Interreg

EUROPEAN UNION

Danube Transnational Programme

GRENDEL

Green and efficient Danube fleet

"Towards modernisation & greening of Danube inland waterborne sector and strengthening its competitiveness"

Output 4.1 – Innovative & greening inland vessel concepts of DANUBIA

Work Package 4 Preparatory actions

Version: 1.0

Date: 30/11/2020

FINAL

O 4-1_GRENDEL_Innovative vessel concepts_DANUBIA_v1.0_FINAL_2020-11-30

Project co-funded by European Union Funds (ERDF, IPA)

Interreg

EUROPEAN UNION

Danube Transnational Programme

GRENDEL

Green and efficient Danube fleet

"Towards modernisation & greening of Danube inland waterborne sector and strengthening its competitiveness"

Output 4.1 – Innovative & greening inland vessel concepts of DANUBIA Part 1: On-board Sewage Treatment

Work Package 4 Preparatory actions

Version: 1.0

Date: 30/11/2020

FINAL

O 4-1_GRENDEL_Innovative vessel concepts_DANUBIA_v1.0_FINAL_2020-11-30

Project co-funded by European Union Funds (ERDF, IPA)

Document History

Version	Date	Authorised
1.0	30.11.2020	DANUBIA

Contributing Authors

Name	Organisation	Email
Angelo de Mul	PureBlue Water	ademul@pureblue.nl
	DANUBIA	

Executive Summary

Consulting Service No.1 explored the possibilities for improving the environmental performance of river cruising related to on-board wastewater treatment. ES-TRIN (Technical Requirements for Inland Navigation Vessels) sets out technical requirements for on-board sewage treatment plants, including limit values for the outflow and conditions for type-approval of such plants.

Danubia Kreuzfahrten GmbH decided early-on to voluntarily equip their growing fleet of river cruise vessels with on-board sewage treatment plants even before harmonised European technical requirements entered into force. The main points examined through this consulting exploration related to the older cruise ships are:

- whether it is technically possible and economically feasible to install up-to-date on-board sewage treatment plants on those vessels which are so far equipped with collection tanks, and
- whether it is technically possible and economically feasible to upgrade existing on-board sewage treatment plants to current outflow emission standards.

Lot 1 - Technical study on installation of new on-board sewage treatment plants

The dominant developments regarding the on-board sewage treatment systems are the Moving Bed Biofilm Reactor (MBBR) and the Membrane Bioreactor (MBR). Both technologies are based on two steps, waste conversion and separation.

Pureblue Water completed a technical feasibility study based on the MBBR technology for the model vessel Amadeus Rhapsody, which is a vessel equipped only with collection tanks. The main limitations, in the case of this type of vessels, arise because of the lack of space on-board. This investigation focused on all the possible options for the installation of a new MBBR sewage treatment system despite the space constraints. The most technically possible plan, that can ensure the ES-TRIN effluent standards, includes the use of existing vessel tanks (bioreactor, sludge tank, emergency tank) and the addition of extra equipment e.g. vacuum system, DAF unit, grease separator and air treatment.

The upgrade does not only improve the environmental performance of the vessel but also the financial one. The total annual operational costs can be decreased up to 70%.

Lot 2 - Technical study on upgrade of existing on-board sewage treatment plants

The conversion of the old sewage treatment plants to advanced sewage systems was studied in Lot 2. The main obstacle of these cases is their low BOD removal efficiency which results to high effluent values. In order to overcome this issue and reach the effluent standards, the amount of bacteria per m^3 needs to be increased. This is possible to be achieved by introducing the MBBR technology. A number of mechanical and electrical works have to be implemented and a few new equipment to be installed e.g. DAF unit, grease separator and air treatment, to achieve the upgrade of the existing unit.

The question arisen, when it comes to the financial feasibility of these cases, is what would be the best to choose. The CAPEX costs of an existing sewage plant upgrade and the ones of a brand new sewage treatment unit differ slightly.

Lessons learned through the present consulting service/investigation

- Old type sewage treatment plants are designed based on old parameters and for 50% of the real pollution levels. Therefore, they do not function properly, effluent is still polluted and the units get blocked rapidly. Finally, the units need to be shut down regularly.
- Due to the high loads, the unit capacity needs to be 100% higher. This implies that most probably the floorspace of the old unit will not be sufficient. Either you need more space (room) or you will need more treatment capacity per m^2.
- The galley and laundry processes influence the performance of the sewage treatment plant

substantially. Proper treatment of these streams is highly needed.
- Food compactors increase the load substantially and overload the sewage plants.
- Cleaning agents influence the performance of sewage plant significantly. The use of chlorine is prohibited.
- Water treatment is too complex for engineers and they need backup from professionals.
- Biological processes are sustainable if chemicals are avoided. Sludge valorisation is recommended.
- Membrane systems are more complex, consume more energy, produce more sludge, have a higher operational demand. The annual maintenance costs are higher in comparison to the MBBR systems. Thus, they are not the most environmentally friendly choice.
- Buffer tanks increase the total weight of the ship which affects the fuel consumption.

The key elements for the future on-board sewage treatment systems are related to higher hydraulic and pollution capacities, smaller footprint, lower water consumption, operational and maintenance simplicity, limited sludge production, data normalisation and sustainability.

Interreg
EUROPEAN UNION
Danube Transnational Programme
GRENDEL

DANUBIA KREUZFAHRTEN GMBH

PURE BLUE

Annex 1.

Development of innovative and greening inland vessel concepts

On-Board Sewage Treatment

Extensive version of the first part of the presentation held by Radu Comanici (DANUBIA) at the GRENDEL Final Event on 29 October 2020

Project co-funded by European Union Funds (ERDF, IPA)

Scope of work

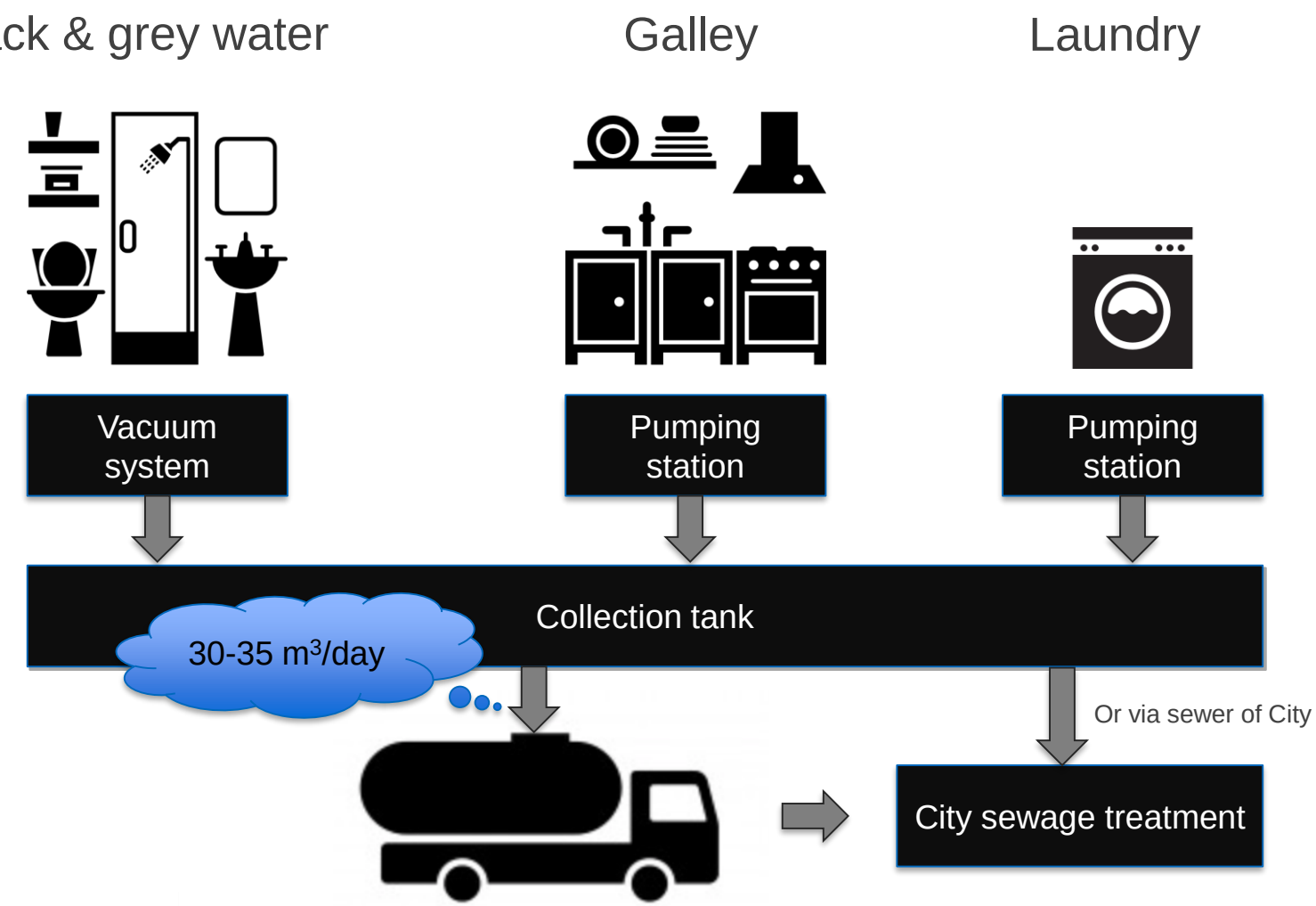
General:

Transitional provisions of ES-TRIN (Chapter 32) in general grant continuous use of on-board treatment plants installed before the entering into force of harmonised European legislation.

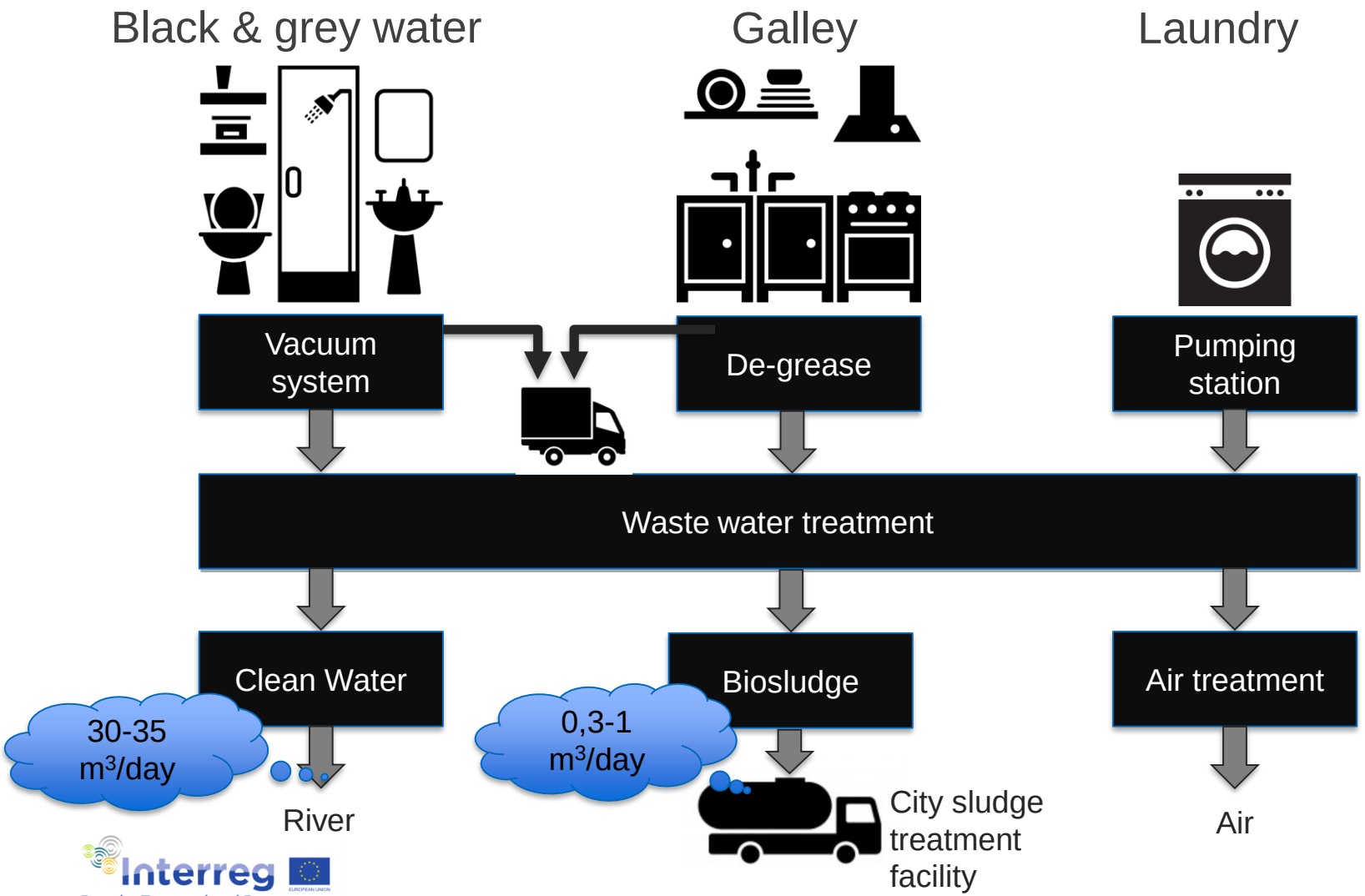
Detail:

- whether it is technically possible and economically feasible to install up-to-date on-board sewage treatment plants on those vessels which are so far equipped with collection tanks;
- whether it is technically possible and economically feasible to upgrade existing on-board sewage treatment plants to current outflow emission standards.

General information wastewater disposal to shore

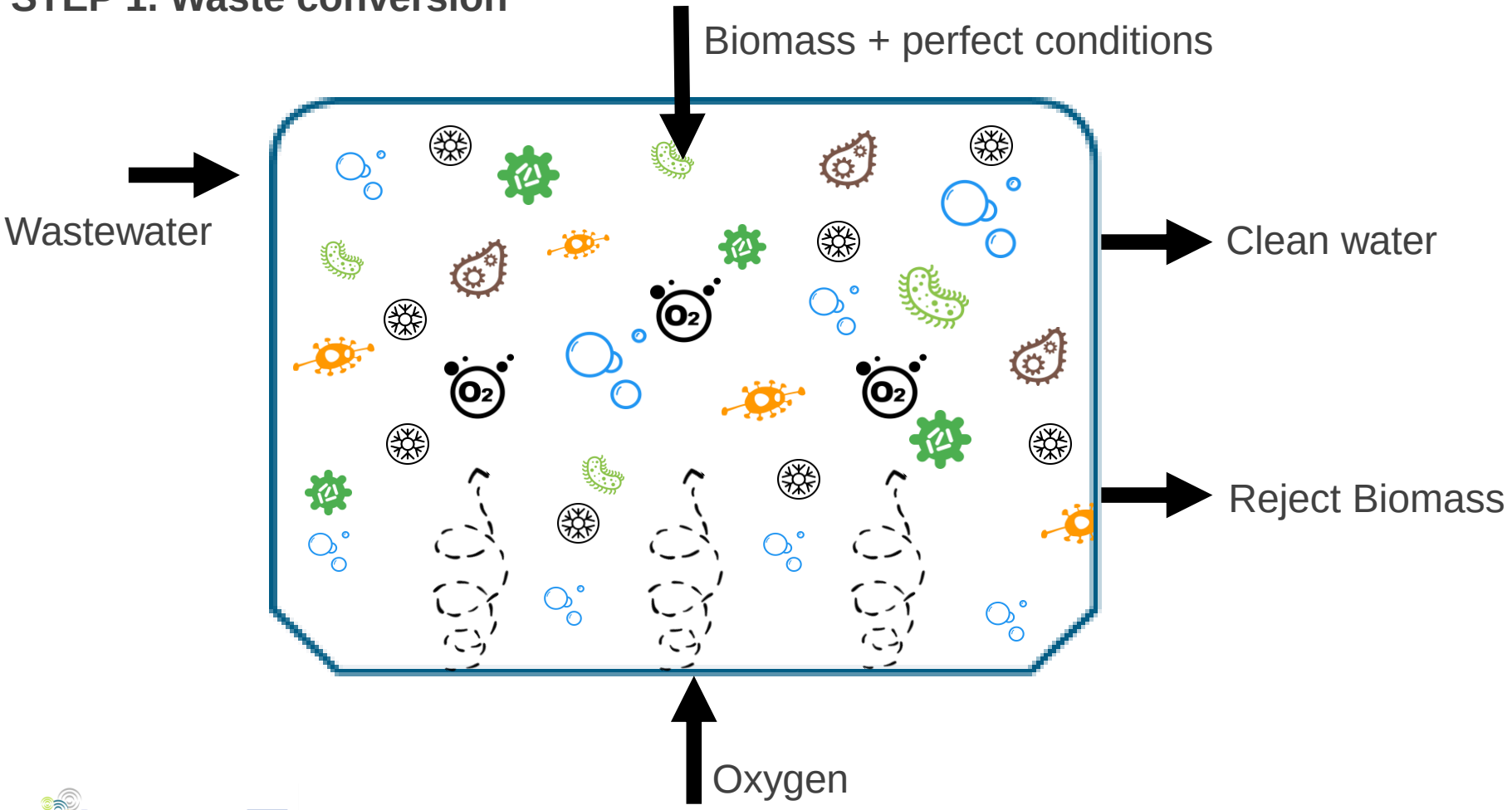


General information wastewater On-board treatment



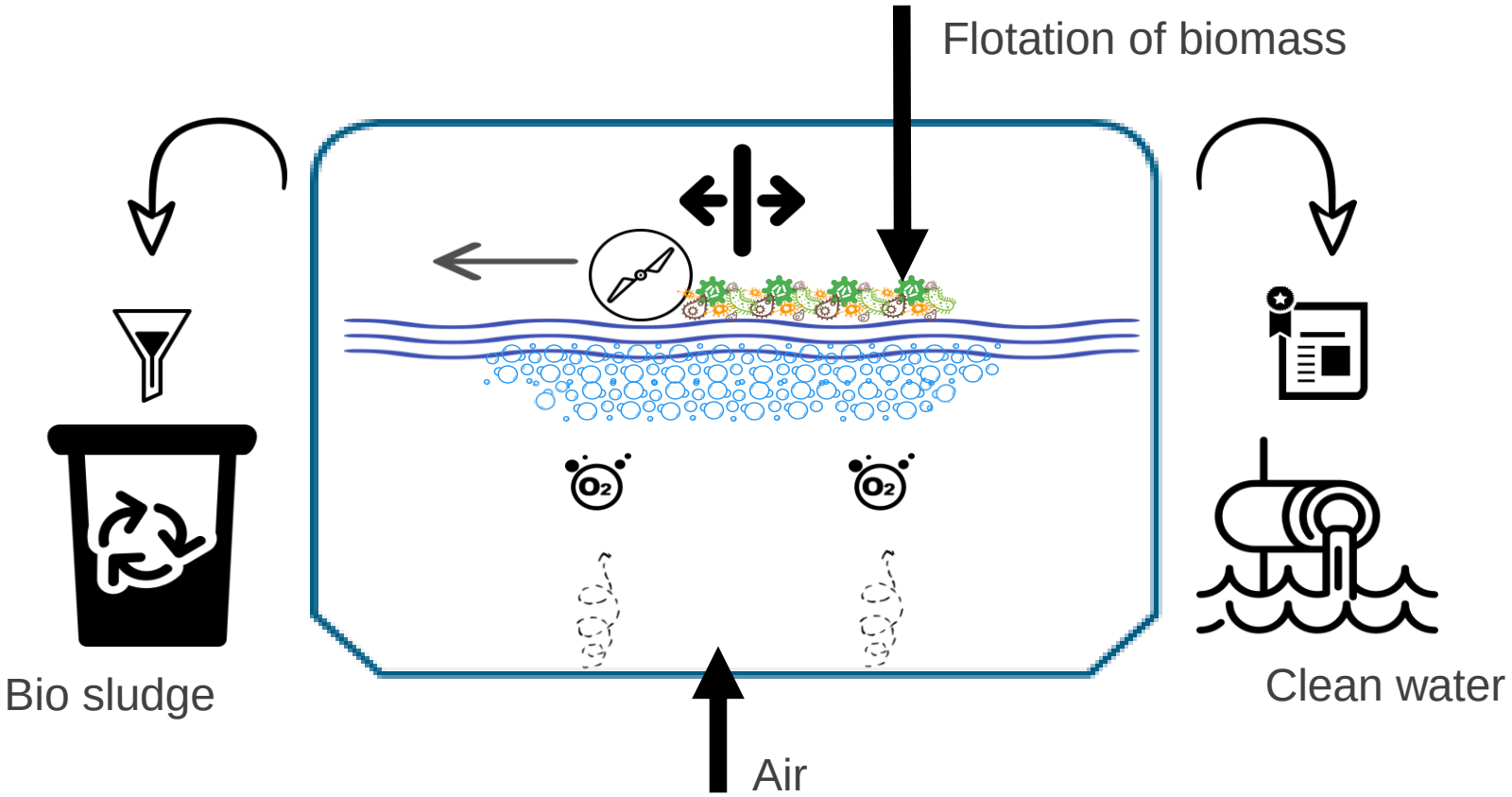
General information wastewater On-board treatment

STEP 1. Waste conversion



General information wastewater On-board treatment

STEP 2. Separation



General information wastewater On-board treatment

Possibilities

Step 1. Conversion

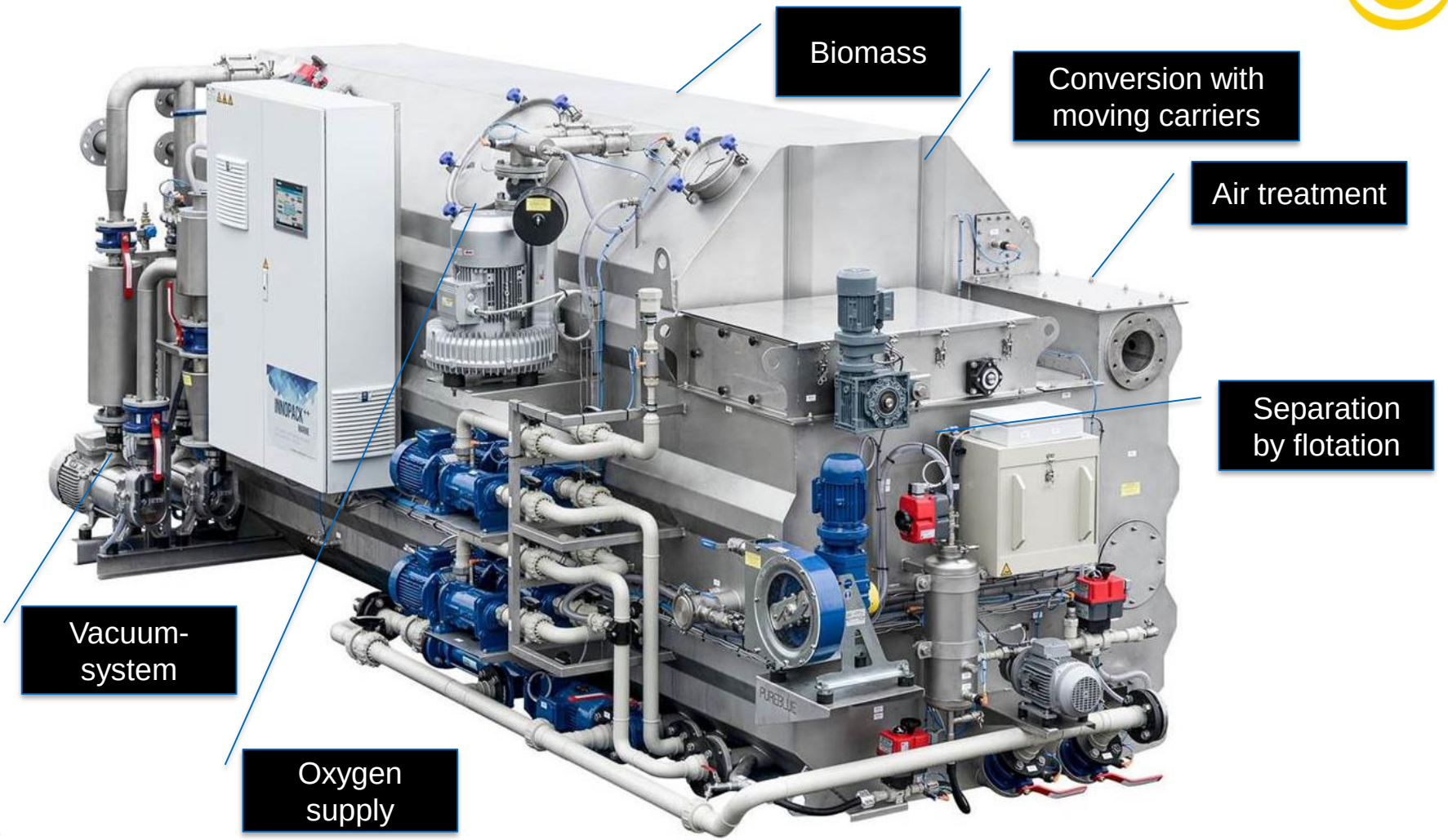
1. Biomass in suspension MBR
2. Biomass on moving carriers MBBR

Step 2. Separation

1. Separation by membranes MBR
2. Separation by flotation MBBR

Carrier MBBR INNOPACK++	MBR
Separation of water and sludge: membranes?	
No **Flotation separation**	Yes Membranes
No clogging possible **Free flow throughout the unit** **No physical barrier** **Automated control and cleaning of DAF System**	Vulnerable to clogging & blockage with high loads of COD, oil, fat, grease, solids Membrane = physical barrier Regular cleaning and operator knowledge necessary
Pre-screening needed?	
No	Yes
No storage/disposal needed	Storage/disposal for pre-screened waste
Grease Trap needed?	
Optional: **to protect long pipe lines** **or make WWTP smaller**	Yes to prevent membrane clogging
5-20 l of waste per day	500-2000 l waste per day
Clean In Place?	
No	Yes
Treatable waste water	
Galley water: optional, for compact reactor design	Galley water: if screened and grease is removed
Black water: direct	Black water: if screened
Grey water: direct	Grey water: if screened
Laundry water: direct	Laundry water: if screened
Reason: Innopack++ not susceptible to blockage	Reason: susceptible to blockages
Bio-technology	
Biofilm on carrier material	Suspended biomass (Active Sludge)
More active biomass	Less active Biomass on-board
Less energy consumption **Better oxygen transfer**	Higher energy consumption Lower oxygen transfer
No recirculation	Needs recirculation
No consumables	Every 3-4 years cost for new membranes
Waste Sludge	
3 - 5 times more concentrated = lower waste sludge volume = lower disposal cost	3 – 5 times less concentrated = more sludge volume
less storage required	more storage required (at least 3 times more)
Yearly start-up / shut down	
No CIP	Yearly CIP and costs
Direct start after inter-season break	Gradual start-up
No operator time needed	Service time

General information wastewater On-board treatment



Assessment Amadeus Brabant

Vessel of Lot 1. Typical situation: Sewage treatment on-board.

Location: Budapest
Date: 17th of September

Attended: R. Comanici, A. de Mul, C. Mijnders

Inspection report 17-9-2019

Type of vessel: Treatment of wastewater On-board.

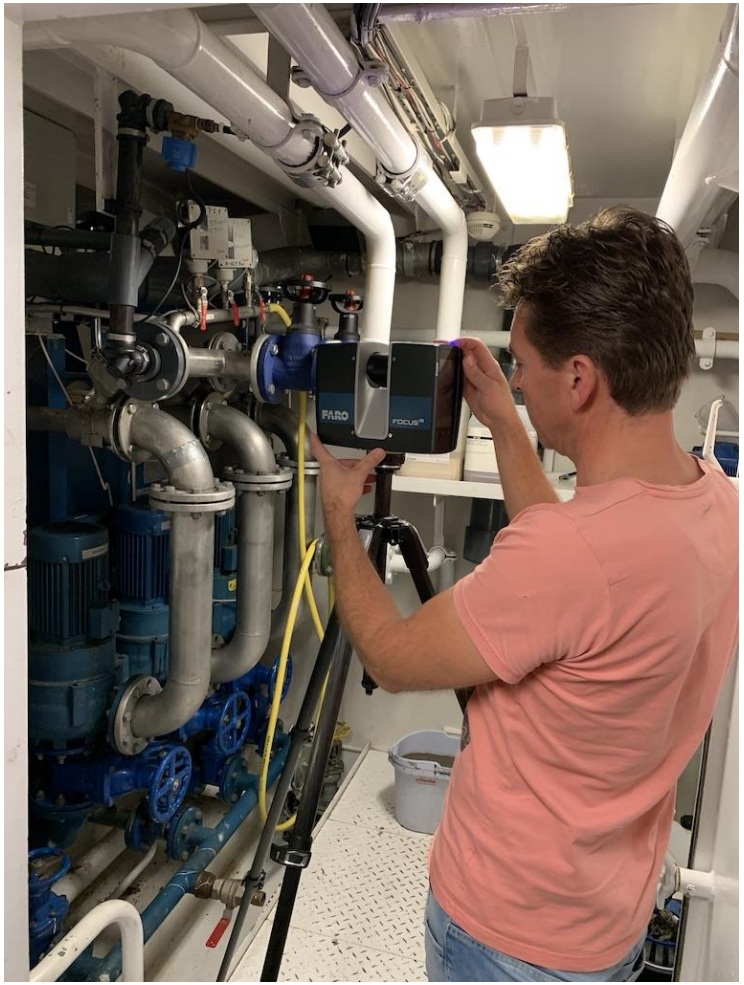
Type: EVAC 2005 4 tank biological conversion with biomass in suspension
Separation by gravity.

Collection: Vacuum system

Grease separation of galley water: Yes

Airtreatment: yes

Inspection report 17-9-2019



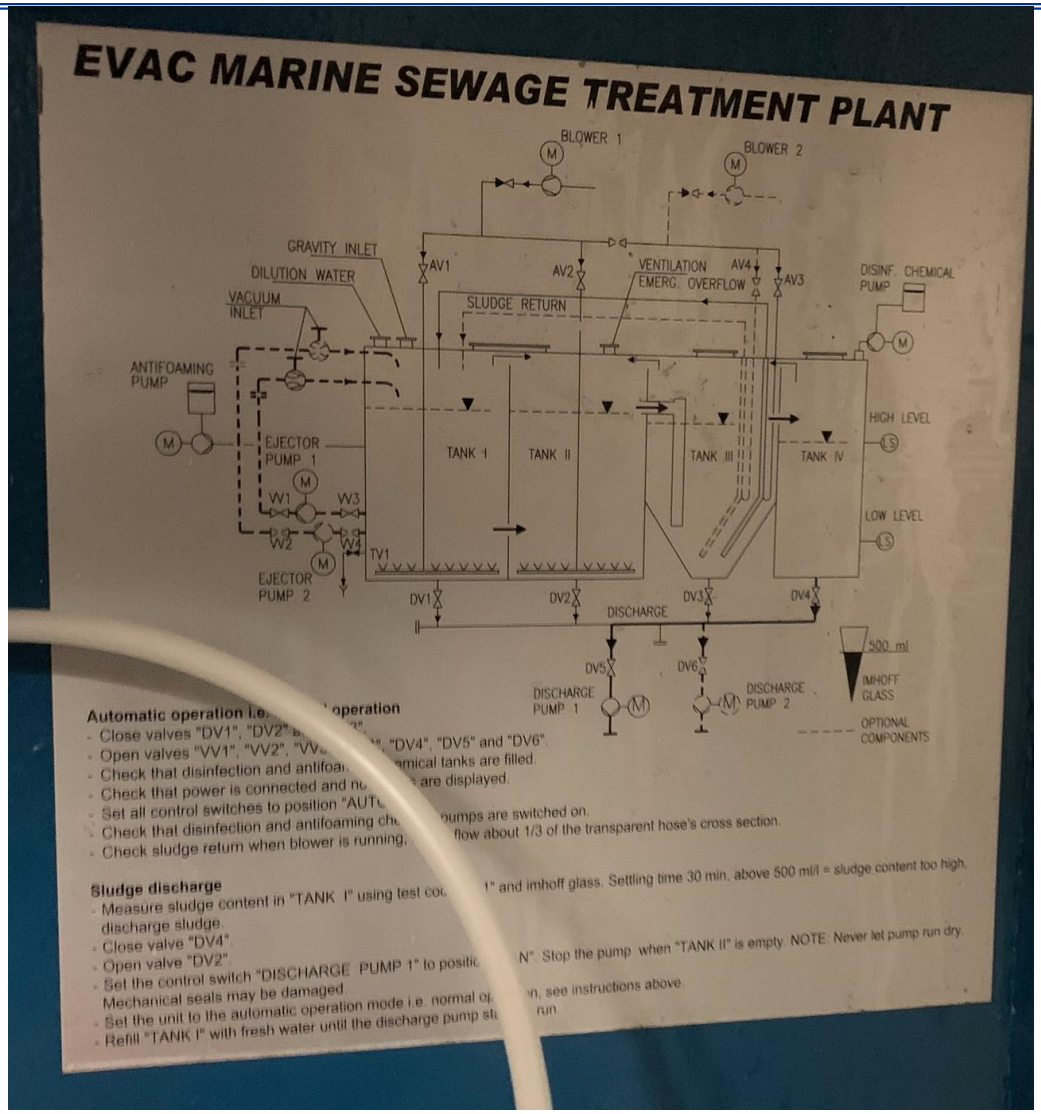
Biomass and reject water

Biomass in suspension

Reject water to river

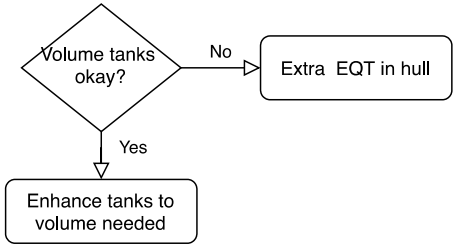
Project co-funded by European Union Funds (ERDF, IPA)

Overview EVAC System

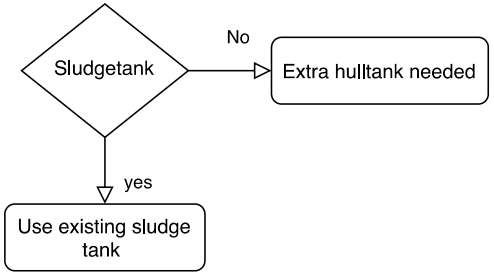


Solution to upgrade existing unit

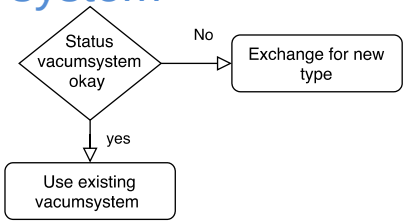
Volume



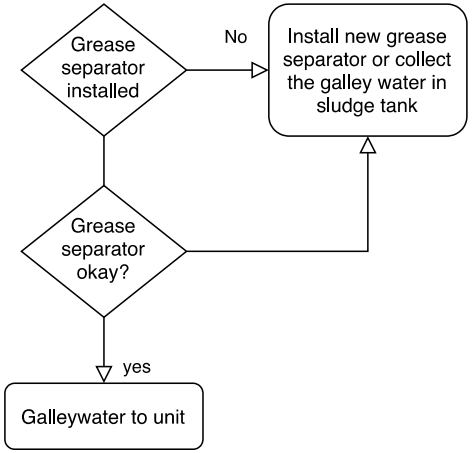
Sludge



Vacum system

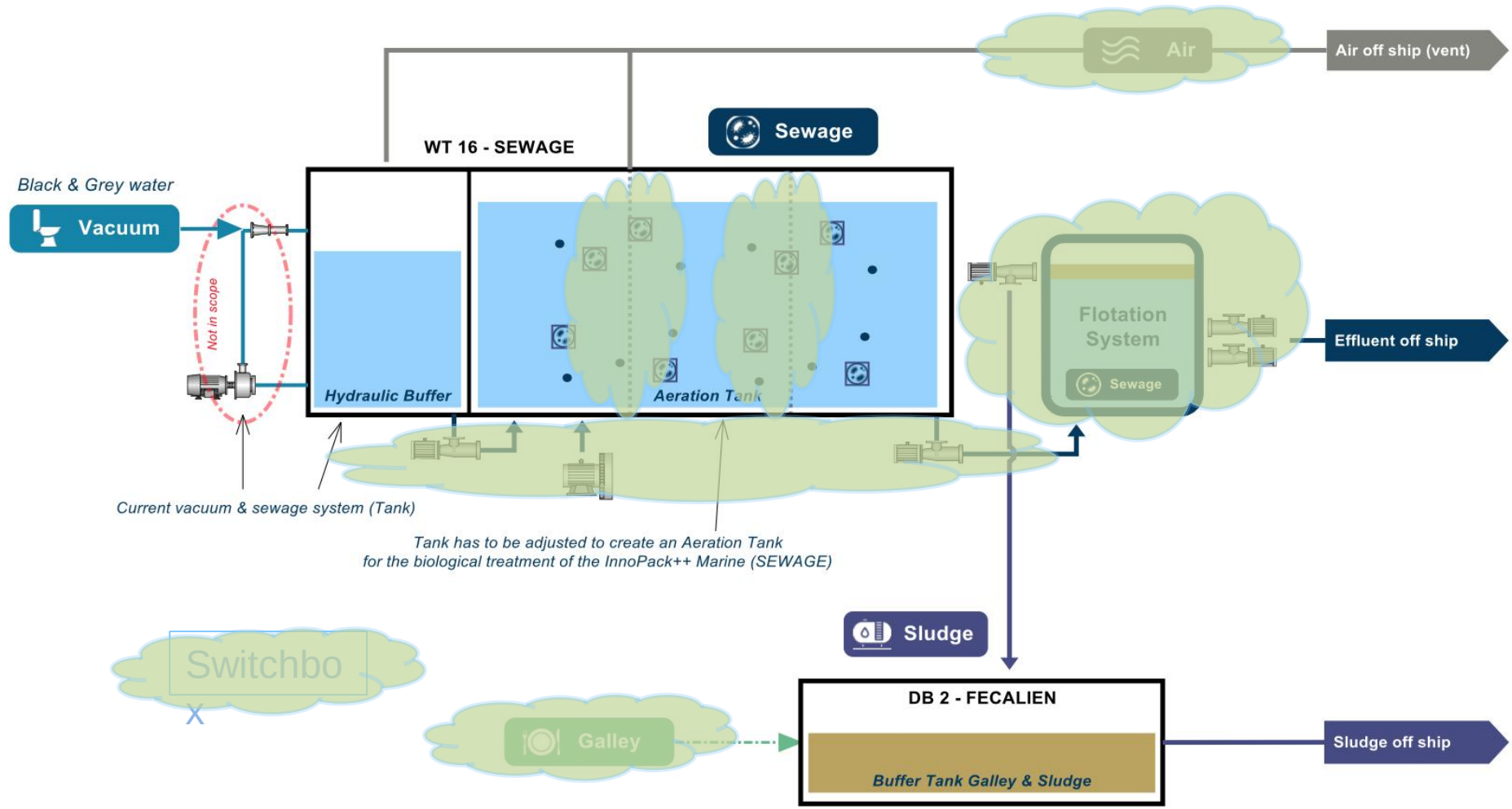


Grease



1. Location separator
2. Power supply
3. Air outlet
4. Planning

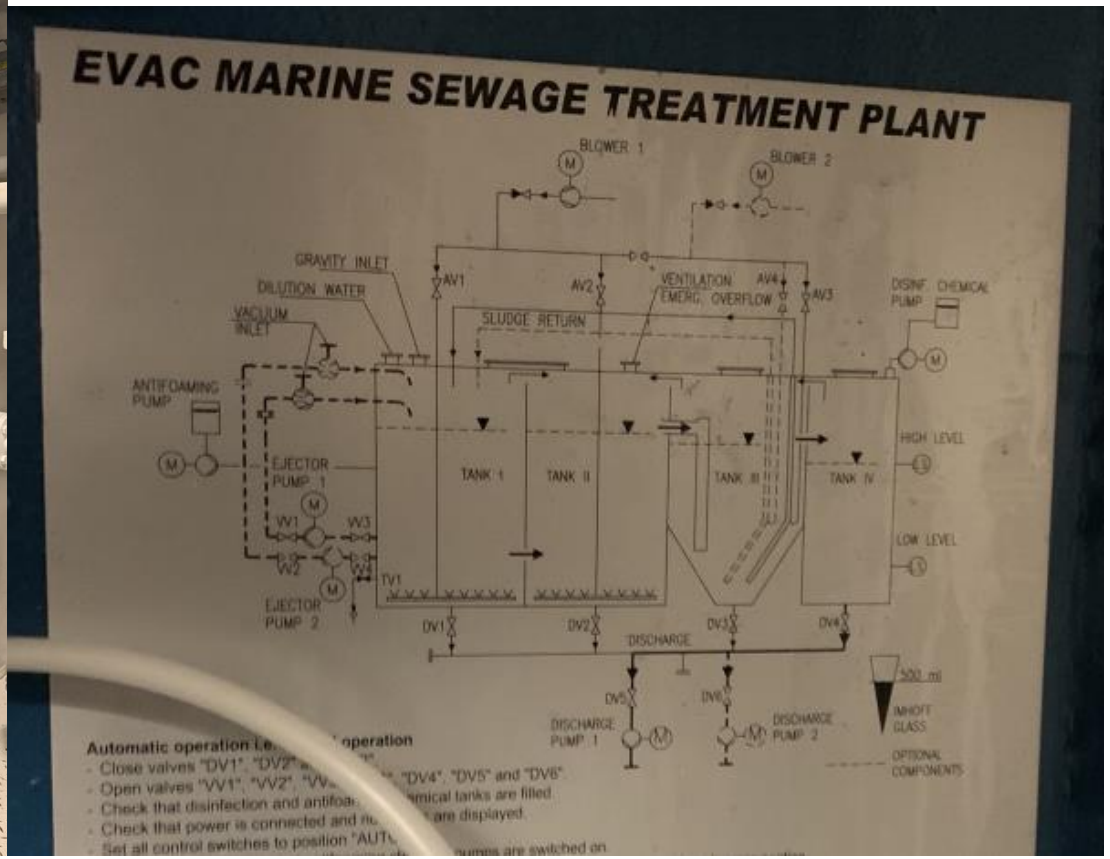
Solution to upgrade existing unit



Solution to upgrade existing unit

1. Cost reduction for revamping by avoiding the hull.
2. No need for a perfect new installation on board.
3. Sustainable.
4. Fast and easy
5. Extending investments in the vessel for multiple years, keep the ship in the certification in the right way
6. Extended functionalities like PureControl possible.
7. Professional company behind the technology and service.

How ?


EVAC MARINE SEWAGE TREATMENT PLANT
BLOWER 1
BLOWER 2
GRAVITY INLET
DILUTION WATER
VACUUM INLET
AV1
AV2
VENTILATION
EMERG. OVERFLOW
AV4
AV3
SLUDGE RETURN
DISINF. CHEMICAL PUMP
ANTIFOAMING PUMP
EJECTOR PUMP 1
EJECTOR PUMP 2
VV1
VV3
VV2
TV1
TANK I
TANK II
TANK III
TANK IV
HIGH LEVEL
LOW LEVEL
DV1
DV2
DV3
DV4
DISCHARGE
DV5
DV6
DISCHARGE PUMP 1
DISCHARGE PUMP 2
500 ml
IMHOFF GLASS
OPTIONAL COMPONENTS
Automatic operation
- Close valves "DV1", "DV2"
- Open valves "VV1", "VV2",
- Check that disinfection and antifoa
- Check that power is connected and
- Set all control switches to position "AUT
"DV4", "DV5" and "DV6".
mical tanks are filled.
are displayed.
are switched on.

How?

1. Projectmanagement in one hand, one stop shop

    - PureBlue arranges assessment of the ship
    - Design of installation
    - Delivery of equipment
    - Mechanical works on the vessel
    - Electrical works on the vessel
    - Start-up
    - Certification

2. Pricing strategy
    - Fixed

3. Planning
    - 2-4 weeks even in free moments during season.

4. Maintenance contract
    - 5 years

Assessment Amadeus Rhapsody

Vessel of Lot 1. Typical situation: Collection of wastewater and disposal to shore.

Location: Budapest
Date: 18th of September

Attended: R. Comanici, P. Persch, A. de Mul, C. Mijnders

Inspection report 18-9-2019

Type of vessel: Collection of wastewater and dispose to shore.

Collection: Vacuum system

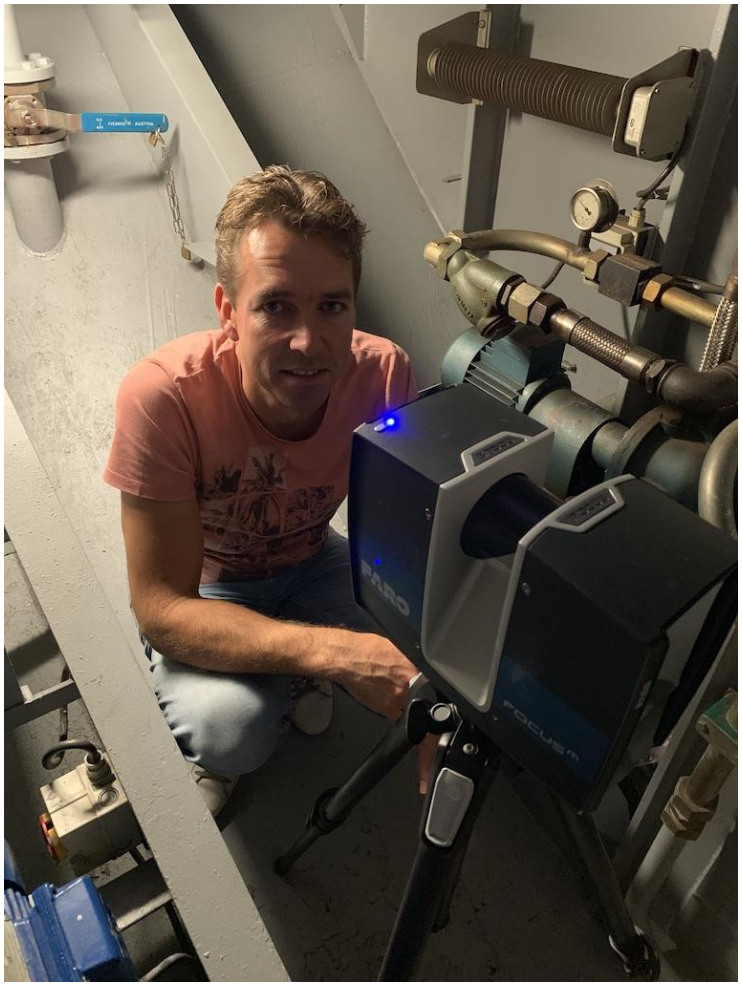
Grease separation of galley water: Yes

Airtreatment: No

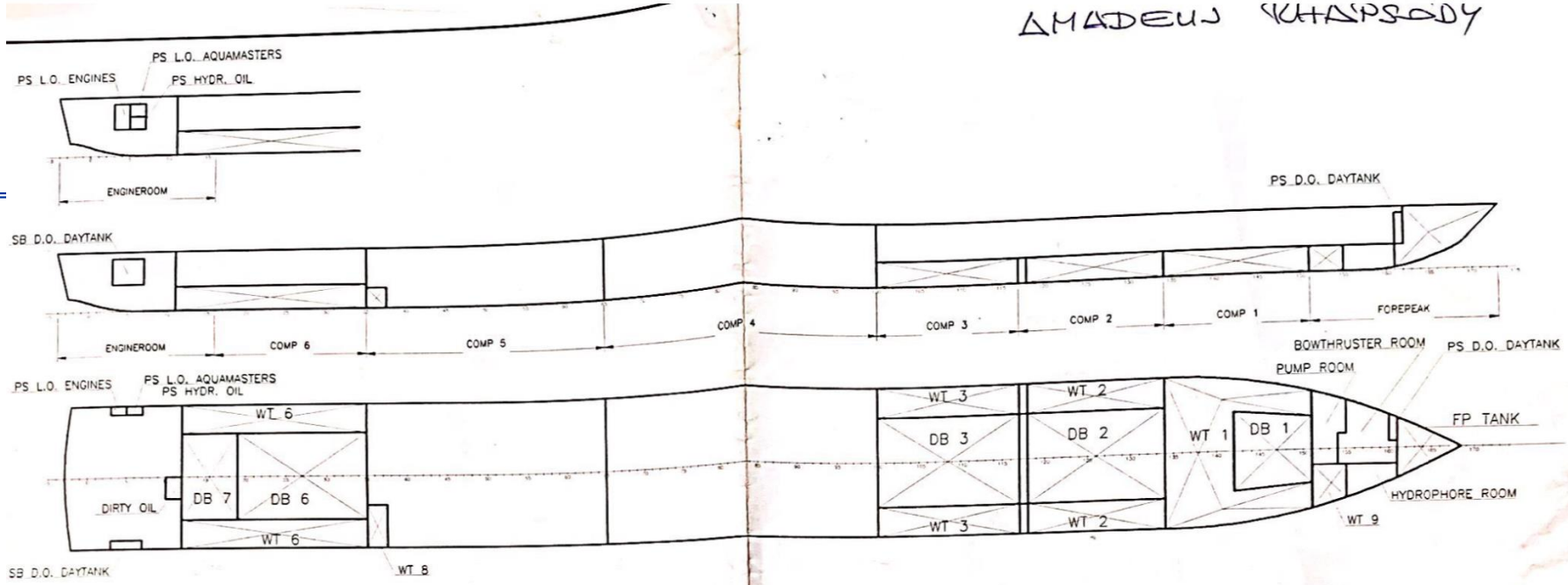
Storage wastewater in DB 2: Feacalien tank in the front of the ship. volume: 115 m^3

Storage of wastewater in WT 9: Feacalien tank of vacuum system. Volume 7,5 m^3

Assessment with 3 D scanner



AMADEUS RHAPSODY



TANK ID	CONTENTS	VOLUME
FP TANK	WATERBALLAST	22 M^3
WT 1	WATERBALLAST	110.5 M^3
DB 1	FUELOIL	51.6 M^3
WT 2 P+S	WATERBALLAST	71.4 M^3
WT 3 P+S	FRESHWATER	78.9 M^3
DB 2	FEACALIEN	115.5 M^3
DB 3	FRESHWATER	122.7 M^3
WT 6 P+S	WATERBALLAST	98.2 M^3
DB 6	WATERBALLAST	115.5 M^3
DB 7	FUELOIL	50.3 M^3
WT 8	DRAIN TANK GALLEY	7.5 M^3
WT 9	FEACALIEN	7.5 M^3

APPROVED BY CLIENT	APPROVED BY CLASSIFICATION	APPROVED BY	CHECKED BY	SCALE	DRAFTSMAN FINISHED DATE

CLIENT :

PROJECT REF. :

CLIENT'S DOC No :

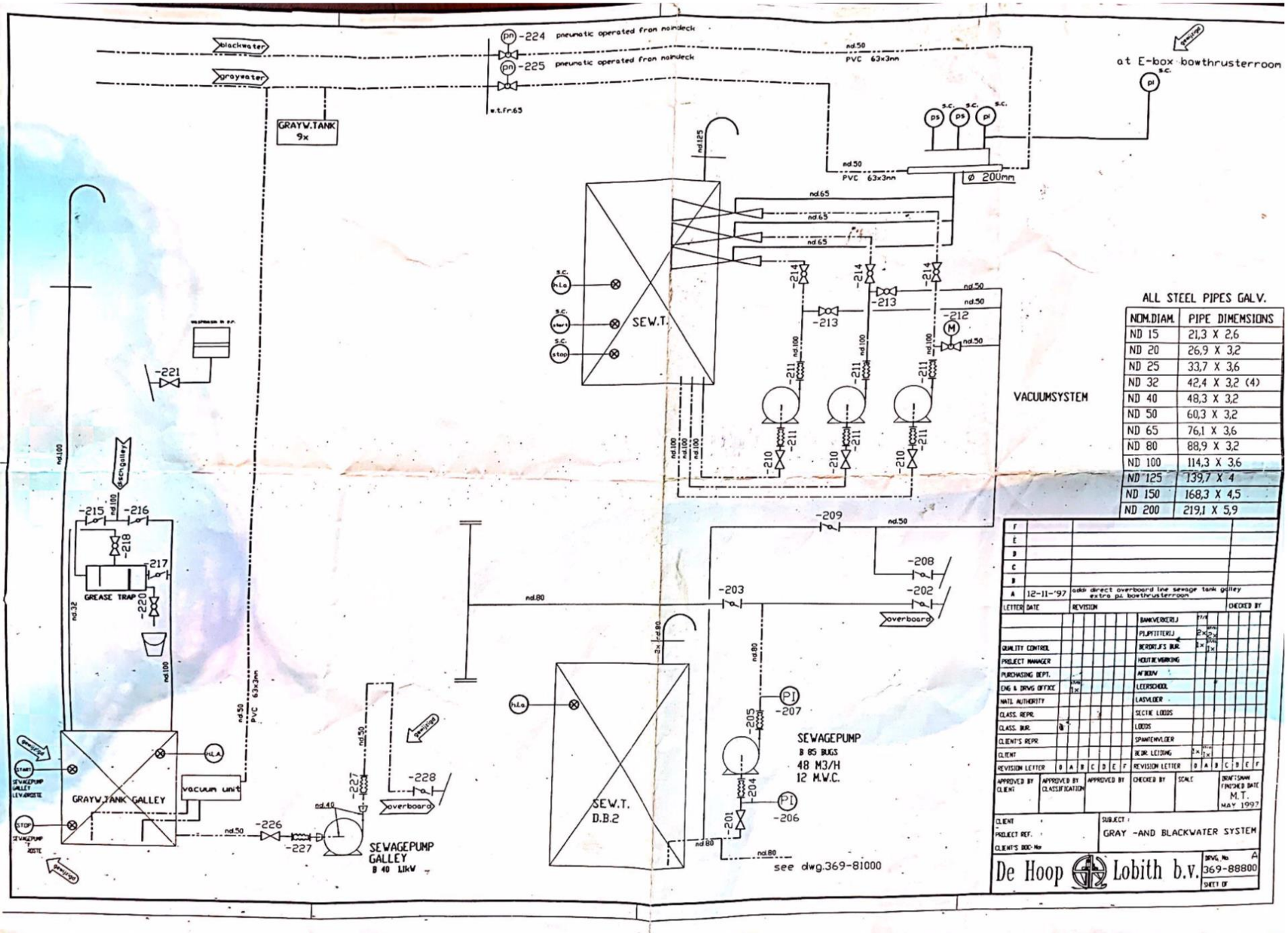
SUBJECT :

TANKENPLAN

De Hoop Lobith b.v.

DRWG. No. 369-01304

SHEET OF 1-1



ALL STEEL PIPES GALV.

NOM.DIAM.	PIPE DIMENSIONS
ND 15	21,3 X 2,6
ND 20	26,9 X 3,2
ND 25	33,7 X 3,6
ND 32	42,4 X 3,2 (4)
ND 40	48,3 X 3,2
ND 50	60,3 X 3,2
ND 65	76,1 X 3,6
ND 80	88,9 X 3,2
ND 100	114,3 X 3,6
ND 125	139,7 X 4
ND 150	168,3 X 4,5
ND 200	219,1 X 5,9

LETTER	DATE	REVISION	CHECKED BY
A	12-11-'97	add: direct overboard line sewage tank galley extra pi. bowthrusterroom	

QUALITY CONTROL		BANKVERBERIJ	
PROJECT MANAGER		PIJPFITTERIJ	
PURCHASING DEPT.		BEDRIJFS BUR.	
ENG & DRWG OFFICE		HOUTBEWERKING	
NATL AUTHORITY		AFBOUW	
CLASS. REPR.		LEERSCHOOL	
CLASS. BUR.		LASVLOER	
CLIENT'S REPR		SECTIE LOODS	
CLIENT		LOODS	
REVISION LETTER	0 A B C D E F	SPANTENVLOER	
		BEJK LEIDING	
		REVISION LETTER	0 A B C D E F

APPROVED BY CLIENT	APPROVED BY CLASSIFICATION	APPROVED BY	CHECKED BY	SCALE	DRAFTSMAN FINISHED DATE
					M.T. MAY 1997

CLIENT :
PROJECT REF. :
CLIENT'S DOC-No :

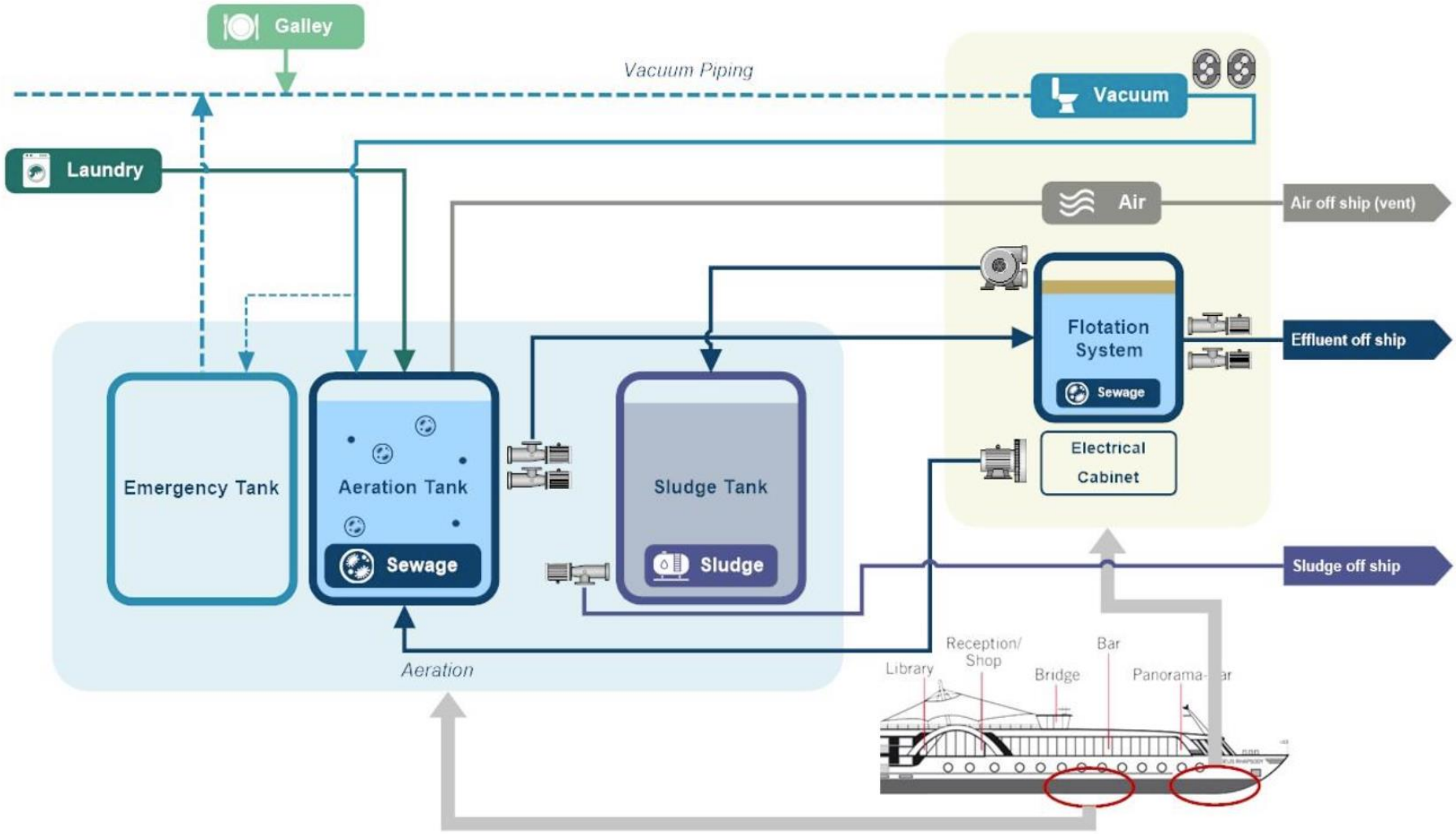
SUBJECT : GRAY -AND BLACKWATER SYSTEM

De Hoop Lobith b.v.

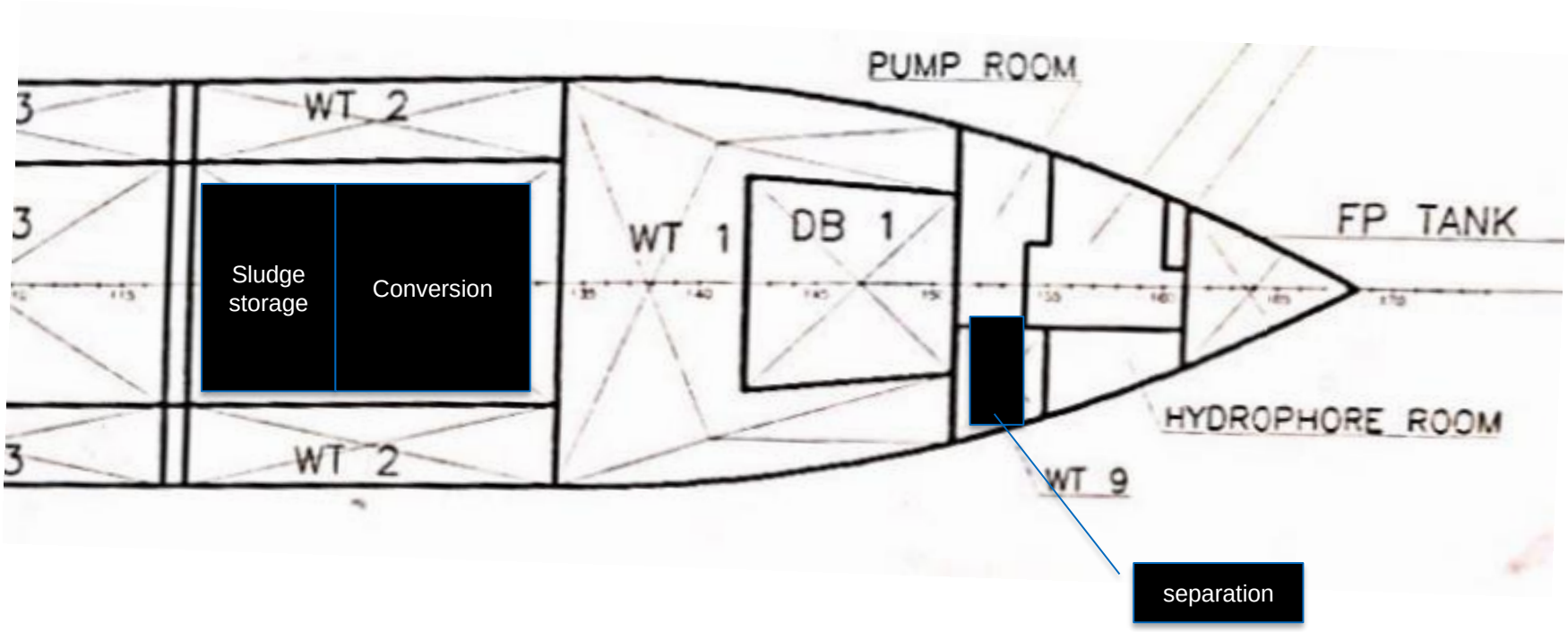
DRWG. No 369-88800 A

SHEET OF

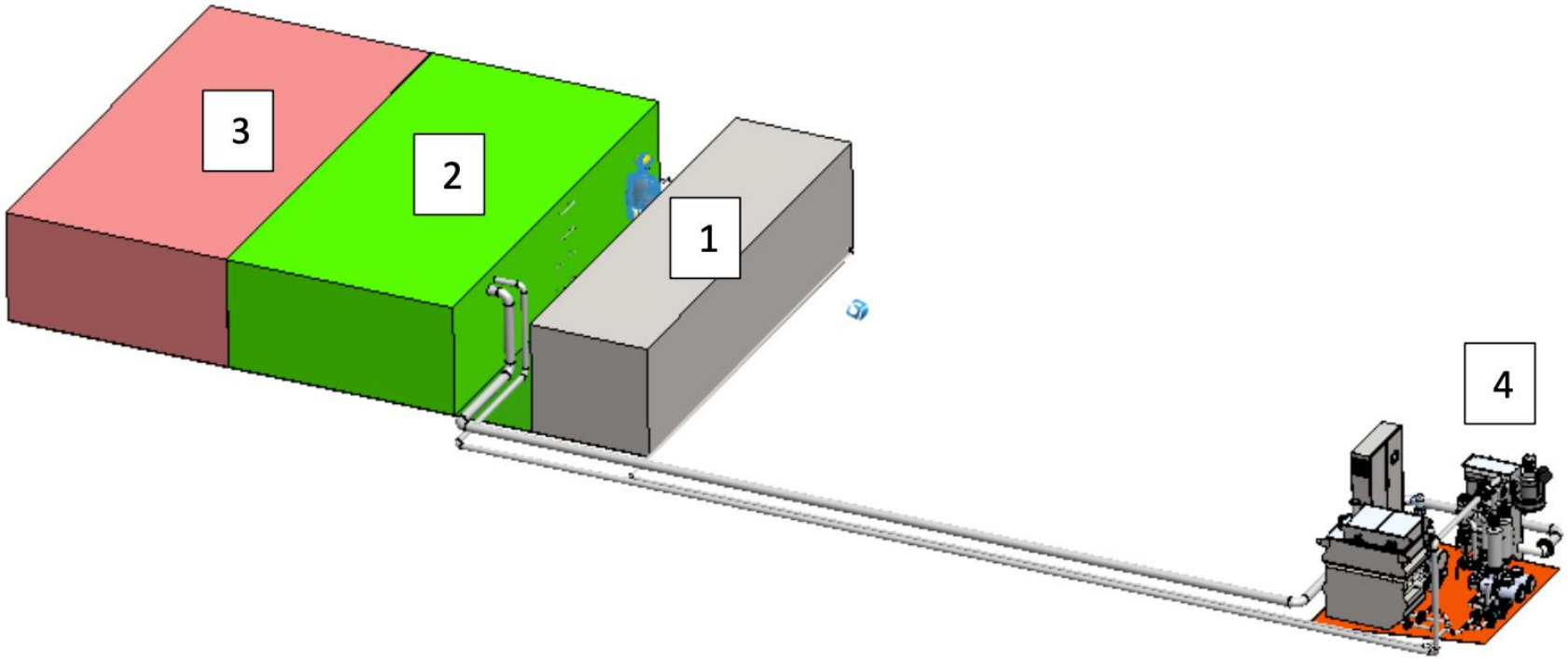
Possible solution



Possible solution



Possible solution



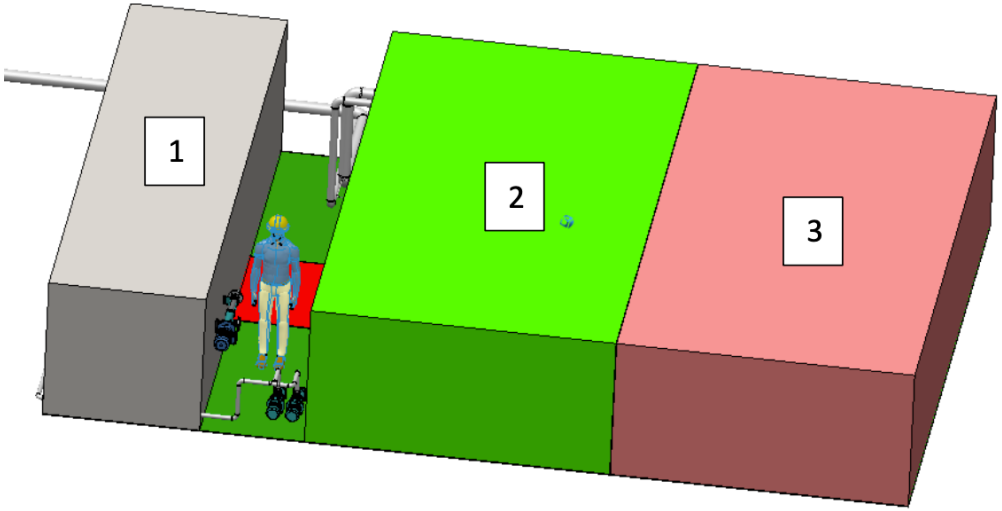


Figure 7: Close view of the tanks and equipment arrangement.

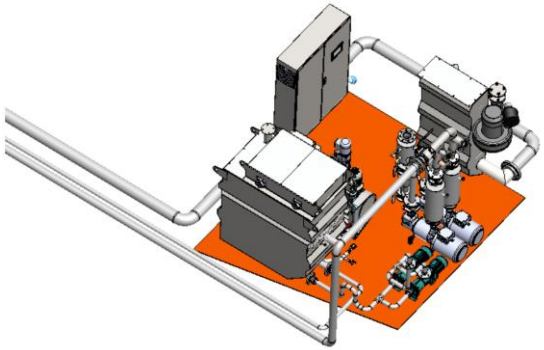


Figure 6: Pre-design.

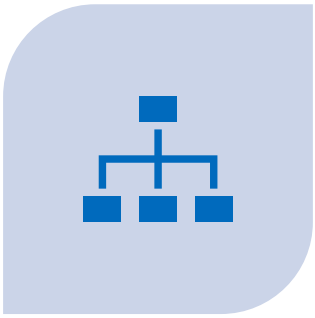
Financial evaluation

Change in annual operational costs due to changed discharge cycles in comparison to collection tank

	Sewageplant			Collection	
Investment unit	€ 319.550			€ -	
Investment yard	€ 150.000			€ 50.000	(treatment tanks)
Lifetime	15	years		15	years
Deprication over lifetime	€ 31.303	per year		€ 3.333	per year
Annual maintenance cost incl. consumables ect.	€ 15.000	per year		€ 2.500	per year (cleaning)
Sludge disposal	246	m3 sludge per year		€ -	
Sludge disposal cost	€ 25	per m3		€ -	
Annual sludgecost	€ 6.159	per year		€ -	
Water collected per year				8.213	per year
Water disposal cost (avr)				€ 20	per m3
Disposal cost per year				€ 164.250	per year
Additional cost for waiting and schedule changes				€ 15.000	per year
Total annual cost	**€ 52.463**			**€ 185.083**	
Price per m3/year	**€ 6,39**	**per m3 treated**		**€ 22,54**	**per m3 disposed**
ROI	**3,54**	**year**			

Lessons learned.

CAPACITY OF WASTEWATER TREATMENT AND THE LOADING PATTERNS



INFLUENCES OF DIFFERENT PROCESSES ON BOARD

MAINTENANCE AND TRAINING OF ENGINEERS

Main facts

Wishlist key elements of the Future Wastewater Treatment

- Capable to treat > 70 kg COD per day
- Capable to treat > 35 m3 water per day
- Footprint of max. 15 m2 (typical for the old installations)
- Maximum volume of water on board of 14 m3 (in installation and incl. buffer)
- Easy to operate, no specialists needed on board
- Easy to maintain, no tank cleanings in wintertime
- Interactive with grease separator
- No pre-treatment and buffering
- Low sludge production
- Online accessible for contact with experts
- Sustainable treatment ad green label
- No operational implications during winterstop
- Effluent of the unit must be always good.

Lessons learned

- **Old type sewage treatment plants are designed on old parameters and for half of the real pollution. Because of that reason the do not function well, effluent is still polluted and the unit will be blocked rapidly. That's the reason to shut down the unit;**
- **Due to the high incidental loads during the day the capacity needs to be 100% higher. This implies that most of the times the floorspace of the old unit will not be big enough. Either you need more space (room) or you will need more treatment capacity per m^2;**
- **Processes in galley and laundry influence performance of sewage plant substantial. The need for a proper treatment is high;**
- **Foodcompactors increase the load substantially and are overloading the sewage plants;**
- **Cleaning agents could influence performance of sewage plant substantial. The use of chlorine is prohibited;**
- **Watertreatment is too complex for engineers and they need backup from professionals;**
- **Biological processes are sustainable if chemicals will be avoided. Sludge treatment chain could be enhanced and made more sustainable;**
- **Membranesystems are more complex, use more energy, make more sludge, have a higher demand for follow up, increases the annual maintenance cost and are therefor not the greenest choice;**
- **Buffertanks will increase the total weight of the ship which will influence the fuel consumption.**

Knowledge transfer:
How to make a retrofit possible

Step 1 Invertory:

- Make a good inventory of the water flows
- Where could the water be processed, how much water is constant on board to store?
- How much space is available for the installation?

Step 2 Preliminairy sketch:

Options:

1. New technology in old installation
2. New installation (prefab) at old location
3. New installation (prefab) at new location
4. New hull made installation at new location

Step 3 Choice of technology.

- Chemical proces
- Biological proces without membranes
- Biological proces with membranes

Knowledge transfer:

Step 4 Rate of automation

- Local or online control
- Full watermanagement will increase sustainability

Step 5 Decision making

- Installation manufacturer based on green record. Innovation is key in retrofit…
- Shiphard needed? If yes, which one,
- Invest in project coördinator

Step 6 Follow up

- Invest in good training
- Invest in spare parts and service contracts

Green Award inland cruise vessels for Innopack^{++} Marine of PureBlue Water

Interreg
EUROPEAN UNION
Danube Transnational Programme
GRENDEL

Radu Comanici
Danubia Kreuzfahrten GmbH

Photo: © NAVROM

GRENDEL “Green and efficient Danube fleet”

Towards modernisation & greening of Danube inland waterborne sector and strengthening its competitiveness

www.interreg-danube.eu/grendel

Project co-funded by European Union Funds (ERDF, IPA)

Interreg

EUROPEAN UNION

Danube Transnational Programme

GRENDEL

Green and efficient Danube fleet

"Towards modernisation & greening of Danube inland waterborne sector and strengthening its competitiveness"

Output 4.1 – Innovative & greening inland vessel concepts of DANUBIA Part 2: Improvement of noise and vibration characteristics

Work Package 4 Preparatory actions

Version: 1.0

Date: 01/10/2020

FINAL

O 4-1_GRENDEL_Innovative vessel concepts_DANUBIA_v1.0_FINAL_2020-11-30

Project co-funded by European Union Funds (ERDF, IPA)

Document History

Version	Date	Authorised
1.0	01.10.2020	DANUBIA

Contributing Authors

Name	Organisation	Email
	Cergol Engineering Consultancy	
	DANUBIA	

Executive Summary

The following studies have been performed:

- Main technical study: A technical study with the objective to propose structural improvements based on the design of "Amadeus Silver III" in order to achieve a reduction of noise and vibration levels in the crew quarters of an advanced sister-ship.

After the technical investigation, three options have been analyzed and they are listed below:

- Option 01: Based on the findings of the main technical study the supplier shall elaborate recommendations for possible retrofitting measures with view to improving noise and vibration levels of the existing fleet.

- Option 02: Based on the findings of the main technical study the supplier shall guide the design office respectively the building yard of the next newbuilding of Danubia Kreuzfahrten GmbH during the structural design and actual building phase in order to ensure appropriate implementation of the recommended measures. The supplier shall propose in particular a sufficient number of on-site surveys and milestones where the supplier's intervention would seem to be necessary, including in any case a final measurement of noise and vibration levels after completion of the vessel and comparison with calculated values.

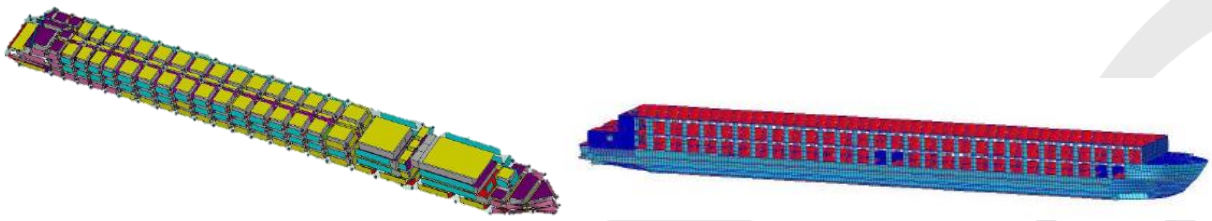
- Option 03: The supplier shall conduct a technical study using the models created in the main technical study with the objective of reducing the external noise of the vessel stationary at a berth and assuming the presence of electric shore connection.

The activities have been developed following the below listed phases:

- Collection of the material of interest of similar ship (Amadeus Silver III)

- Definition of the main exciting sources installed on board and critical areas

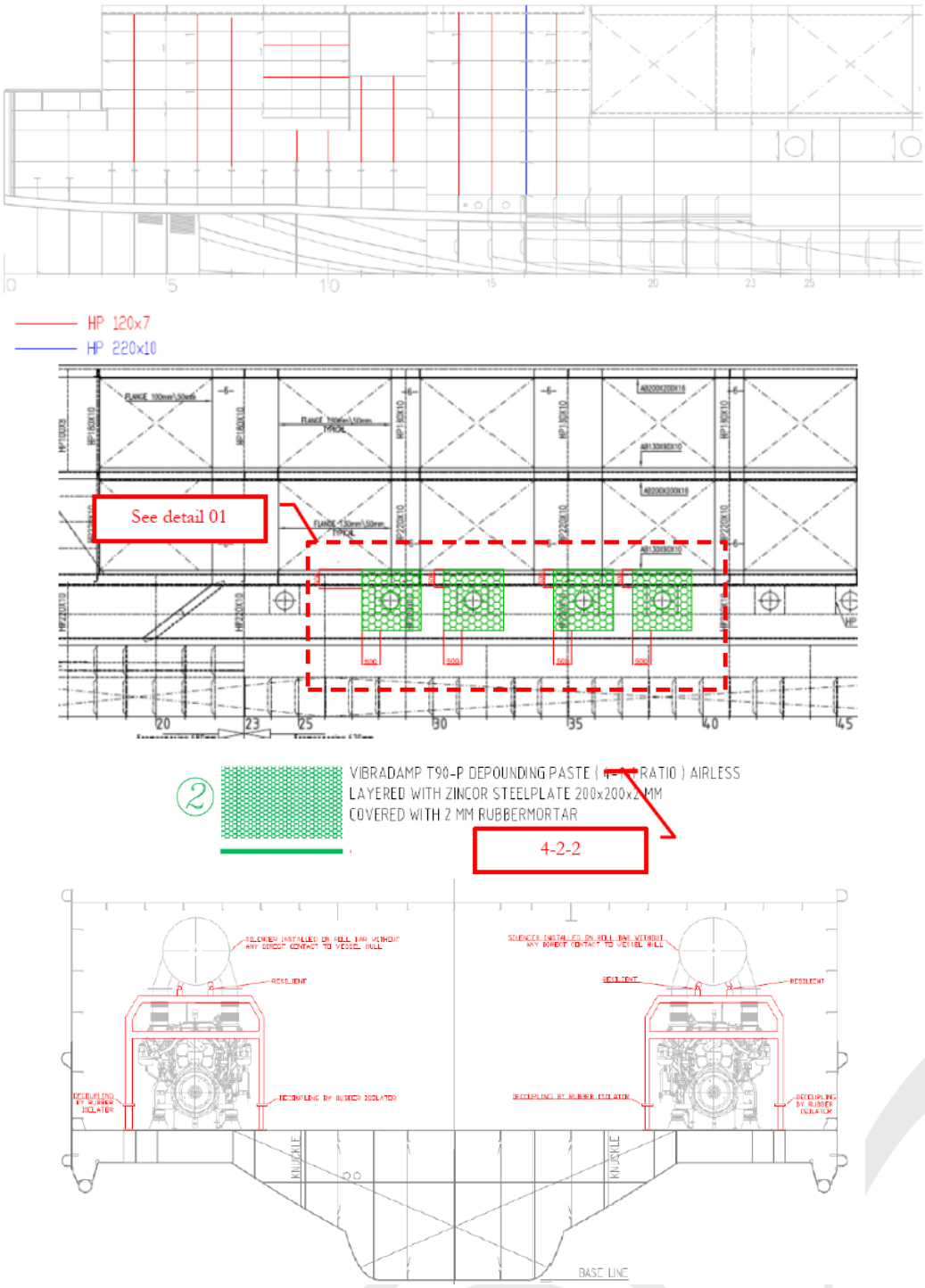
- Development of numerical models



Developed vibro-acoustic numerical models

- Vibro-acoustic measurements on board and calibration of the developed numerical models with the data measured on board during the performed river trials.

- Design of structural improvements and insulation improvements for vibro-acoustic levels mitigation which have been tested by performing iterative acoustic and FE analysis.



Some of the typical proposals of improvements studied and tested during the project

The proposals of improvements have been implemented on the last delivered Lüftner Cruise vessel and the noise levels measurement campaign has been performed by a third party during the official river trials.

For the crew accommodation areas, an average reduction of 2 dB(A) has been achieved. Also for the passenger cabins, the achieved noise reduction can be considered satisfactory.

Annex 1.

Development of innovative and greening inland vessel concepts

Improvement of noise and vibration characteristics

Extensive version of the second part of the presentation held by Radu Comanici (DANUBIA) at the GRENDEL Final Event on 29 October 2020

AIM OF THE WORK

This work consists in a technical study with the objective to propose structural improvements based on the design of “Amadeus Silver III” in order to achieve a reduction of noise and vibration levels in the crew quarters of an advanced sister-ship.

The technical investigation includes:

- noise and vibration measurements in representative positions aboard “Amadeus Silver III”
- creation of mathematical models of “Amadeus Silver III” to perform a dynamic finite element analysis for the prediction of vibration levels at low frequencies and a statistical energy analysis for the prediction of noise levels
- calibration of the models against the results of the measurements
- analysis of possible improvement measures taking into account a significant reduction of noise and vibration values and an optimization of the structural design considering low weight solutions
- derivation of recommendations for concrete structural improvements

AIM OF THE WORK

- identification of remaining sources of external noise
- recommendation for reducing noise emissions from these sources

AIM OF THE WORK

After the technical investigation, three options have been analyzed and they are listed below:

Option 01: Based on the findings of the main technical study the supplier shall elaborate recommendations for possible retrofitting measures with view to improving noise and vibration levels of the existing fleet.

- **Option 02:** Based on the findings of the main technical study the supplier shall guide the design office respectively the building yard of the next newbuilding of Danubia Kreuzfahrten GmbH during the structural design and actual building phase in order to ensure appropriate implementation of the recommended measures. The supplier shall propose in particular a sufficient number of on-site surveys and milestones where the supplier's intervention would seem to be necessary, including in any case a final measurement of noise and vibration levels after completion of the vessel and comparison with calculated values.

- **Option 03:** The supplier shall conduct a technical study using the models created in the main technical study with the objective of reducing the external noise of the vessel stationary at a berth and assuming the presence of electric shore connection. This study shall in particular address identification of remaining sources of external noise and recommendations for reducing the noise emissions from these sources.

MAIN TECHNICAL STUDY

- Collection of the material of interest of similar ship (Amadeus Silver III): scantling plans, general arrangements, insulation plans, floor plans, technical report of measured noise and vibration levels.
- Definition of the main exciting sources installed on board: analysis of the propulsion system and auxiliary machinery;
- Definition of the critical areas: study of the crew quarters layout;
- Development of numerical models: both acoustic and finite element (FE) models of the vessel of interest (Lüftner Cruise similar ship) have been developed in order to deeply investigate the vibro-acoustic issues and test the proposals of improvements.
- Vibro-acoustic measurements on board: measurements have been performed on Amadeus Silver III crew quarters.

MAIN TECHNICAL STUDY

- Calibration of the developed numerical models with the data measured on board during the performed river trials.
- Design of structural improvements and insulation improvements for vibro-acoustic levels mitigation to be implemented in the Lüftner Cruise similar ship (actually under construction).
- Test of the studied improvements by performing iterative acoustic and FE analysis.
- Evaluation of achieved benefits in terms of noise and vibration levels mitigation

NOISE AND VIBRATION LEVEL LIMITS

ADMISSIBLE NOISE LEVELS LIMITS

Locations	*Comfort rating number (cn)*		
	1	*2*	*3*
Wheelhouse	60	60	65
Radio room	55	55	60
Crew cabins	50	55	60
Crew public spaces	55	60	65
Hospital	55	58	60

ADMISSIBLE VIBRATION LEVELS LIMITS

Locations	*Comfort rating number (**cn**)*		
	1	***2***	***3***
Cabins	2.0	2.7	3.5
Mess/recreation rooms	2.0	2.7	3.5
Offices	2.0	2.7	3.5
Navigation bridge	2.0	2.7	3.5

EXTERNAL NOISE LEVELS LIMITS

ES-TRIN

Chapter 8
Engine design

Article 8.10
Noise emitted by vessels

1. The noise produced by a vessel under way, and in particular the engine air intake and exhaust noises, shall be damped by using appropriate means.

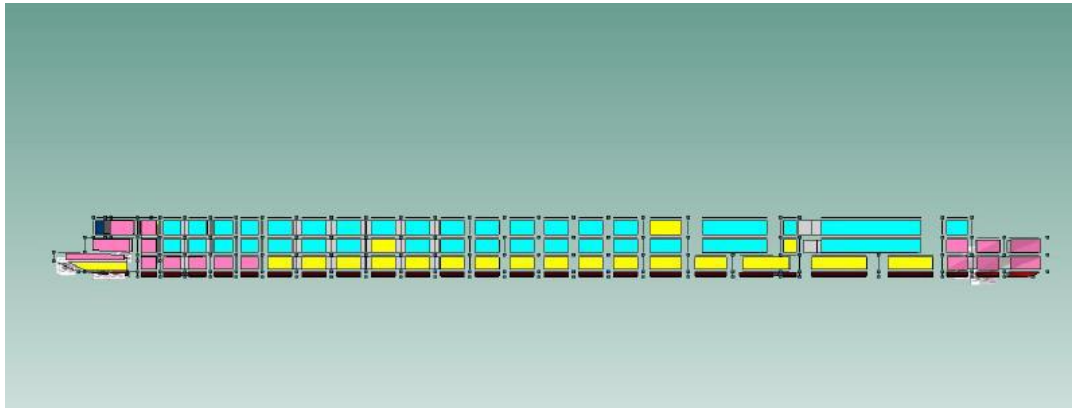
2. The noise generated by a vessel under way shall not exceed 75 dB(A) at a lateral distance of 25 m from the ship's side.

3. Apart from transhipment operations the noise generated by a stationary vessel shall not exceed 65 dB(A) at a lateral distance of 25 m from the ship's side.

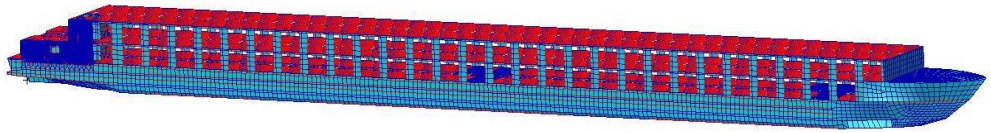
CRITICAL AREAS AND CALIBRATED MODELS

Critical areas will be investigated with both FEM-SEA analysis and during the measurement campaign on board.

Starting from the general arrangement, scantling plan, main frame, insulation and floor plans, the SEA and FEM models of the Lüftner Cruise similar ship has been realized.



SEA model



FEM model

AMADEUS SILVER III

Dedicated measurements campaign on similar vessels of Amadeus SIlver III have been performed in order to have a global overview of noise and vibration levels on board vessel in previously defined critical areas.

Those data have been used to calibrated the SEA-FEM models to represent the actual status of noise and vibration levels on board.

Calculations have been performed considering the main exciting sources as well as main engines, propellers, DD.GG. and HVAC and Chiller units.

Before the measurement campaign, a dedicated test protocol with details of measurement procedure and locations has been developed.

STRUCTURE OF TEST PROTOCOL

The main topics of the developed test protocol for vibro-acoustic measurements are listed below:

Measurement procedure

Measurement conditions

Noise and vibration levels measurements in crew quarters

External noise levels measurements

Vibration levels on main propulsion system and diesel generator

AMADEUS SILVER III – MEASUREMENTS

Measurements have been performed in accordance with developed test protocol and in accordance with the time available for the measurements due to vessel schedule.

Measurements location are shown in the following pictures:

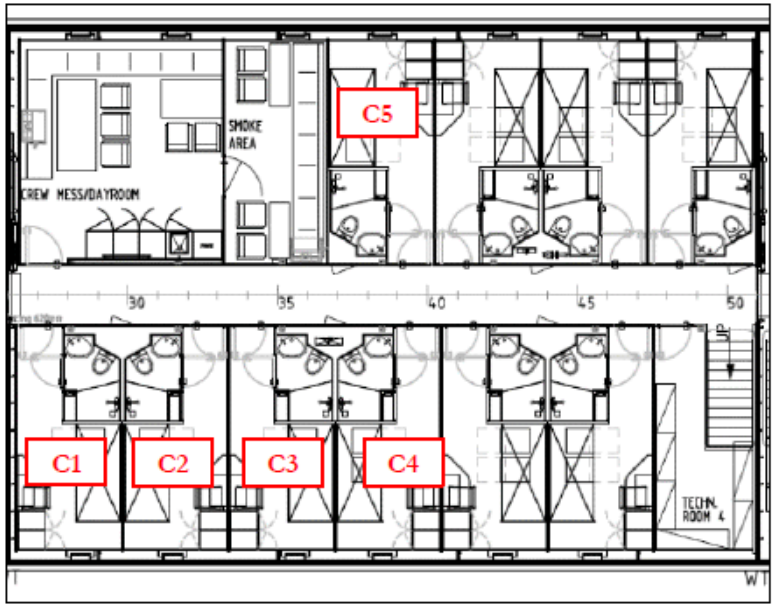


Figure 38 – Crew accommodation areas on Haydn deck aft

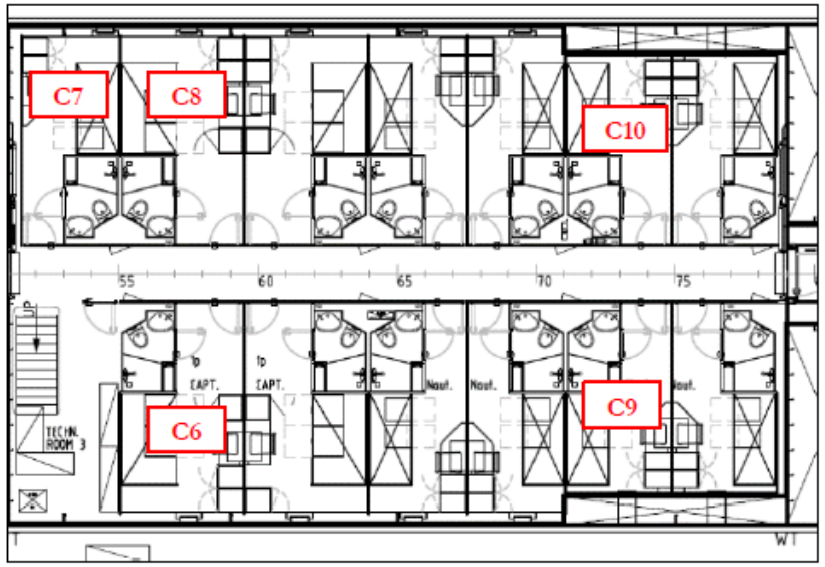


Figure 39 – Crew accommodation areas on Haydn deck middle

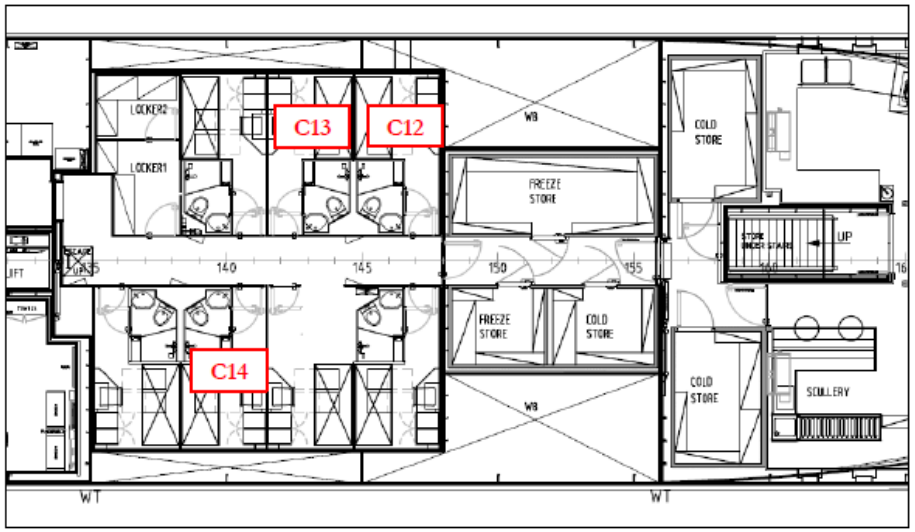


Figure 40 – Crew accommodation areas on Haydn deck fore

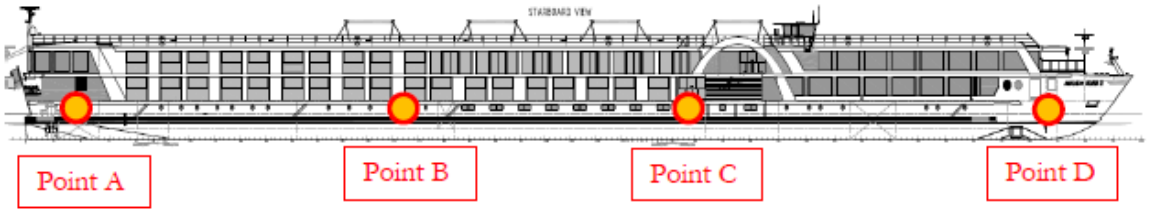


Figure 41 – Overview of the external noise measurement points (each point is at 25mt from the berthing side of the vessel)

External noise measurements have been performed to evaluate the environmental noise generated by the ship.

On board measured dB(A) noise levels upstream

Area	Deck	Measured dB(A) noise level
Crew cabin – C1	Haydn	60.2
Crew cabin – C2	Haydn	58.2
Crew cabin – C3	Haydn	54.9
Crew cabin – C10	Haydn	49.1

Table 1 – Measured noise levels in crew quarters, ship cruising upstream

On board measured dB(A) noise levels downstream (for information only)

Area	Deck	Measured dB(A) noise level
Crew cabin – C1	Haydn	56.5
Crew cabin – C2	Haydn	55.3
Crew cabin – C3	Haydn	53.9
Crew cabin – C4	Haydn	55.1
Crew cabin – C5	Haydn	55.7
Crew cabin – C6	Haydn	49.7
Crew cabin – C7	Haydn	51.9
Crew cabin – C8	Haydn	49.5
Crew cabin – C9	Haydn	47.0
Crew cabin – C10	Haydn	48.9
Crew cabin – C11	Haydn	43.5
Crew cabin – C12	Haydn	39.9
Crew cabin – C13	Haydn	39.6
Crew cabin – C14	Haydn	42.2

Table 1 – Measured noise levels in crew quarters

Measured vibration levels

Area	Deck	Measured o.a. rms vibration level (mm/s)
Crew cabin – C1	Haydn	0.80
Crew cabin – C2	Haydn	0.52
Crew cabin – C3	Haydn	0.51
Crew cabin – C4	Haydn	1.10
Crew cabin – C5	Haydn	0.75
Crew cabin – C6	Haydn	0.40
Crew cabin – C7	Haydn	0.60
Crew cabin – C8	Haydn	0.40
Crew cabin – C9	Haydn	0.20
Crew cabin – C10	Haydn	0.20
Crew cabin – C11	Haydn	0.20
Crew cabin – C12	Haydn	0.10
Crew cabin – C13	Haydn	0.20
Crew cabin – C14	Haydn	0.30

Table 2 – Measured vibration levels in crew quarters

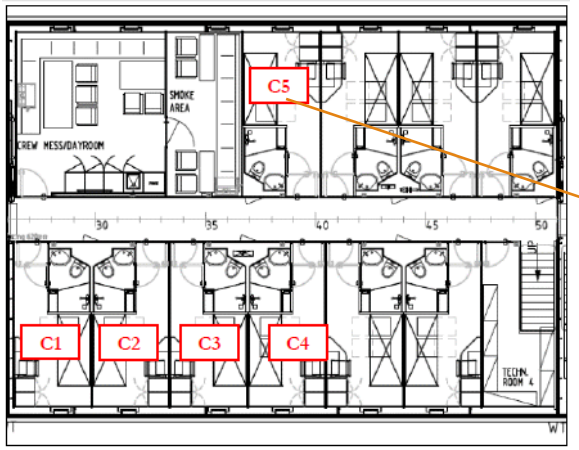
Additional external noise level measurements (dB(A))

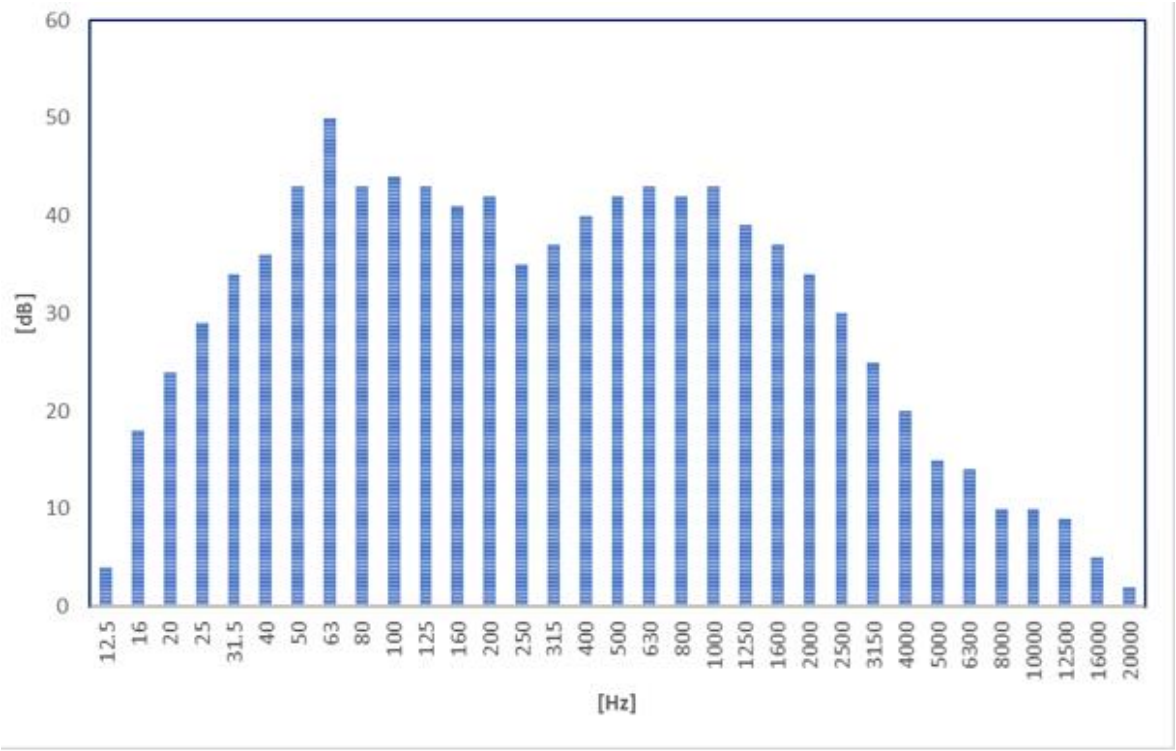
Location	Measured dB(A) noise level
Point A	55.1
Point B	52.2
Point C	50.2
Point D	52.2

Table 3 – External noise levels measurement results

Some noise spectra upstream

the measured dB(A) noise levels are shown on Y-axis while X-axis shows the third octave frequency band

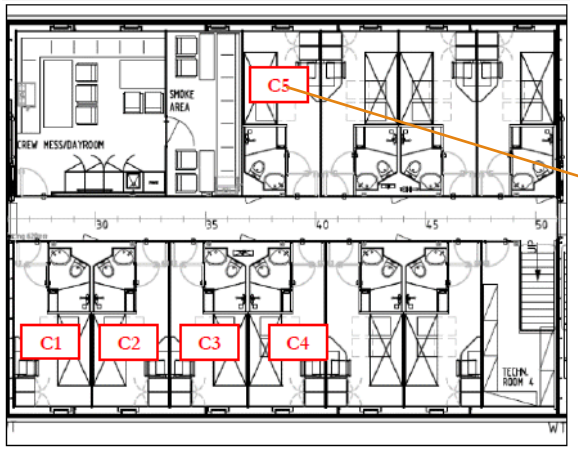




Figure·5·—·Measured·noise·level·spectrum·Crew·Cabin·C5,·55.1·dB(A)¶

Some noise spectra downstream (for information only)

the measured dB(A) noise levels are shown on Y-axis while X-axis shows the third octave frequency band



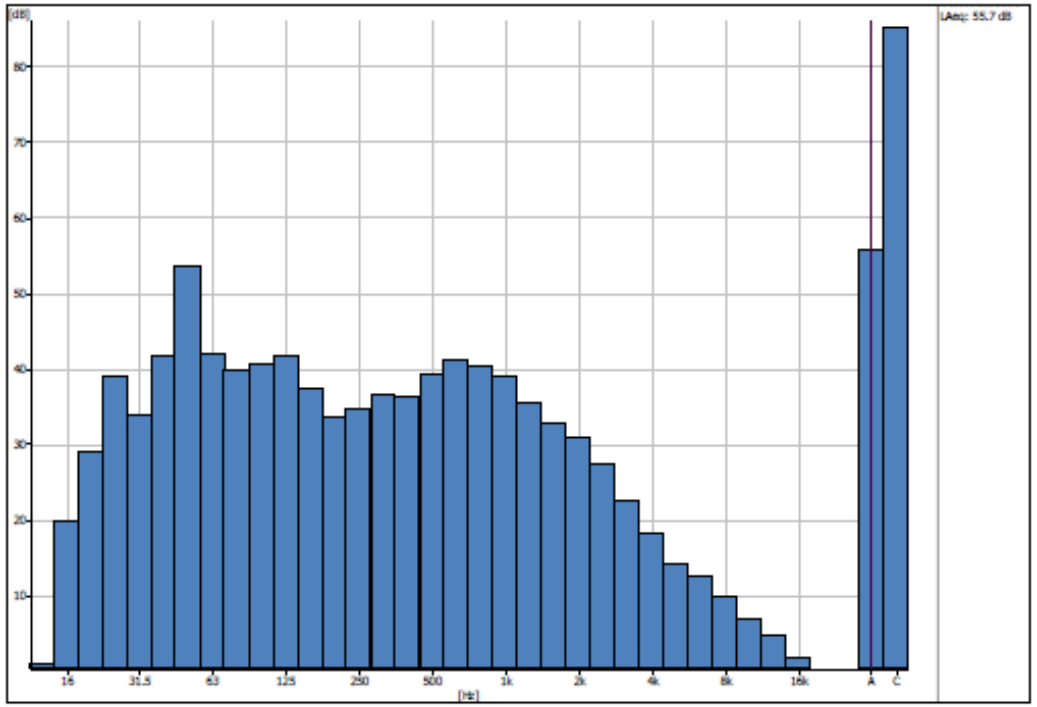
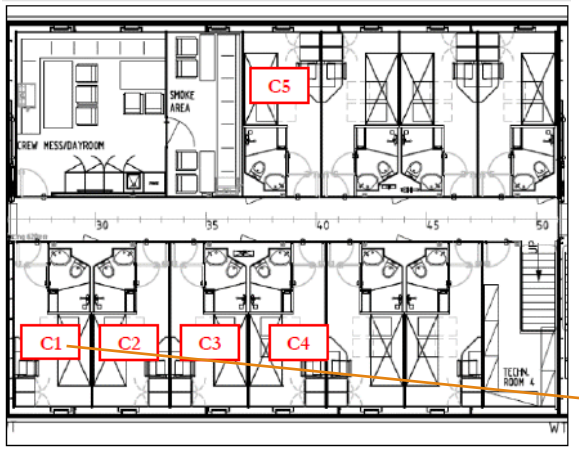
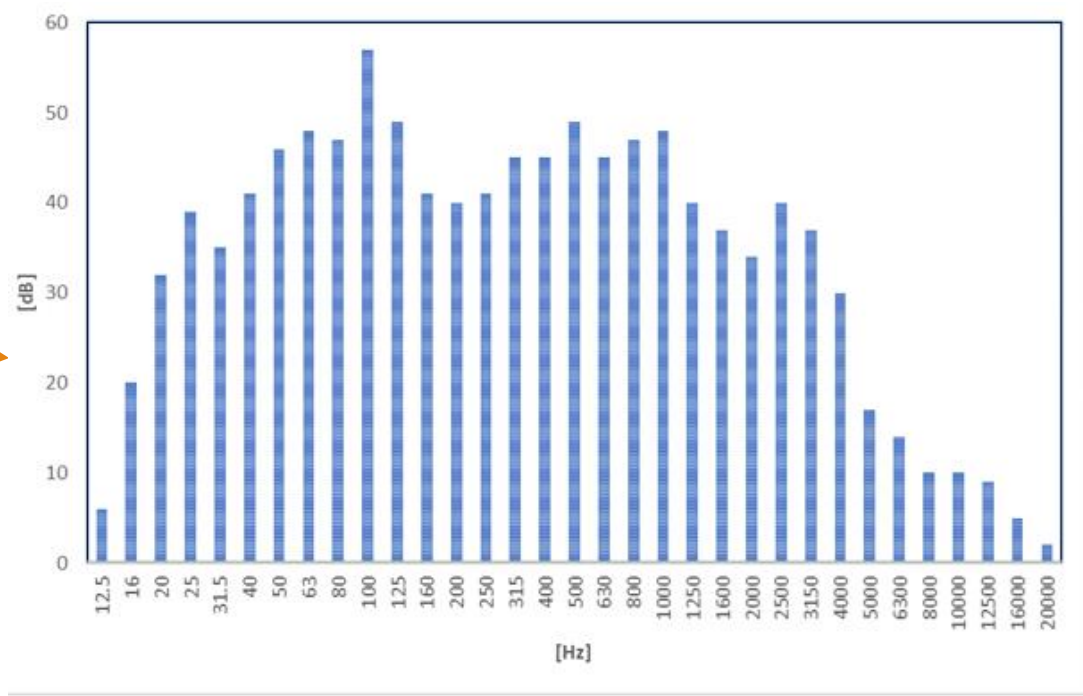


Figure 46 – Measured noise level spectrum Crew Cabin C5

Some noise spectra upstream

the measured dB(A) noise levels are shown on Y-axis while X-axis shows the third octave frequency band

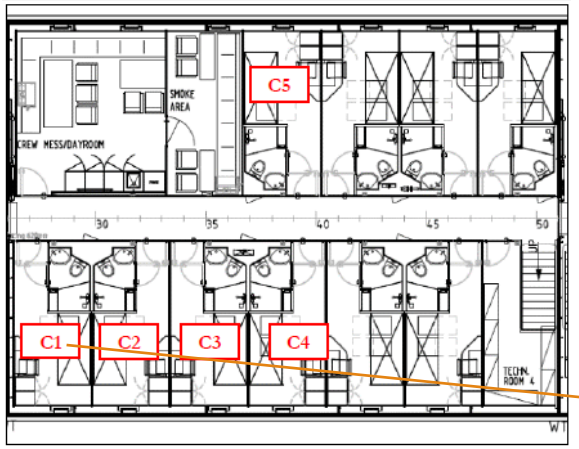




Figure·1·—·Measured·noise·level·spectrum·Crew·Cabin·C1,·60.2·dB(A)¶

Some noise spectra downstream (for information only)

the measured dB(A) noise levels are shown on Y-axis while X-axis shows the third octave frequency band



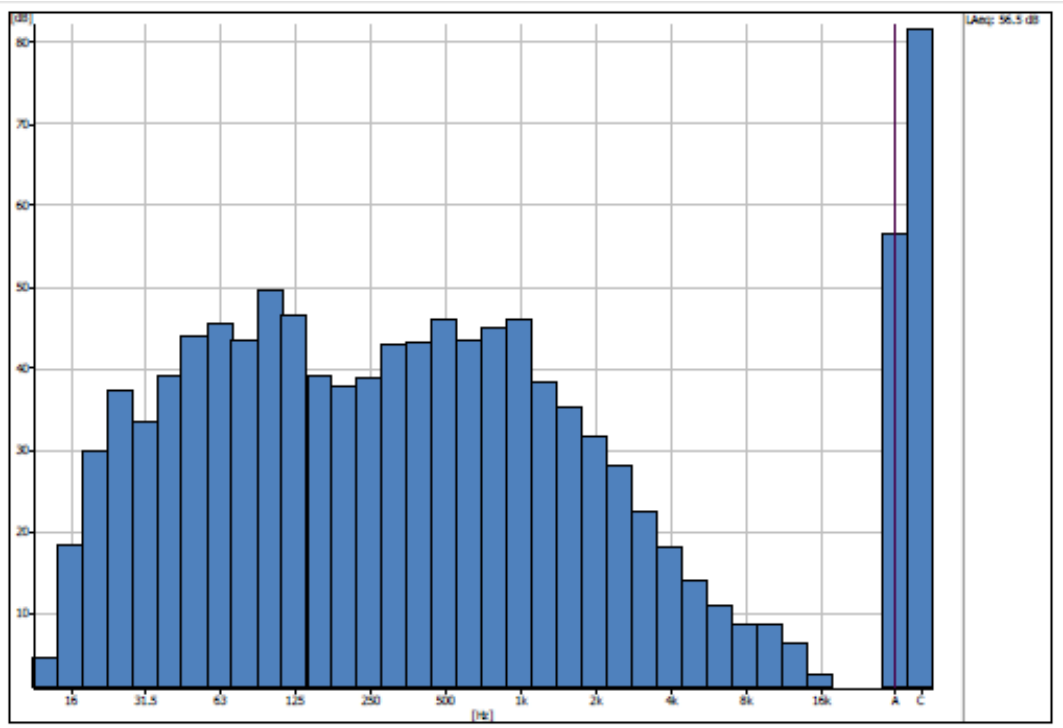


Figure 42 – Measured noise level spectrum Crew Cabin C1

Structure borne noise

SBN levels measurements have been performed on main propulsion machinery and used for calibrating SEA-FEM models for vibro-acoustic analysis.

Some measurements are reported in the following.

On Y-axis, the measured dB (ref. 5e-8 m/s) are shown for longitudinal direction (red curve), transverse direction (blue curve) and vertical direction (green curve). Third octave frequency bands (Hz) are shown on X-axis.

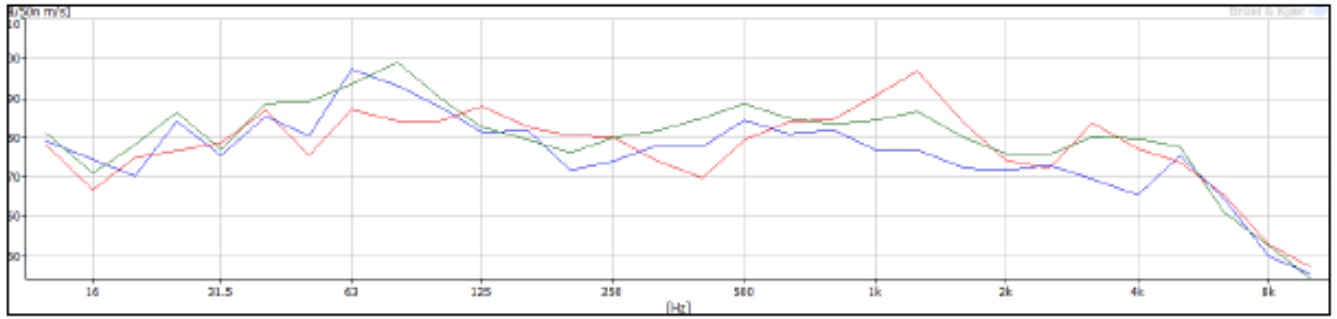


Figure 74 – Measured SBN level spectrum on DD.GG. alternator

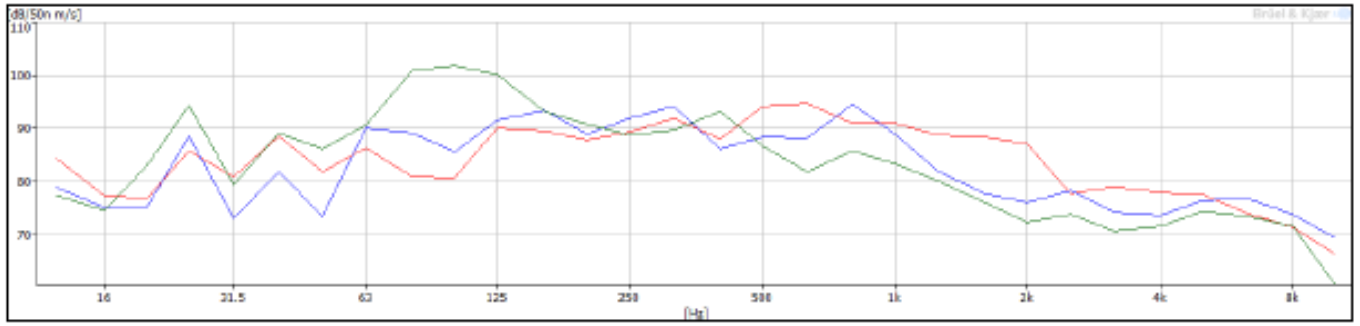


Figure 78 – Measured SBN level spectrum on port side DD.GG. head

CALIBRATED SEA MODEL - NOISE LEVELS

Measured data on Amadeus Silver III have been used to calibrate the SEA models as per following table of noise levels:

Cabin	Deck	Noise level measured on board [dB(A)]	Calculated dB(A) noise level
Crew cabin – C1	Haydn	60.2	60.0
Crew cabin – C2	Haydn	58.2	58.0
Crew cabin – C3	Haydn	54.9	54.6

Table 7 – Comparison between measured and calculated noise levels in crew cabins aft ship area

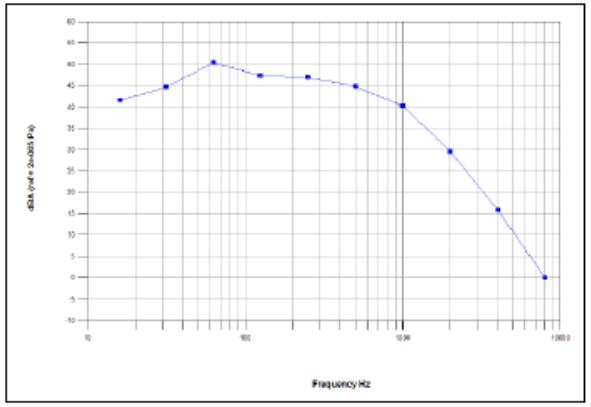


Figure 93 – Crew cabin C3, calculated noise level spectrum

CALIBRATED FEM MODEL - VIBRATION LEVELS

Measured data on Amadeus Silver III have been used to calibrate the FEM models as per following table of vibration levels:

Cabin	Deck	Vibration level measured on board [overall weighted mm/s]	FEM maximum calculated vibration level [overall weighted mm/s]
Crew cabin – C1	Haydn	0.80	0.72
Crew cabin – C2	Haydn	0.52	0.55
Crew cabin – C3	Haydn	0.51	0.50
Crew cabin – C4	Haydn	1.10	0.95
Crew cabin – C5	Haydn	0.75	0.81

Table 8 – Comparison between measured and calculated noise levels in crew cabins aft ship area

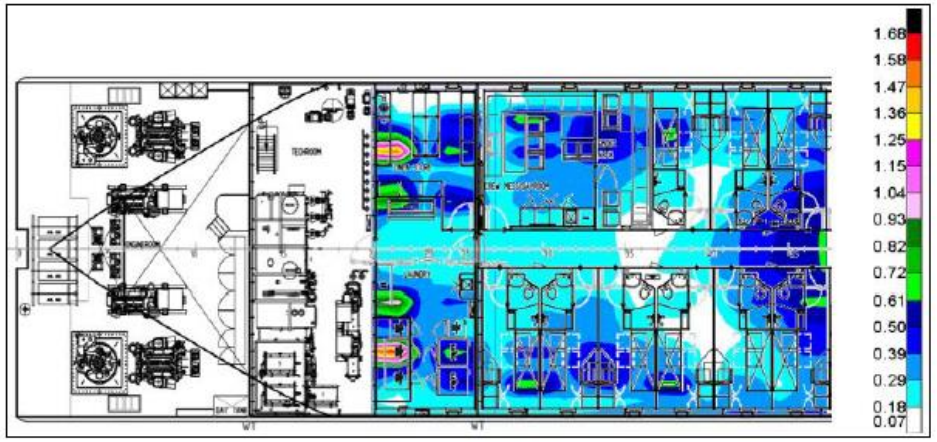
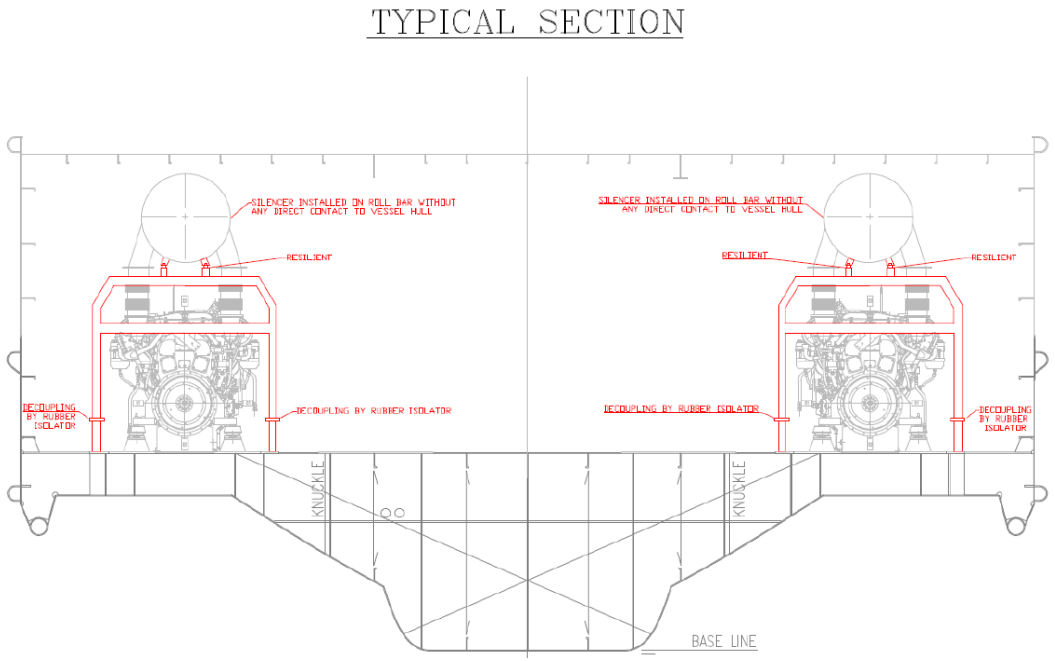
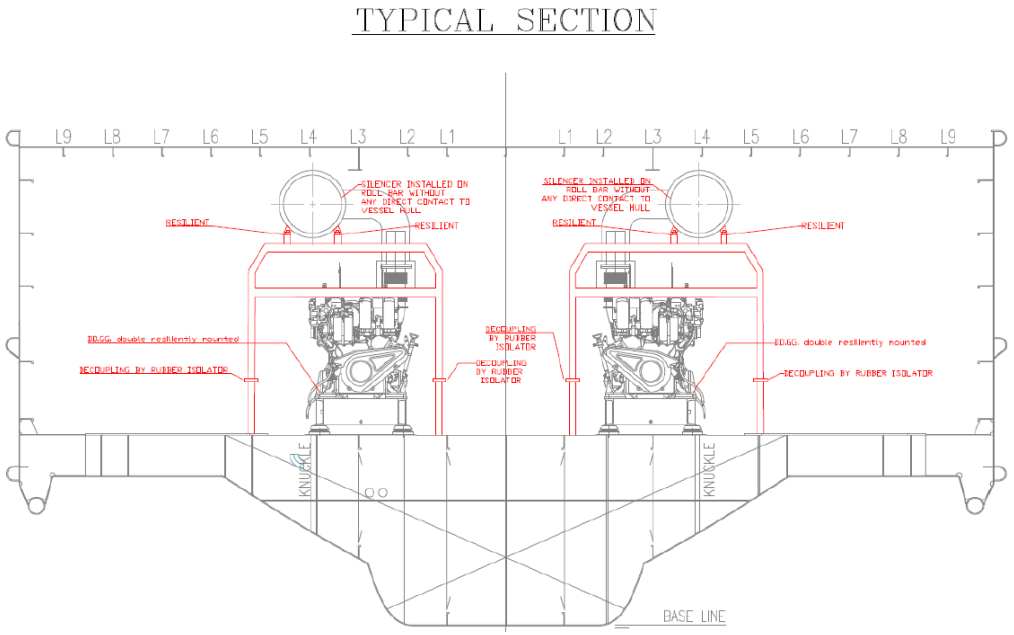


Figure 89 – Calculated vibration level in aft crew accommodation areas

PROPOSALS OF IMPROVEMENTS – AMADEUS SILVER III

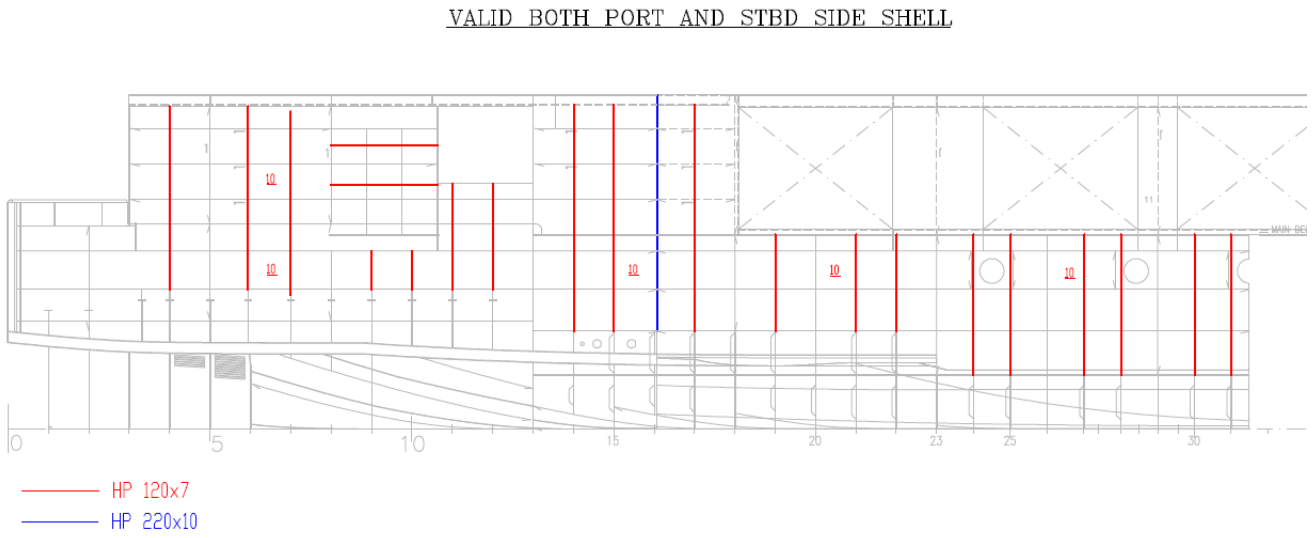


Proposal of improvements for main propulsion engines silencer/exhaust piping installation

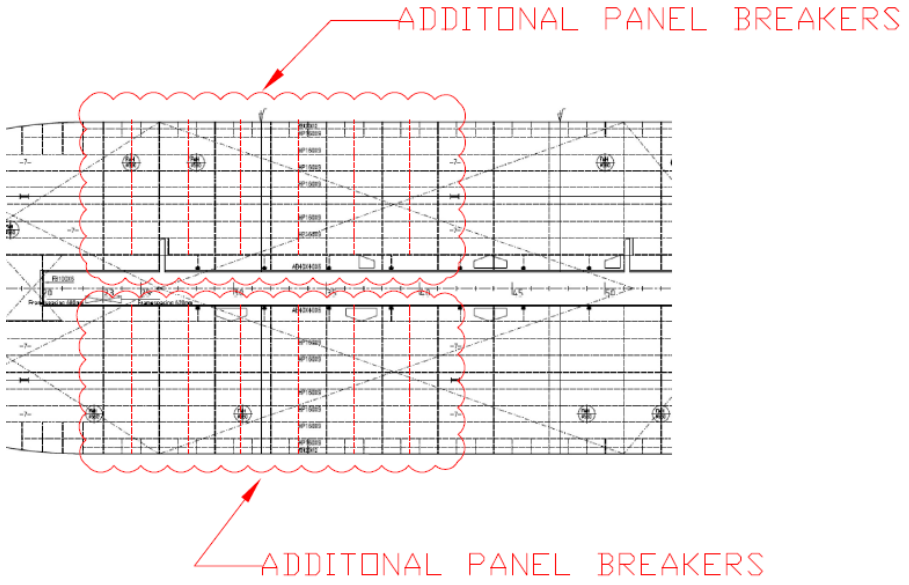


Proposal of improvements for DD.GG. silencer/exhaust piping installation

PROPOSALS OF IMPROVEMENTS – AMADEUS SILVER III

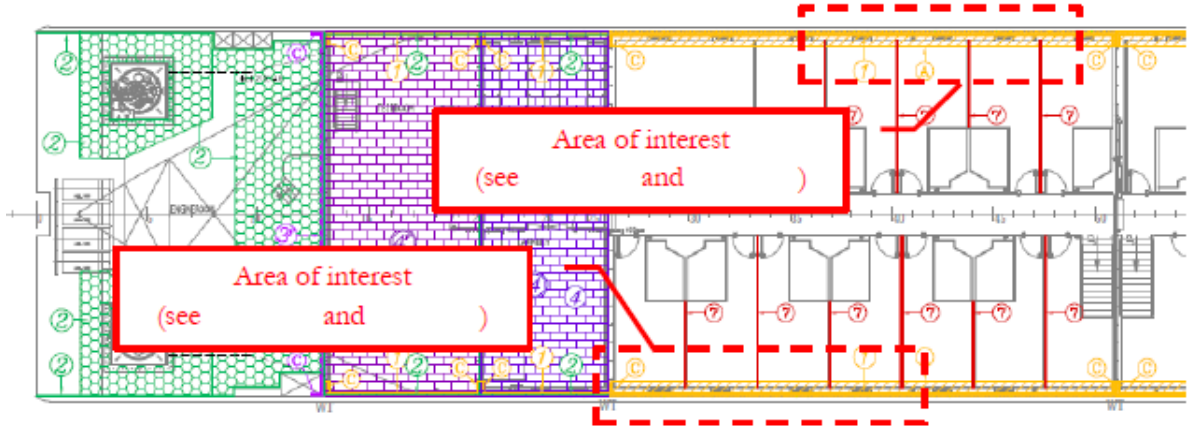


Side shell improvements

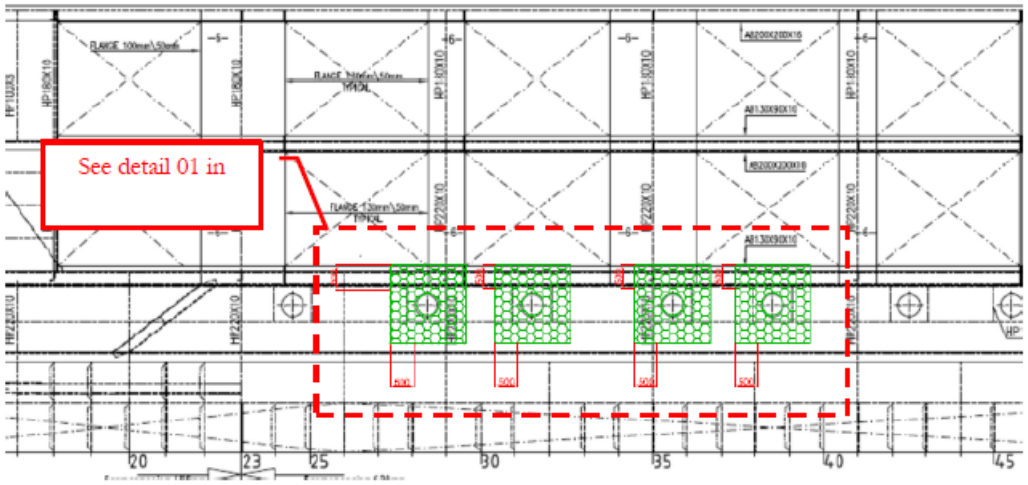


Tank deck improvements

PROPOSALS OF IMPROVEMENTS – AMADEUS SILVER III

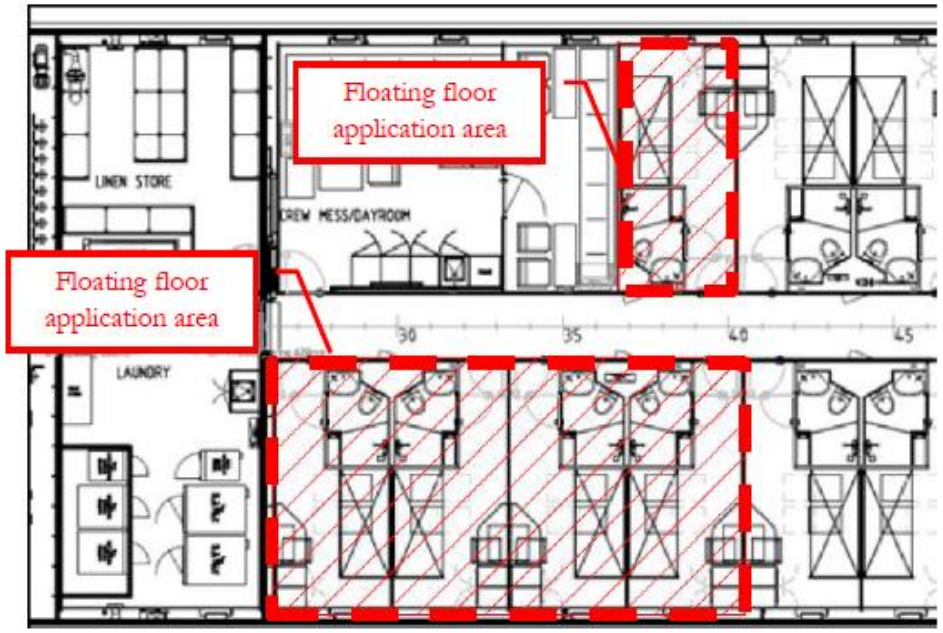


insulation plan improvements

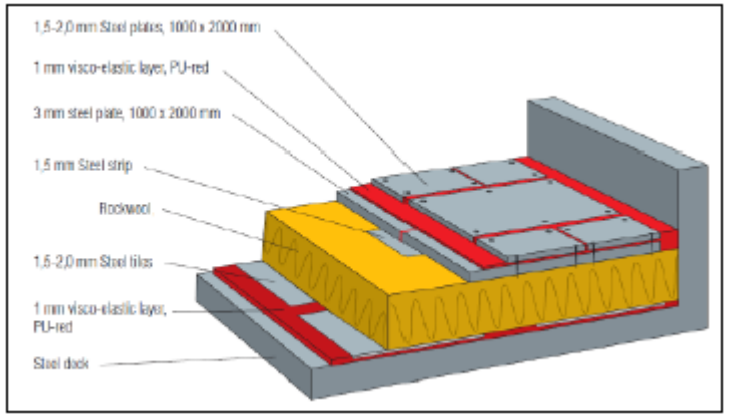


damping treatment improvements

PROPOSALS OF IMPROVEMENTS – AMADEUS SILVER III



floor plan improvements



Detail

Noise levels mitigation after improvements

Cabin	Calculated dB(A) noise level Before improvements	Calculated dB(A) noise level after improvements	Noise levels reduction [dB(A)]
Crew cabin – C1	60.2	58.9	-1.3
Crew cabin – C2	58.2	56.1	-2.1
Crew cabin – C3	54.9	53.3	-1.6

Table 10 – Comparison between calculated noise levels in crew cabins aft ship area

Cabin	DNV-GL comfort class before improvements	DNV-GL comfort class after improvements
Crew cabin – C1	CRN 3	CRN 3
Crew cabin – C2	CRN 3	CRN 3
Crew cabin – C3	CRN 2	CRN 2

Table 11 – Comparison between comfort class level before and after improvements

Noise levels mitigation after improvements

Cabin	Calculated dB(A) noise level Before improvements (original configuration)	Calculated dB(A) noise level After improvements (modified configuration)	Noise levels reduction [dB(A)]
Pax cabin - P1	56.1	55.0	-1.1
Pax cabin - P2	55.9	55.0	-0.9
Pax cabin - P3	52.5	51.1	-1.4
Pax cabin - P4	52.2	50.9	-1.3
Pax cabin - P5	54.2	53.1	-1.1
Pax cabin - P6	54.2	53.0	-1.2
Pax cabin - P7	52.0	51.0	-1.0
Pax cabin - P8	52.3	51.4	-0.9

Table 12 – Comparison between calculated noise levels in passenger cabins aft ship area

Vibration levels mitigation after improvements

Cabin	Maximum calculated vibration level Before improvements (o.a. mm/s)	Maximum calculated vibration level After improvements (o.a. mm/s)	Vibration levels reduction [mm/s]
Crew cabin – C1	0.72	0.45	-0.27
Crew cabin – C2	0.55	0.35	-0.20
Crew cabin – C3	0.50	0.35	-0.15
Crew cabin – C4	0.95	0.45	-0.50
Crew cabin – C5	0.81	0.50	-0.31

Table 14 – Calculated vibration levels in crew cabins aft ship area, comparison table

Cabin	Maximum calculated vibration level Before improvements (o.a. mm/s)	Maximum calculated vibration level After improvements (o.a. mm/s)	Vibration levels reduction [mm/s]
Pax cabin - P1	0.50	0.25	-0.25
Pax cabin - P2	0.58	0.35	-0.23
Pax cabin - P3	0.45	0.35	-0.10
Pax cabin - P4	0.45	0.25	-0.20

Table 15 – Comparison between calculated noise levels in passenger cabins aft ship area, Strauss deck

OPTION 01 – RECOMMENDATION FOR EXISTING FLEET

The activity has been developed following the below listed phases:

- **Vibro-acoustic measurements on board**: measurements have been performed on Amadeus Diamond, Amadeus Brabant and Amadeus Royal. Noise and vibration measurements have been performed in the crew quarters and on propulsion system machinery.

- **Calibration of the developed vibro-acoustic numerical models** with the data measured on board during the performed river trials.

- **Study of improvements** for vibro-acoustic levels mitigation.

- **Test of the studied improvements** by performing iterative acoustic and FE analysis.

- Evaluation of **achieved benefits** in terms of noise and vibration levels mitigation.

OPTION 01 – NOISE LEVEL AMADEUS ROYAL

Area	Area	Measured dB(A) noise level before improvements	Predicted dB(A) noise level after improvements	Noise levels reduction [dB(A)]
Amadeus Royal	Crew cabin – C1	56.0	55.0	-1.0
	Crew cabin – C2	56.5	55.0	-1.5
	Crew cabin – C3	54.3	53.0	-1.3
	Crew cabin – C4	53.3	52.0	-1.3
	Crew cabin – C5	52.6	52.0	-0.6

Table 24 – Noise levels reduction

Area	Area	DNV-GL comfort class before improvements [CRN1 – CRN2 – CRN3]	DNV-GL comfort class after improvements [CRN1 – CRN2 – CRN3]
Amadeus Royal	Crew cabin – C1	CRN3	CRN2
	Crew cabin – C2	CRN3	CRN2
	Crew cabin – C3	CRN2	CRN2
	Crew cabin – C4	CRN2	CRN2
	Crew cabin – C5	CRN2	CRN2

Table 25 – Comparison between comfort class level before and after improvements

OPTION 01 – NOISE LEVEL AMADEUS DIAMOND

Area	Area	Measured dB(A) noise level before improvements	Predicted dB(A) noise level after improvements	Noise levels reduction [dB(A)]
Amadeus Diamond	Crew cabin – C1	58.2	55.0	-3.2
	Crew cabin – C2	57.5	55.0	-2.5
	Crew cabin – C4	54.4	53.0	-1.4
	Crew cabin – C5	55.4	53.0	-2.4

Table 26 – Noise levels reduction

Area	Area	DNV-GL comfort class before improvements [CRN1 – CRN2 – CRN3]	DNV-GL comfort class after improvements [CRN1 – CRN2 – CRN3]
Amadeus Diamond	Crew cabin – C1	CRN3	CRN2
	Crew cabin – C2	CRN3	CRN2
	Crew cabin – C4	CRN2	CRN2
	Crew cabin – C5	CRN2	CRN2

Table 27 – Comparison between comfort class level before and after improvements

OPTION 01 – NOISE LEVEL AMADEUS BRABANT

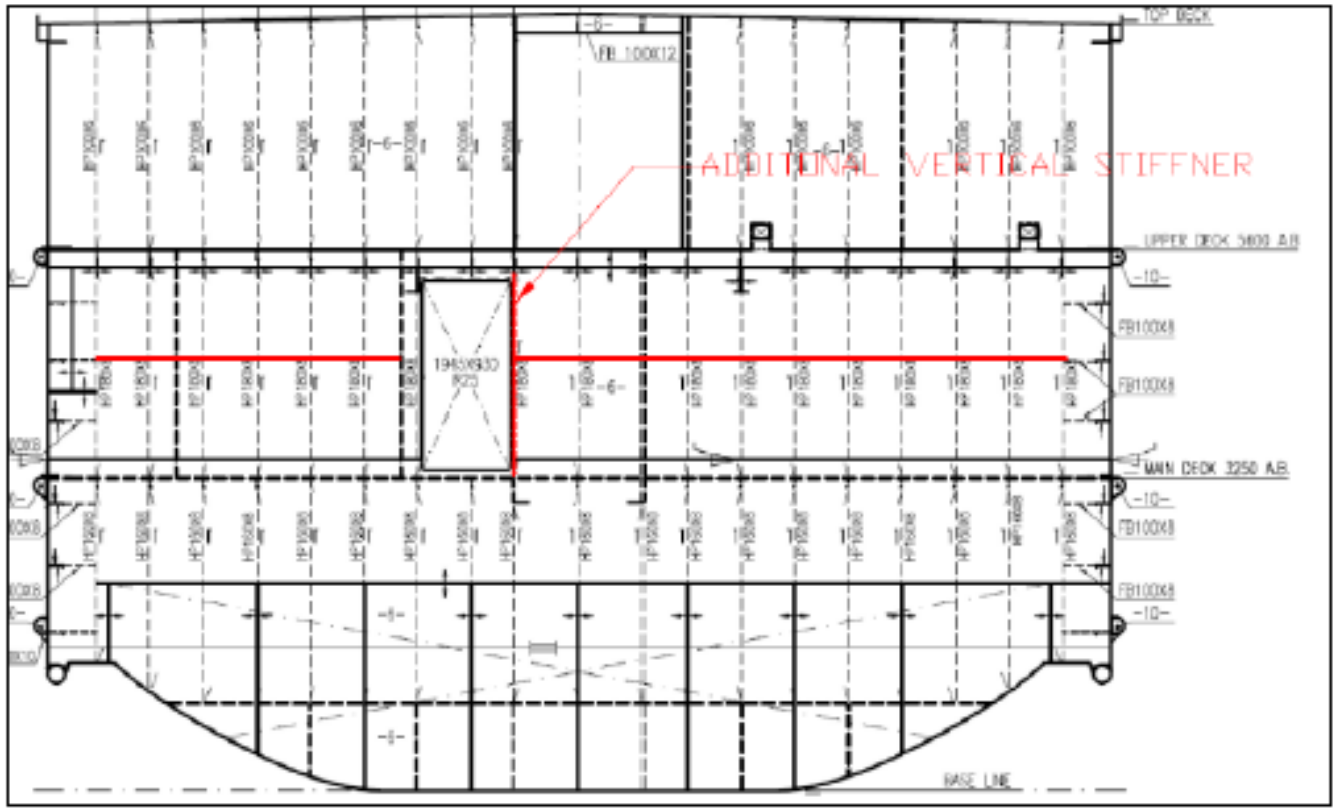
Area	Area	Measured dB(A) noise level before improvements	Predicted dB(A) noise level after improvements	Noise levels reduction [dB(A)]
Amadeus Brabant	Crew cabin – C1	59.4	55.4	-4.4
	Crew cabin – C2	59.1	54.7	-4.3
	Crew cabin – C3	58.5	54.7	-3.8
	Crew cabin – C4	55.7	53.0	-2.7
	Crew cabin – C5	50.1	49.0	-1.1

Table 28 – Noise levels reduction

Area	Area	DNV-GL comfort class before improvements [CRN1 – CRN2 – CRN3]	DNV-GL comfort class after improvements [CRN1 – CRN2 – CRN3]
Amadeus Brabant	Crew cabin – C1	CRN3	CRN3
	Crew cabin – C2	CRN3	CRN2
	Crew cabin – C3	CRN3	CRN2
	Crew cabin – C4	CRN3	CRN2
	Crew cabin – C5	CRN2	CRN2

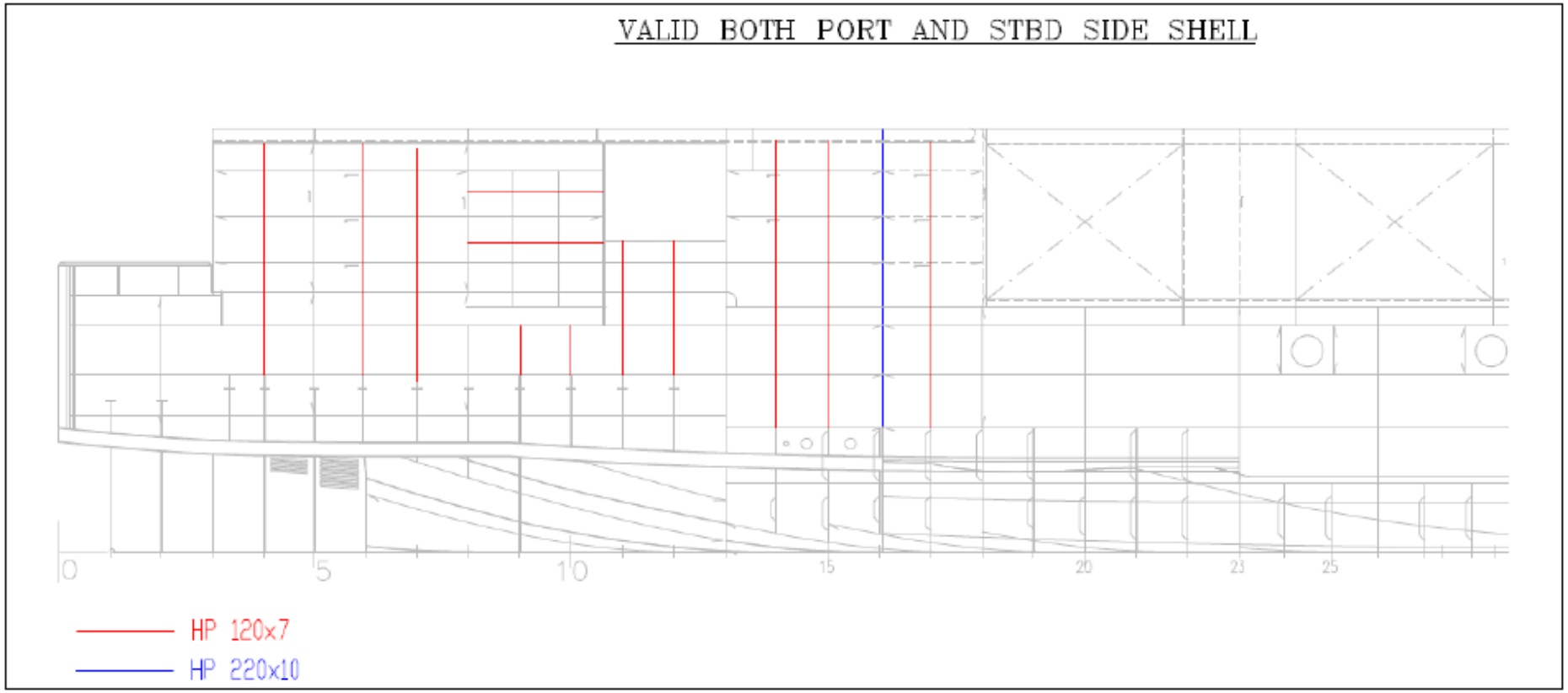
Table 29 – Comparison between comfort class level before and after improvements

OPTION 01 - PROPOSALS OF IMPROVEMENTS AMADEUS ROYAL



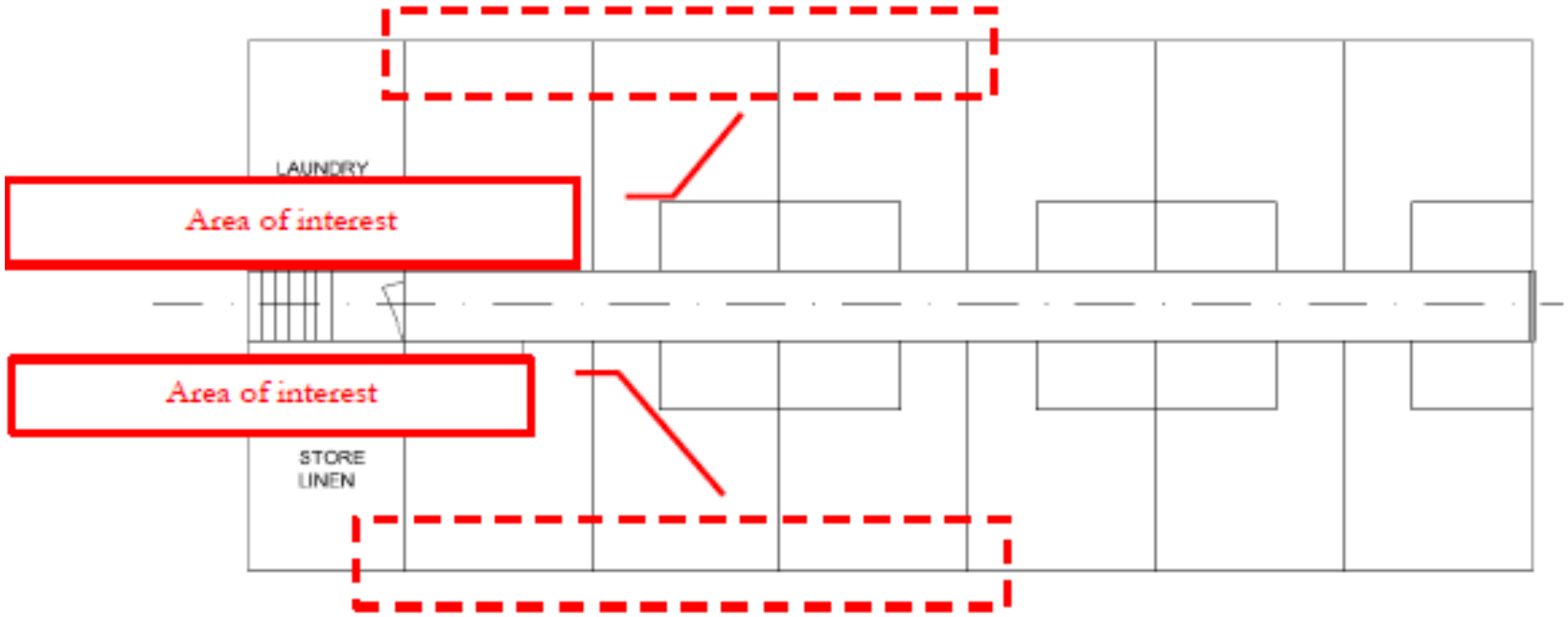
Detail of the structural improvements

OPTION 01 - PROPOSALS OF IMPROVEMENTS
AMADEUS ROYAL



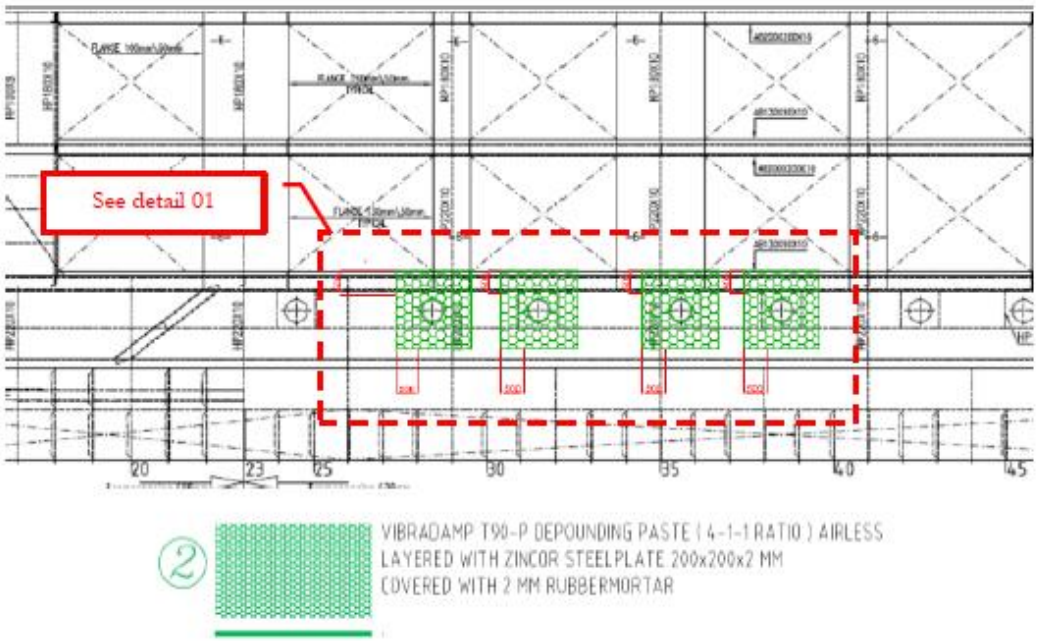
Detail of the structural improvements

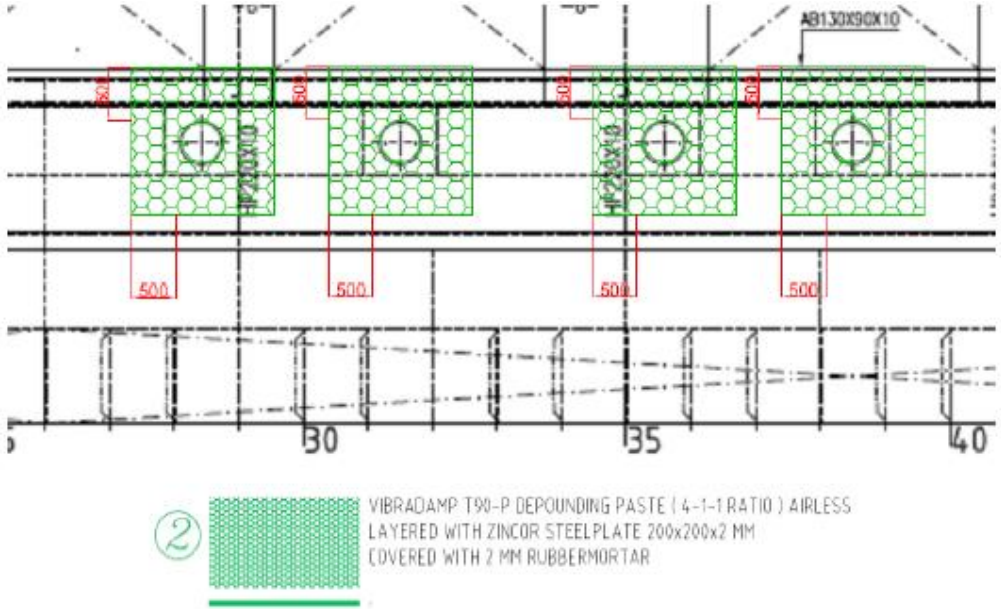
OPTION 01 - PROPOSALS OF IMPROVEMENTS
AMADEUS ROYAL



Proposed additional damping treatment

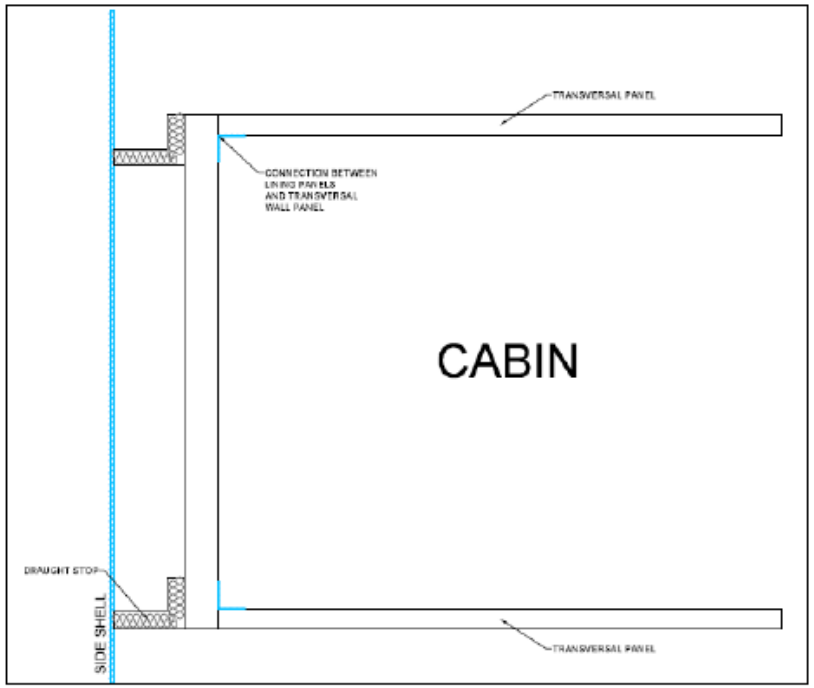
OPTION 01 - PROPOSALS OF IMPROVEMENTS
AMADEUS ROYAL



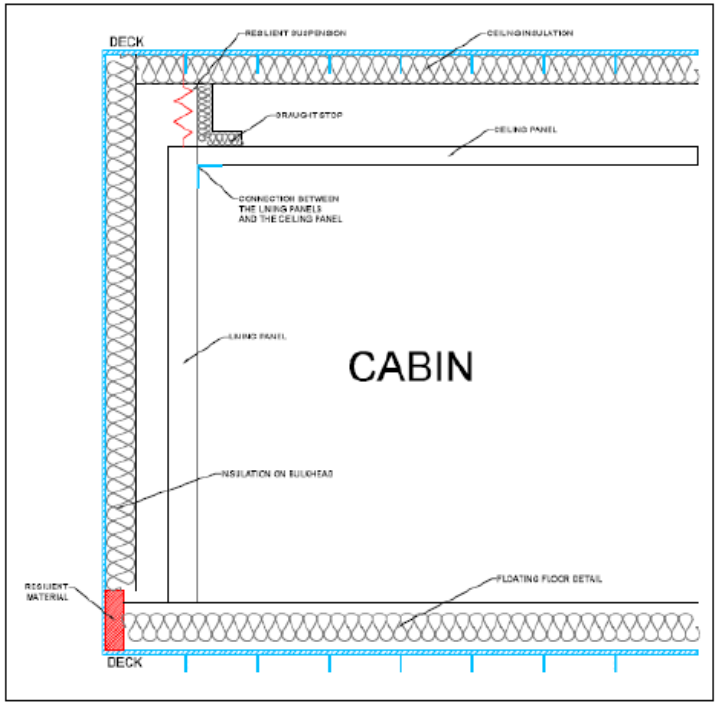


Proposed additional damping treatment

OPTION 01 - PROPOSALS OF IMPROVEMENTS
AMADEUS ROYAL

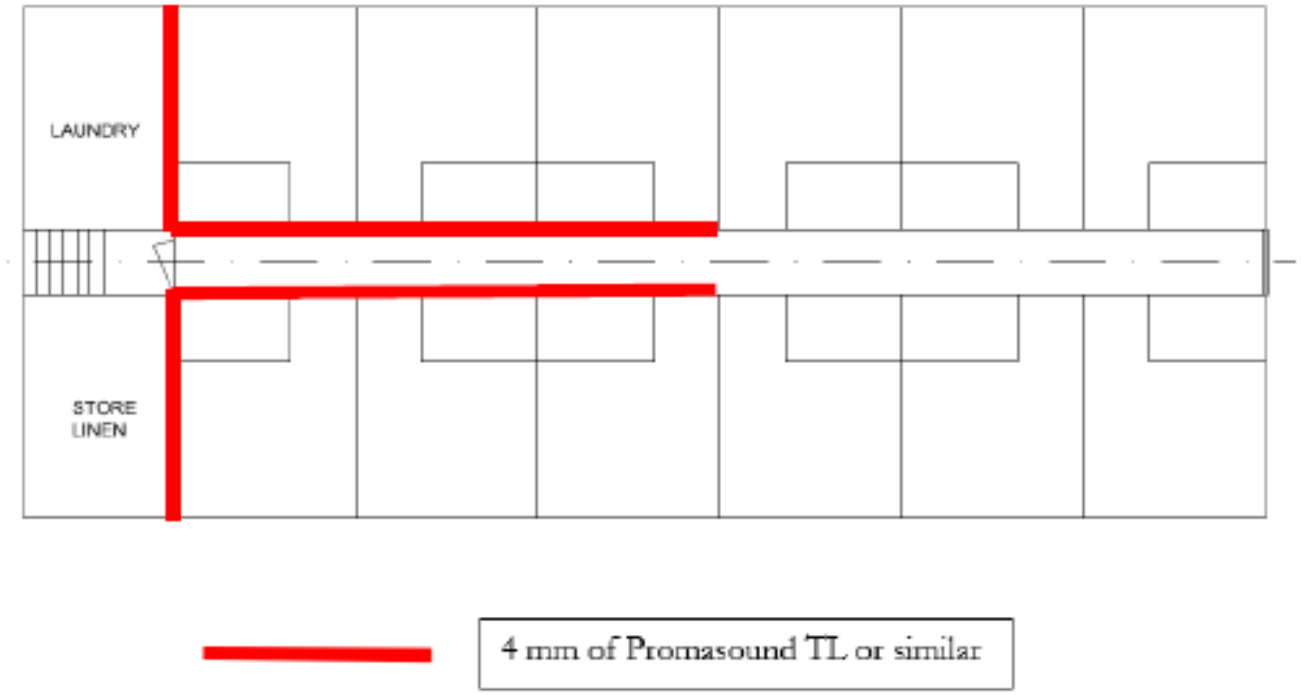


Proposed acoustic barrier preventing, wall detail



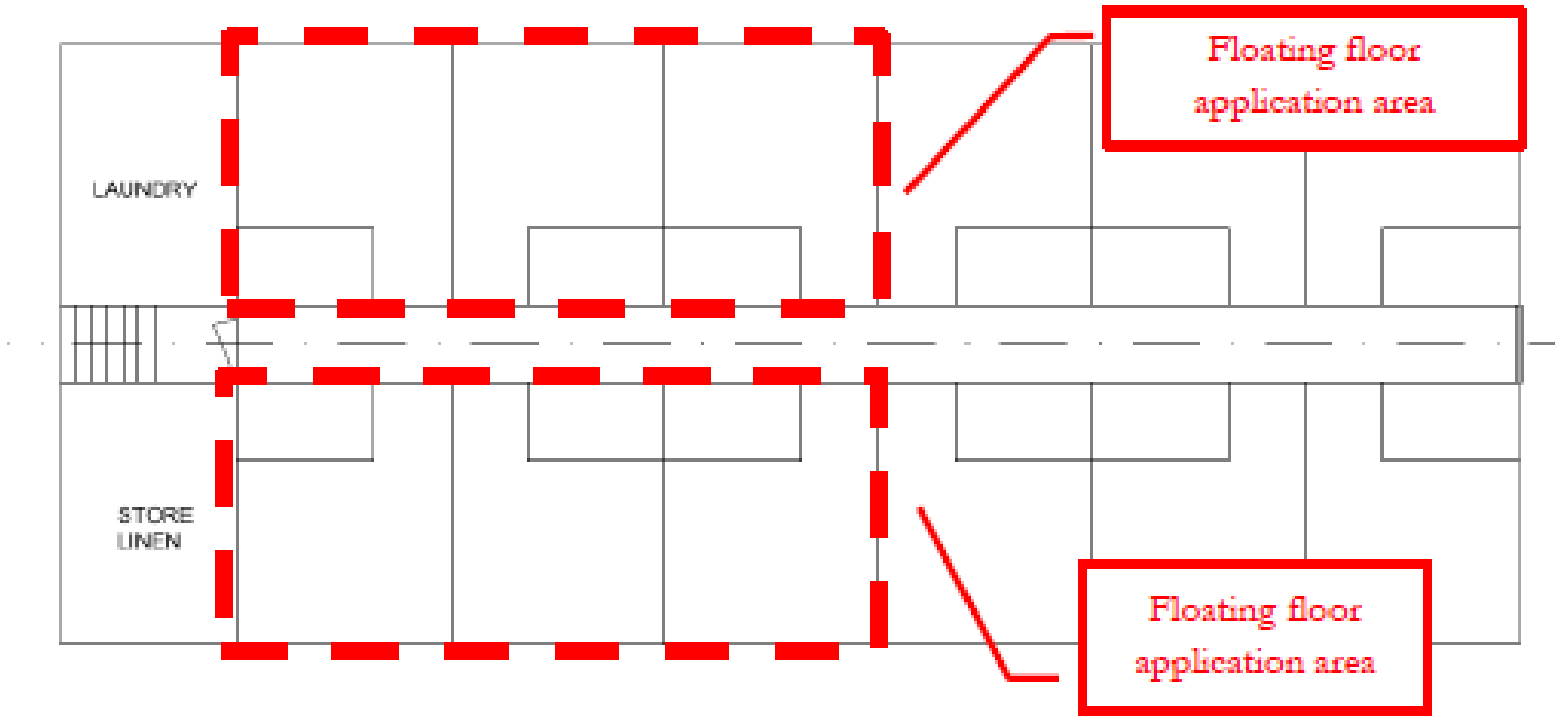
Proposed acoustic barrier preventing, floor and ceiling details

OPTION 01 - PROPOSALS OF IMPROVEMENTS AMADEUS ROYAL



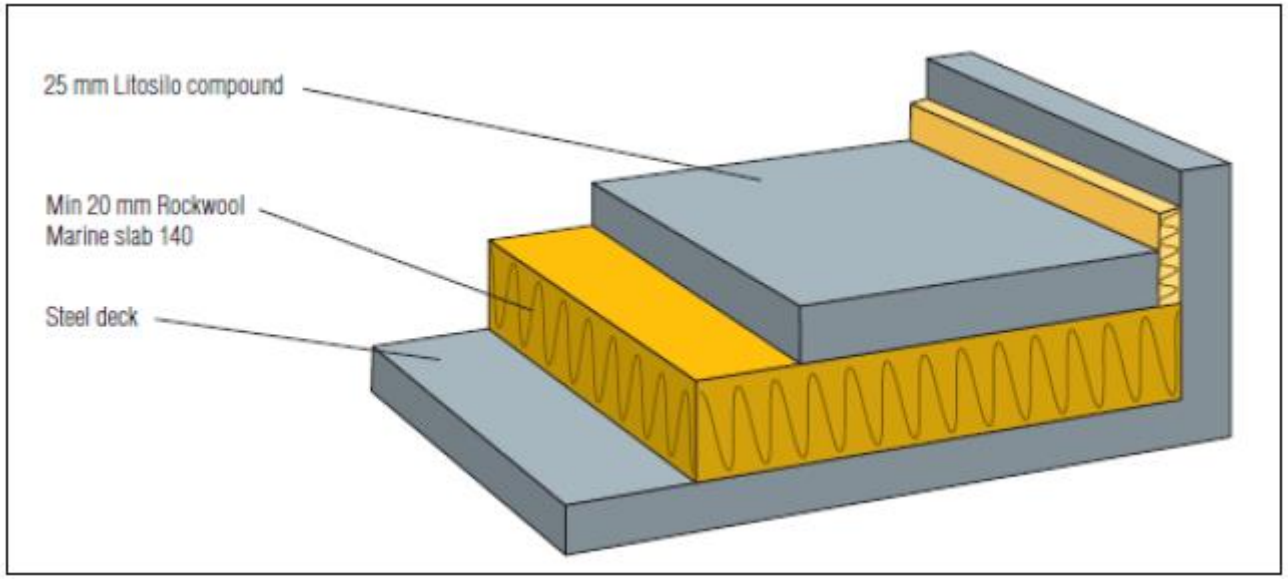
Promasound TL (4mm) proposed application areas

OPTION 01 - PROPOSALS OF IMPROVEMENTS AMADEUS ROYAL



Proposed floating floor application area

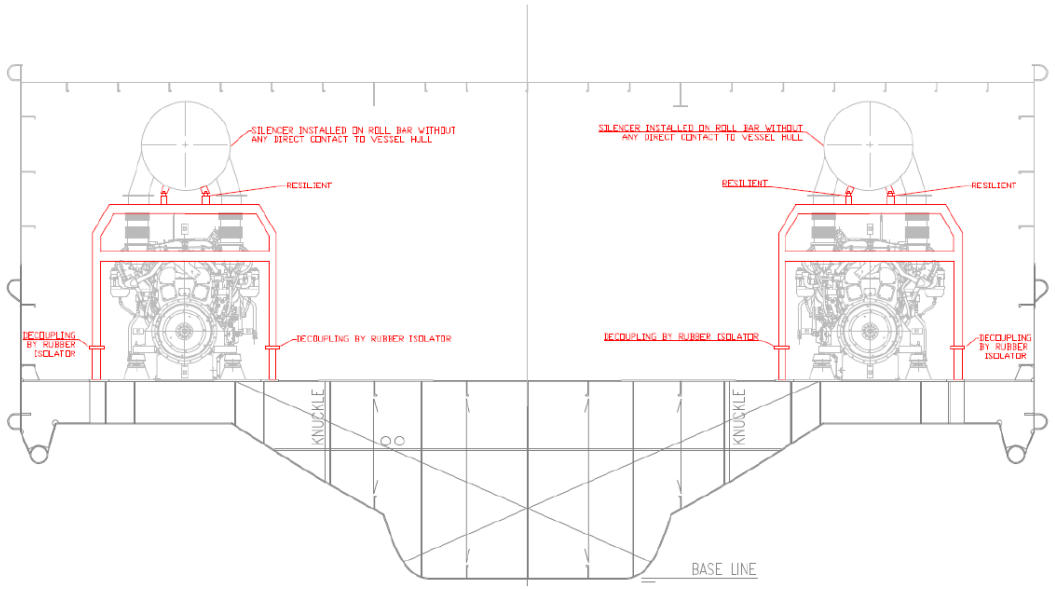
OPTION 01 - PROPOSALS OF IMPROVEMENTS AMADEUS ROYAL



Proposed floating floor typology

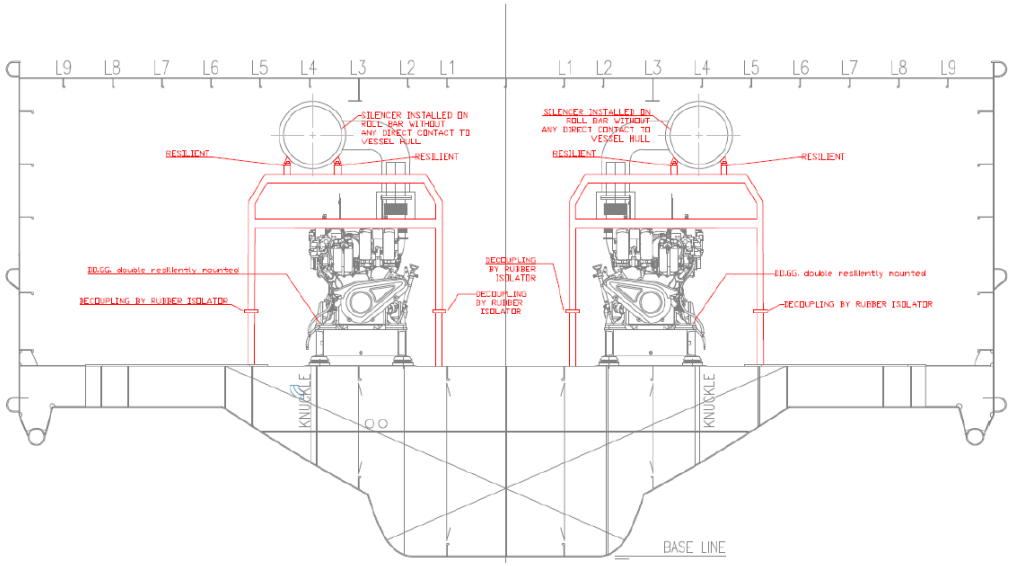
OPTION 01 - PROPOSALS OF IMPROVEMENTS AMADEUS ROYAL

TYPICAL SECTION



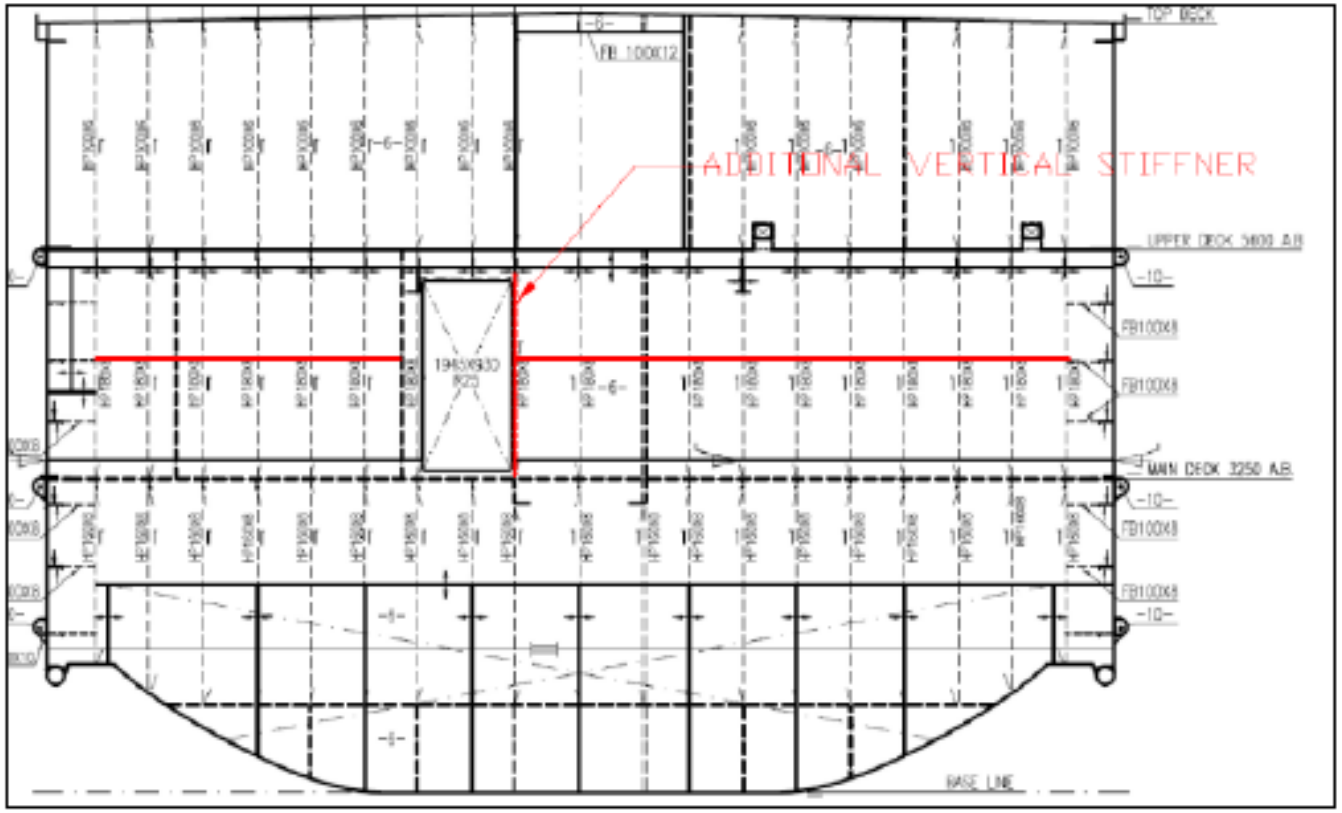
Proposal of improvements for main propulsion engines silencer/exhaust piping installation

TYPICAL SECTION



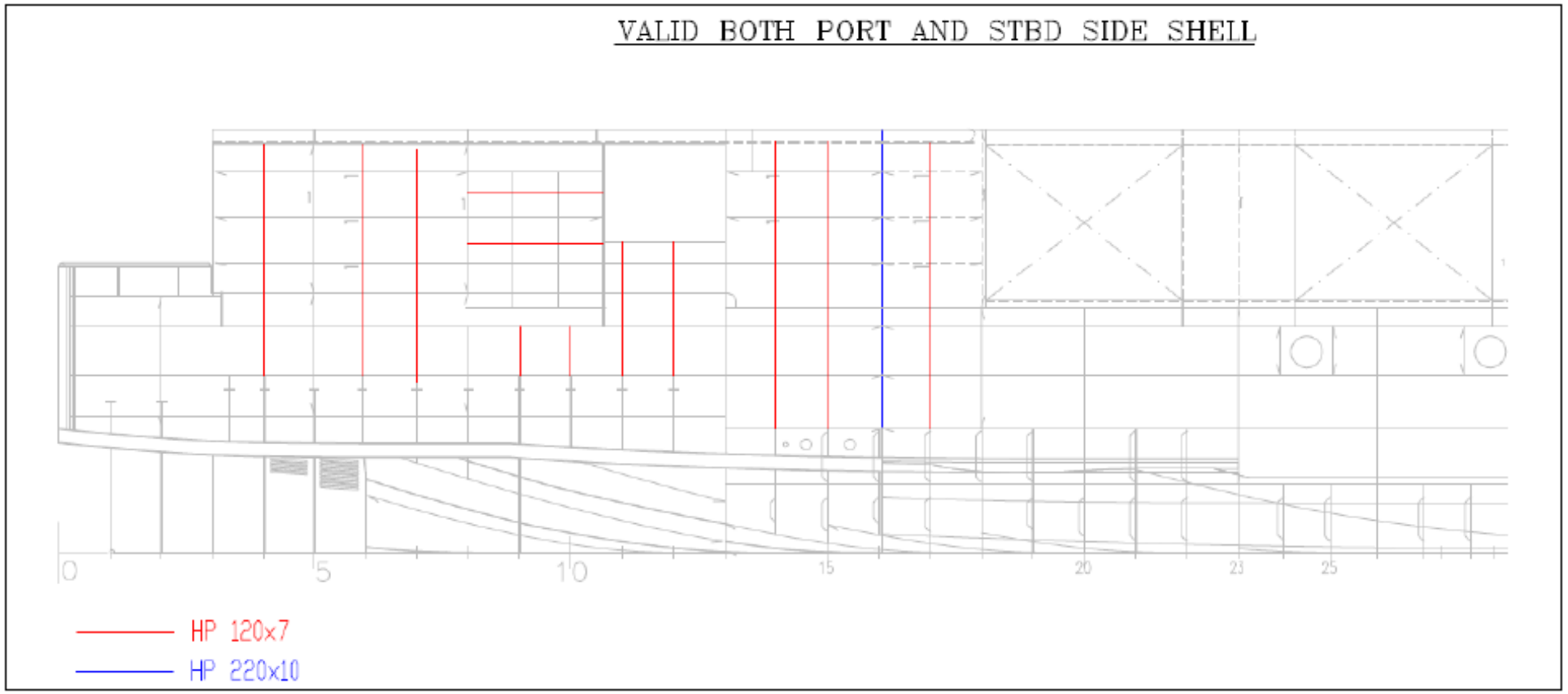
Proposal of improvements for DD.GG. silencer/exhaust piping installation

OPTION 01 - PROPOSALS OF IMPROVEMENTS AMADEUS DIAMOND



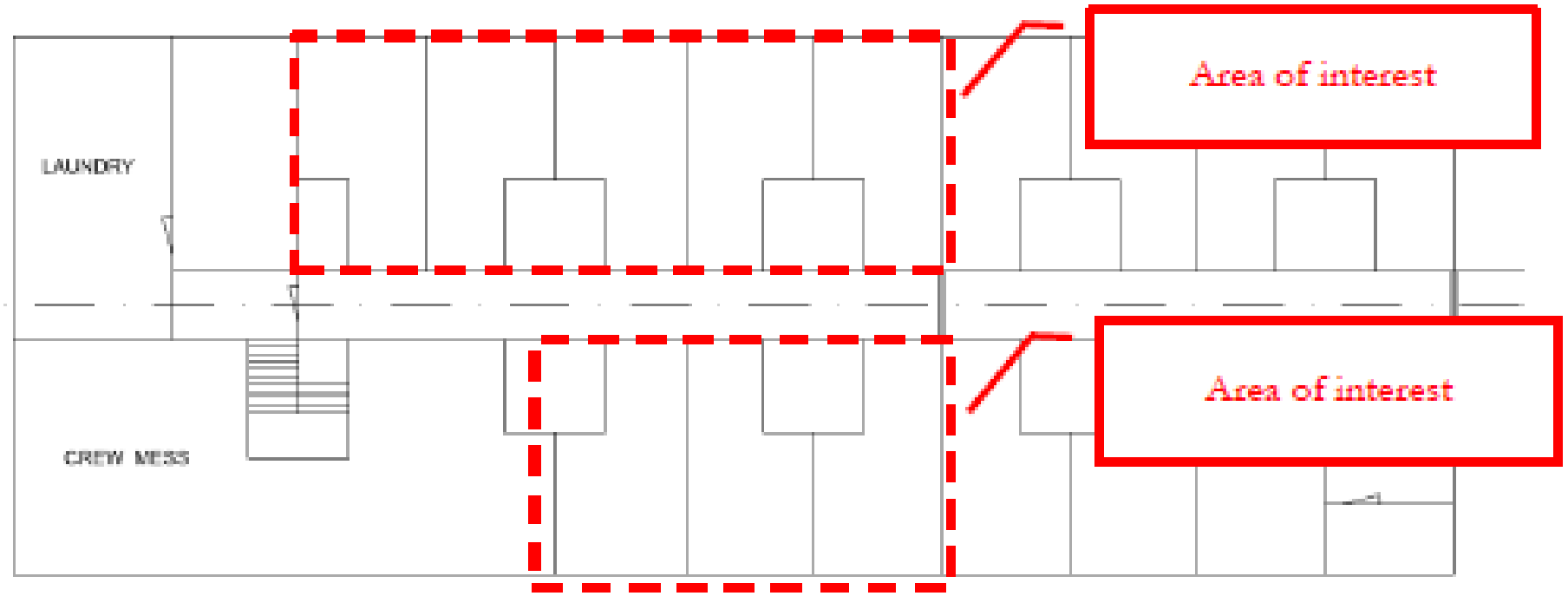
Detail of the structural improvements

OPTION 01 - PROPOSALS OF IMPROVEMENTS
AMADEUS DIAMOND



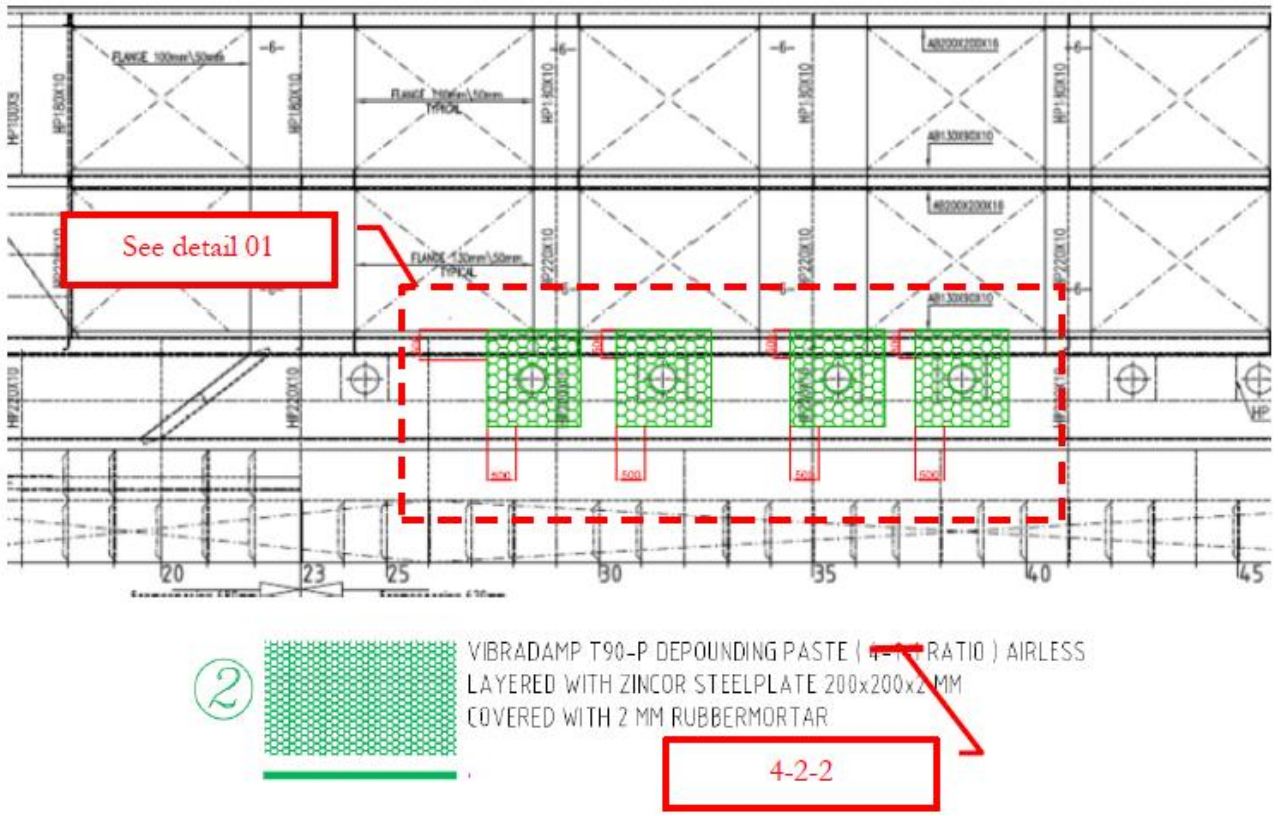
Detail of the structural improvements

OPTION 01 - PROPOSALS OF IMPROVEMENTS AMADEUS DIAMOND



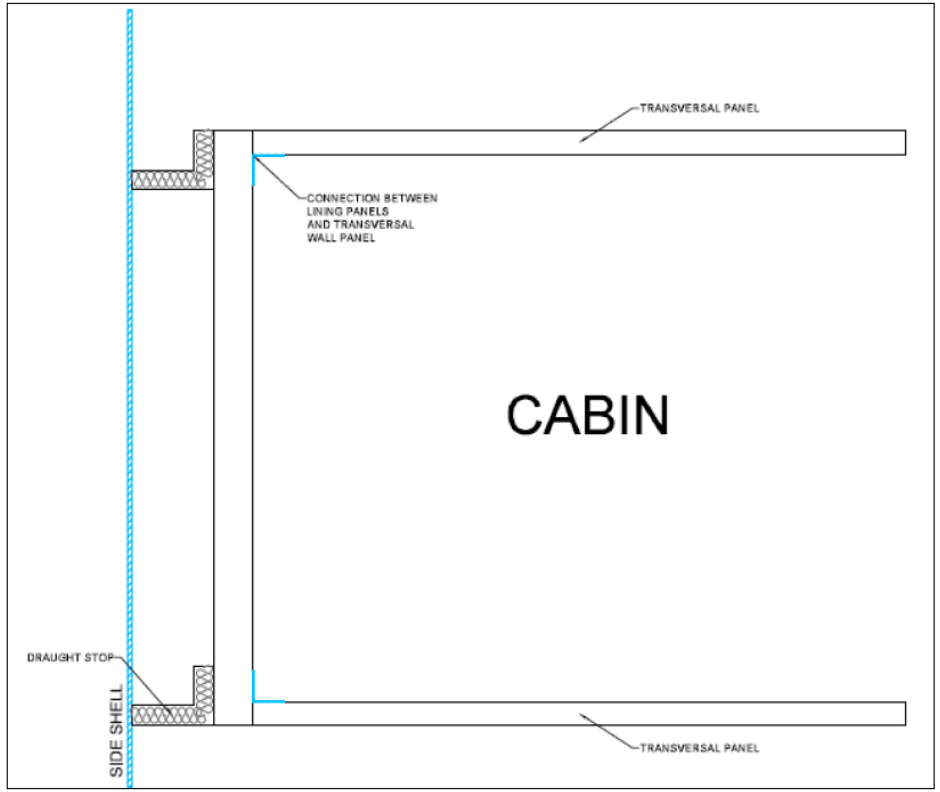
Proposed additional damping treatment

OPTION 01 - PROPOSALS OF IMPROVEMENTS AMADEUS DIAMOND

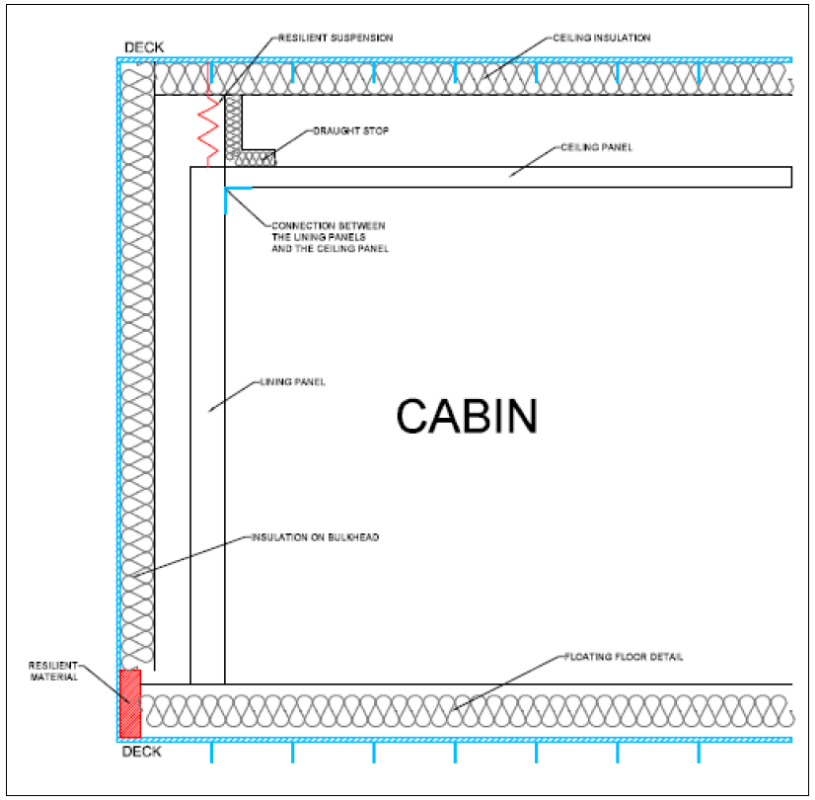


Proposed additional damping treatment

OPTION 01 - PROPOSALS OF IMPROVEMENTS
AMADEUS DIAMOND

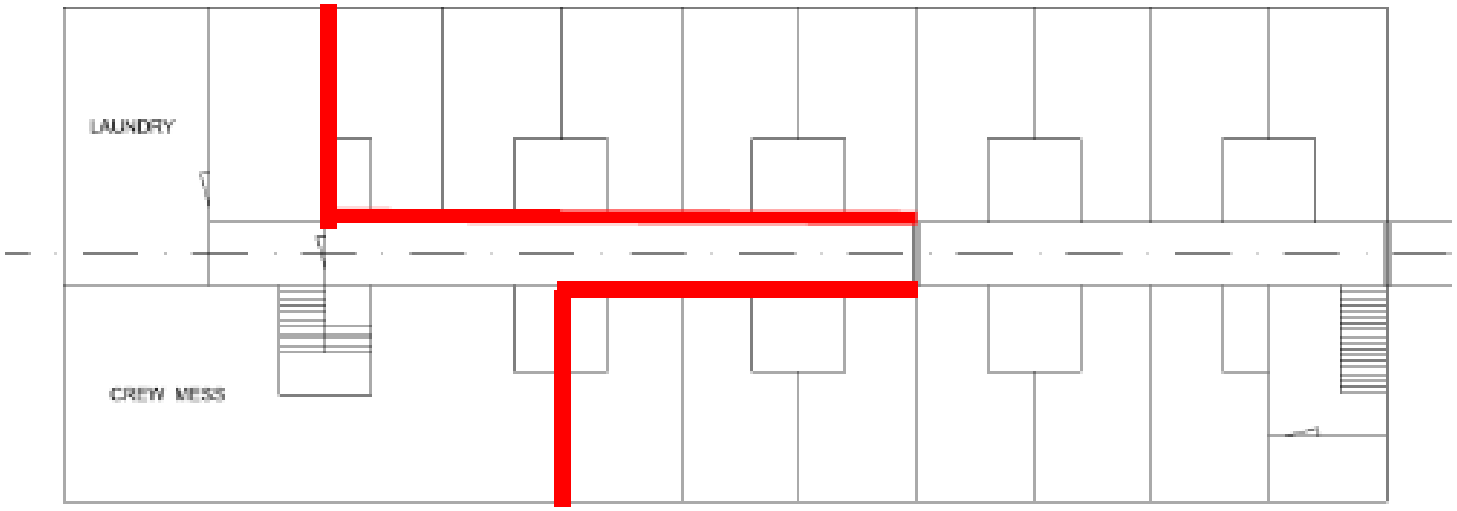


Proposed acoustic barrier preventing, wall detail



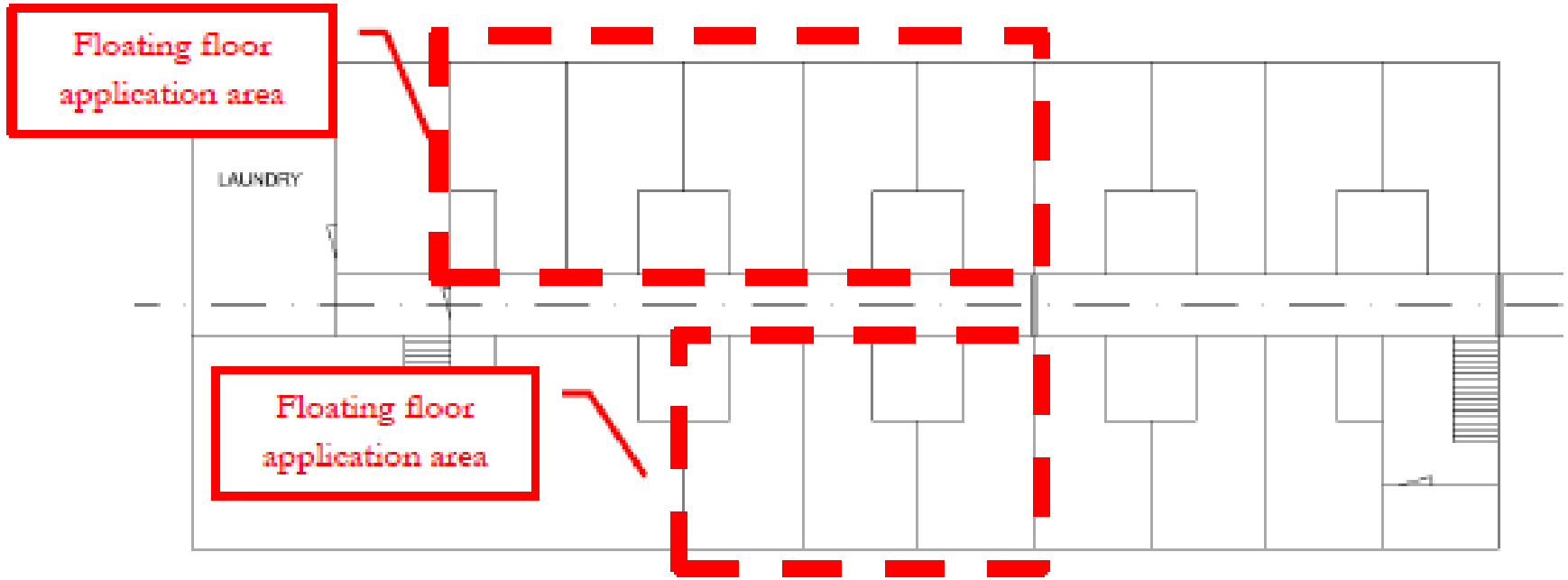
Proposed acoustic barrier preventing, floor and ceiling details

OPTION 01 - PROPOSALS OF IMPROVEMENTS AMADEUS DIAMOND



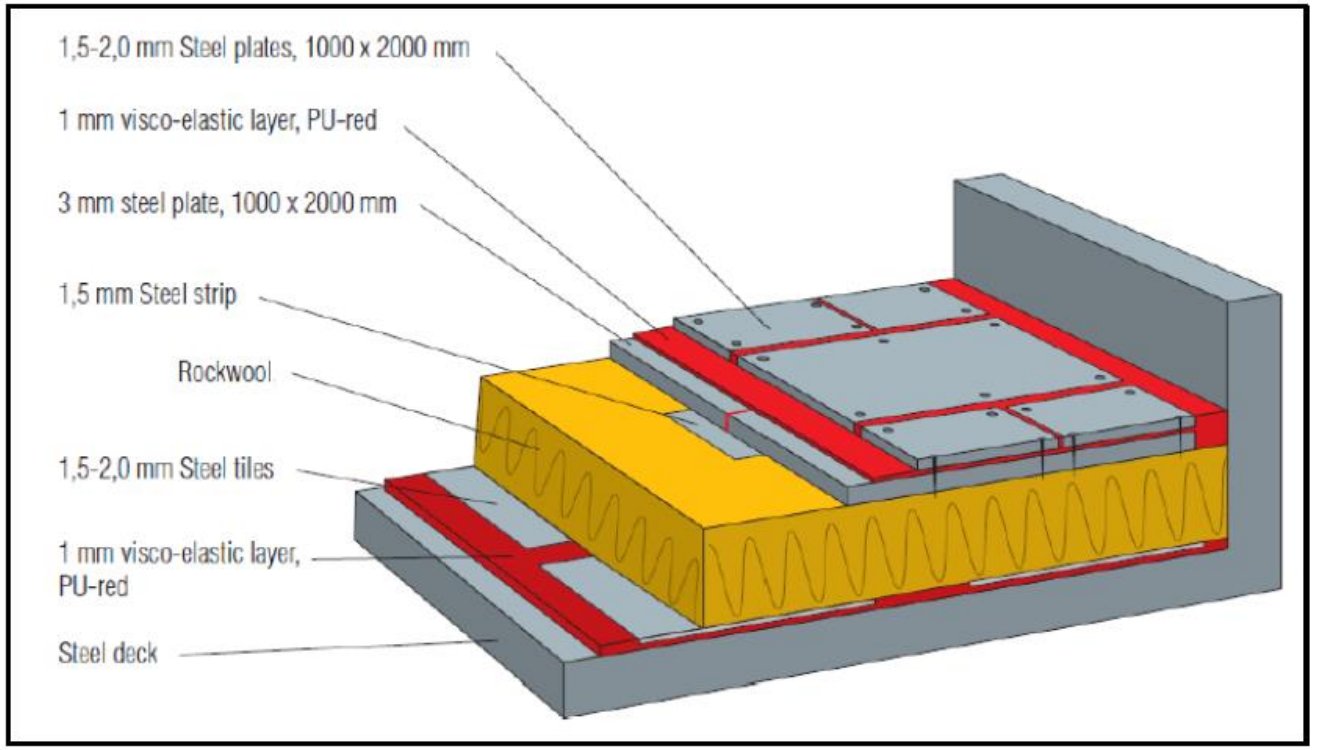
Promasound TL (4mm) proposed application areas

OPTION 01 - PROPOSALS OF IMPROVEMENTS
AMADEUS DIAMOND



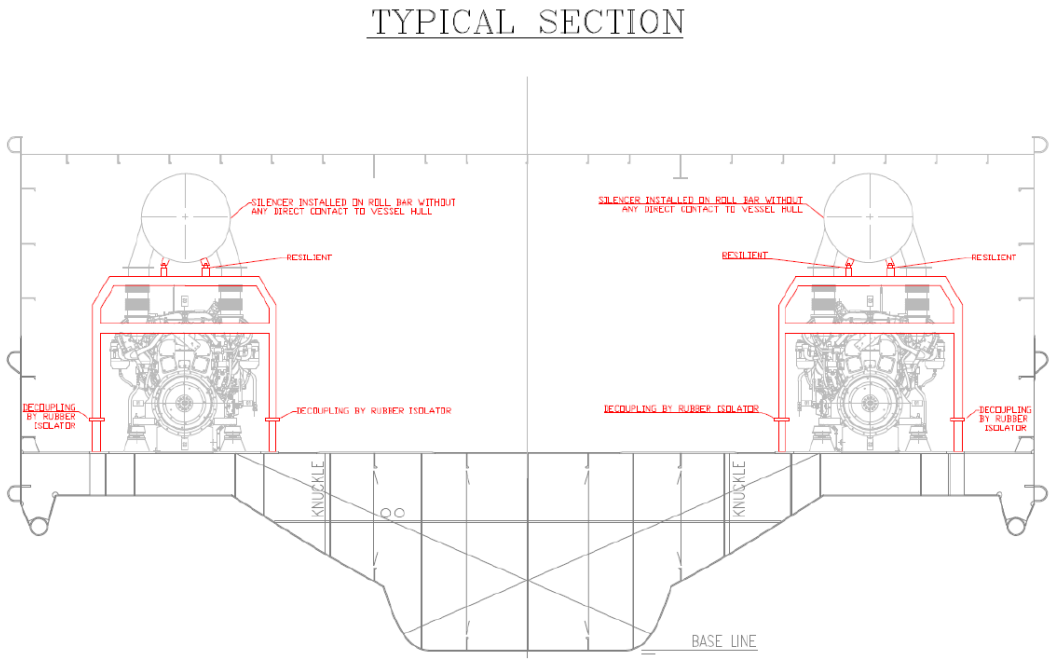
Proposed floating floor application area

OPTION 01 - PROPOSALS OF IMPROVEMENTS AMADEUS DIAMOND

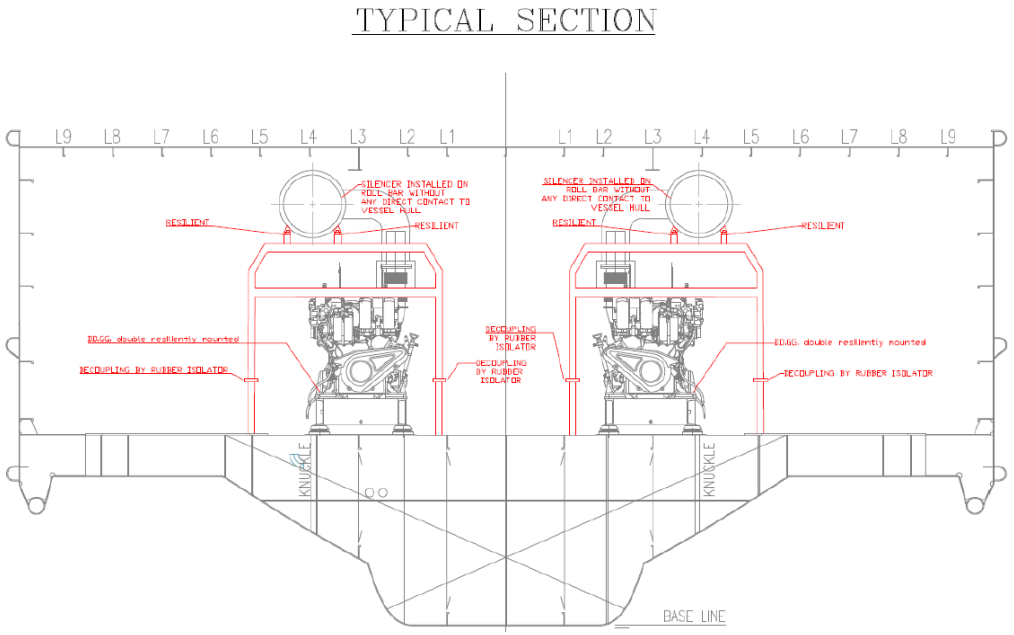


Proposed floating floor typology

OPTION 01 - PROPOSALS OF IMPROVEMENTS AMADEUS DIAMOND

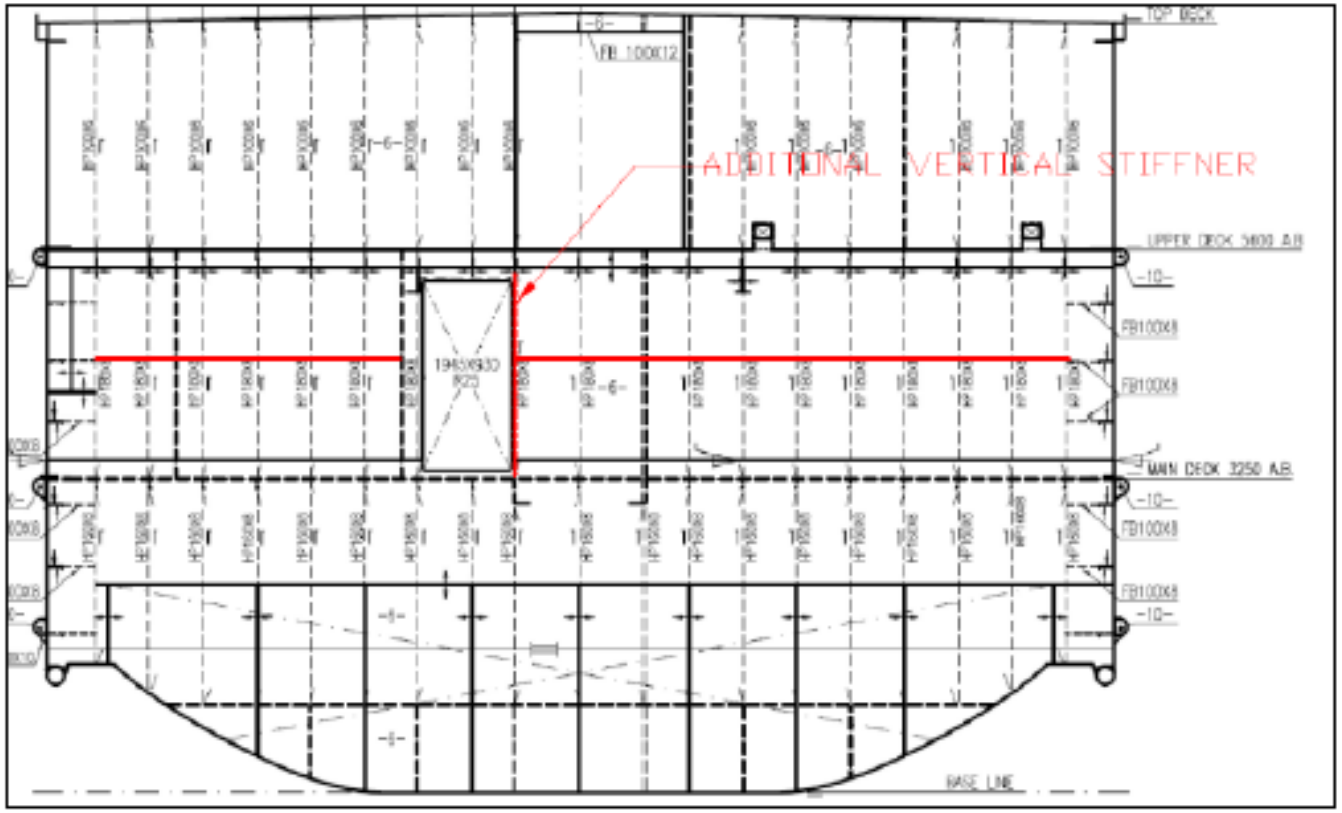


Proposal of improvements for main propulsion engines silencer/exhaust piping installation



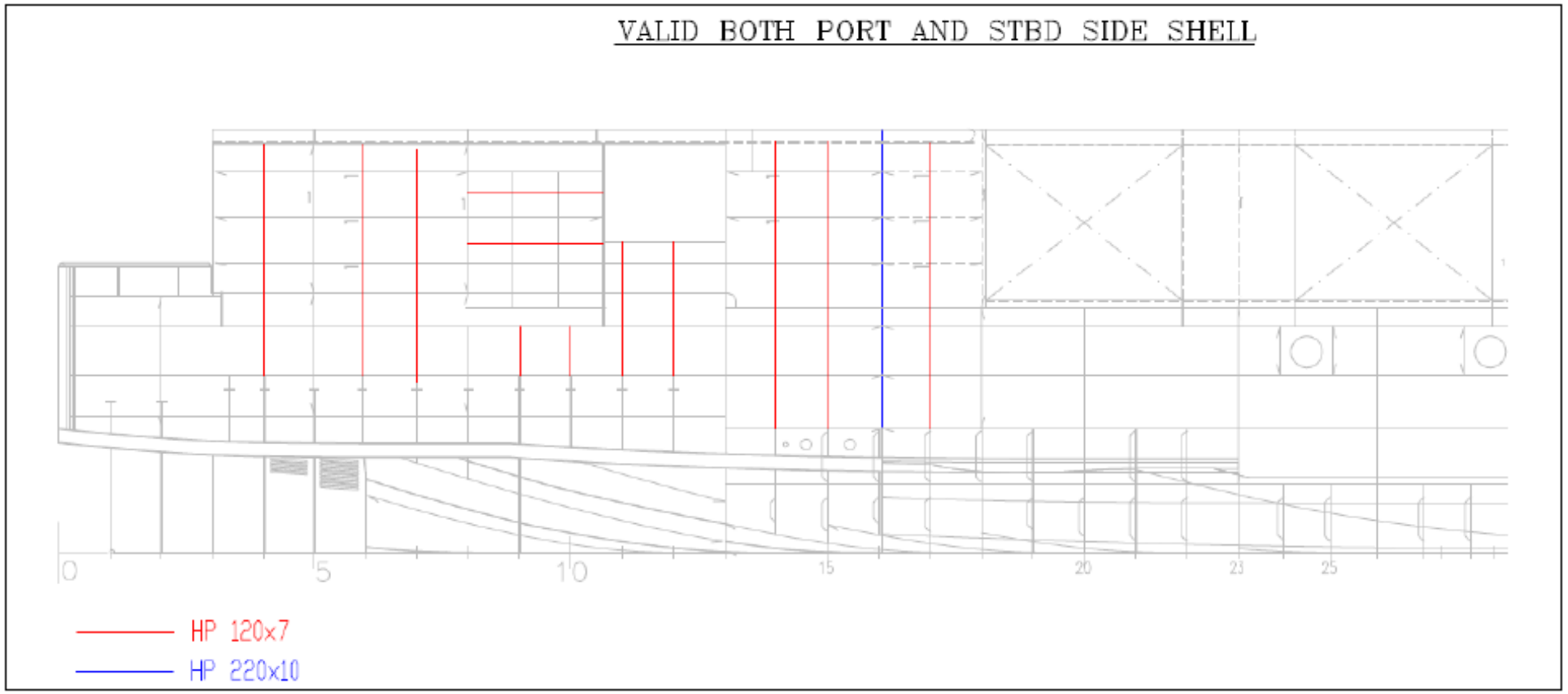
Proposal of improvements for DD.GG. silencer/exhaust piping installation

OPTION 01 - PROPOSALS OF IMPROVEMENTS AMADEUS BRABANT



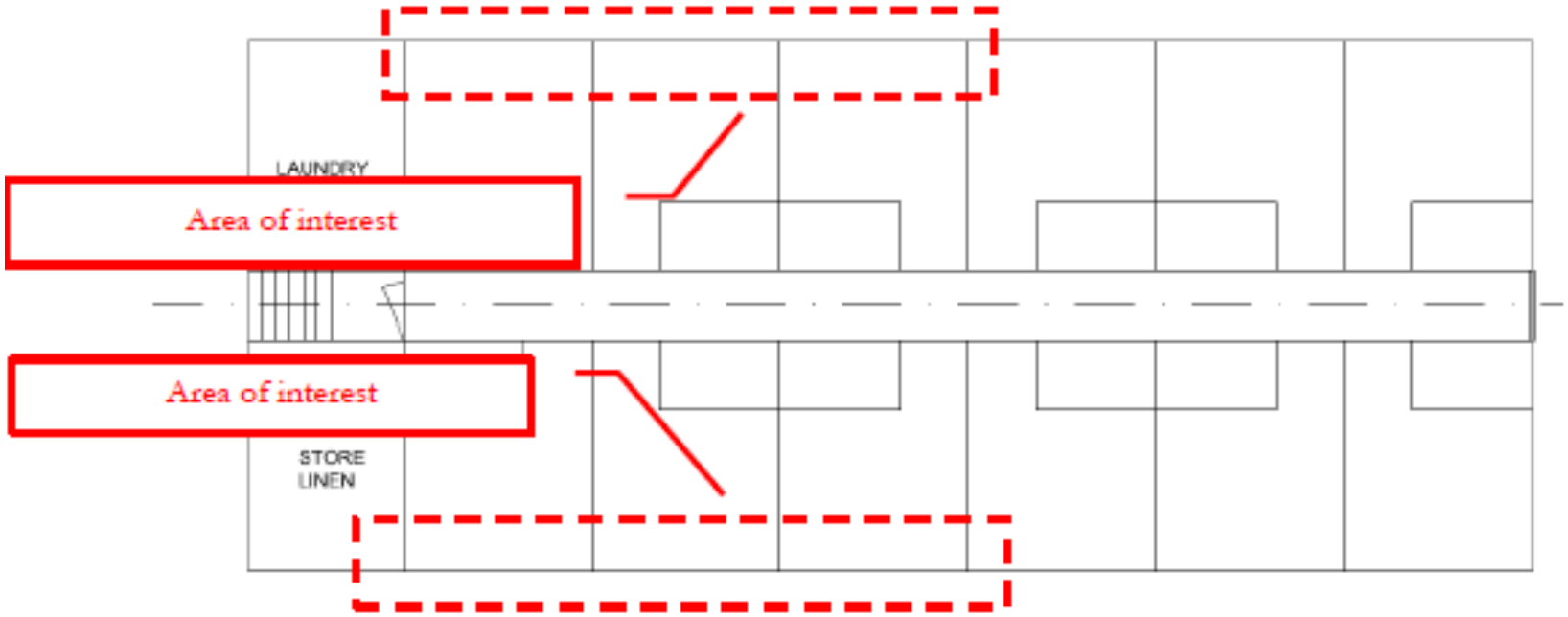
Detail of the structural improvements

OPTION 01 - PROPOSALS OF IMPROVEMENTS
AMADEUS BRABANT



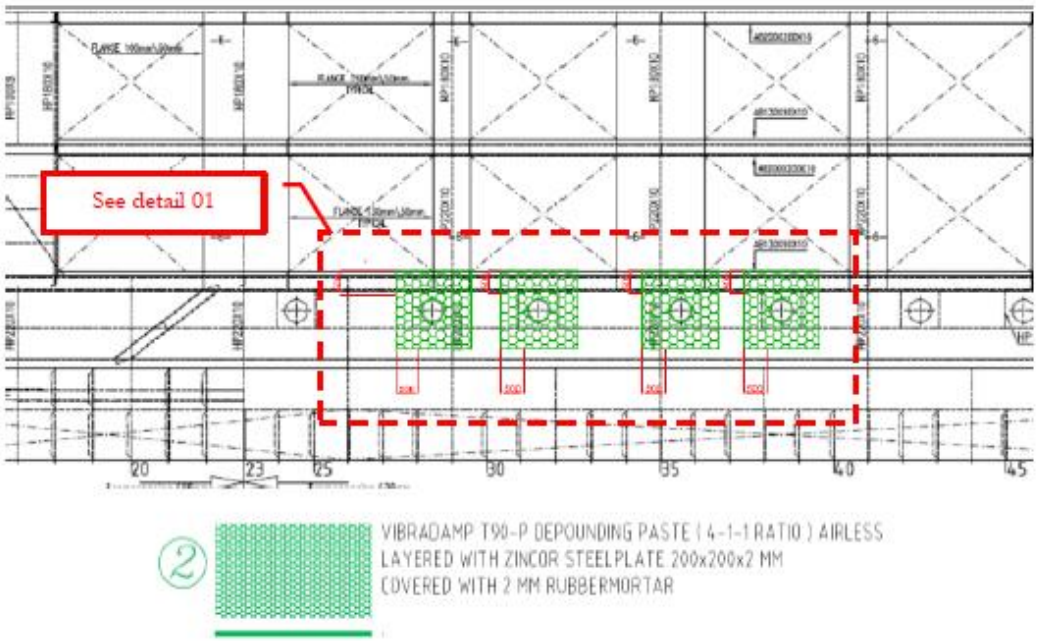
Detail of the structural improvements

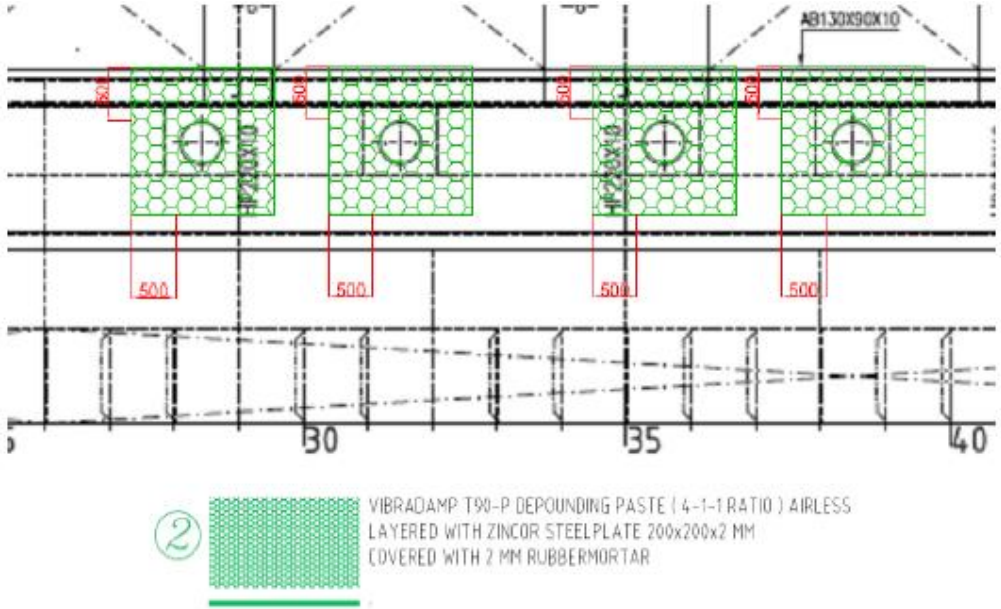
OPTION 01 - PROPOSALS OF IMPROVEMENTS AMADEUS BRABANT



Proposed additional damping treatment

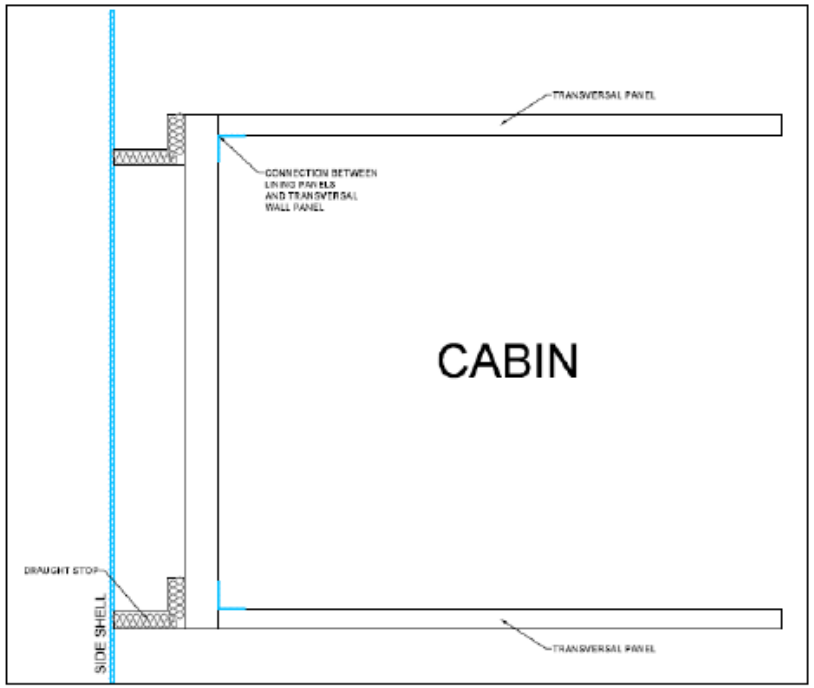
OPTION 01 - PROPOSALS OF IMPROVEMENTS
AMADEUS BRABANT



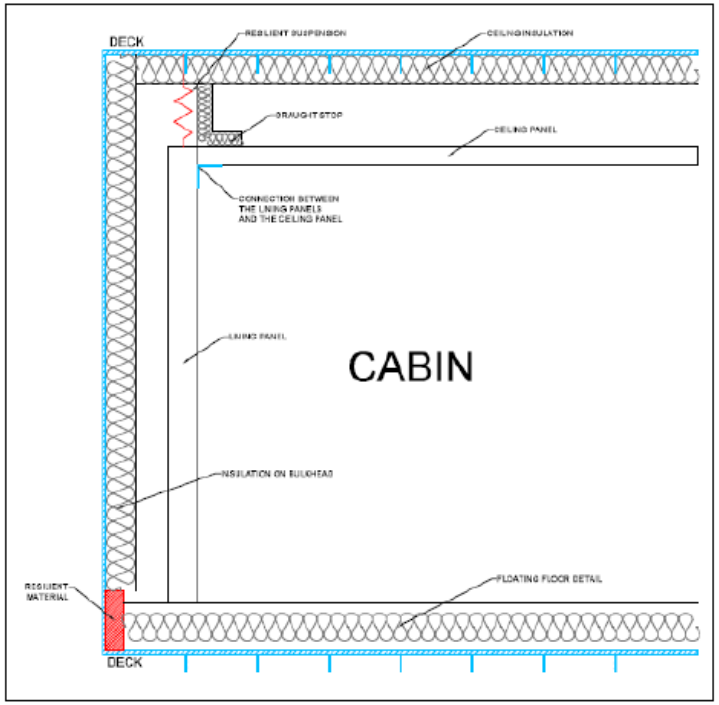


Proposed additional damping treatment

OPTION 01 - PROPOSALS OF IMPROVEMENTS AMADEUS BRABANT

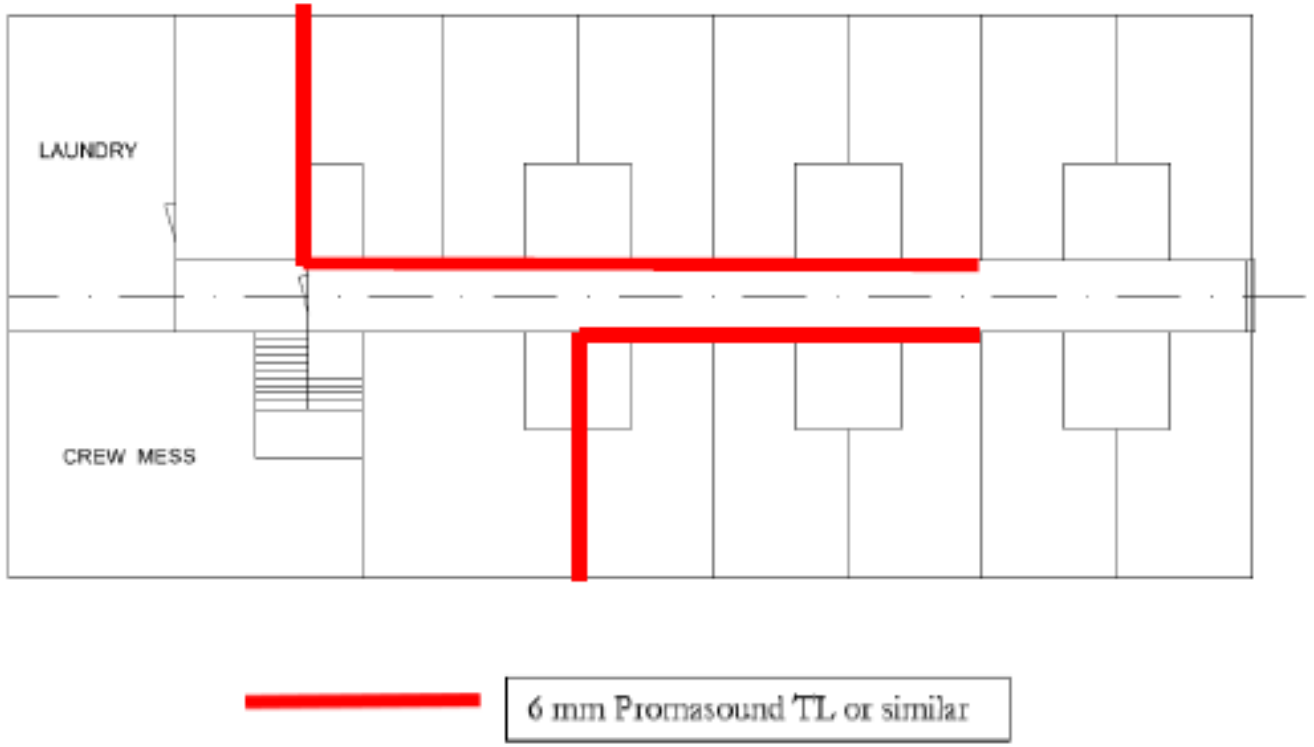


Proposed acoustic barrier preventing, wall detail



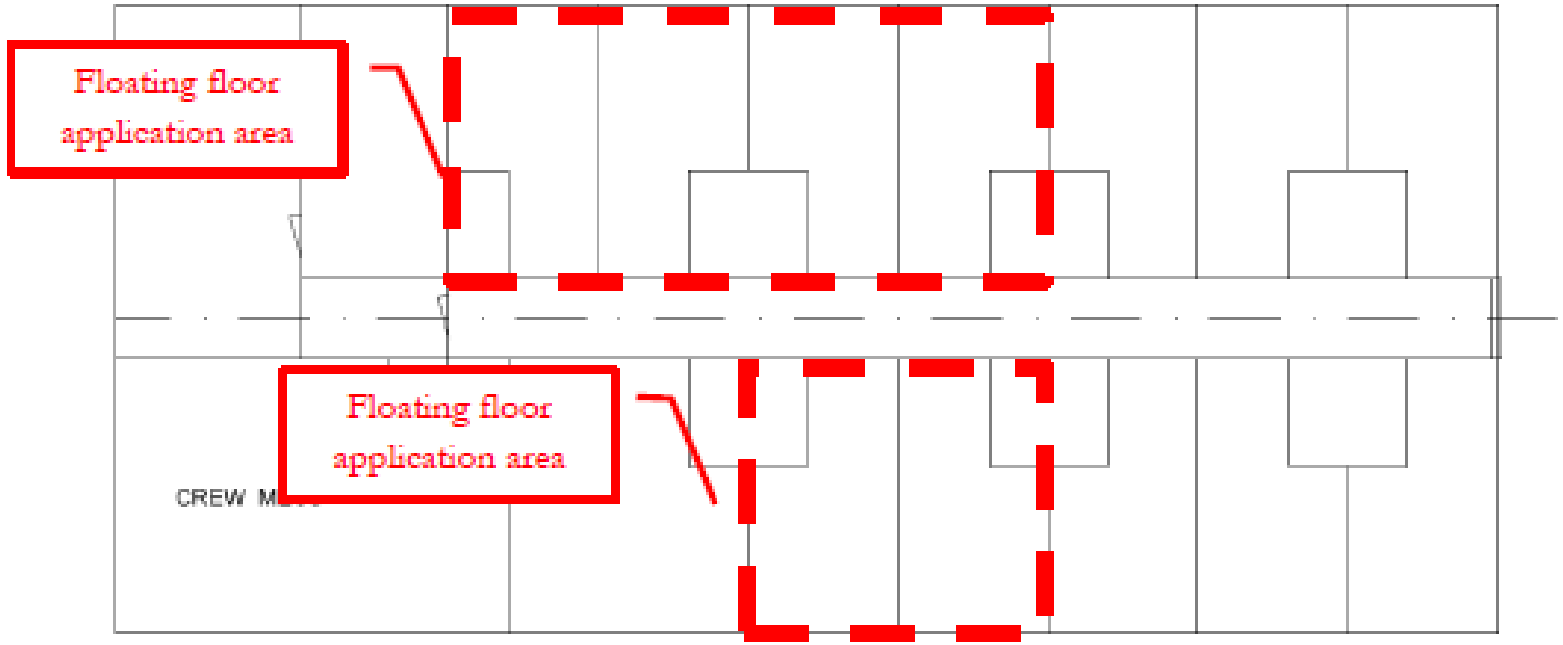
Proposed acoustic barrier preventing, floor and ceiling details

OPTION 01 - PROPOSALS OF IMPROVEMENTS AMADEUS BRABANT



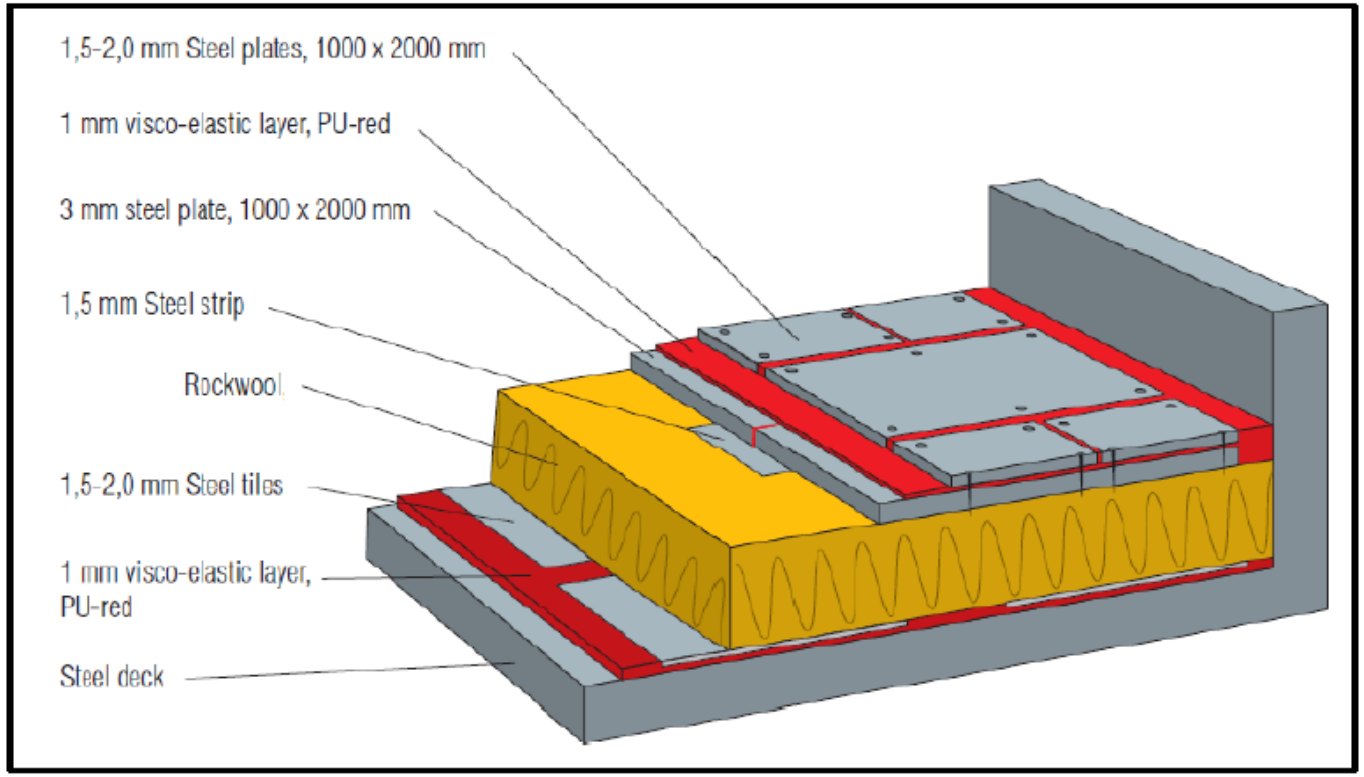
Promasound TL (4mm) proposed application areas

OPTION 01 - PROPOSALS OF IMPROVEMENTS AMADEUS BRABANT



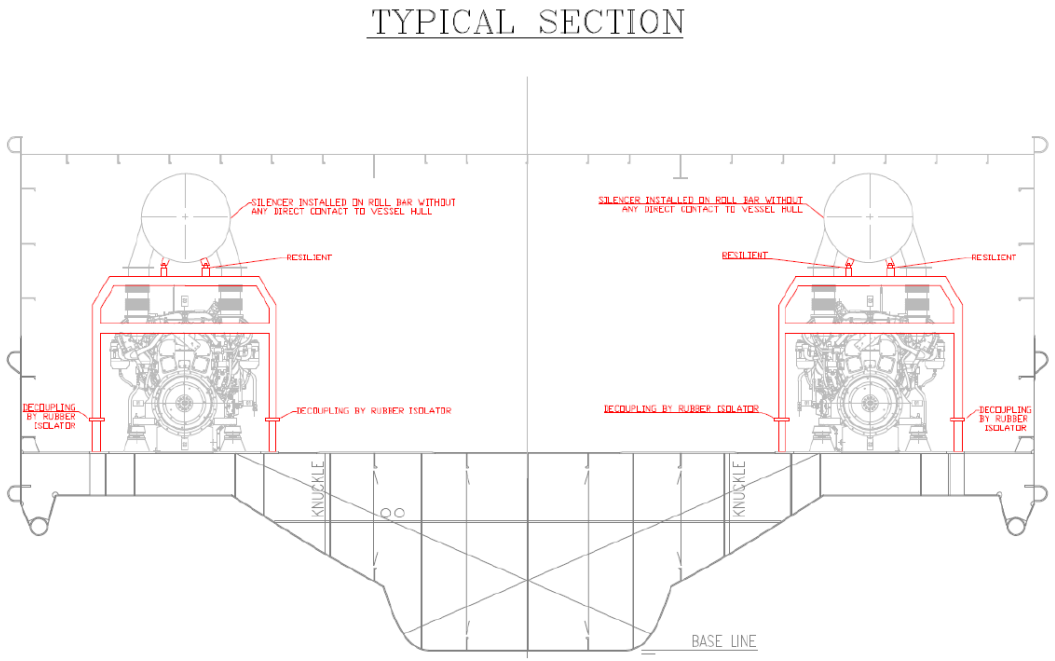
Proposed floating floor application area

OPTION 01 - PROPOSALS OF IMPROVEMENTS AMADEUS BRABANT

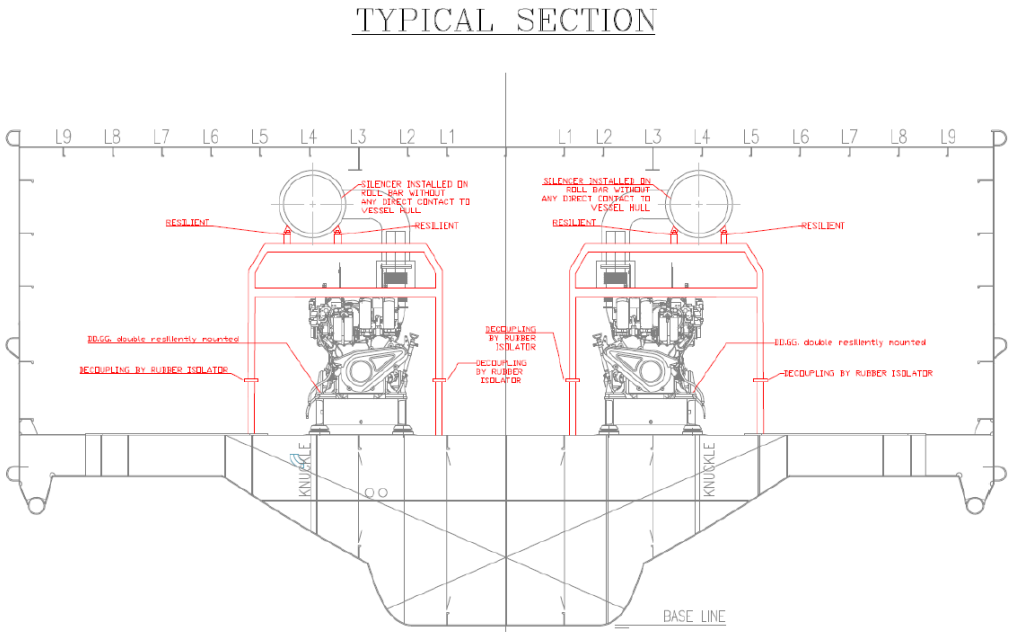


Proposed floating floor typology

OPTION 01 - PROPOSALS OF IMPROVEMENTS AMADEUS BRABANT



Proposal of improvements for main propulsion engines silencer/exhaust piping installation



Proposal of improvements for DD.GG. silencer/exhaust piping installation

OPTION 02 – GUIDELINES FOR YARD IN DESIGN PROCESS

This activity is actually in development for the Lüftner Cruise new building under construction.

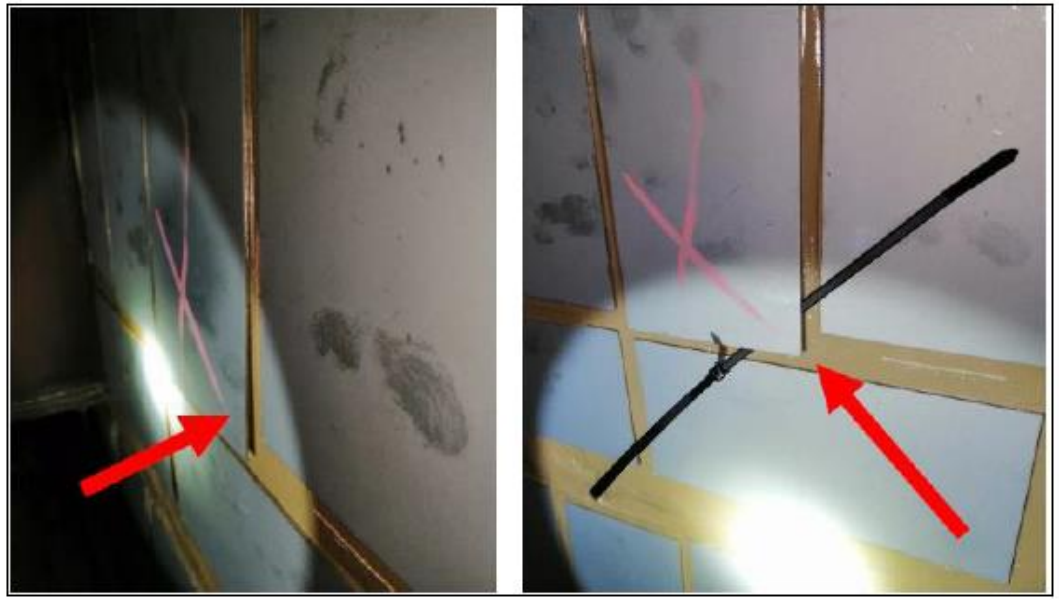
The supplier shall propose in particular a sufficient number of on-site surveys and milestones where the supplier's intervention would seem to be necessary, including in any case a final measurement of noise and vibration levels after completion of the vessel and comparison with calculated values.

OPTION 02 – GUIDELINES FOR YARD IN DESIGN PROCESS

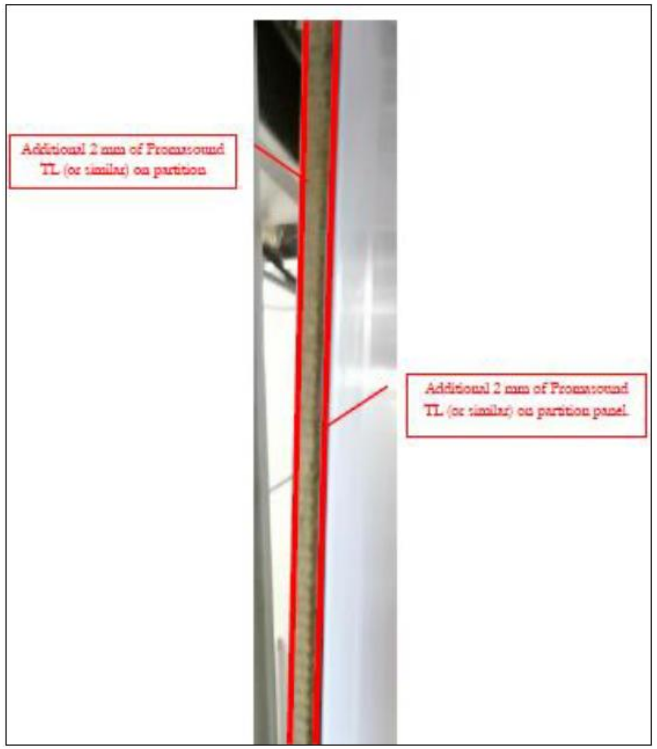
Abstract from developed technical report after survey performed on board, floating floor check

Abstract from developed technical report after survey performed on board, check of exhaust piping resilient mounting system

OPTION 02 – GUIDELINES FOR YARD IN DESIGN PROCESS



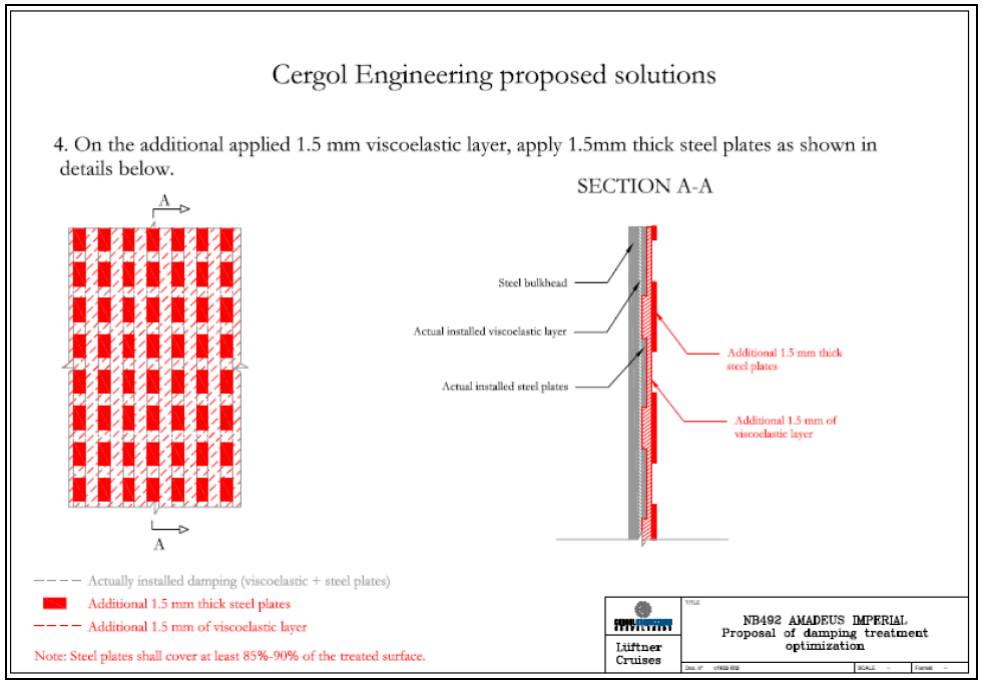
Abstract from developed technical report after survey performed on board, check of damping treatment correct application



Abstract from developed technical report after survey performed on board, proposed massive layer on partition wall

OPTION 02 – GUIDELINES FOR YARD IN DESIGN PROCESS

Abstract from developed technical report after survey performed on board, proposals for damping treatment optimization

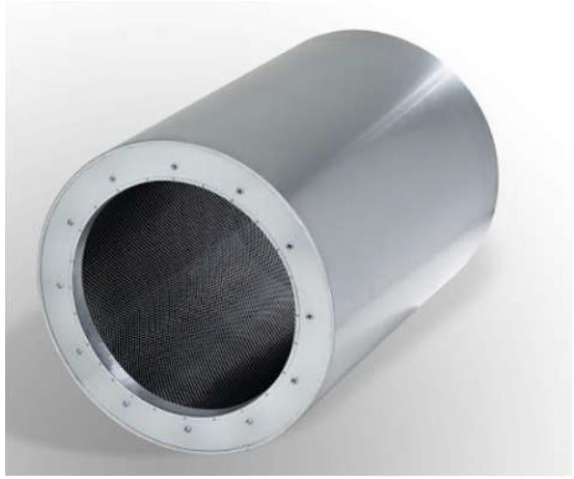


Abstract from developed technical report after survey performed on board, proposals for damping treatment optimization

OPTION 03 – REDUCTION OF EXTERNAL NOISE

In the cities where the shore connection is required, the main external noise sources become the HVAC system extraction outlets, due to the ventilation fans.

In these cases, it is suggested to install adequate silencers, i.e. with a high TL in order to minimize the noise at the ventilation extraction grilles.



Typical cylindrical silencer

CERGOL ENGINEERING CONSULTANCY
MARINE . OFFSHORE . YACHT INDUSTRY

DANUBIA KREUZFAHRTEN GMBH

Interreg
Danube Transnational Programme
GRENDEL

www.interreg-danube.eu/grendel
Project co-funded by the European Union (ERDF, IPA)

NOISE LEVELS MEASUREMENTS RESULTS AFTER INSTALLATION OF PROPOSED IMPROVEMENTS

Case study: **Lüftner Cruise next new building [delivered in 2020]**

NOISE LEVELS MEASUREMENTS RESULTS AFTER INSTALLATION OF PROPOSED IMPROVEMENTS

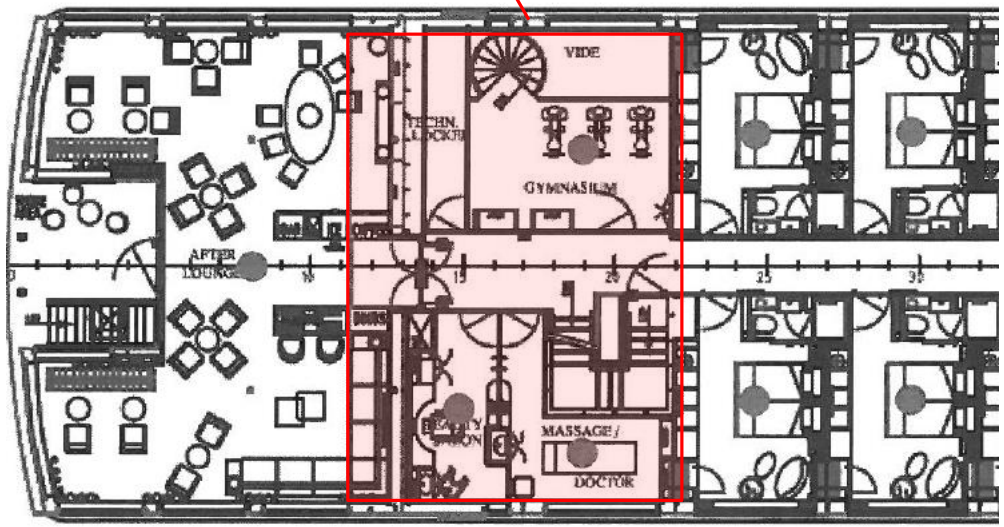
Lüftner Cruise next new building, has been delivered in 2020.

On this vessel, the proposed vibro-acoustic mitigation measures have been implemented.

The results of the performed noise levels measurement campaign (performed by **third party**) and a summary of the achieved noise levels mitigation (comparison analysis with older sister ships noise levels) are shown in the following pages.

NOISE LEVELS MEASUREMENTS RESULTS AFTER INSTALLATION OF PROPOSED IMPROVEMENTS

Average measured noise level: 55 dBA



Reference sister ship

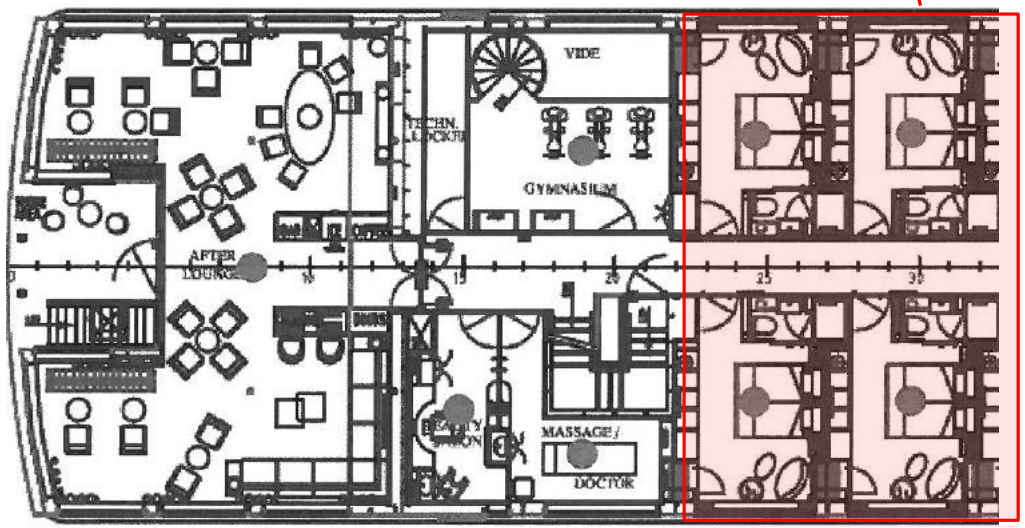
Average measured noise level: 53 dBA

Next new building

PASSENGER CABINS ON UPPER DECK

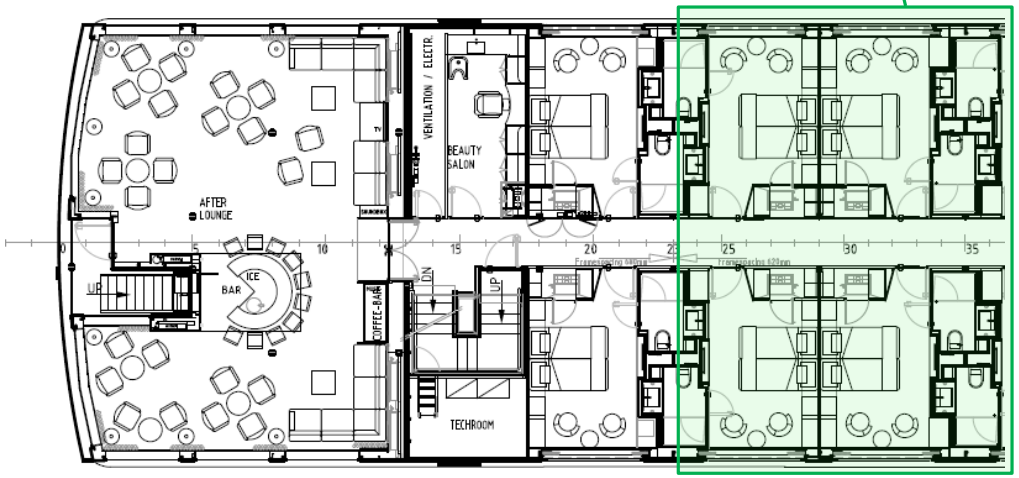
NOISE LEVELS MEASUREMENTS RESULTS AFTER INSTALLATION OF PROPOSED IMPROVEMENTS

Average measured noise level: 51 dBA



Sister ship

Average measured noise level: 50 dBA

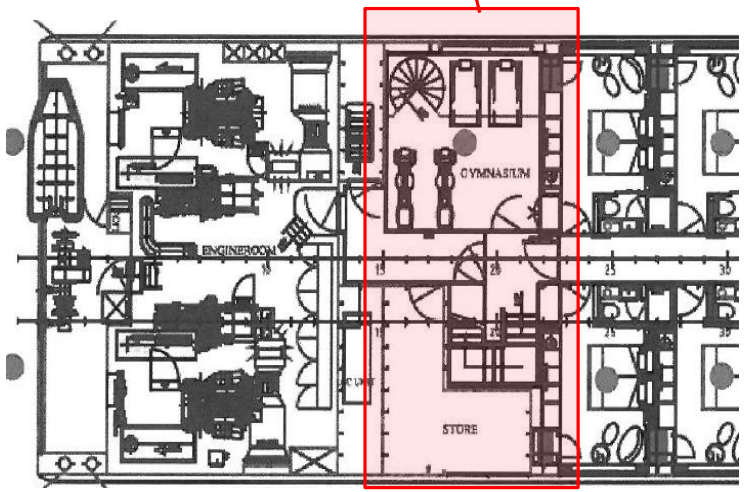


Next new building

PASSENGER CABINS ON UPPER DECK

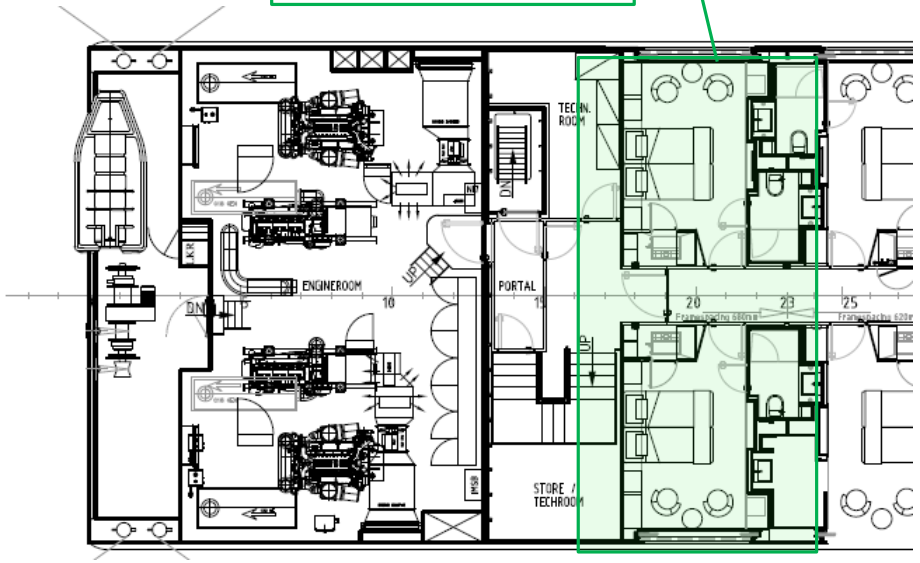
NOISE LEVELS MEASUREMENTS RESULTS AFTER INSTALLATION OF PROPOSED IMPROVEMENTS

Average measured noise level: 55 dBA



Reference sister ship

Average measured noise level: 54 dBA

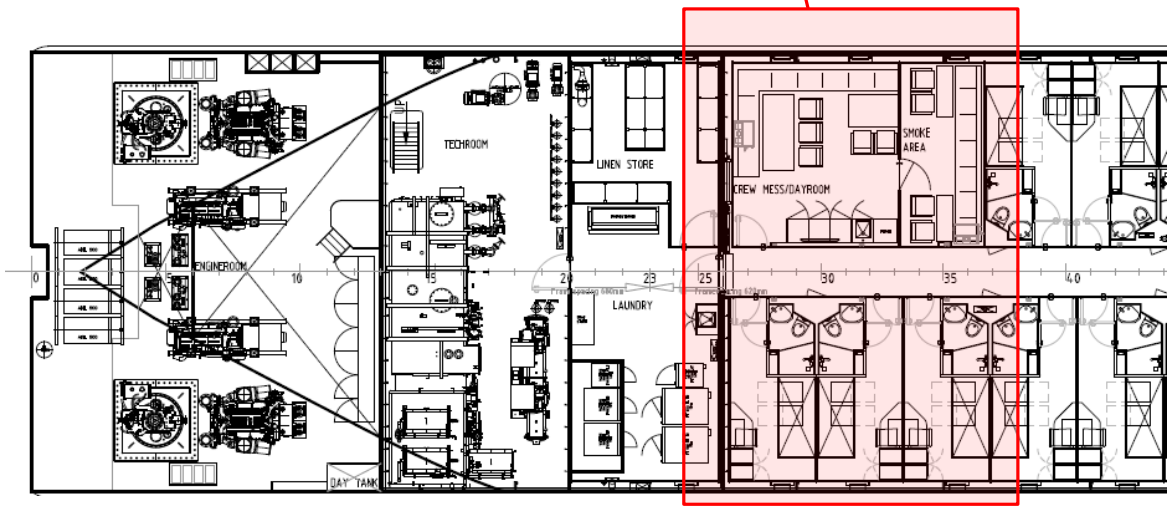


Next new building

PASSENGER CABINS ON MAIN DECK

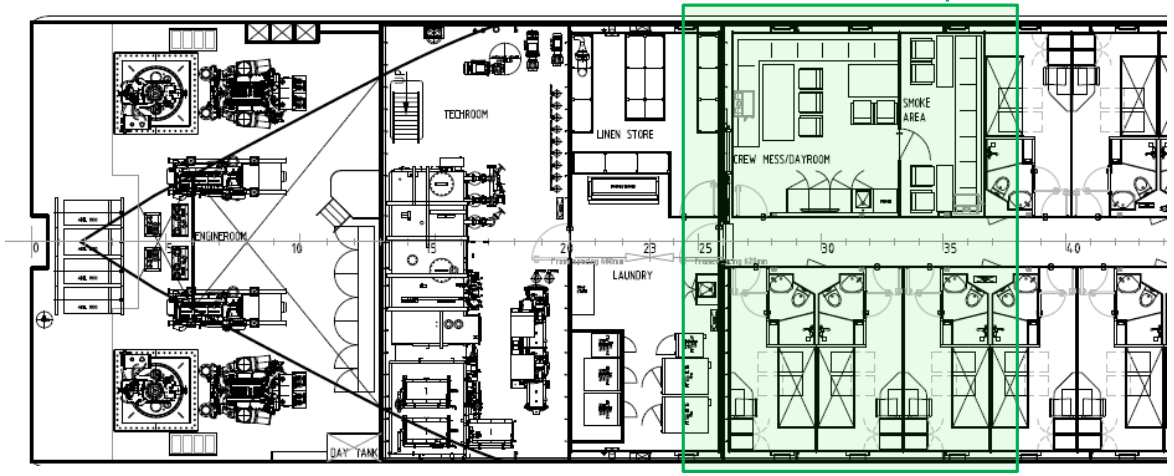
NOISE LEVELS MEASUREMENTS RESULTS AFTER INSTALLATION OF PROPOSED IMPROVEMENTS

Average measured noise level: 58 dBA



Reference sister ship

Average measured noise level: 56 dBA



Next new building

CREW CABINS ON LOWER DECK

NOISE LEVELS MEASUREMENTS RESULTS AFTER INSTALLATION OF PROPOSED IMPROVEMENTS

CONCLUSIONS:

FOR THE CREW ACCOMMODATION AREAS, AN AVERAGE **REDUCTION OF 2 DBA** HAS BEEN ACHIEVED.

ALSO FOR THE PASSENGER CABINS, THE ACHIEVED NOISE REDUCTION CAN BE CONSIDERED SATISFACTORY.