CAD/CAM/CAE

INTEGRATION OF PIPING LAYOUT EVOLVES SHIP STABILITY ASSESSMENT TOWARDS REALITY

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An external damage might not only flood a damaged compartment but extend through openings or compartment connections further into the vessel. In stability regulations, this often is described as progressive flooding. PIAS accommodates this phenomenon by a sub-system that dates back to the 1990s called Complex Intermediate Stages of Flooding. It works on the basis of non-uniform preset filling percentages per compartment and, where necessary, supplemented by virtual compartment connections. Although as such it works well and is widely used, this sub-system was never conceived for intensive usage. It has served the program users well over the past decades, however it has some limitations:

- Only virtual connections between compartments are supported. That means that a point in 3D space can be assigned as being 'the connection location', without any physical object connected to that point.
- Only one single location is supported as a connection point between two tanks.
- Data input and output is only in text.
- The computation of time to equalisation is supported, this however only for a single compartment connected to the sea and as a disconnected calculation, not integrated in the stability computation and assessment.

Considerations and development that let to evolvement

Since its establishment in 1980, SARC has been active in the shipbuilding industry developing software for, among other things, hull shape design, stability calculations and loading computer software. Its integrated computer program for ship design is PIAS, which is an acronym for Program for the Integral Approach of Ship design. PIAS comprises modules for the design of hull and internal geometry and for the computation and assessment of, among others, intact stability, deterministic and probabilistic damage stability, longitudinal strength, resistance and propulsion.

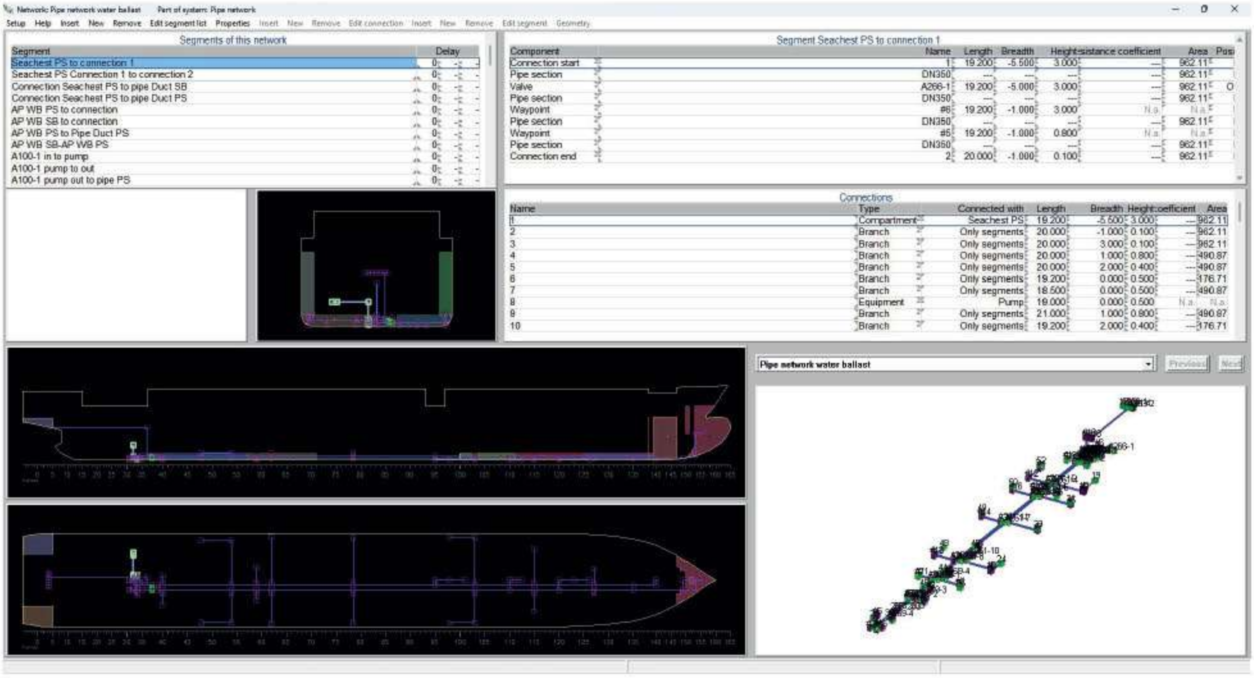
At SARC we anticipated an ever-increasing attention of ship designers to the effects of filling and flooding through holes, openings, ducts and pipes, caused by stringent rules and increasing scrutiny by authorities and classification societies. Rules and regulations address the aspects of openings, internal connections and damage to piping systems numerously. IACS Unified Interpretations, for example, states: "Progressive flooding through internal pipes: in case of damage of an internal pipe which is connected to an undamaged compartment, the undamaged compartment should also be flooded, unless arrangements are fitted which can prevent further flooding of the undamaged compartment." Another example is taken from IMO (2020) [1] on probabilistic damage stability: "The factor s_i is to be taken as zero in those cases where the final waterline immerses the lower edge of openings through which progressive flooding may take place and such flooding is not accounted for in the calculation of factor s_i. Such openings shall include air pipes, ventilations and openings which are closed by means of weathertight doors or hatch covers." Finally, MSC (2020) [2] links consequences to equalisation times by cross-flooding arrangements, which are constructed to reduce the heel in the final equilibrium condition, with thresholds of one and 10 minutes.

In recent years advances in modelling of algorithms on internal flooding after damage have been made. With an eye on these developments, dedicated decisions and software development have resulted in a new PIAS subsystem for next-level damage stability assessments, including major effects of internal flooding and its progression.

Paving the way for a new method in PIAS

Based on pipe connections, the new system is built on the DEPXI standard. This extensive standard describes a wide variety of entities. Five entities have been chosen for the modelling of the shipboard piping system:

- Equipment that is connected to a pipeline but is not a part of the latter such as an engine or a chiller. Equipment plays no role in the computations, it is defined for the completeness of the definition and drawings.
- Piping system – which is a collection of pipes belonging to the same type of application. For example, 'Ballast water' or 'Methanol'.
- Piping network – a closed system of connected pipes which belongs to a piping system. A piping network is the core of the piping data structure.
- Piping segment – a branch of the piping network, that extends between two points without sub-branching in between.
- Piping connection – a part located at the extremities of piping segments, which are:
    - At a branch, where multiple piping segments meet.
    - At the outside of the vessel as unprotected openings connecting with the atmosphere.
    - At the outside of the vessel as an opening



Segments of this network

Segment	Delay		
Seachest PS to connection 1	0	-	-
Seachest PS Connection 1 to connection 2	0	-	-
Connection Seachest PS to pipe Duct SB	0	-	-
Connection Seachest PS to pipe Duct PS	0	-	-
AP WB PS to connection	0	-	-
AP WB SB to connection	0	-	-
AP WB PS to Pipe Duct PS	0	-	-
AP WB SB-AP WB PS	0	-	-
A100-1 in to pump	0	-	-
A100-1 pump to out	0	-	-
A100-1 pump out to pipe PS	0	-	-

Segment Seachest PS to connection 1

Component	Name	Length	Breadth	Height	sistance coefficient	Area	Pos
Connection start	1	19.200	-5.500	3.000	---	962.11	
Pipe section	DN350	---	---	---	---	962.11	
Valve	A266-1	19.200	-5.000	3.000	---	962.11	O
Pipe section	DN350	---	---	---	---	962.11	
Waypoint	#6	19.200	-1.000	3.000	N.a.	N.a.	
Pipe section	DN350	---	---	---	---	962.11	
Waypoint	#5	19.200	-1.000	0.800	N.a.	N.a.	
Pipe section	DN350	---	---	---	---	962.11	
Connection end	2	20.000	-1.000	0.100	---	962.11	

Connections

Name	Type	Connected with	Length	Breadth	Height	coefficient	Area
1	Compartment	Seachest PS	19.200	-5.500	3.000	---	962.11
2	Branch	Only segments	20.000	-1.000	0.100	---	962.11
3	Branch	Only segments	20.000	3.000	0.100	---	962.11
4	Branch	Only segments	20.000	1.000	0.800	---	490.87
5	Branch	Only segments	20.000	2.000	0.400	---	490.87
6	Branch	Only segments	19.200	0.000	0.500	---	176.71
7	Branch	Only segments	18.500	0.000	0.500	---	490.87
8	Equipment	Pump	19.000	0.000	0.500	N.a.	N.a.
9	Branch	Only segments	21.000	1.000	0.800	---	490.87
10	Branch	Only segments	19.200	2.000	0.400	---	176.71

GUI PIPING

with a Weathertight Air Pipe Closing Device (WAPCD)

- With a compartment, a connection to a tank or compartment at a certain location.
- With equipment, a connection to a piece of equipment at a certain location.
- With a piping component, as a part located in a piping segment. A piping component can be, for example, a waypoint, elbow, valve, pressure relief valve, reducer, check valve, internal WAPCD or a pipe section.

The inclusion of the connections between compartments in their actual arrangement brings the assessment of damage stability a step closer to reality. The damage stability is assessed based on initial damage cases and the flooding of undamaged compartments through pipe or duct connections with damaged compartments. In that sense, damage cases are no longer necessarily static with predefined stages of flooding but have evolved to cases where the initial damage case is defined, the progress of additional flooding can be assessed time dependant and with consideration of the flow characteristics of the connections between the damaged and undamaged compartments.

Flow characteristics depend on numerous aspects of which the frictional resistance of pipes is a complex matter. The frictional resistance will be determined based on, amongst others, the following user-defined information: cross-sectional shape, cross-sectional dimension and a resistance coefficient. The coefficient can be determined from one of three available methods. Another complex matter is the energy loss due to fluid outflow from a pipe. For flow resistance of pipes and components, IMO has adopted three resolutions. These treat the reduction of velocity as similar but not equal. In order to harmonise these regulations, as well as to accommodate more than a single pipe outlet, the user can choose between the denominator or user-defined outflow energy loss. Both options enable users to adapt the calculations to the specific application and needs of each calculation.

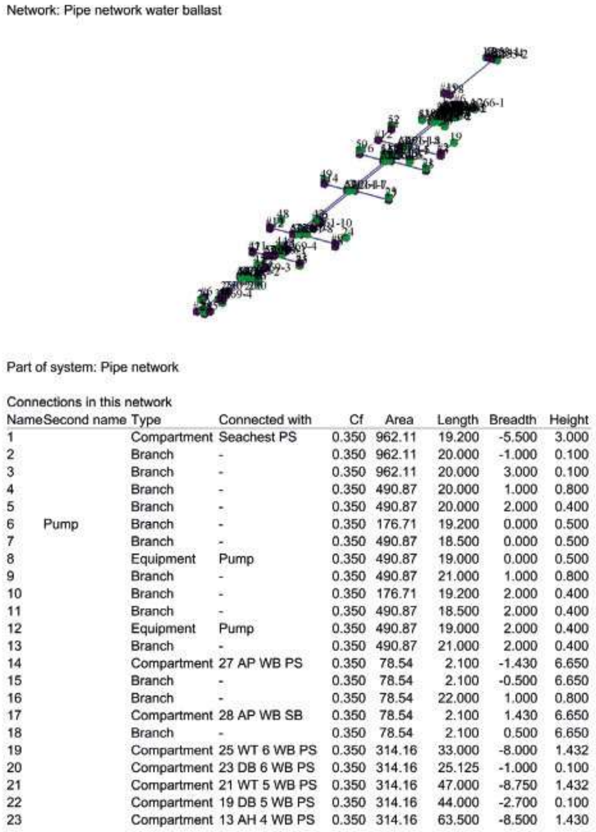
Where does the way lead to in PIAS?

The damage stability calculations based on the new piping-based system has been developed with the aim to create a framework for next-level damage stability assessments, which is suitable for large-scale application and comprehensible for the commonly trained naval architect. The presented piping networks, combined with existing representations of loading conditions, hull shape and compartments provide two categories to compute the damage stability; as a time-domain analysis and as an analysis divided over stages of flooding.

The first category, time-domain analysis, is based on the physical method that one or more compartments will be flooded over time. This system has a clear understandable physical meaning and represents the reality better than the conventional system of intermediate stage of flooding. Moreover, time is an aspect in some stability criteria and time-to-capsize assessments.

The analysis as per stages of flooding is the second system, which models the flooding in stages and independent of time. The implementation of this system has been developed on standard stability regulations where the concept of intermediate stages of flooding is applied with fixed percentages, i.e. 25%, 50%, 75% and 100%. Also, compartments may not always be flooded with the same percentages, a small connection between compartments may lead to a slower flooding than the damaged compartment.

Maintaining the notion of percentual stages of flooding is based on the fundamental concept in present stability regulations, which is familiar to authorities and



Network: Pipe network water ballast

Part of system: Pipe network

Connections in this network

Name	Second name	Type	Connected with	Cf	Area	Length	Breadth	Height
1		Compartment	Seachest PS	0.350	962.11	19.200	-5.500	3.000
2		Branch	-	0.350	962.11	20.000	-1.000	0.100
3		Branch	-	0.350	962.11	20.000	3.000	0.100
4		Branch	-	0.350	490.87	20.000	1.000	0.800
5		Branch	-	0.350	490.87	20.000	2.000	0.400
6	Pump	Branch	-	0.350	176.71	19.200	0.000	0.500
7		Branch	-	0.350	490.87	18.500	0.000	0.500
8		Equipment	Pump	0.350	490.87	19.000	0.000	0.500
9		Branch	-	0.350	490.87	21.000	1.000	0.800
10		Branch	-	0.350	176.71	19.200	2.000	0.400
11		Branch	-	0.350	490.87	18.500	2.000	0.400
12		Equipment	Pump	0.350	490.87	19.000	2.000	0.400
13		Branch	-	0.350	490.87	21.000	2.000	0.400
14		Compartment	27 AP WB PS	0.350	78.54	2.100	-1.430	6.650
15		Branch	-	0.350	78.54	2.100	-0.500	6.650
16		Branch	-	0.350	78.54	22.000	1.000	0.800
17		Compartment	28 AP WB SB	0.350	78.54	2.100	1.430	6.650
18		Branch	-	0.350	78.54	2.100	0.500	6.650
19		Compartment	25 WT 6 WB PS	0.350	314.16	33.000	-8.000	1.432
20		Compartment	23 DB 6 WB PS	0.350	314.16	25.125	-1.000	0.100
21		Compartment	21 WT 5 WB PS	0.350	314.16	47.000	-8.750	1.432
22		Compartment	19 DB 5 WB PS	0.350	314.16	44.000	-2.700	0.100
23		Compartment	13 AH 4 WB PS	0.350	314.16	63.500	-8.500	1.430

EXAMPLE OUTPUT

easy to understand. This concept has been labelled fractional, because in the essence compartments are filled by fractional amounts of the final volume. Additionally, a delay is available to specify a lagging in time. This finalises a simple system that supports the conventional intermediate stages and a bit beyond.

Imagine a compartment that is divided by a half-height bulkhead. Water can flow in a waterfall over the full length of the bulkhead edge, possibly without backflow when rolling back to the other side. When the compartment would only be connected through a small diameter pipe, it would not allow significant fluid to transfer during the roll period. To differentiate between the two example cases, a 'minimum cross-sectional area for instantaneous fluid passage' can be specified. This user defined program setting allows the flow when the actual area is larger than this minimum and blocks the flow if the actual area is less than this minimum.

In calculations regarding larger angle stability the transferring fluid may not result in a significant increase of the heeling moment and the time between time steps may not suffice for the vessel to heel. While analysing the stability in time-domain, to solve this issue the GZ curve is computed without time effects while the ingressed or shifted fluid during heel in the next time step is omitted. For each time step a complete stability report could be computed, however the amount of GZ evaluations can be defined by the user. For each time step at the least draft, trim, heel and fluid quantities are available.

Expected embracement by users and authorities

Developing software that deals with phenomena in a different manner always raises questions around how users and authorities will appreciate the working of the software and the results it will produce.

The design of our piping software and its underlying algorithms, data structures and choices are well documented in a specification document, a scientific paper (Koelman, 2024 [3]) and a bit more extensively in the manual. Additionally, design considerations or sketches from the implementation record can be made available on request.

That should enable inspection bodies to perform their independent verification of the proper functioning of the software. A reassuring idea, incidentally, is that a time domain calculation is explicitly supported by regulations such as MSC (2020). Concerning the ship design verification, i.e. the appraisal of damage stability computations, the clarity of the input data will only improve. Where with older PIAS's compartment connection facility the physical reality was to be translated into tables with numbers representing virtual 'connection', now the basis is a topological and geometrical model which is easy to verify, as demonstrated by the report of the input.

Outlook for the future

Looking towards the near future, the next development of this system will comprise time domain computations integrated in probabilistic damage stability. In this way, the exceedance of the maximum allowable equalisation time can automatically be determined and incorporated in the table of results of damage cases and their probabilities, and ultimately in the attained subdivision index. Moreover, the introduction of damage to pipes is a development that will be added to the system. In PIAS's probabilistic damage stability module, for example, the damage cases are presently generated on the basis of compartment boundaries. This will be extended to include piping edges and corners as well.

Resuming, the new PIAS sub-system Piping offers users a clear, structured interface and menus where piping systems of various levels of complexity and their specific characters can be modelled. By including an intuitive definition of compartment connections with the piping systems, Piping is aimed to evolve stability assessment towards reality. SARC trusts that the newest addition to its software will help users assess stability in a modern manner that will be accepted and understood by authorities and users. ■

More information on the development of Piping can be found at the SARC website hwww.sarc.nl.

References

1. IMO (2020). *SOLAS Consolidated Edition, chapter II-1, part B.*
2. MSC (2020). *Resolution MSC.429(98)/rev.1: revised explanatory notes to the SOLAS chapter II-1* subdivision and damage stability regulations.
3. Koelman (2024). *Piping Layout Integrated in Ship Design and Stability.* IMDC2024.