M4 Smart Motorway - Sydney, Australia

ARUP
M4 Smart Motorway

CLIENT: Roads and Maritime NSW

12d DIMENSIONS:
- Drafting
- Water
- Customisation

Project Summary

The M4 Smart Motorway will introduce a smarter way of travelling the M4 by using real time information, communication and traffic management tools to provide motorists with a safer, smoother and more reliable journey.

The M4 Smart Motorway will be the first smart motorway for NSW and will bring together intelligent traffic technologies in one place to maximise the performance of the motorway.

Arup was awarded the Detailed Design of the M4 Smart Motorway project, which consists of approximately 47km of the M4 Motorway in Western Sydney being upgraded to enable the installation and operation of "smart motorways" technology to enhance travel time and driver safety.

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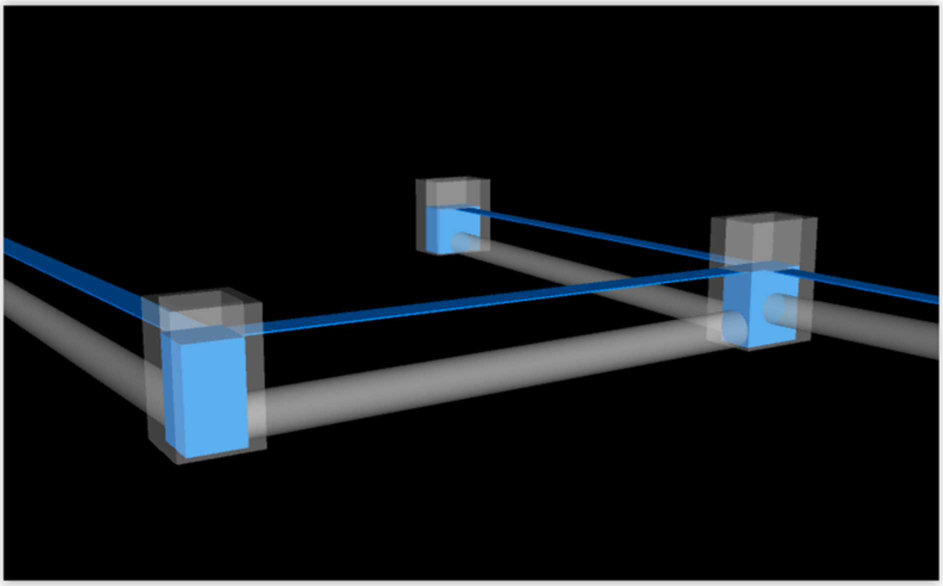

Figure 2 - Trimeshes as viewed in Navisworks

The Challenge

For this project and others, Arup had a strong push from innovative team members to move to a paperless review process on major projects, and to generate detailed federated models for projects. They developed numerous processes to generate detailed federated models containing construction-relevant information, but these models are not always useful for design technical reviews.

As such, Jeremy Harrington looked into the ability to undertake technical design reviews within these federated models. He said, *"This will be an ongoing task that will continue to grow, but my first task was to develop a method to enable review of a drainage design with respect to the hydraulic performance, within a federated 3D model. This is something that is generally done through longitudinal sections on drawings, or within 12d Model. My aim was to generate an IFC format file export that can be used to review the performance of a stormwater drainage network."*

One of the other major considerations for this project was that, when dealing with large scale road design projects, the automation of longitudinal section exports can be complicated, due to the need to include a superelevation diagram which references unique strings for each carriageway.

In order to get around this, the Arup team had previously utilised a custom PPF per control alignment, which was manually filled out to specify the relevant road name suffix and superelevation diagram reference strings. This process presented a significant QA risk, given that if a change to the standard PPF was required, the user then needed to go through and amend every single custom PPF to reflect this change - a very inefficient process which can lead to inaccuracies and inconsistencies.

Mr Harrington decided to further automate this process by creating a large chain which utilised parameters in order to manage the custom inputs required for each control alignment. However, this method was also prone to errors, and required a user with a strong understanding of complex chain creation in order to first put together the chain, and then to make any changes moving forward, which in itself reduced the efficiency of the process. Further innovation was required.

A further challenge faced by the Arup team was a common task in any road design project - the identification and review of aquaplaning risk through flat spots and superelevation development along the carriageway. Aquaplaning is assessed by reviewing the path that a rain drop would take should it fall at a given location on the carriageway and determining the build-up of flow depth along that path, and the resultant risk factor that a car would be caused to hydroplane should it cross this flow path.

12d Model software has a built-in macro that utilises the *Gallaway Equation* to analyse the aquaplaning risk profile along a flow path that has been drawn by the designer. This macro works well and has been a staple tool for generating accurate and visual representations of the aquaplaning potential on past projects.

However, Mr Harrington identified that the need for the designer to manually draw a flow path was a limitation of that process for completing aquaplaning checks, as it lead to the potential for human error, while also resulting in the need to undertake quite a number of trial overland flow paths in order to determine the worst-case risk area.

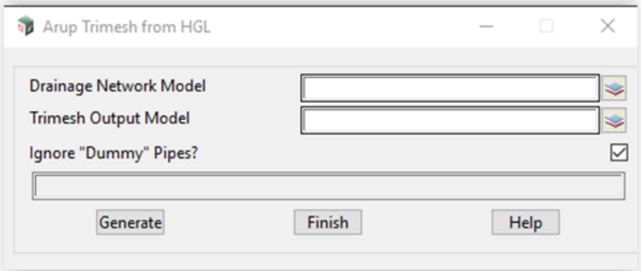

Figure 1 – Arup Trimesh from HGL macro panel

Darren Stewart, also of Arup, was similarly concerned with the sheer size and volume of the longitudinal drainage network across the extent of the project, which was significant. As with any drainage design undertaken in any analysis software, as more pits and pipes are added to the network the design becomes more and more difficult to manage. The resources and memory required by workstations increases, operation of the software becomes clunky, and storm events (particularly dynamic analysis) take increasingly longer durations to run. To offset these performance issues, it became necessary to split the design into individual drainage models, which could be managed and analysed individually. It was not unusual to have multiple models in each project – in some packages the team had up to six separate drainage models to maintain.

Part of their deliverables was to provide a range of hydraulic outputs, including:

- Minor (10 year ARI) results
- Major (100 year ARI) nuisance flooding checks
- Self-cleansing Velocity checks (6 month ARI)
- Allowable flow across noses checks (2 year ARI)
- Outfall scour protection requirements (50 year ARI)

In the past, the approach would have been to run one event for each drainage network, combine all the networks into one single model, and export the combined model in the required format. The process was then repeated over again for each of the required storm events.

Although this approach removes the need to stitch together multiple outputs (which requires a lot of postprocessing), it does not remove the need to run back-to-back storm events. Something different needed to be done.

The Solution

In a step towards undertaking technical design reviews within federated models, Mr Harrington developed a custom 12d Model macro that was able to convert the Hydraulic Grade Line into attributed trimesh objects. The macro contains a simple panel which requires the user to only input the model containing the drainage network to be reviewed, the output model for the trimeshes, and a toggle to review pipes with names containing "dummy*" (see Figure 1).

Once the user selects a drainage network, the macro reviews the pit and pipe attributes associated with each pipe reach in the network and gets to work recreating the HGL information as a trimesh for each individual pit and pipe. The trimesh for a pipe is created with a width matching the diameter of the respective pipe, and the trimesh for a pit is generate to match the internal shape and dimensions of the pit chamber, as well as provided a depth to meet the invert of the pit itself, essentially showing the peak water level within the pit. (see Figure 2 - headline image).

The pit and pipe attributes are also reviewed to identify key analysis results information, such as velocity, freeboard, capacity, *etc.,* which are then applied to the trimesh objects to enable a simple technical review to be undertaken.

Similarly, when seeking to overcome the problem of risk of human error with chains, and to increase efficiency and ensure consistent documentation, Mr Harrington decided to develop another 12d Model macro. The 'Arup Long Section Plot' macro has been developed to allow batch plotting of road longitudinal sections with custom inputs automatically captured for each alignment. The macro initially opens on to a simplified 'Quick Plot' panel (see Figure 8), which also includes a prefilled Settings tab.

First time use of the macro requires users to fill out the relevant information on the 'Quick Plot' panel, and then

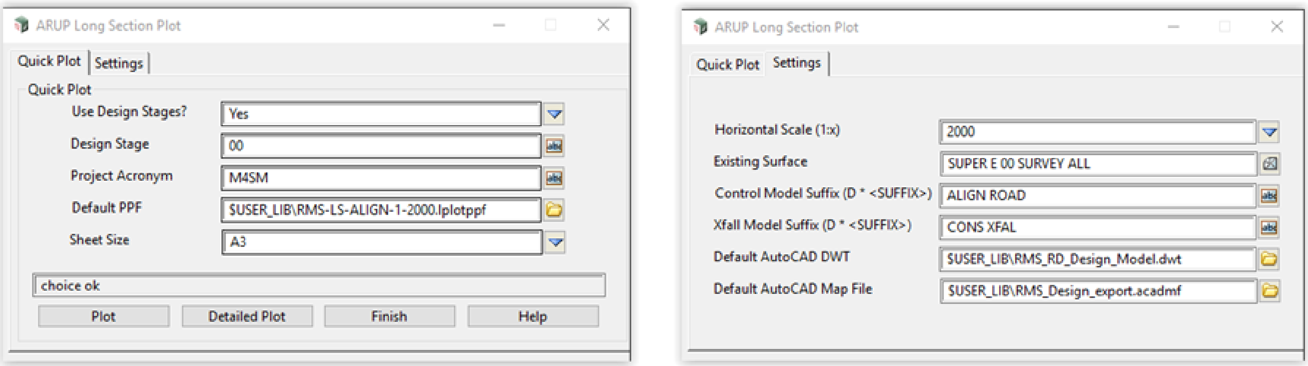

Figure 8 – Quick Plot Panel

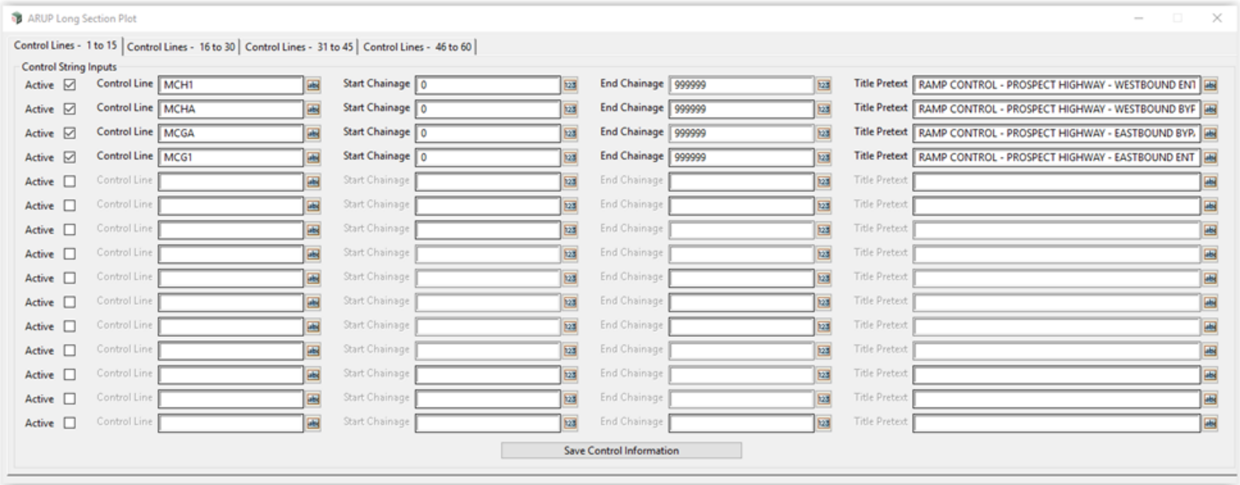

Figure 9 – Detailed Plot Panel

launch the ‘Detailed Plot’ panel (see Figure 9). Upon launching the ‘Detailed Plot’ panel, the information in the ‘Quick Plot’ panel is assessed by the macro, and all control alignments in the Control Model are automatically loaded on the panel for review by the user (the relevant model is determined from the Design Stage and Control Model Suffix, as well as Arup design standards).

As can also be seen in Figure 9, the ‘Detailed Plot’ panel allows users to review and specify whether a control line is to be active or inactive in the plot process, the start and end chainage for the longsection plot, and the custom Title Pretext for each control line. The control Title Pretext is added to each control superalignment as a custom attribute through the use of a separate macro that Mr Harrington also created, and this attribute text is automatically loaded into the ‘Arup

Plot’ panel. The text file containing the ‘Quick Plot’ information is automatically read back into 12d Model the next time the macro is launched, prefilling the panel with the most recently used settings for that project. Upon launching the ‘Detailed Plot’ panel, the macro interrogates the Design Stage chosen and reads in the associated defaults for that Design Stage. This is a beneficial process as it means that a large-scale project can be managed and plotted numerous times with no need to re-enter a large amount of control line information, such as custom chainage ranges – meaning a user can plot longitudinal sections for up to 60 control alignments with a single click.

And finally, when needing to overcome the requirement for manual input with assessment of aquaplaning risk, and trial and error required in order to find the worst-case flow path, Mr Harrington developed yet another custom Dynamic Aquaplaning macro for use within 12d

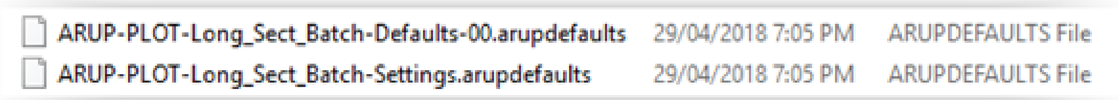

Figure 10 – ARUPDEFAULTS Files

Long Section Plot’ macro. Once all inputs are reviewed and finalised, the user can save the information and return to the ‘Quick Plot’ panel.

Upon hitting the Plot button, the macro process is launched. The macro then grabs the Default PPF as specified, where it modifies the inputs in a temporary copy of the PPF for each control line. The superelevation cross fall strings are automatically modelled through Arup’s standard snippets during the design process, and are named under a strict naming standard which allows the macro to automatically detect and specify these strings in the PPF for development of the superelevation diagram. The macro modifies and then runs the PPF, which plots the longitudinal section to a 12d model. The model is then modified to shift the superelevation box into the correct location, before exporting the model to a correctly named and mapped AutoCAD .dwg file, ready to be used as an external reference for a set of design drawings with no drafting required.

During this plot process, the macro also generates two custom text files within the current 12d Model project working folder. Two “*.ARUPDEFAULTS” files are created (see Figure 10), one containing all the information entered into the ‘Quick Plot’ panel, and the other containing all information entered into the ‘Detailed

Model (see Figure 3).

This ‘Arup Aquaplaning Assessment’ macro enables users to undertake a live and dynamic check of aquaplaning risk along a design before specifying the locked-in coordinates for the start of an overland flow path. The ‘Settings’ tab has been prefilled to suit the requirements of *Austroads Guide to Road Design Part 5*, and is essentially an extension of the settings included in the current built-in Aquaplaning Risk macro which is shipped with 12d Model.

Once the user is comfortable with the specified settings, the Finished Surface TIN can be specified on the ‘Dynamic Path’ tab (this allows for supertins). If the user then clicks the select widget captioned ‘Use Selection to

Create Dynamic Flow Paths’ and hovers over the finished surface anywhere in a 12d Model plan view, the macro goes to work. At this point, the macro gathers the coordinates of the cursor and automatically draws a flow path from that point until the flow string encounters an uphill slope, or the downhill slope exceeds the maximum allowable slope specified in the Settings tab (see Figure 4).

The dynamic flow path that is being created based on

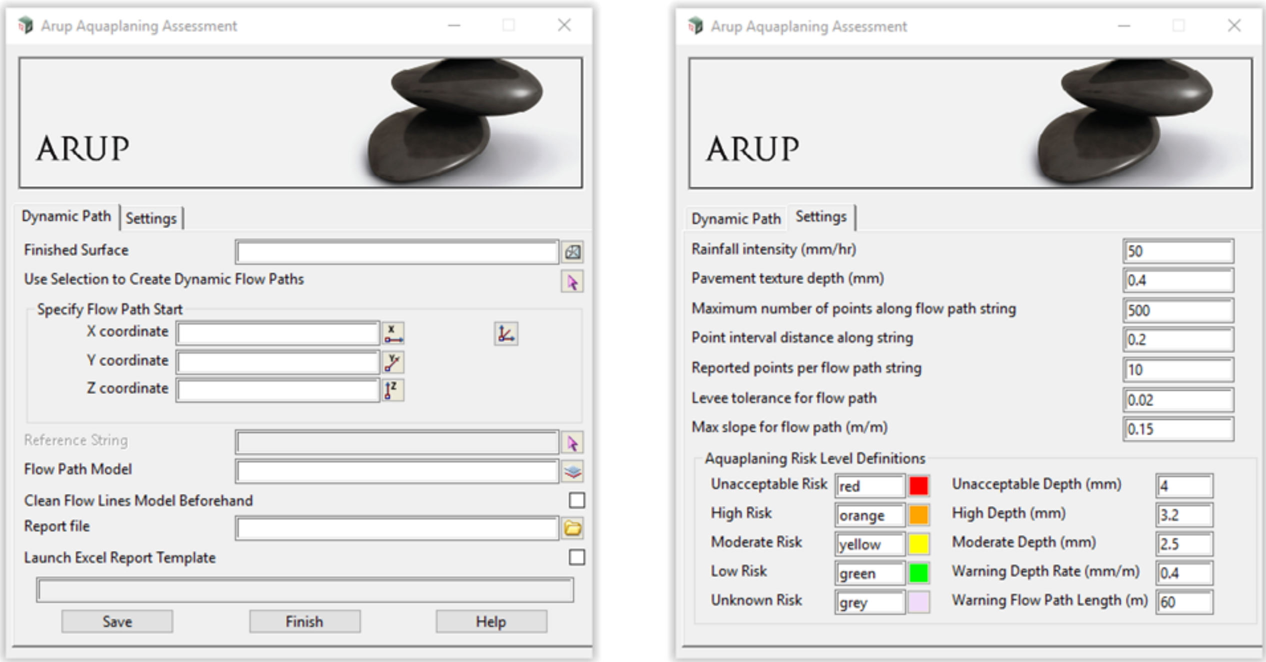

Figure 3 – Dynamic Aquaplaning Macro panels

the cursor position is also dynamically analysed in accordance with the *Gallaway Equation* (1979), based on the settings specified. The flow path is generated with each segment analysed and coloured to visually indicate the risk profile, and the string is give the flow line linetype to clearly show the path of the overland flow.

Once the user has identified a critical flow path, hitting the ESC key will break the dynamic path generation, leaving a temporary flow path string on the active plan view. The user can then pick the start vertex of the temporary flow path to lock in the start coordinates for the overland flow that is to be analysed and exported for use in design review documentation. The overland flow path that is created has also been given attributes at each vertex displaying relevant analysis information, much the same as the built-in 12d Aquaplaning Risk macro.

As per the current 12d Aquaplaning Risk macro, the user then has the option to specify a relevant Reference String,

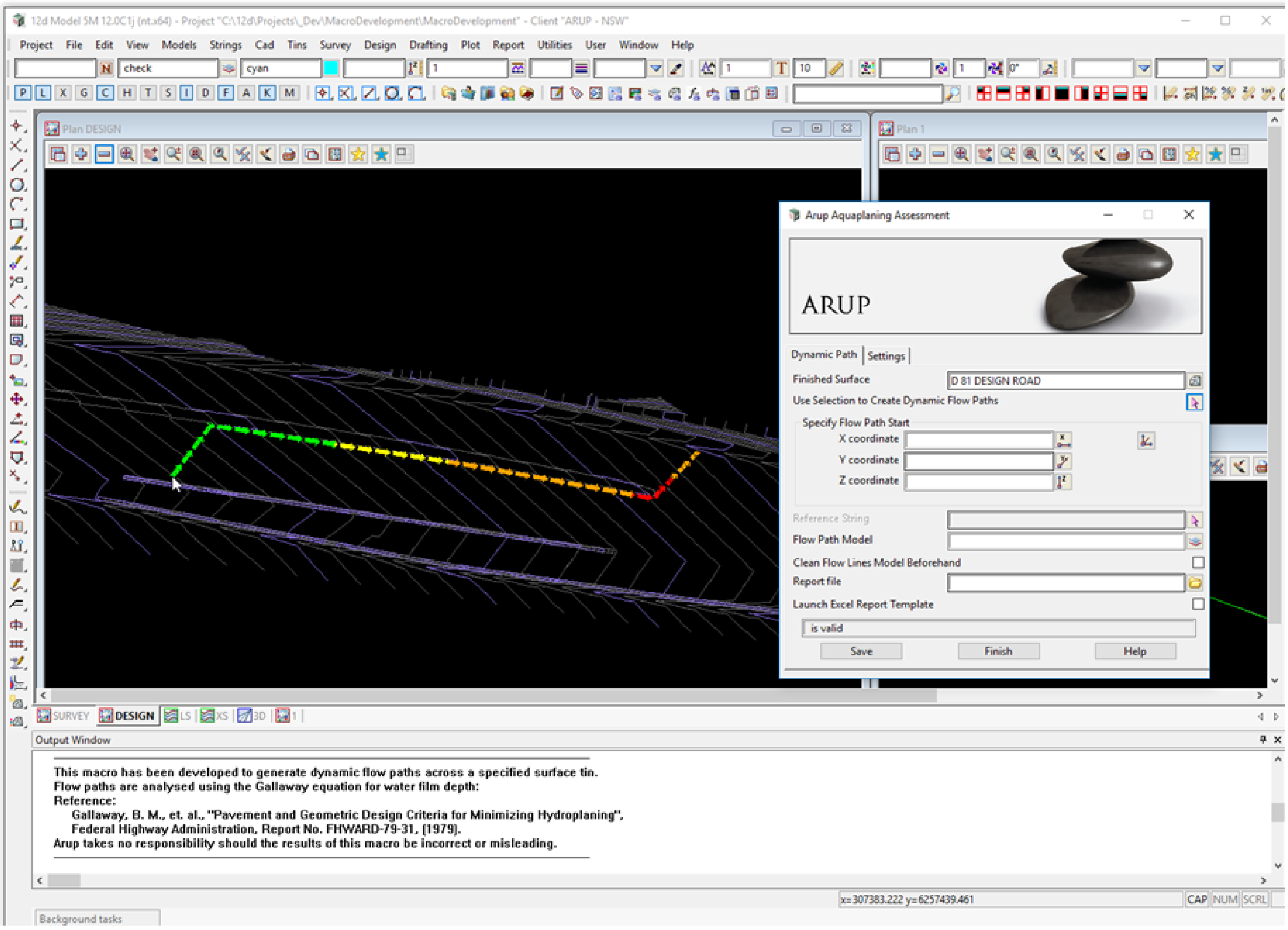

Figure 4 – Dynamic flow path generated from cursor position

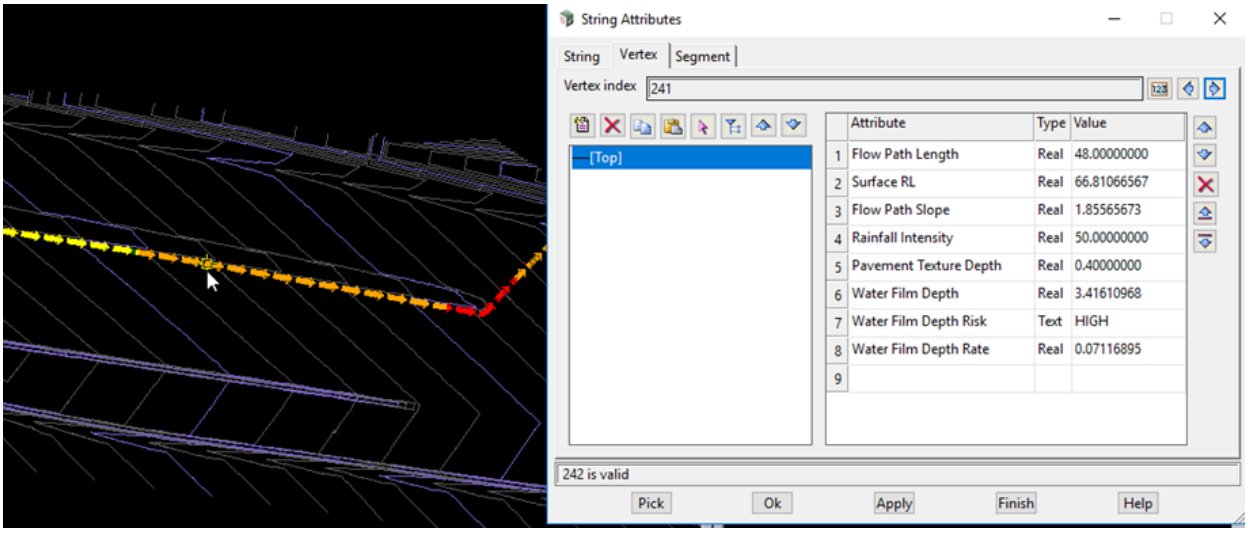

Figure 6 – Macro-enabled Microsoft Excel template

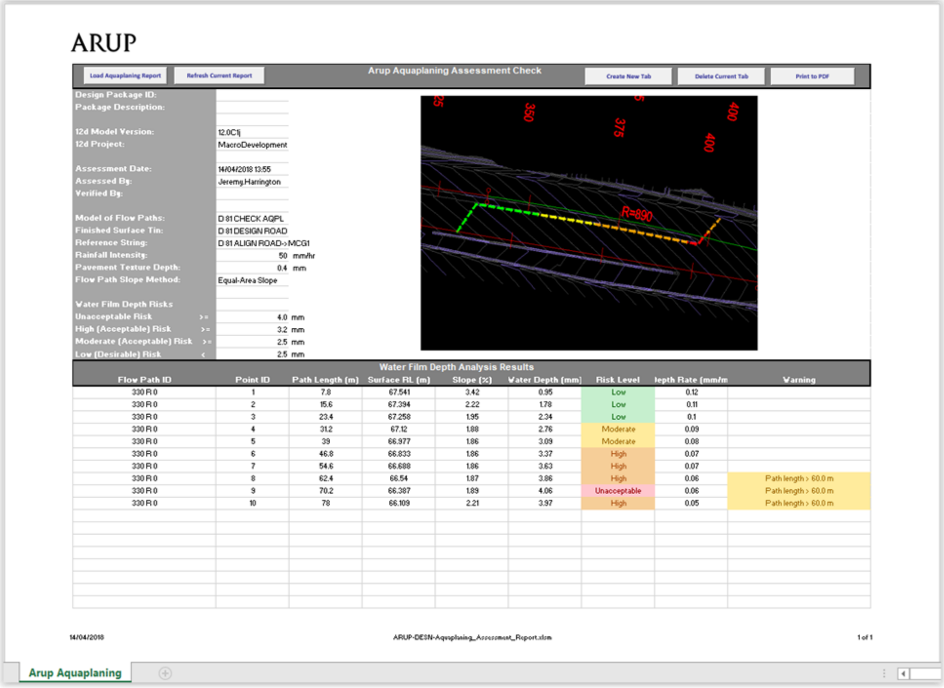

Figure 7 – Macro panel upon successful completion

as well as the model on which to generate the flow path, whether to clean that model before creation, and where to export the aquaplaning check results .CSV file that is generated by the macro.

Lastly, the macro includes a check box to specify whether to launch the custom Microsoft Excel aquaplaning results template file. This is a simple macro-enabled Excel spreadsheet which has been developed to load in the results that are exported to CSV and display them in a presentable manner (see Figure 6).

This macro is essentially an extension on the capabilities of the current Aquaplaning Risk macro that is shipped with 12d Model by default. However, by building in the ability to automatically and dynamically determine and draw an overland flow path from the cursor position, this macro has applications outside that of standard aquaplaning checks. It can be used to review flow paths anywhere in the design or survey model to further inform the road and drainage design, and it removes the potential for human error. This can assist designers in identifying the best locations for inlet pits and kerb breaks to efficiently manage the capture of overland flows during rainfall events.

The macro has also been further developed to create a trimesh of each segment of the resulting flow path, with all design check and flow risk attributes added to each trimesh. This trimesh creation allows the user to export the aquaplaning risks to IFC which can then be reviewed in a federated 3D model environment such as Navisworks, allowing the design review process to move away from paper-based reviews.

Similarly, to overcome the requirement to run multiple analyses individually, Mr Stewart developed the ‘Batch Network Analysis’ macro to enable the batch-running of drainage networks (refer to Figure 11).

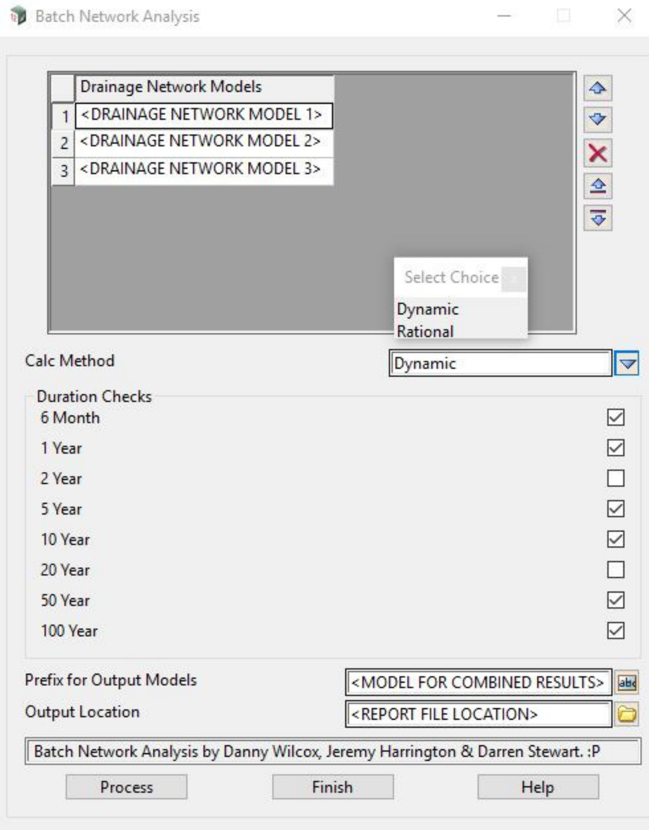

Figure 11: Batch Network Analysis panel

This macro enables users to undertake the following in the confines of a single 12d Model panel:

• Nominate all drainage network models to be analysed--

o The user selects which network models they require to be included in the analysis. The models that are selected are analysed for each storm event. When all storm events are completed, the macro moves on to the next network model and repeats the process.

• Select whether rational or dynamic analysis is used--

o The required analysis type can be selected prior to running.

• Select the storm events to be run from 6 month ARI up to 100 year ARI--

o A number of storm events can be selected prior to running.

• Specify the output models and assign prefixes--

o The user enters the prefix as the name of the combined model. When all analyses are complete, the macro combines the resulting models, names it as the nominated prefix, and applies a suffix depending on the event type and current date. The suffixes outputted include event type, flooded widths, and sag ponds. For example, the outputs provided by a single run of the macro may be:

- D 30 NETWORK 6m 20180120
- D 30 NETWORK 10Y 20180120
- D 30 NETWORK 50Y 20180120
- D 30 NETWORK 10Y FLOODED WIDTHS 20180120
- D 30 NETWORK 10Y SAG PONDS 20180120
- Output a series of trimeshes for flooded widths, sag ponds, HGLs (refer to Figure 12)

o Trimeshes are exported for inclusion in a BIM model if required. HGL trimeshes contain attributes that can be interrogated by reviewers.

• Output a report spreadsheet of design non-conformances--

o An Excel spreadsheet is outputted highlighting non-conformances in the design, including:

- Are pit freeboard requirements achieved?
- Have minimum self-cleansing velocities been met?
- Has the minimum drop across pits been applied?
- Have minimum and maximum pipe grades been met?
- Have the allowable pipe cover limits been exceeded?
- What pits are deep enough to require step irons?
- Are there any lost flows within the network (*i.e.* are bypass strings all linked up)?
- Are there any unacceptable pipe lengths?

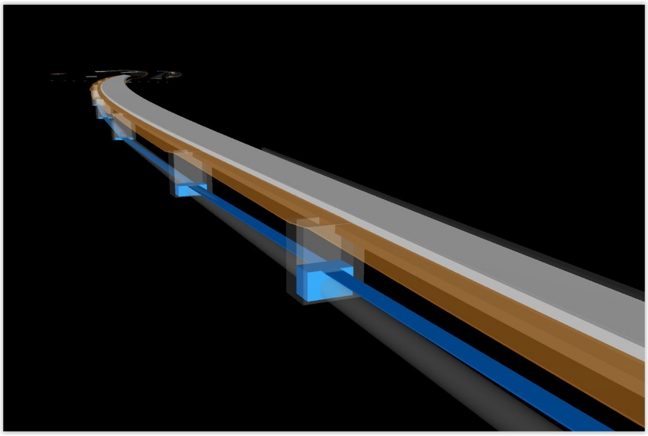

Figure 12 – Flow Width / Sag Pond / HGL Tri-Meshes

The Result

These macros have now been used on a number of projects within Arup, and have dramatically increased efficiency and design consistency, which significantly reduces the need for any drafting input, saving the team time and money across the board.

Roads and Highways

12d Model's design option is the smarter solution for the design, modification and maintenance of Road and Highway projects.

Enjoy advanced 3D tools to design local and major roads, intersections, roundabouts, highways, interchanges and much more.

Ports and Dredging

12d Model is the solution for port infrastructure and dredging, easily managing the very large datasets and complex volume calculations often required by these projects.

A complete range of flexible and customisable volume calculation tools allow teams to extract and present the information quickly and easily.

Land Development

12d Model is the most versatile solution for the creation of sustainable land development projects, including residential, commercial and industrial developments, recreational areas, landfills, and agriculture projects.

Easily manage all aspects of your land development project from earthwork quantities, road design utilities and drainage design.

Airport Infrastructure

12d Model provides a solution for the design, construction and analysis of new airports, as well as the upgrade and maintenance of existing runways and airport infrastructure.

Easily manage large airport infrastructure projects and share data across multi-disciplinary teams.

Rail

12d Track has been specifically designed for the survey, design and construction of light, heavy and high speed rail projects.

Extensive railway tools in 12d Track allow the rail designer to quickly and easily design their projects. These options are built on the existing 3D modelling and design tools available in 12d Model.

Mining Infrastructure

12d Model's powerful set of exploration, site investigation, survey and analysis tools are crucial for the initial design, construction and ongoing operation of mining projects.

Comprehensive tools for the survey, design and construction of access roads, railways, earthworks and services allow for the coordinated design and management of mining infrastructure from within 12d Model.

Drainage, Sewer and Utilities

12d Model provides comprehensive tools for the design, analysis and optimisation of stormwater and sewer projects using rational, dynamic (hydrograph) and 2d drainage methods.

Powerful clash detection management allows for efficient 3D modelling of service networks such as gas, electricity, telecommunications and water prior to construction.

Surveying

12d Model is a complete surveying package providing the tools to manage all facets of surveyed data including LIDAR, topographical, as-built, conformance, traversing, geodetics, data mapping, labelling and much more.

The 12d Field option runs on a ruggedized tablet and gives the user access to full 12d Model functionality, allowing you to take the entire project into the field with the most comprehensive pick-up and set-out tools.

Oil and Gas

12d Model assists with the design, construction and mapping of oil and gas pipelines, original site exploration and the wide range of infrastructure required for oil and gas projects.

Accurate 3D modelling and the ability to share data between users allow teams to quickly and easily coordinate designs.

Construction

12d Model is the ultimate software for construction with powerful set-out options, direct interfaces to machine control and detailed conformance reporting and auditing.

Manage 3D data and control volumes, quantities and progress claims with 12d Model. Set-out your project and undertake conformance and as-built surveys live on-site using 12d Field.

Rivers, Dams and Hydrology

12d Model handles very large datasets and interfaces with a wide range of analysis packages, making it perfect for flood studies and the management of rivers and dams.

12d has partnered with industry leading analysis software, allowing users to apply 2D drainage analysis from within 12d Model.

Environmental

12d Model's ability to handle very large datasets combined with flexible and comprehensive 3D analysis and modeling tools make it perfect for a wide variety of environmental projects.

Existing workflows can adopt 12d Model easily as it allows users to directly interface with GIS systems and most software packages and file formats.

Why Choose 12d?

- **Powerful data processing & intelligent functionality.**
- **Modular, easy to update & completely customisable.**
- **Seamless integration with major industry software and hardware.**
- **Used in over 55 countries worldwide.**
- **Friendly support & training from industry experts.**

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