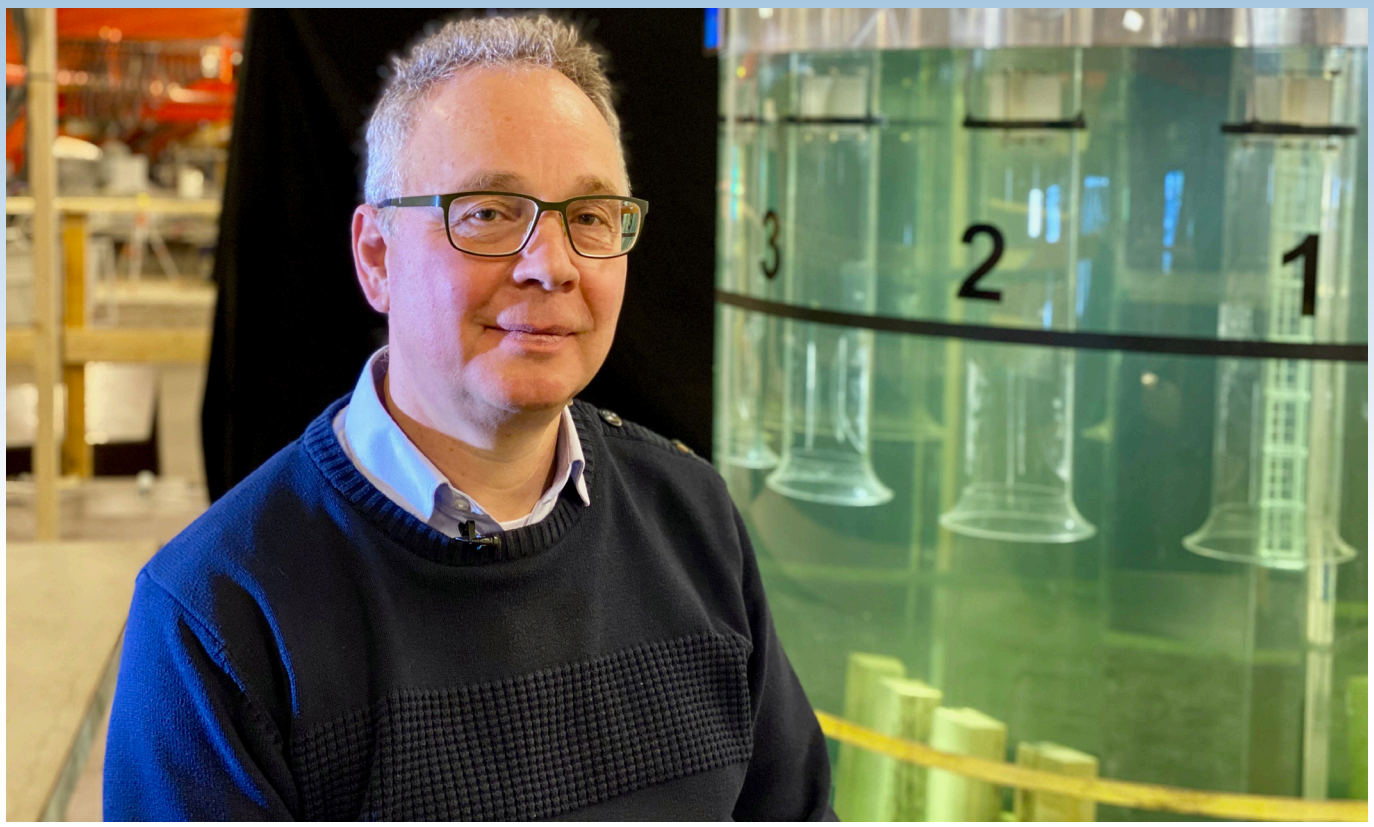
Hydraulic experts validate urban flood pumping station with scale model tests



Niels Eriksen, Senior Consultant from HOFOR, Copenhagen's water utility, by the 1:12-scale model of the Kalvebod pumping station at Danish Hydraulic Institute.

OVERVIEW

Copenhagen's water utilities HOFOR and Frederiksberg Forsyning are building cloudburst flood control tunnels from low-lying areas of the city and adjacent municipalities out to the harbour or sea. In the first project, Kalvebod Brygge, a pumping station supplied with Grundfos submersible propeller pumps will lift the water from the end of a 1.3 km-long tunnel up and out into the harbour. DHI A/S (formerly the Danish Hydraulic Institute) and Grundfos have completed extensive validation tests with a 1:12-scale model of the pumping station. The model allowed testing of water flow structures and hydraulic conditions inside the pumping station and pump inlets. It also allowed for optimisation of the design. The hydraulic inlet condition of the pumping station was thereafter verified according to ANSI/HI guidelines.

THE SITUATION

A massive cloudburst flooded the heart of Copenhagen in July 2011, bringing up to a half-meter of water to the low-lying Vesterbro neighbourhood and neighbouring municipality of Frederiksberg. Insurance companies paid out DKK 7 billion (about EUR 1 billion) in damages to critical infrastructure as well as to home- and building owners, but total damages were estimated to be at least double that figure. Other less-extreme storm events have also deluged Copenhagen in the years since.

"We know that due to climate changes, more water will be coming more frequently, and more heavy," says Niels Eriksen, Senior Consultant from HOFOR, Copenhagen's water utility. "So we've made a plan to prevent the situation from becoming worse."

HOFOR and Frederiksberg Municipality are thus investing DKK 11 billion (about EUR 1.6 billion) over 10 years to build a series

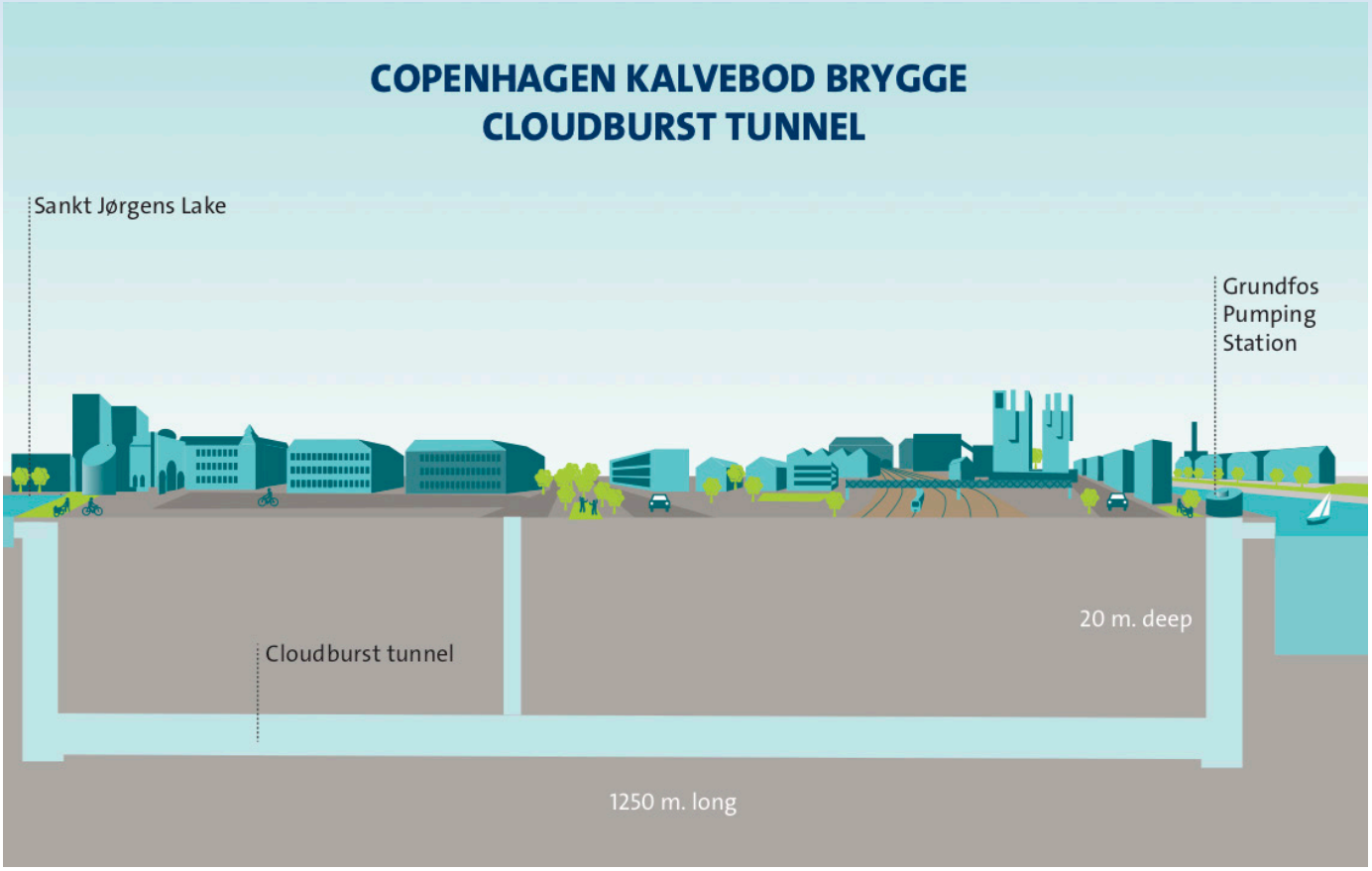
of cloudburst flood control projects to minimise the future damage from flooding in the city.

The first large project, Kalvebod Brygge Cloudburst Tunnel, will evacuate stormwater from the low-lying areas in Frederiksberg and Vesterbro by Sankt Jørgens Lake out to Copenhagen Harbour. It is expected that the stormwater will also contain wastewater from sewer overflows. The tunnel will be 2-3 metres in diameter, 12-20 metres deep and 1,250 metres long (see illustration).

A pumping station with Grundfos equipment will bring up to 20.4 cubic metres of stormwater per second (20.4 m^3/s) from a large underground pump pit out to the harbour. It will be installed with six KPL type submersible axial flow propeller pumps. Two of the pumps will act as stand-by units. The pump pit will be mushroom-shaped and located inside a round shaft 17 metres in diameter and 24 metres deep. The pumps will be placed in steel columns mounted at the top of the shaft.

"A special thing about this installation is that the pumps are only meant to work during cloudbursts," says Niels Eriksen. "It will take on average something between 5-10 years before we have a situation where this installation is meant to work. It provides a kind of challenge, because it's difficult to test the equipment. And we definitely need to be sure it works the day we need it.

So for that reason, we are putting in a lot of effort to make it possible to test the facility with water."



Underground, cross-section map of the HOFOR Kalvebod Brygge Cloudburst Tunnel in Copenhagen, where stormwater is taken from Sankt Jørgens Lake to the Grundfos pumping station, which flushes the water out to Copenhagen Harbour.

"Our experience with Grundfos and DHI has been very nice. I'm very happy. And I'm also happy with the result of the test"

- Niels Eriksen, Senior Consultant from HOFOR, Copenhagen's water utility

Bjarne Jensen, Senior Engineer at DHI, by the Kalvebod pumping station model.

THE SOLUTION

Grundfos partnered with DHI A/S (formerly the Danish Hydraulic Institute) to design and build a 1:12-scale model of the Kalvebod pumping station for ANSI/HI validation. It stands about 2 metres high on a platform in a large, enclosed test laboratory at DHI north of Copenhagen.

"One of the main challenges for us was that the entire model should be transparent," says Bjarne Jensen, Senior Engineer in DHI's Ports and Offshore Department. "It's a challenge to build such a large model with this complicated geometry, all in acrylic glass," he says.

"But with that done, we installed test pumps (for water circulation) and instrumented them with equipment to measure water level, flow velocities and very importantly, to measure how the water will be spinning around inside the pump pit and pump inlets."

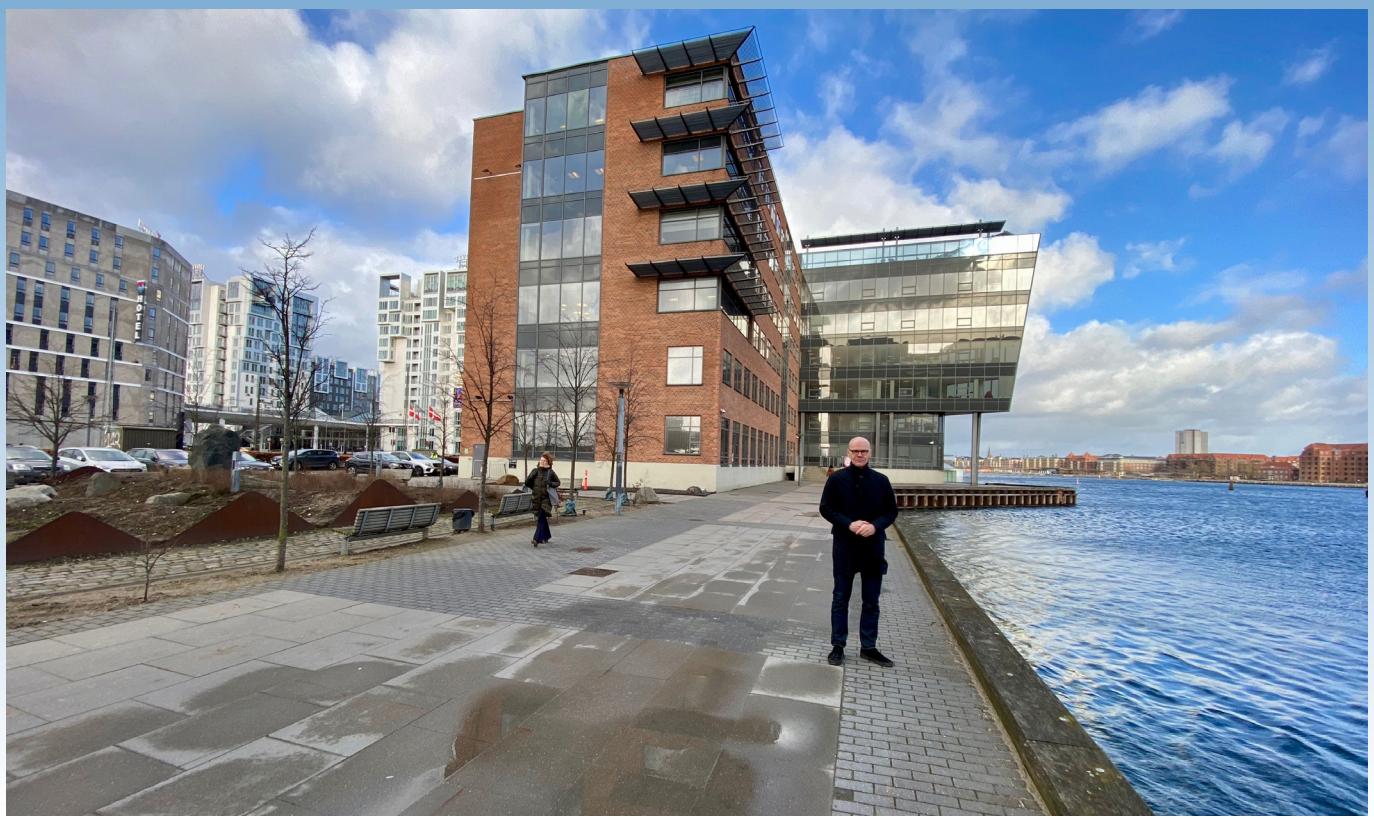
With that, he adds, it was possible to test basically any kind of operational condition with the pumps.

"Of course, we look at the design flow that we expect to enter the pumping station. We look at the flow distribution into the pumping station. We can go into the model and visualise by dye injection how flow is entering the pumps and to see any flow structures or any critical aspects of the hydraulic conditions," Bjarne Jensen explains.

Continent:	Europe
Country:	Denmark
Market areas:	Water
Industry:	Wastewater transport and Flood control
Applications:	Wastewater transport and flood control - Flood control
Products:	KPL

On a more detailed level, he says that they could measure how the velocity is distributed inside the suction pipes to the pumps, and then detect pre-swirl – or how the water spins around inside the suction pipes with very detailed measurements.

"And then we also, of course, measure the overall condition in terms of water level," he adds. "So we can go through any water levels that we can imagine that would appear during operational conditions – very high or very low levels. And we also go in and inject sediment into the flow to model the case where a lot of sediment from the streets is flushed through the system. We can see how that enters and where it ends up in the pumping station to basically optimise operation and how it is cleaned and flushed out after a very large event."



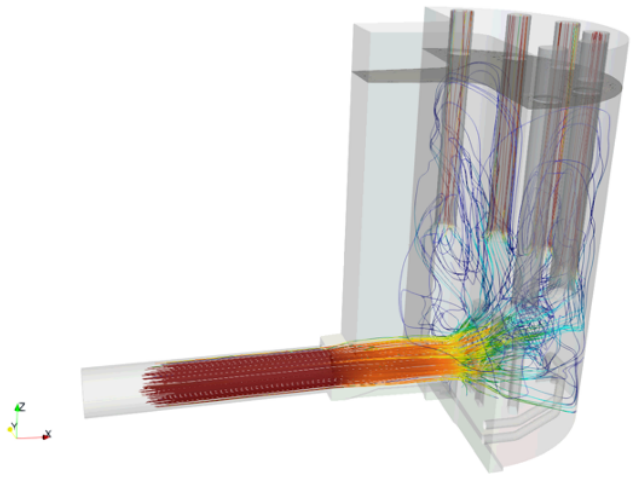
Jens Bjerritsgaard, Head of Project Department at Grundfos DK, stands at the dock at Kalvebod Brygge where the flood waters will enter the harbour. The flower bed at the centre-left side of the photo is the location of the future pumping station.

USED CFD TO OPTIMISE THE DESIGN

Bjarne Jensen says that the initial Grundfos design of the pump inlet configuration actually "complied with the ANSI guidelines on all parameters." But a number of very detailed tests revealed a turbulent, strong flow inside the pumping station, with tendencies to develop subsurface vortices.

Grundfos's Global Water Utility (GWU) centre thus ran a number of computational fluid dynamics (CFD) scenarios in order to optimise the design, prior to implementing any design changes at the test facility.

"With the help of the CFD, we did some modifications – particularly the 'baffle walls' – in order to obtain the accessible values," says Karl Norbert Kiniger, Application Manager in Grundfos GWU. The baffle walls are essentially a number of columns placed in the pump pit where the water enters the pumping station. They have the effect of slowing down the flow and taking out energy to get a more calm and more uniform flow inside the pumping station, he says.



Streamlines from a Grundfos CFD results visualize the effect of baffle walls and the stormwater's approach towards the pump inlets.

Topic:	Flood control pumping station design
Location:	Copenhagen, Denmark
Customer:	HOFOR – Copenhagen's water utility

The cloudburst tunnel will start at the southwest corner of Sankt Jørgens Lake (lower right side of image) and take water 1250 metres underground to Kalvebod Brygge at Copenhagen Harbour – behind the white high-rise buildings at the centre of the image, below the horizon.

THE OUTCOME

With the Kalvebod Brygge pumping station design optimised and verified, the next step is to build the civil works. HOFOR expects to start the tunnelling in 2021. The finished project is expected to be ready by 2024.

"Scale model testing of pumping stations is definitely beyond what's normal in HOFOR and in Denmark," says Niels Eriksen. "Mostly we would like water to go by gravity out into the harbour, because that is the cheapest and safest way of doing it.

But we can foresee that because of rising seawater levels, we may have to pump a lot of places in the future. The experience from this project will be part of the consideration when doing the next ones."

He adds, "Our experience with Grundfos and DHI has been very nice. I'm very happy. And I'm also happy with the result of the test."

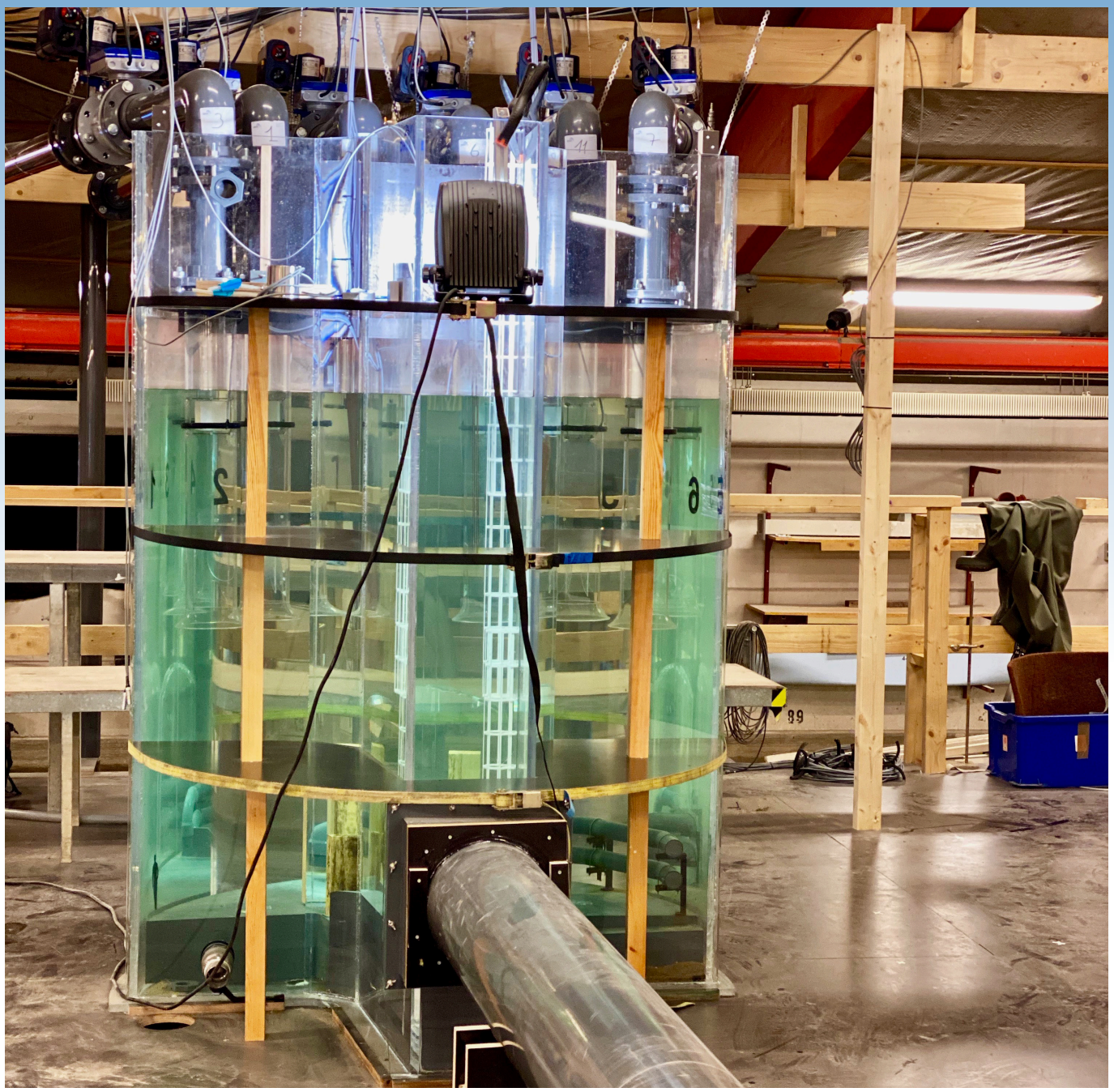
Bjarne Jensen says for DHI, it has similarly been a good experience. "We have actually formed more like a partnership with Grundfos than a client-employee relationship. We entered into this basically on equal terms and have worked closely together to find a good solution and to make this work."

He adds that the experience has implications on a larger scale than one city managing its flood control. "Many cities around the world are looking at Copenhagen and learning from us. And that also involves model testing and learning how to actually design, optimise and verify a pumping station. So as things are now – and with the expected more severe rainfall events and so on – this is definitely something that we will see more and more in the big cities around the world," says Bjarne Jensen.

"And the fact that we actually contribute to securing that part of Copenhagen will not be flooded some years from now is something that we are proud of."

GRUNDFOS SUPPLIED:

Grundfos worked closely with engineering contractors NIRAS to improve and finalize the design of the wet well and the pump installations for HOFOR, Copenhagen's water utility. The pumping station will contain six KPL DN1500 500 kW submersible, axial flow propeller pumps (type KPL.1500.500.12.T.50.L.69.Z). Grundfos Global Water Utility (GWU) experts worked with the DHI A/S and HOFOR to optimise and verify the design with a 1:12-scale model. Grundfos also supplies six large, steel pump columns for the pumping station. Grundfos Water Utility (GWU) further partnered with a supplier for hydroelectrical simulations to verify the sizing of the electro-mechanical equipment, including transformers and capacitor banks at the pump station.



The 1:12-scale model of the Kalvebod Brygge pumping station at DHI.

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- Bjarne Jensen, Senior Engineer at DHI A/S

See video

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