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COUPLING OF SIMULATION MODELS FOR MIXED GRAVITATIONAL AND PRESSURIZED SYSTEMS

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ABSTRACT

Several hydrodynamic simulation models have already been developed for gravitational and pressurized drinking water networks. The simulation of different transport types is based on different mathematical and physical models. Both the gravitational and pressure type models can simulate the selected transport type appropriate, while simulation of the other type is missing or only approximate. However, the complex, mixed networks are including both gravitational and pressurized parts. The exact simulation of mixed networks needs the connection of the gravitational and pressurized elements. We developed a new coupling method for mixed models. The introduced new objects, their functions and operations are presented. The coding of a new coupled simulation software for mixed systems can be based on the presented methods.

Keywords: drinking water network; coupling; hydrodynamics; simulation; mixed network

1. INTRODUCTION

In drinking water networks, the question of the quality change is emerging recently. The pollutants transport in the objects of water acquisition, distribution and reservation is in the focus. Most of theories describing the water quality change is regarding the residence time as one of the most important simulation parameter [1]. The determination of residence time and the transport processes is simulated by hydrodynamic network models. Some drinking water networks are transporting the collected the drinking water in gravitational pipes and then pumping stations are forcing the water into pressurized pipe network. The drinking water quality is changing permanently in the network from the production until the consumption. In order to simulate the quality change, the hydraulic model of both the gravitational and the pressurized system should be built. The two systems having different calculation methodology can be connected by the calculation background, providing the stable mass balance. In order to connect the systems, the capabilities of the different hydrodynamic network simulation software (available results, access points etc.).

2. MATERIALS AND METHODS

2.1 Common practice

The pressurized drinking water distributing networks nowadays are generally modelled by computer simulations. There are available several open source and commercial software for model building and simulation task. Most of the software are based on the computational engine of EPANET 2.0 [4]. Its wide spreading was helped by the public domain licence providing free copy and distribution. For our developments we selected the EPANET version improved by OWA. Its main advantage is the continuously updated python wrapper. This python wrapper is bringing the independent python wrappers (owa-epanet, pyswmm, flopy etc.) into one integrated development environment, providing the coherent management of the results.

The several gravitational simulation software (EPA SWMM [2][3], Mouse/Mike Urban etc.) are quite similar regarding their technical efficiency, capacity and reliability. All of them can solve the generally accepted Saint Venant equations by dynamic wave methods. Only their user interface and data management are significantly different. The EPA SWMM can be qualified weak only in IT views like relatively simple database management, the missing integration into GIS and the missing calibration. Its open source feature was providing several free and commercial improvements (XPSWMM, PCSWMM, C3D SSA). Based on the examined possibilities the SWMM software published and continuously updated by EPA was selected for our developments. The available open source code and the detailed documentation are enabling the required modifications.

2.2 Methods

Both the gravitational and pressurized system models and their simulation is well developed and some simulation models can compute the mixed systems, but only with several approximations and simplifications [5]. We developed a methodology for coupling of gravitational and pressurized networks in an integrated model.

2.2.1 Topology of connections

The hydrodynamic models included in the integrated model should be connected by common objects by their cross-compliances. We introduced the submodel term: the gravitational or pressurized network constituting one part of the integrated model and the submodel is connected to one or more other submodels at the given boundary.

The connections between each submodel should be designated regarding the given physical connection. The objects constituting the EPANET and SWMM models can not be matched directly to each others. Complex objects built from basic objects should be created during the definition of boundary conditions. This way the mass balance will be stable, which is crucial for the computation of water age calculations and the transport processes.

2.2.2 Storage – Tank Type Connection

In case of the suction tank of a pumping station in the water supply system is directly (without breaking the fluid line) connecting to the gravitational network, both of the gravitational and pressurized system should contain a storage tank (Figure 1). The surface level of the storage tank

Vol. 5, No. 02; 2020

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(the absolute pressure head) influencing the duty point of the pump and the transported flow of the gravitational system.

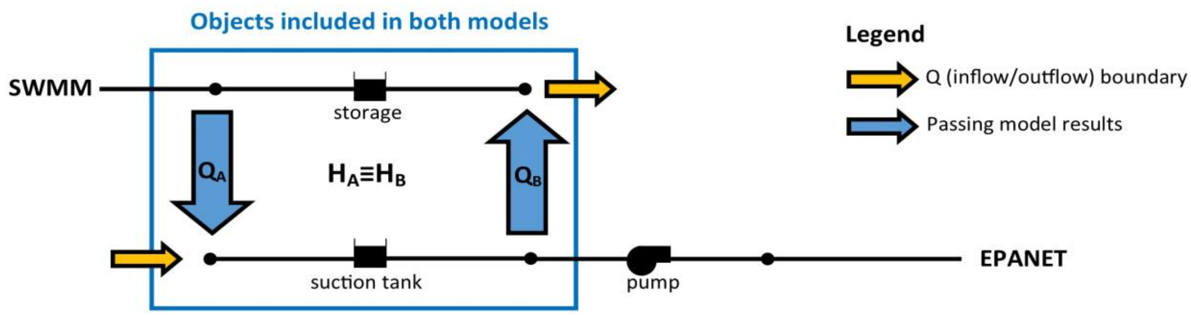

Figure 1: Storage-tank type connection

2.2.3 Outfall – Tank Type Connection

In case of the suction tank of a pumping station in the water supply system is not directly (with breaking the fluid line) connecting the gravitational network, the gravitational system ends in an outfall (Figure 2). The surface level of the storage tank (the absolute pressure head) influencing the duty point of the pump, but not the transported flow of the gravitational system.

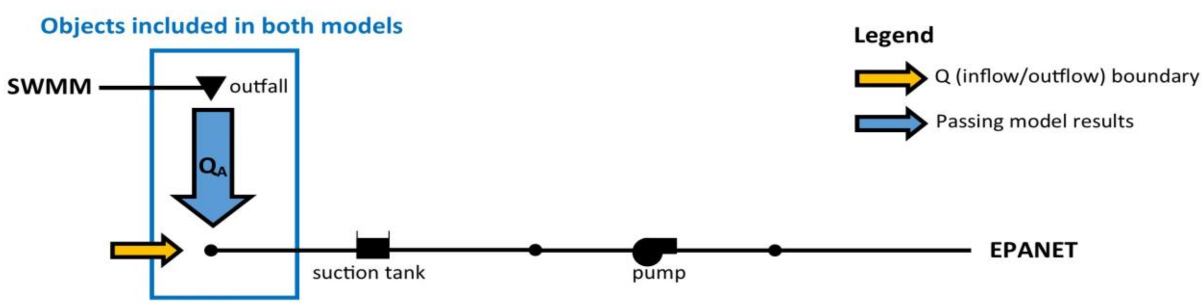

Figure 2: Outfall-tank type connection

2.2.4 Junction – Junction Type Connection

Two pressurized network can be connected with a Junction-Junction type connection (Figure 3). But this connection has significantly stronger limits then the previously introduced connections. The flowrate inputs can be given by pre-set or measured time series, the direct consideration of the characteristic curve of the substituted pump is not possible. This limit is not problematic, if the measured flow rate of the given boundary is available and the purpose of the modelling is to track the route of the fluid and not the energy consumption computations.

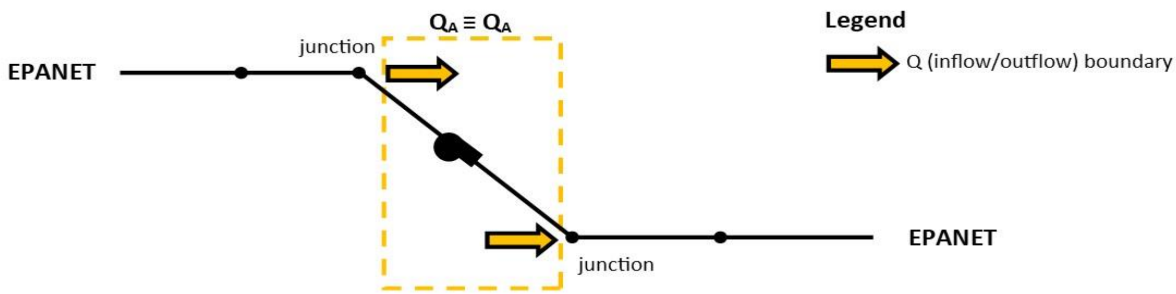

Figure 3: Junction-junction type connection

On the output side there should be an open boundary regarding the flowrate, typically a tank, reservoir or pressure dependent outlet (emitter). Otherwise the equations describing the flowrates can not be solved explicitly.

2.2.5 Data Storage of the Submodel Connections

In order to store the data of submodels, those python classes and methods were necessary to develop, which are essential for reading and storing the submodels in memory. The simultaneous simulation is requiring the load of different type connections. The load of each connection and submodel is executed by the parser of the JSON file after the load of the integrated project file.

2.2.6 The Structure of the Integrated Project File

In order to save and continue an earlier started model building and mode connecting task, the structure of the integrated project file had to be first prepared. Since each submodel is stored in different format depending on its type (gravitational or pressurized), better to store the path of the models and the project file describing their connections to each other, than to import all the submodel into one monolithic file.

This principle has more advantages. The developing project is not sensitive to the change of the software running the submodels and several developers can work simultaneously on the whole project. Finishing the tasks and updating the description files of each submodels, the whole integrated model is also updated.

The project description file should contain:

- The metadata regarding the project:
    - name of the project
    - solver version
    - project file version
    - date of creation
    - date of saving

- Data regarding the submodels:
  - name of submodels (identifiers)
  - type of the submodel
  - the solver applied for solving the submodel
  - the path of the submodel (absolute or relative)
  - start time of simulation of submodel
  - default time step of submodel simulation
- Connection between submodels:
  - names of A and B side (identifiers)
  - type of connection
  - direction of connection
  - identifiers of connection points
- Data regarding the result files
  - name of result file
  - path of the result file
  - date of last simulation

In order to have the project file easily editable and viewable, it is stored in a predefined JSON structured file. The JSON is a de facto industrial standard, which is much more readable and having less memory demand. JSON is editable in stand-alone text editors, and there are several free, even browser based editors enabling structural edition of the file.

3. RESULTS

Based on the described methodology we can introduce some preliminary results.

3.1 Stability

The solver of the integrated model should be prepared for the handling of such exceptions when a submodel is running into an error. The error should be preferably avoided, but in case of some events or controls, when any submodel is running into error or terminating before planned.

3.2 Mass Balance

In order to simulate the route of the water and the pollutions at the highest possible precision, the mass balance error of each submodel should be insignificant.

3.3 Pressure and Velocity

The pressure and velocity relations can be seen on an integrated directed graph or independently for each submodels. For displaying the simulation results shapefile are applicable.

3.4 Accuracy

In case of the storage-tank connection applied in the test model, there is a possibility to compare the accuracy of the simultaneously running models to each other. The accumulated error can be quantified by the surface level of the two basins.

Vol. 5, No. 02; 2020

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3.5 Multi-Threading

Both the SWMM and the EPANET 2.1 can be run parallel, which has great prospect regarding the scalability of the integrated model. The EPANET models are typically running as 1 thread, while the SWMM solver is prepared for multi-thread running. Therefore, not critical to run the SWMM models sequentially between 2 time steps. However, having more EPANET models in the integrated project, they are worth to run parallel. Based on this principle, best results can be achieved by preparing multi-thread running of each submodels.

3.6 Profiling the test model

During the development and running of the test model the profiling of the code necessary in order to utilize the available computational capacity by the integrated model at the highest level. During the profiling the time consumption is measured for running of each submodel, the data process, the save process and the data transfer required for the submodel connections.

The purpose of the profiling is to have the submodels running not slower in case of integrated model than in case of their stand-alone running.

3.7 Saving the results

The results are saved in the format based on the type of each submodel. For post-processing and display the results are read into numpy matrices. Because of the different number of dimensions, the data storing of the submodel are differing. After the creation of the result files, the creation date is registered into the project file. Based on this information, further check of result file is possible, whether the integrated model should be rerun.

4. Discussion

The optimal software development environment and the modelling software were selected: SWMM, EPANET. The connection topology of the modelling software was developed providing their further hydraulic and water quality interoperability. The coding process can be executed by the described developed coupling methods and principles.

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Dr. Roland Fulop was graduated at the Budapest University of Technology as civil engineer and has been working for the same university at the Department of Sanitary and Environmental Engineering as researcher and teacher. He has significant results on the fields of drinking water networks. He certificated his PhD degree in the field of the reconstruction. His current research scope is modelling and reconstruction of drinking water networks.

Dr. Marcell Knolmar was graduated at the Budapest University of Technology as civil engineer and has been working for the same university at the Department of Sanitary and Environmental Engineering as researcher and teacher. He has significant results on the fields of computer aided sewer design, geographical information system of sewer networks and designing of rain monitor device. He certificated his PhD degree in the field of the computer aided sewer design. His current research scope is the hydraulic modelling of sewer networks, specially the sediment transport of sewer networks.