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# Concept development for deployment of a modular, floating, tidal-stream device

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ABSTRACT: The Modular Tide Generators (MTG) project is now in its second phase; the present design concept has been completed including structural, hydrostatic and basic hydrodynamic modelling; a series of scale-model experiments are being undertaken to validate a fully-nonlinear numerical tool and confirm the design assumptions. Flume tests are used to calibrate a 1:25 scale turbine model (porous disc), and basin tests are used to model the complete system, including: freely, floating, twin-hulled structure; 4-point mooring system, and submerged turbine model, at 1:12 scale. Moorings loads, thrust on the turbine and 6DoF motions of the platform are recorded over a range of wave and current conditions based on two proposed deployment sites at Carrick roads on the Truro River, UK. Initial observations confirm the assumptions made in the design as well as the predictive capability of the numerical tool.

## 1 INTRODUCTION

Tidal-stream energy is a renewable source with potential; it is predictable and shares many of the technological challenges of established industries (e.g. hydro and offshore wind). Furthermore, based on the “2017 allocation round for contracts for difference” in the UK, tidal-stream is approaching a position of cost competitiveness with more mature renewable industries (like offshore wind) and is sure to make a positive contribution to the future energy mix.

However, despite a positive outlook for the tidal-stream industry, the levelised cost of energy (LCOE) remains high. Furthermore, for the most ‘technologically ready’ devices, i.e. large gravity-based or seabed-mounted turbines, there is a distinct lack of suitable deployment sites. Therefore, in order to establish a sustainable industry (including a supply chain with sufficient potential to attract significant investment), novel solutions are still required to reduce costs further and exploit the tidal-stream resource at a greater number of (less traditional) sites.

Consequently, a number of floating tidal-stream concepts are under development; these types of devices benefit from a more cost-effective installation and have the potential to unlock a greater number of deployment sites by reducing the limitations associated with the water depth and the bathymetry (they also access the higher velocity flow in the upper part of the water column). However, having the device positioned at the free-surface introduces a series of additional complexities requiring underpinning research and an improved understanding of various phenomena. Crucially, floating devices are subject to both wave loading and the associated body motions which raise further concerns over the power delivery and the survivability of the system.

Over the last few years, Modular Tidal Generators Ltd. (MTG) have been developing a floating tidal-stream concept in line with the company’s strategic vision to supply cost-effective renewable electricity across the World. The MTG concept aims to reduce the LCOE further (compared to other floating devices) and encourage deployment in remote (and less-well-developed) areas (where energy costs are already inflated) by utilising modularity, standardising components and ensuring a design that can be easily manufactured, deployed and maintained with a minimum of requirements on skilled personnel.

This article summarises the process employed to develop the MTG concept under the company’s novel paradigm for tidal-stream devices, highlights key milestones in the project to date and discusses the present plans for future development of the device.

## 2 THE MTG CONCEPT DEVELOPMENT

The Modular Tide Generators (MTG) project is now in its second phase. A feasibility study, in which a high-fidelity numerical tool was developed to assess the initial concept design, was completed in 2016 (Ransley et al., 2016a, Ransley et al., 2016b). In the second phase, a series of physical, scale-model experiments are being undertaken to provide validation data for the numerical model and assessment of the latest MTG design concept. The purpose of the modelling work is to provide a better understanding of the behavior of the device, confirm assumptions and refine the present design solution ahead of manufacturing and deploying a full-scale prototype. Field trials and an in situ monitoring campaign will then be utilised to improve the predictive capability of the models and refine the device design further.

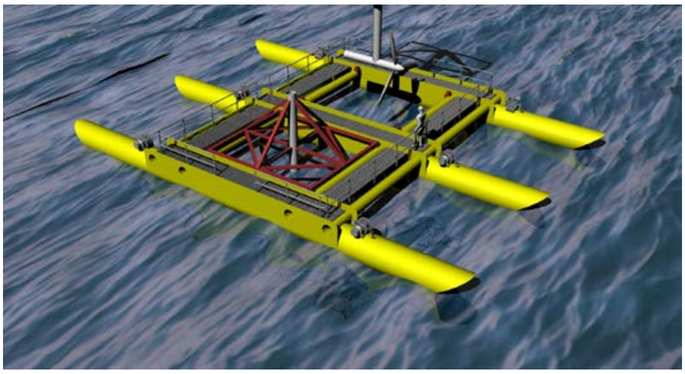

Figure 1. An artist's impression of the 'two-turbine' version of the MTG concept.

### 2.1 *The MTG device concept and Schottel SIT250*

The present MTG device has been designed around removable, 'turbine-modules' consisting of a support structure and the 4m diameter, 62kW SIT250 turbine; taking advantage of Schottel's existing lightweight, simple and robust generator and staying in-tune with the company's flexible modular approach.

The turbine modules are positioned between cylindrical hulls which are connected via a 'space-frame' walkway, allowing for simple scaling up of the device (by adding additional hulls and modules) and reduced maintenance costs and downtime (through an effective 'plug-and-plug' system for the turbines). Figure 1 gives an artist's impression of the '2-turbine' version of the MTG device with one turbine installed and another being installed.

### 2.2 *Naval architecture and structural modelling*

The present MTG device concept is 20m in length and has a beam (single-turbine version) of 7.44m. The draft of the device (turbine installed) is 6.15m. The hulls are standard 'off-the-shelf' ASTM/ASME B36.10M steel pipe as are the cross beams that make up the space frame walkway. The rest of the structure, including the bulkheads and end caps for the hulls, is made using steel plate, avoiding any complex manufacturing processes. The frame for the turbine module is made from standard steel box section and the turbine frame fixings are again off-the-shelf components (as are the mooring winches) in order to minimize the cost of the device and take advantage of components with an existing ISO rating.

Hydrostatic analysis demonstrates that the single-turbine version of the platform is stable up to extreme values of pitch and roll and preliminary hydrodynamic analysis, using Ansys AQWA (i.e. linearised and excluding both currents and contributions from the turbine), suggests that the excitation due to wave loading is sufficiently suppressed with a peak in the pitch response of 7.765 deg/m at 0.214Hz (for head seas) and a peak in the roll response of 22.405 deg/m at 0.347 Hz (in beam seas). Figure 2. Shows a screenshot from the AQWA analysis.

Preliminary structural analysis (also using the Ansys modelling suite) demonstrates that the structure is sufficiently strong to survive even the most extreme static loading cases, e.g. Figure 3 shows a screenshot of the structural analysis for the 'simply supported' test (where the mass of the turbine module has been included as an additional 10te load).

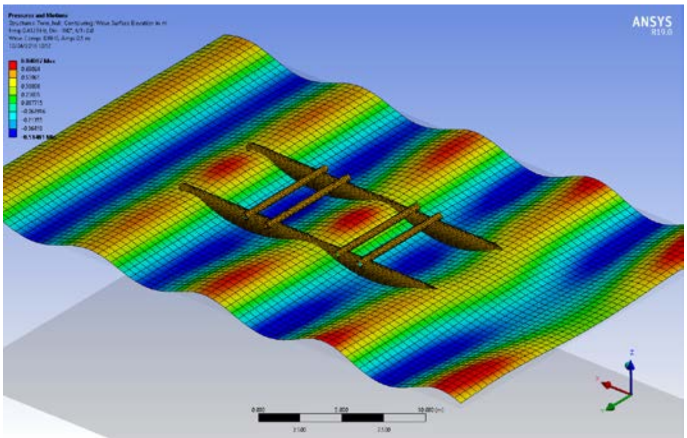


Figure 2. A screenshot from the preliminary hydrodynamic analysis using Ansys AQWA (the amplitude of the surface elevation has been greatly increased for visualization purposes).

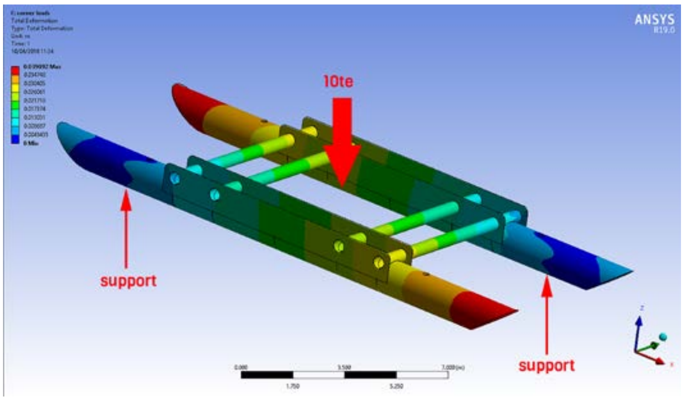


Figure 3. A screenshot of the preliminary structural analysis, using Ansys, showing the 'simply supported' test.

### 2.3 *Physical modelling (hydrodynamics)*

The MTG project experiments, performed in the COAST Laboratory at the University of Plymouth, consist of a series of flume tests, at 1:25 scale, and basin tests, at 1:12 scale.

The flume tests consider a fixed turbine and support structure and are used to calibrate a turbine model (porous disc) and provide a better understanding of the loads on, and power delivery of, a turbine when in close proximity to the free surface and when subject to coherent turbulent structures and waves. As, in this project is it has been deemed only necessary to model the total thrust force on the turbine accurately; a porous disc is used to alleviate issues surrounding the scaling of a miniature turbine model. A range of methods including both particle tracking velocimetry (PTV) and particle image velocimetry (PIV) are utilised to characterise the flow conditions in the flume; the centre of effort and the total load on the turbine model are measured via an arrangement of three load cells attached near the centre of the disc. Figure 4 shows a photograph from the flume experiments using PTV to characterise the flow.

The initial flume experiments demonstrate that the thrust on the disc returns the desired quadratic profile, relative to incident flow velocity, and that the present results fit a linear trend between porosity and thrust coefficient (Figure 5); a porosity of 50% was found to best match the thrust coefficient of the SIT250 turbine. It is, however, worth noting that the SIT250 has 'over-speed control' above its rated flow velocity of $3ms^{-1}$ and that this is not captured by the porous disc model (which will give higher thrust values for very high flow speeds). This is not critical to the design of the floating system at this stage as the target deployment sites for the prototype do not exceed $3ms^{-1}$. However, the numerical model under development (Section 2.4) does include the over-speed characteristics of the turbine and so, once validated, will be used to provide the required information to describe the dynamics of the system and the characteristics of the turbine at high flow speeds.

The basin tests consider the complete MTG device including the twin-hulled structure; 4-point mooring system, and submerged turbine model. Experiments are run with the device either fixed in place or freely floating as well as with both the turbine installed and removed. This strategy was selected in order to provide an incremental increase in complexity that ensures the numerical model being developed (see Section 2.4) can be validated robustly and later used to assess the required design points in more detail.

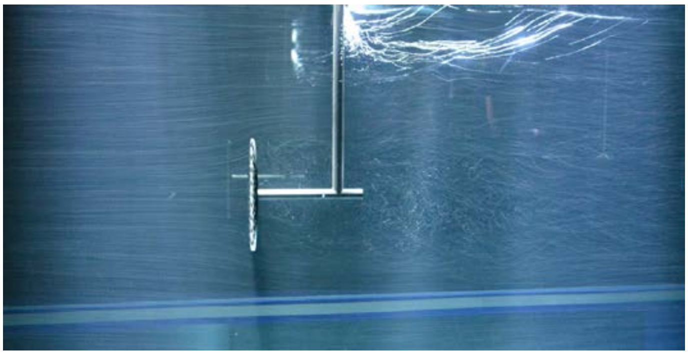

Figure 4. Photograph from the 1:25 scale flume tests, utilizing PTV, with a fixed porous disc turbine model and support.

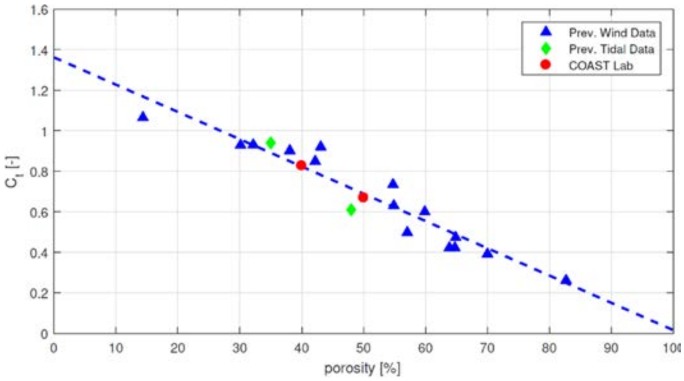


Figure 5. Thrust coefficient ($C_t$) vs. disc porosity (%): present study (red circles); previous work using porous discs to model wind turbines (blue triangles) (Lignarolo, 2016), and; previous work considering porous disc representations of tidal turbines (green diamonds) (Bahaj, 2007).

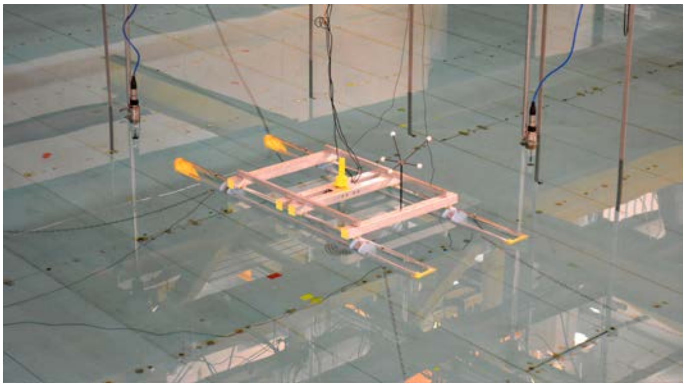

Figure 6. Photograph of the 1:12 scale MTG device in the Ocean Basin at the COAST Laboratory.

In the fixed basin cases, global loads on the structure and on the turbine are measured in a range of wave and current conditions, based on those at the proposed deployment site in the Truro River, Carrick Roads, UK (see Section 2.5).

In the free cases, for the same environmental conditions, the load in the moorings, thrust on the turbine and 6DoF motions of the platform are recorded as well as the surface elevation in the vicinity of the device and the velocity deficit in the wake of the turbine model. Figure 6 shows a photograph of the 1:12 scale model in the basin. Further details from the initial basin tests are given in Xie et al. (2018).

As well as providing validation data for the numerical model (Section 2.4), the critical design points selected for analysis include: the motion of the floating structure (particularly in heave, pitch and surge) as these are key considerations in confirming the assumptions from the naval architecture (incl. the loading regime and sea-worthiness); the loads in the mooring lines, as these are a critical component of the system with notable uncertainty, and; the thrust on the turbine (particularly in oscillating flow), as this is directly linked to the power output from the device, and so the economic viability of the system, as well as being important in understanding the fatigue loading on the turbine which is crucial for assessment of maintenance protocols and lifetime cost estimates. For each of these points, the combined effect of waves and currents as well as the additional loading, on the floating structure, due to the thrust on the turbine are of particular interest in the design of the prototype as these complexities are not easily included in the preliminary naval architecture analysis. Therefore, the physical modelling explores a wide parameter space consisting of combinations of various wave frequencies, wave amplitudes and current velocities and the analysis being undertaken will related these to the real-world conditions expected.

Initial results from the physical experiments demonstrate that the assumptions made, and numerical results produced, as part of the naval architecture (using Ansys AQWA) appear to be reasonably accurate; the thrust on the turbine does not seem to effect the motion of the device in waves only but significantly damps the motion when a current is introduced (Xie, 2018). Further, initial observations highlight additional design points for consideration including green water effects, in large waves at pitch resonance, and trapping of waves between the two hulls of the structure. These phenomena will be considered in more detail using the high fidelity numerical model being developed as part of the project.

## 2.4 *Numerical modelling (CFD)*

As well as serving to confirm the assumptions made in the naval architecture (at least at scale), the physical experiments have been designed to provide incremental validation data to verify the predictive capability of the numerical model developed in the first phase of the MTG project (Ransley et al., 2016a, Ransley et al., 2016b).

The numerical model (an open-source, Navier-Stokes solver based on OpenFOAM) couples the fully-nonlinear, hydrodynamic loading on the buoyant structure, the thrust on the submerged turbine model and the loads in the mooring system with the rigid-body motion of the device.

Once validated, the numerical model is to be used to assess the behavior of the device, and the various loads, in specific conditions that cannot be assessed easily using simpler models (such as wave and current conditions, crossing seas and extreme wave events), as well as provide high resolution data to fine-tune the design of the device. Furthermore, the validated numerical model is to be used to test alternative design concepts, including multi-turbine devices and new mooring configurations, without the need for further physical modelling. Further still, the numerical model will give an insight into complex nonlinear phenomena such as ‘green water’ loading, ventilation of the turbine at the free-surface and the interactions between multiple devices in close proximity, providing a tool to further optimise the MTG concept, for real conditions, in a cost-effective way.

Initial simulations demonstrate that the numerical tool is capable of predicting the loads on the structure, its motion and the loads on the turbine well, in regular wave cases. Figure 7 shows a screenshot from a simulation with the structure fixed, the turbine in place and incident regular waves of 0.78Hz (frequency of peak pitch response – 1:12 scale).

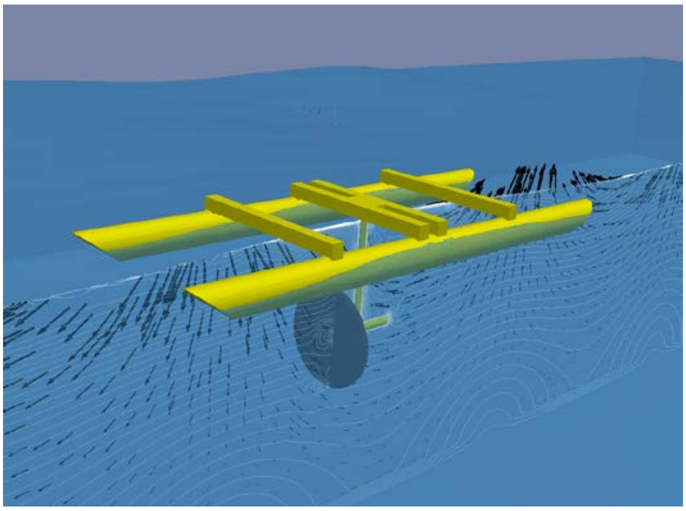

Figure 7. Screenshot from a simulation of the MTG device fixed and with the turbine installed, showing the free-surface (phase fraction, $\alpha = 0.5$) and the velocity of the water along the centre-line (scaled vectors and contours of $|\mathbf{U}|$). $|\mathbf{U}|$ ranges from 0 – 0.3134ms$^{-1}$ (contour increment is 0.03482ms$^{-1}$).

## 2.5 *The proposed deployment site*

To find an appropriate deployment site for the full-scale prototype, two measurement sites, both with a depth of approximately 9m, have been investigated at Carrick Roads in the Truro River. Figure 8 shows the bathymetry and the existing mooring buoys at the ‘Smugglers Cottage’ site (a) and the ‘Turnaware’ site (b), as well as a cross section profile (between points 1 and 2) for both locations.

The Truro River was selected as a deployment location for the prototype based on: its benign wave climate, reducing the risk of excessive wave loading (the prototype is due to be deployed over the British winter); its proximity to harbor and port facilities, greatly reducing the costs associated with installation and maintenance, and; an existing agreement of consent from the local harbor commissioners.

At each site a 5-beam ADCP has been deployed, for 14 days (across a spring tidal cycle), at the deepest point of the cross-section lines in Figure 7. The ADCP used has an integrated beam dedicated to surface tracking giving accurate measurements of both the current conditions and the wave climate.

Preliminary analysis of the ADCP data shows that the current characteristics at both sites have clear directionality with a flow pattern of stronger current strengths in line with the direction of the river. Stronger currents are observed towards the surface and the flow in the downstream direction is noticeable faster than the flow upstream. However, the overall current strength does not exceed $1ms^{-1}$, even at the strongest surface flow, and the mean is only approximate $0.5ms^{-1}$.

## 3 CONCLUSIONS

Tidal stream energy remains a risky option for investors in the renewable energy industry with a relatively high LCOE and a distinct lack of suitable deployment sites (for the established large bottom-mounted devices). Floating concepts relieve some of the constraints, concerning the water depth and seabed characteristics, and provide a quicker and cheaper installation but their design, and predicted power output, must consider the wave loading and device motion associated with their position at the free-surface. The MTG concept presented here is a floating tidal stream concept that reduces the LCOE further by exploiting a modular design and a ‘design-for-manufacture’ based on standardised components and materials. The concept has been developed through a series of physical and numerical modelling campaigns. The initial design work demonstrates that the MTG device is sufficiently strong to survive extreme static loading cases and stable up to extreme values of pitch and roll. The predicted response of the device, using Ansys AQWA, has been corroborated using results from 1:12 scale physical tests in the COAST Laboratory at the University of Plymouth confirming the predicted mooring loads. A porous disc is used to model the 4m diameter turbine at scale. 1:25 scale flume tests confirm that a 50% porosity gives the anticipated quadratic relationship

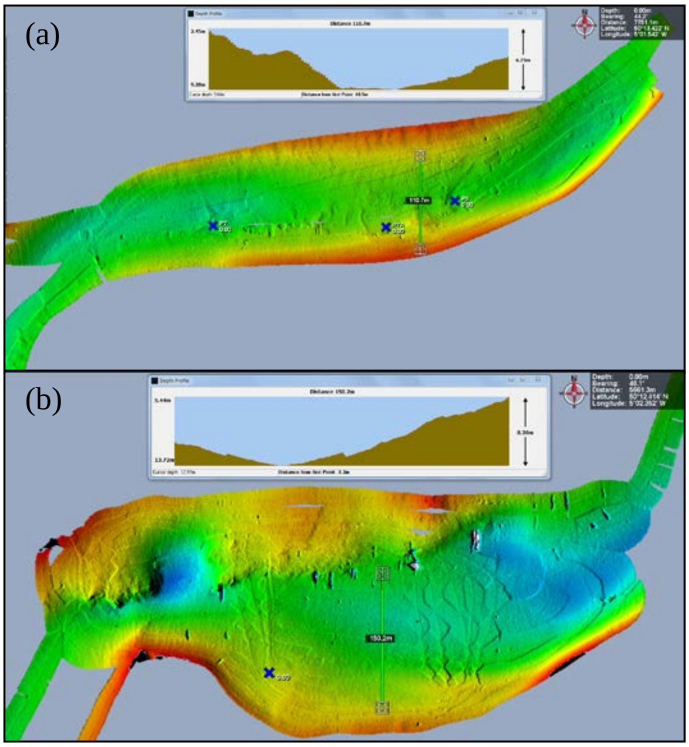


Figure 8. Bathymetric surveys of the two possible deployment sites at Carrick Roads in the Truro River: (a) Smugglers Cottage; (b) Turnaware. Depth profile between point 1 and 2.

and thrust coefficient of the full scale turbine. Fixed and floating experiments, with and without the turbine module in place, provide validation data for incremental development of a numerical model, based on a fully nonlinear Navier-Stokes solver, with a new turbine model coupled to a rigid-body solver. Initial simulations demonstrate the predictive capability of the numerical tool is good allowing for estimates of the thrust variation across the turbine and the variability in the power delivery of the device. Presently, no design issues have been identified from either the physical or numerical analysis, however, there is an expected loss in the annual energy production due to the influence of the waves and motions of the device. Proposed deployment sites has been investigated at Carrick Roads in the Truro River but the flow speed measured appears to be insufficient for the field trials proposed as part of the concept development. Alternative sites are under investigation as are strategies such as towing tests during the full-scale deployment of the prototype.

## 4 ACKNOWLEDGEMENTS

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## REFERENCES

Bahaj, A., Myers, L., Thomson, M., Jorge, N., 2007. Characterising the wake of horizontal axis marine current turbines. In: Proceedings of the 7th European Wave and Tidal Energy Conference. Porto, Portugal.

Lignarolo, L., Ragni, D., Ferreira, C., van Bassel, G., 2016. Experimental comparison of a wind-turbine and of an actuator-disc near wake. J. Renew. Sustain. Energ. 8 (023301), 26.

Ransley, E., Brown, S., Greaves, D., Hindley, S., Weston, P., Guerrini, E., Starzmann, R. 2016a. Coupled RANS-VOF Modelling of Floating Tidal Stream Concepts, in Proceedings of the 4th Marine Energy Technology Symposium (METS), 25-27 April 2016: Washington, D.C., USA.

Ransley, E., Brown, S., Greaves, D., Hindley, S., Weston, P., Guerrini, E. 2016b. Coupled RANS-VOF modelling of floating tidal stream concepts, in Proceedings of the 2nd International Conference on Offshore Renewable Energy (CORE), 12-14 September 2016: Glasgow, Scotland.

Xie, N., Ransley, E., Brown, S., Greaves, D., Nicholls-Lee, R., Johanning, L., Weston, P., Guerrini, E. 2018. Wave tank experiments of a floating, tidal-stream energy device, in Proceedings of the 3rd International Conference on Renewable Energies Offshore, 8-10 Oct. 2018: Lisbon, Portugal.