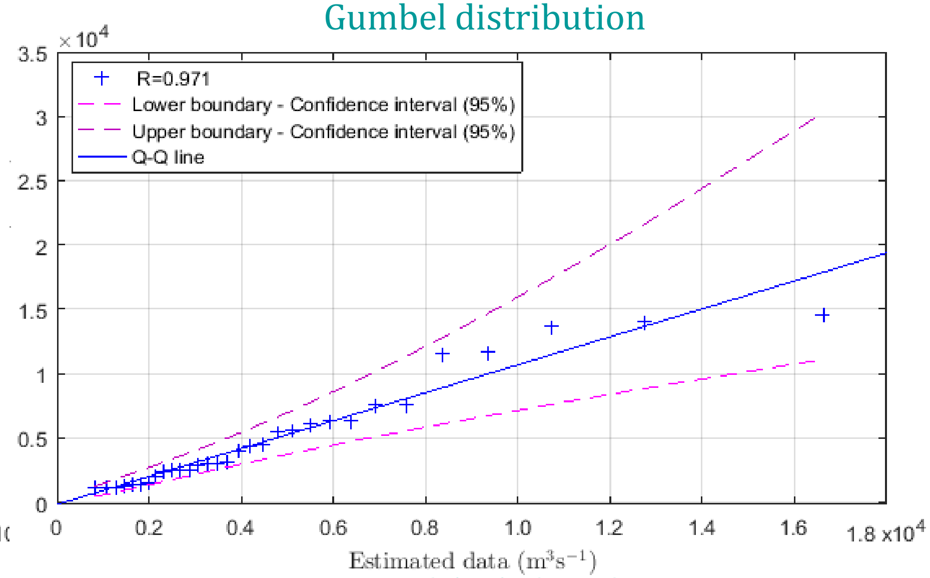

Gamma distribution




Gumbel distribution



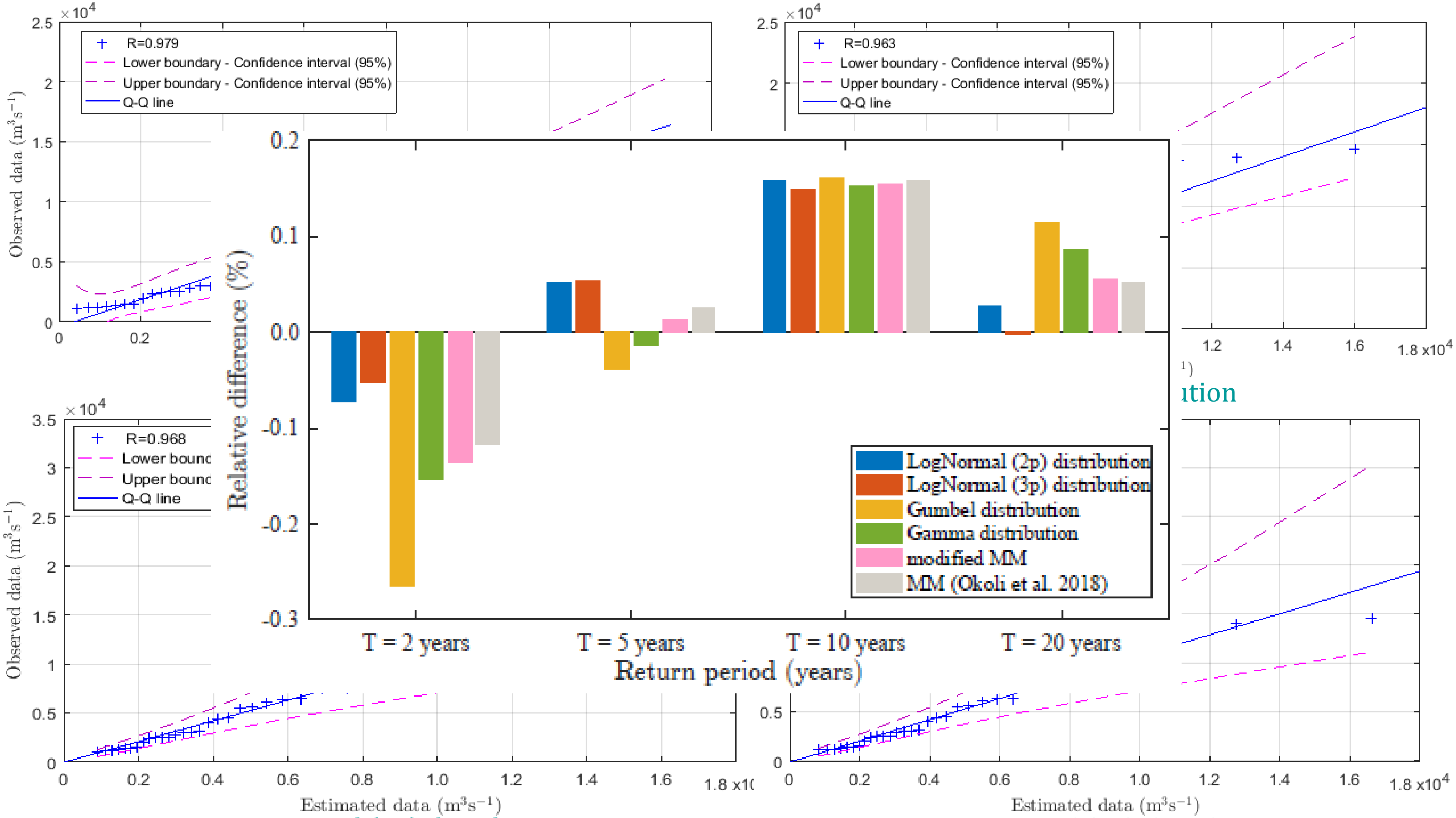

LogNormal (3p) distribution




LogNormal (2p) distribution

# Risk-based Analysis (4/7)

*Assessing extreme hydrological events*

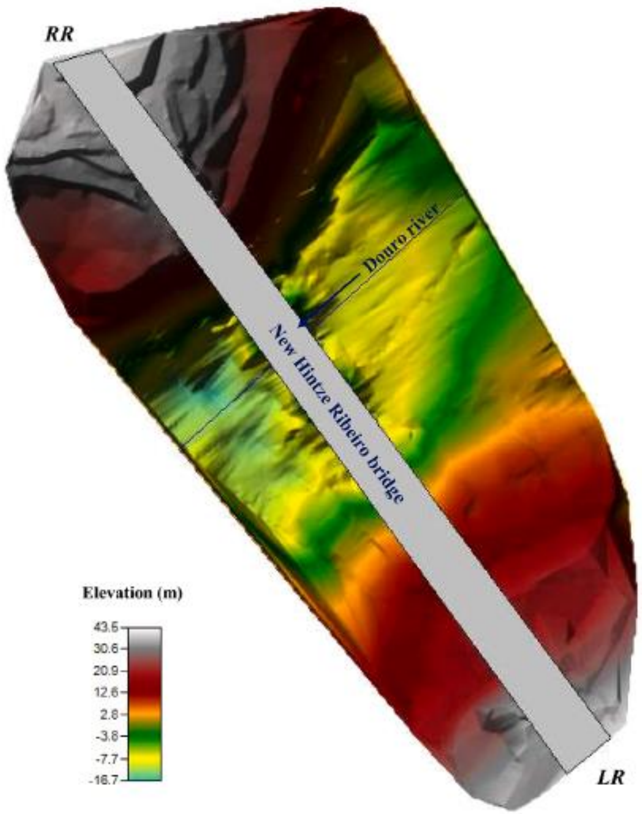


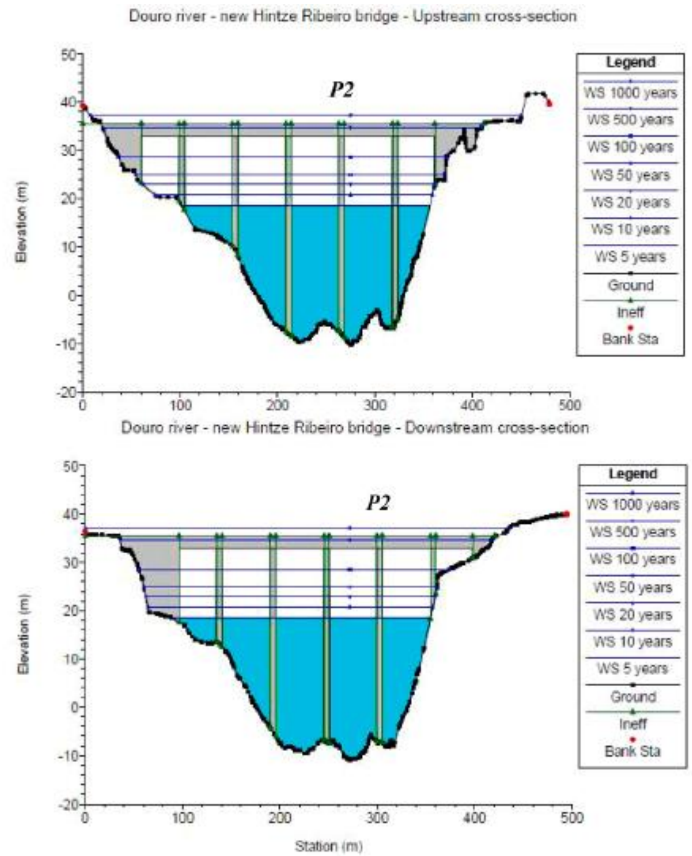

LogNormal (3p) distribution

LogNormal (2p) distribution

# Risk-based Analysis (5/7)

*Modelling river behaviour*



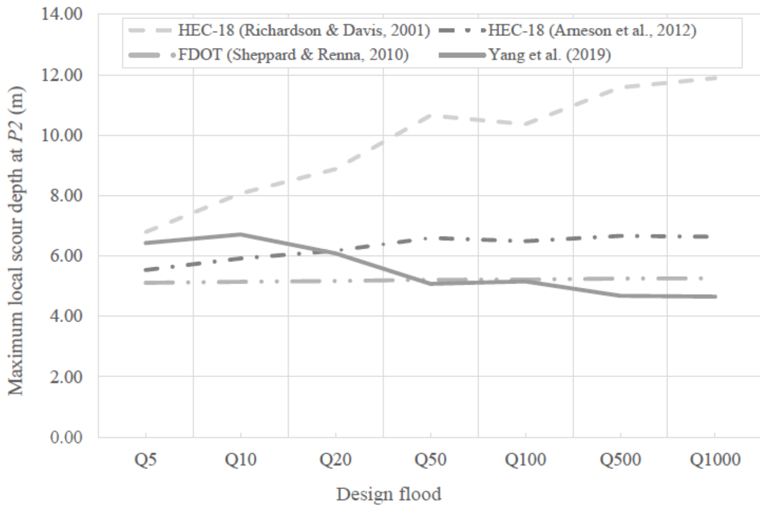




*Hydraulic model built within HEC-RAS software*

| Design flood | Flow depth | Flow velocity | Froude number | Equivalent diameter | Contraction scour depth | Local scour depth | Total scour depth ($D_T$) |
|---|---|---|---|---|---|---|---|

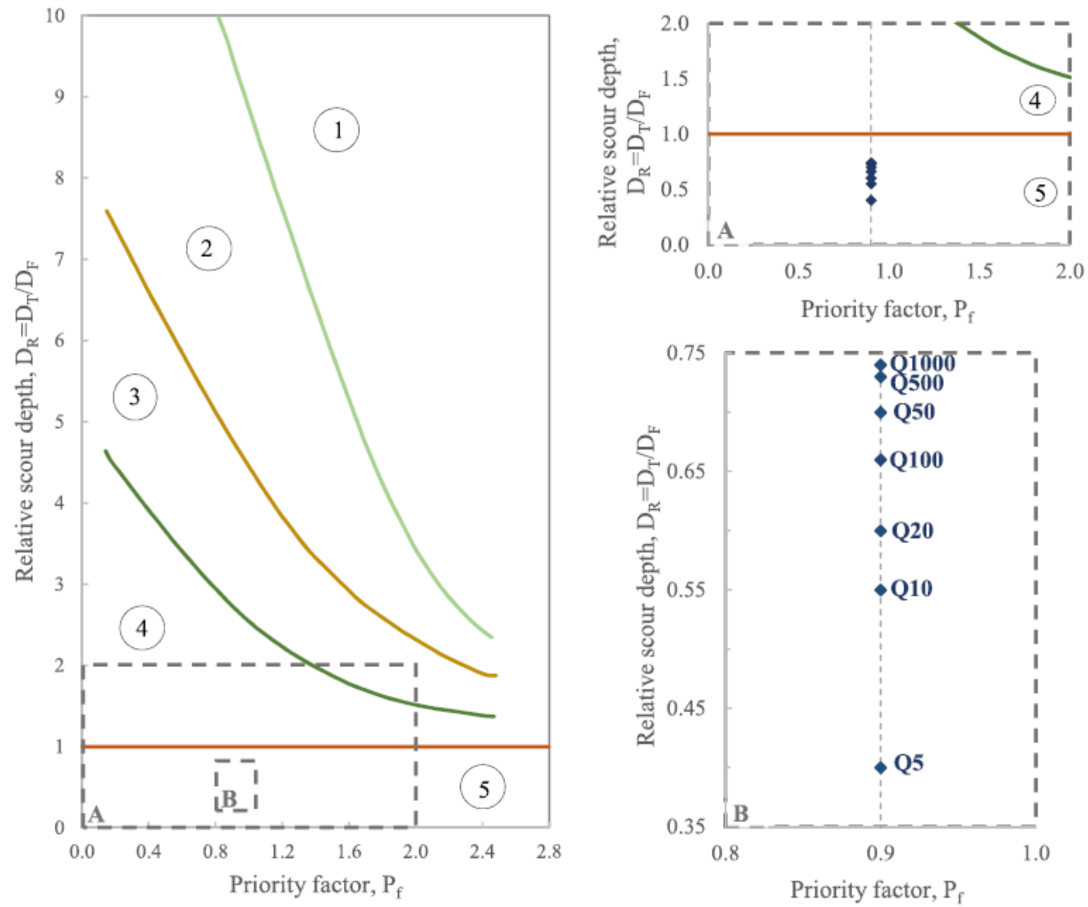
# Risk-based Analysis (6/7)

*Assessing bridge scour risk*




*Maximum local scour depth estimates using four empirical predictors*

| Design flood | $D_T$ (m) | $D_{FT}$ (m) | $D_R$ (-) | Scour risk rating |
|---|---|---|---|---|
| *Q5* | 6.78 | 10.22 | 0.40 | |
| *Q10* | 9.38 | 7.62 | 0.55 | |
| *Q20* | 10.28 | 6.72 | 0.60 | |
| *Q50* | 11.96 | 5.04 | 0.70 | 5 |
| *Q100* | 11.20 | 5.80 | 0.66 | |
| *Q500* | 12.40 | 4.60 | 0.73 | |
| *Q1000* | 12.55 | 4.45 | 0.74 | |




*Scour risk rating of the new Hintze Ribeiro bridge*

# Risk-based Analysis (7/7)

*Dissemination outcomes*

1

***Bento, A.M.***, *Gomes, A., Pêgo, J.P. Viseu T. & Couto, L. (Submitted)* ***Improvement assessment of maximum streamflow approaching a bridge over Douro river. A case study***. *In: Journal of hydrologic Engineering*

2

***Bento, A.M.,*** *Gomes, A., Viseu T., Couto, L. & Pêgo, J.P. (2020)* ***Risk-based methodology for scour analysis at bridge foundations***. *Engineering Structures. 223:111115. doi: 10.1016/j.engstruct.2020.111115*

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# Experimental Work (1/7)

*Tilting flume at LNEC*

***40.7 m long, 2.0 m wide and 1.90 m deep***

*Upstream view*

*Inside view*

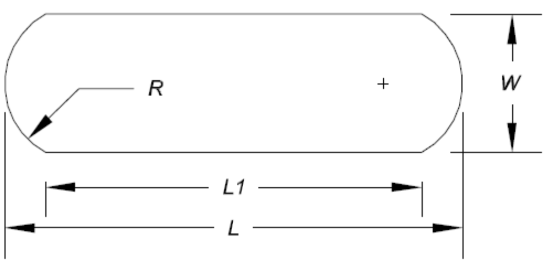
*Downstream view*

# Experimental Work (2/7)

## *Experimental Campaign*

| Scour regime | "Clear water" scour condition - *Run* 1 | | | | | | "Live bed" scour condition - *Run* 4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Oblong pier ID (width) | *Pier* 11 | | | *Pier* 14 | | | *Pier* 11 | | | *Pier* 14 |
| Label | *Exp. 1U* | *Exp. 1U Fbed* | *Exp. 1U Ebed* | *Exp. 1D* | *Exp. 1D Fbed* | *Exp. 1D Ebed* | *Exp. 4U* | *Exp. 4U Fbed* | *Exp. 4U Ebed* | *Exp. 4D* |
| Type of bed | Movable | Fixed | | Movable | Fixed | | Movable | Fixed | | Movable |
| Characterization | Scour geometry | Flow | | Scour geometry | Flow | | Scour geometry | Flow | | Scour geometry |
| Flow depth and discharge | x | x | x | x | x | x | x | x | x | x |
| Point-wise time evolution of scour depth | x | - | - | x | - | - | x | - | - | x |
| Close-range photogrammetry (*3D*) | x | - | - | x | - | - | x | - | - | x |
| Kinect V2 sensor (*3D*) | x | - | - | x | - | - | x | - | - | x |
| Underwater monitoring (*2D*) | * | - | - | x | - | - | ** | - | - | *** |
| Downlooking vectrino | - | x | x | - | x | x | - | x | x | - |

*F bed* = Flat bed; *Ebed* = eroded bed




Uniform quartz sand

$D_{50}$ = 0.86 mm

$\sigma_D$ = 1.28

**10 Experiments:**

4 Movable bed experiments

6 Fixed bed experiments

| Pier geometry dimensions (m) | | |
|---|---|---|
| Oblong bridge pier models | *Pier* 11 | *Pier* 14 |
| Width, *W* | 0.110 | 0.140 |
| Total length, *L* | 0.433 | 0.463 |
| Flat side surface length, *L*1 | 0.372 | 0.380 |
| Semi-cylindrical surface ratio, *R* | 0.065 | 0.080 |

# Experimental Work (2/7)

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| Label | *Exp. 1U* | *Exp. 1U Fbed* | *Exp. 1U Ebed* | *Exp. 1D* | *Exp. 1D Fbed* | *Exp. 1D Ebed* | *Exp. 4U* | *Exp. 4U Fbed* | *Exp. 4U Ebed* | *Exp. 4D* |
| Type of bed | Movable | Fixed | | Movable | Fixed | | Movable | Fixed | | Movable |
| Characterization | Scour geometry | Flow | | Scour geometry | Flow | | Scour geometry | Flow | | Scour geometry |
| Flow depth and discharge | x | x | x | x | x | x | x | x | x | x |
| Point-wise time evolution of scour depth | x | - | - | x | - | - | x | - | - | x |
| Close-range photogrammetry (3*D*) | x | - | - | x | - | - | x | - | - | x |
| Kinect V2 sensor (3*D*) | x | - | - | x | - | - | x | - | - | x |
| Underwater monitoring (2*D*) | * | - | - | x | - | - | ** | - | - | *** |
| Downlooking vectrino | - | x | x | - | x | x | - | x | x | - |

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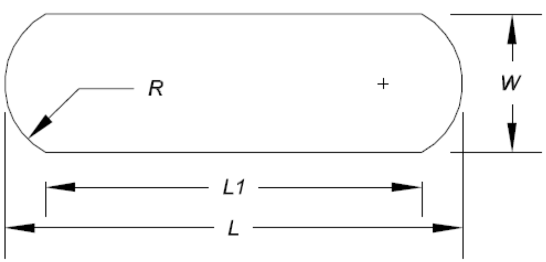


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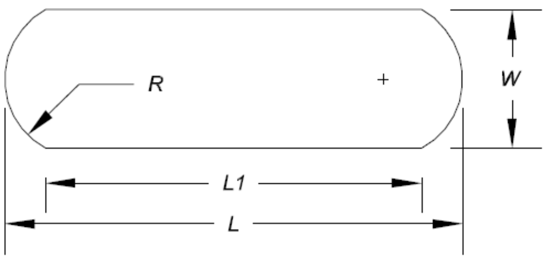
| Type of bed | Movable | Fixed | | Movable | Fixed | | Movable | Fixed | | Movable |
| Characterization | Scour geometry | Flow | | Scour geometry | Flow | | Scour geometry | Flow | | Scour geometry |
| Flow depth and discharge | x | x | x | x | x | x | x | x | x | x |
| Point-wise time evolution of scour depth | x | - | - | x | - | - | x | - | - | x |
| Close-range photogrammetry (3*D*) | x | - | - | x | - | - | x | - | - | x |
| Kinect V2 sensor (3*D*) | x | - | - | x | - | - | x | - | - | x |
| Underwater monitoring (2*D*) | * | - | - | x | - | - | ** | - | - | *** |
| Downlooking vectrino | - | x | x | - | x | x | - | x | x | - |

*Fbed* = Flat bed; *Ebed* = eroded bed

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**10 Experiments:**

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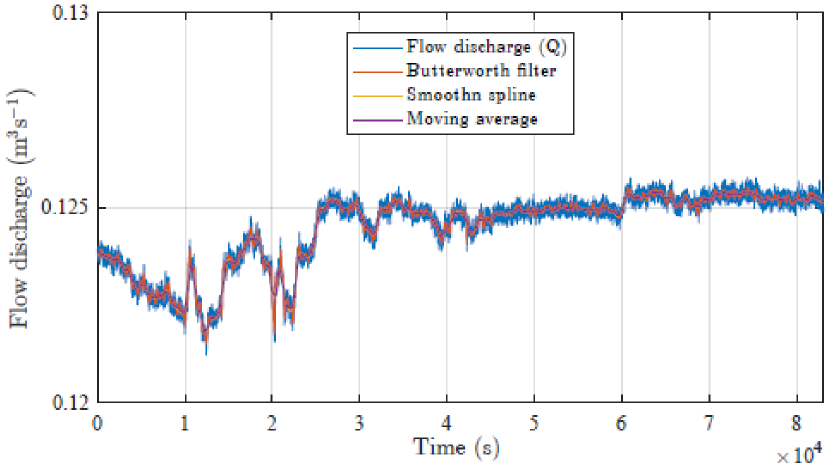
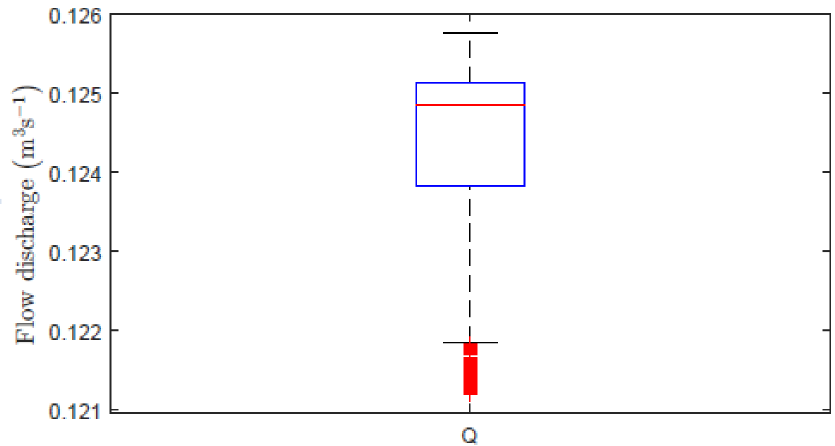
# Experimental Work (3/7)

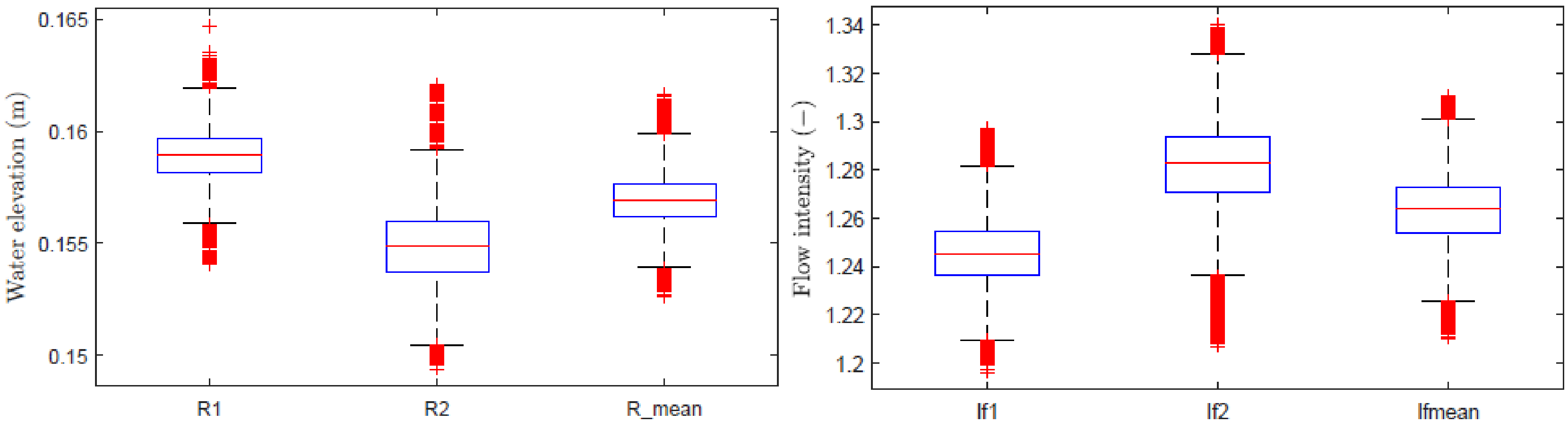
## *Movable bed experiments – Hydraulic conditions*




(a) Approach flow discharge ($Q$) time evolution.




(b) Box-plot graph of $Q$ along experiment's duration.

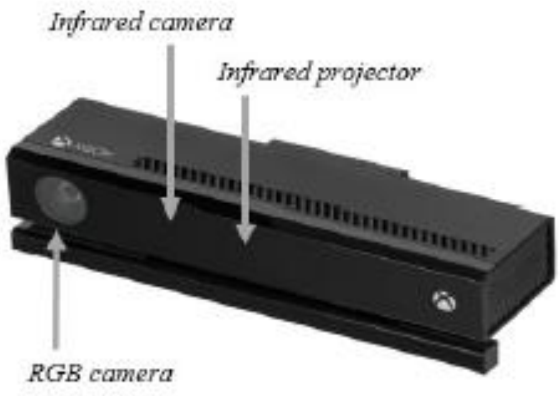


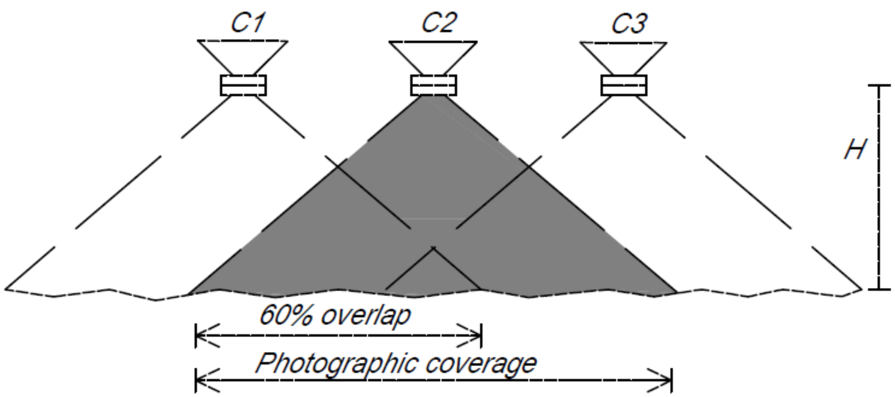

*Hydraulic conditions of Exp. 4D*

# Experimental Work (4/7)

*Movable bed experiments - Scour hole morphology*

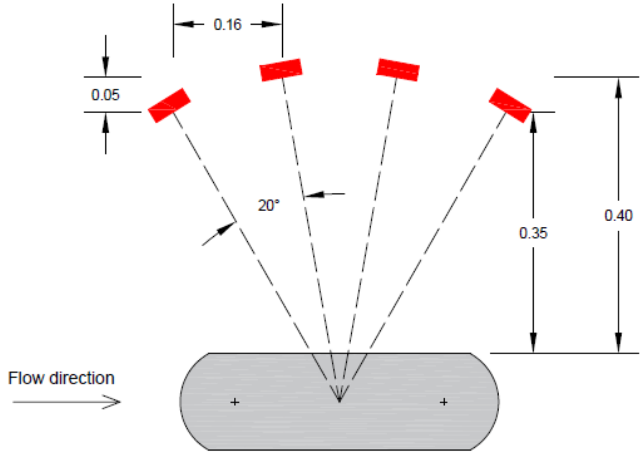
- Temporal evolution of $\mathbf{d_s}$: **Hydrometers** at the pier fronts
- 3D: **Kinect V2 sensor** vs **Close-range photogrammetry**



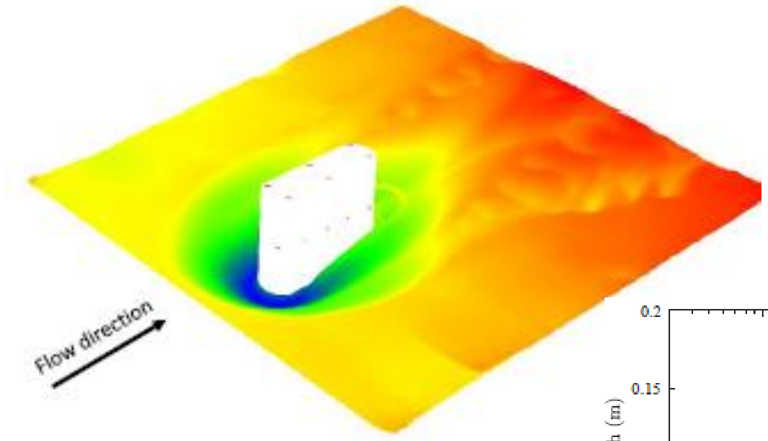

- **Underwater image processing**: during the scouring process

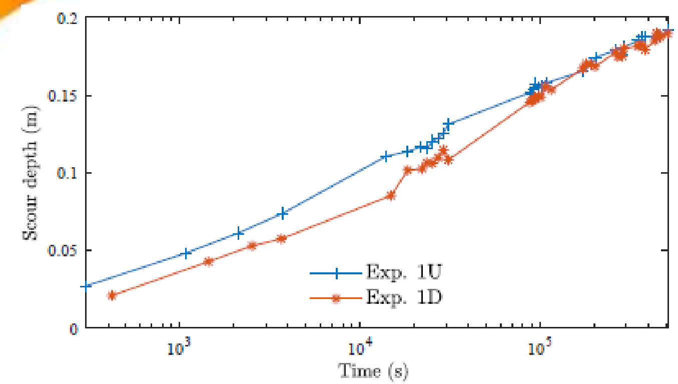
*Action Cam*
*NK 3056 FHD*

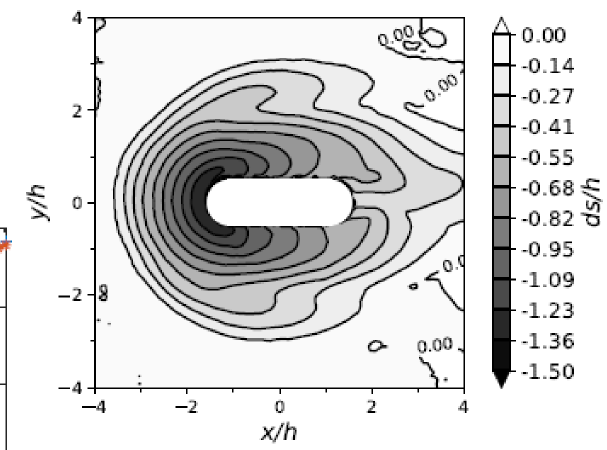


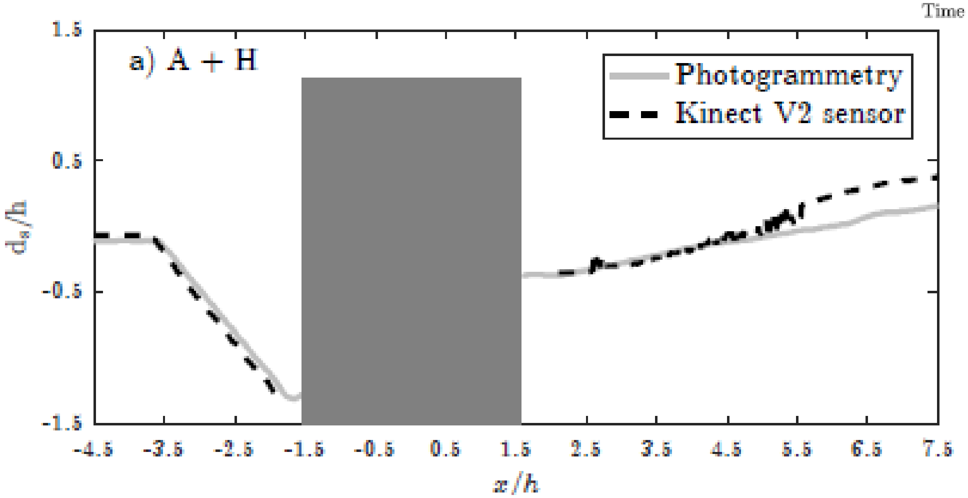

# Experimental Work (5/7)

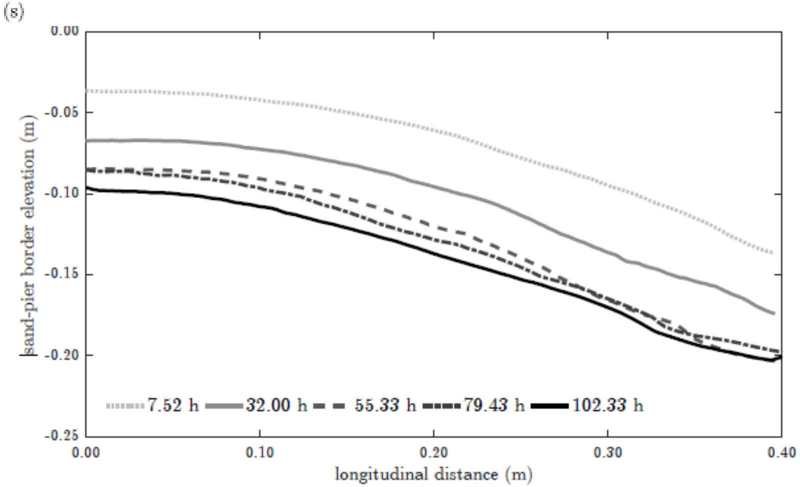
*Movable bed experiments - Results*



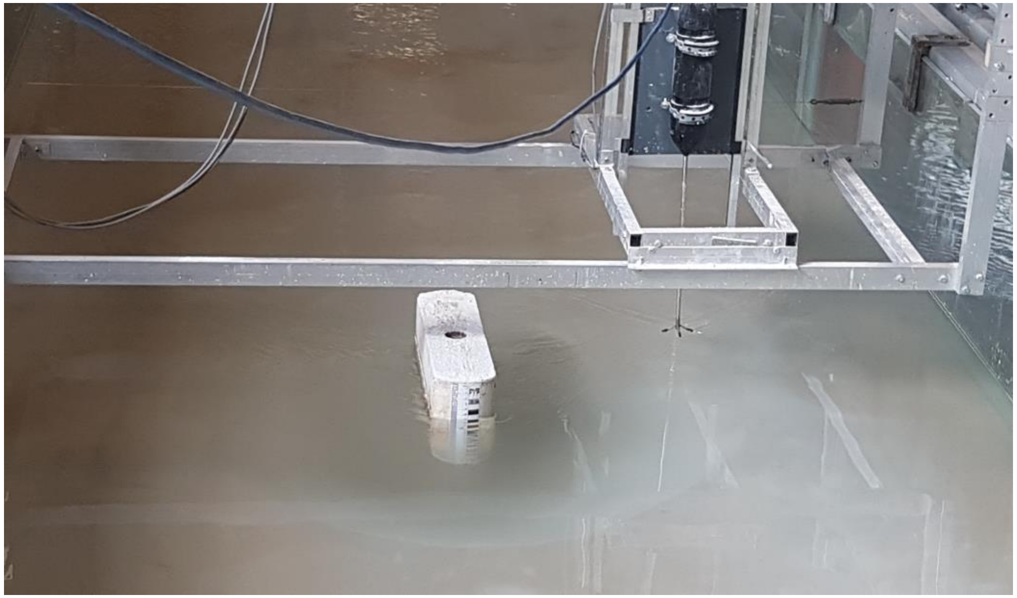
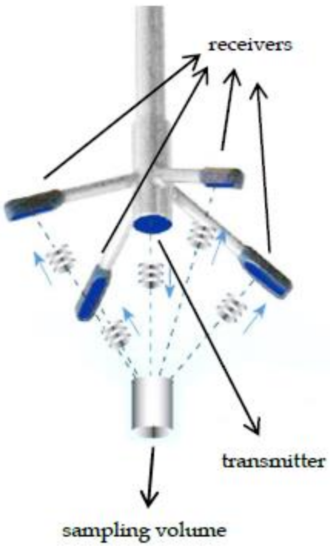



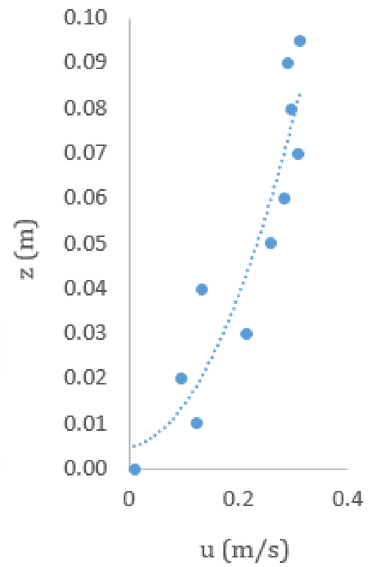



# Experimental Work (6/7)

*Fixed bed experiments – Flow field structure*

- **Flow discharge control:** electromagnetic flowmeter
- **Flow depth control:** resistive probes, hydrometers along CIV, and rulers along the lateral glass windows
- **Instantaneous flow field** in two different moments: (i) at *fixed flat bed and (ii) a*t a fixed eroded bed




*Moving carriage for Vectrino at CIV, vectrino and velocity distribution at the approach section*

# Experimental Work (7/7)

*Dissemination outcomes*

1

***Bento, A.M.***, *Couto, L., Viseu T. & Pêgo, J.P. (Under preparation).* ***Characterizing bridge scour using image-based techniques.*** *To be submitted in the: Journal of Hydraulic Engineering*

2

***Bento, A.M.,*** *Viseu T., Pêgo, J.P. & Couto, L. (Under preparation).* ***Turbulent flow field at bridge piers vicinity****. To be submitted in the: Journal of Hydraulic Engineering*

# Outline

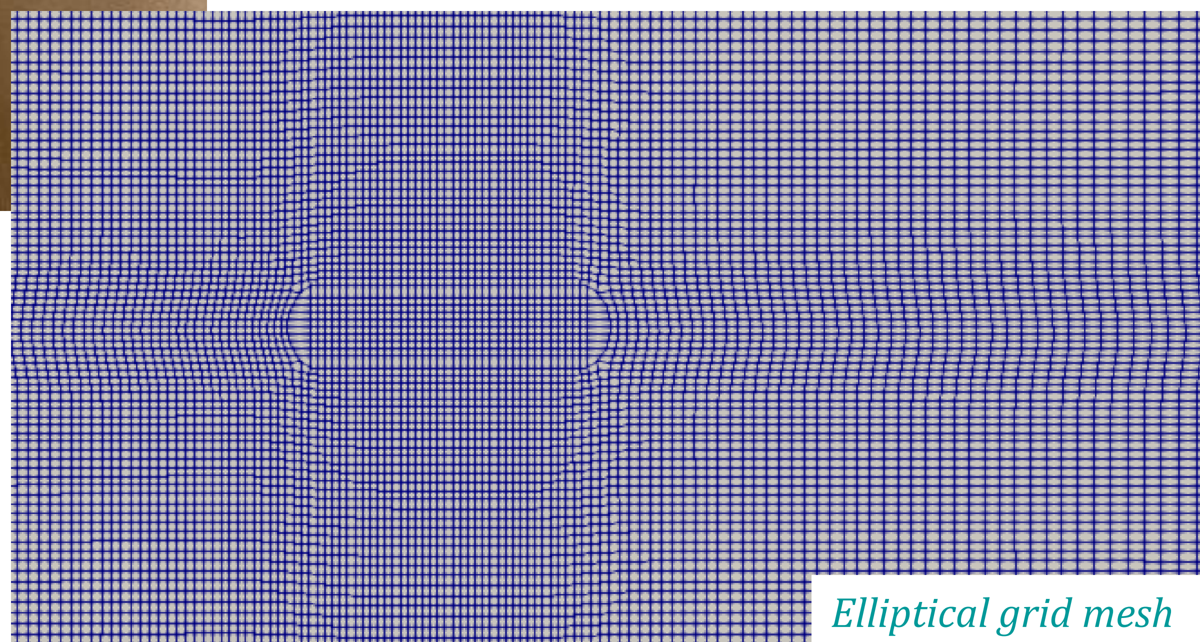
# Numerical Modelling (1/3)

*Computational Domain*

*Experimental boundary conditions*

Experimental Conditions of **Exp. 1D**:

- h = 0.15 m
- Q = 92.3 L/s

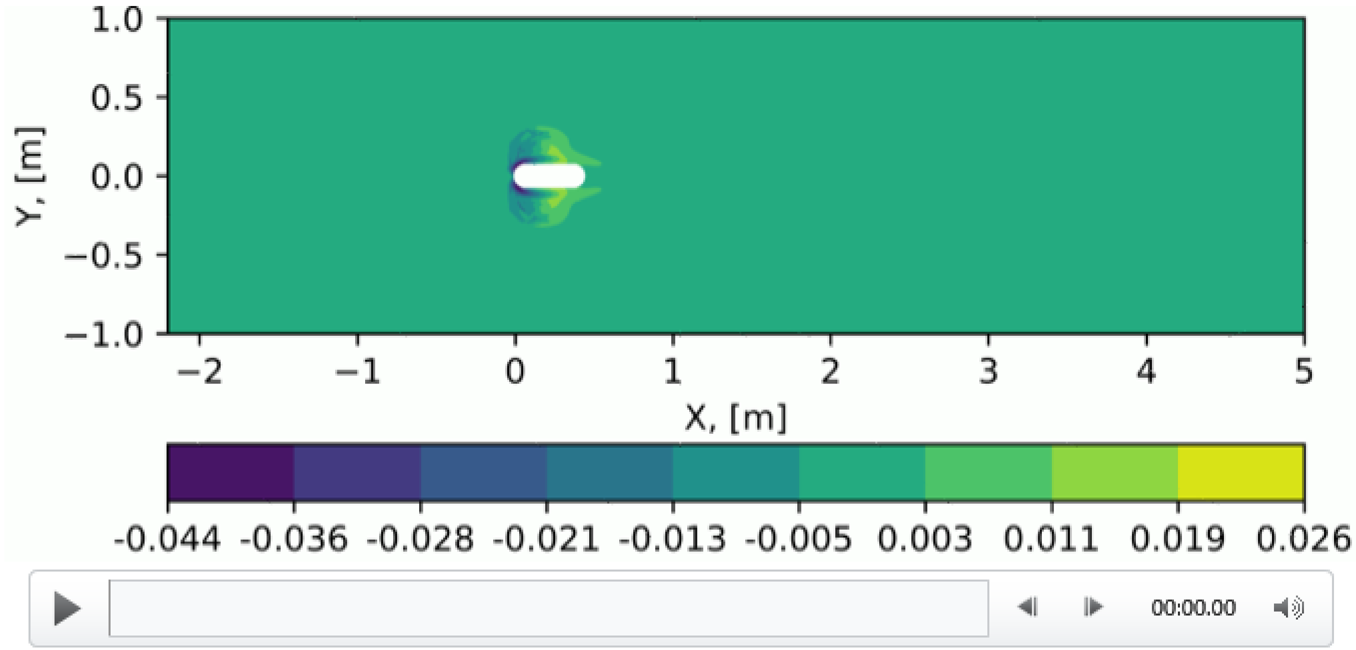


*Elliptical grid mesh*

# Numerical Modelling (2/3)

*SSIIM software*

*Sediment Simulation In Intakes with Multiblock option*




| Computational domain | Bed shear stress | Bed roughness | Turbulence model | Vertical cross-sections | 1st bed cell height |
|---|---|---|---|---|---|

# Numerical Modelling (3/3)

*Dissemination outcomes*

*1*

***Bento, A.M.**, Pêgo, J.P., Viseu T. & Couto, L. (Under preparation). **Numerical modelling of the scouring process at bridge piers**. To be submitted in the Special Issue: "Computational Fluid Dynamics: Applications in Water Resources Engineering" of Journal of Irrigation and Drainage Engineering*

***new Hintze Ribeiro bridge, Portugal***

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# Conclusions and Future Works (1/3)

*Risk-based Analysis*

1. **Consolidate** the connection between the **recent advances on scour depth prediction** and its **applicability on industry** practices

2. **Provide oriented measures and practical recommendations** for reducing the vulnerability and **enhancing the capacity of infrastructures** in coping with **scouring effects**

3. **Apply the proposed methodology** into important **decision-making process of bridge engineers and designers**, and its **incorporation** into regular **bridge inspection schedules**

*new Hintze Ribeiro bridge, Portugal*

# Conclusions and Future Works (1/3)

*Experimental Work*

1

**Detailed 3D models** of the geometry and evolution of the scour hole (and deposition zone) **in the vicinity of two transitional piers** subjected to **clear water and live bed** scour conditions were achieved with a significant level of accuracy

2

The **three-dimensional turbulent structure** was also **investigated** using a **high-resolution acoustic velocimeter** at the beginning of the **scouring process and** within the respective **developed scour holes**

3

Development of a **methodology capable of performing a continuous monitoring** of the **sand-pier border at the pier's lateral surface** along the **scouring process**; the **2D bed profiles** reveled **consistent trends** with the **scouring development** observed for **Exp. 1D**

*new Hintze Ribeiro bridge, Portugal*

# Conclusions and Future Works (1/3)

*Numerical Modelling*

1

In terms of computing the **hydrodynamic variables**, these numerical simulations were **not fully capable** of describing the **complex flow patterns**

2

The results demonstrated that the **calibrated numerical model reproduced**, with acceptable accuracy, the **mechanism of the scour hole formation** in the laboratory environment

3

The adopted CFD tool allowed insights into the mechanism of interaction between **turbulence structures and scour processes** and to increase the number of **experimental observations. In addition, options** for enabling its application for evaluating the scour risk of existing bridges, as well as aiding the design of new bridges **are explored**

***new Hintze Ribeiro bridge, Portugal***

# Thank you very much!

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