Autonomous Robotic Inspection and Maintenance on Ship Hulls and Storage Tanks

Deliverable report – D9.4

Context	
Deliverable title	End-User Evaluation Report
Lead beneficiary	AASA
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Work Package	WP9
Deliverable due date	March 2024 (M51)
Document status	
Version No.	1
Type	REPORT
Dissemination level	Public
Last modified	26 March 2024
Status	RELEASED
Date approved	26 March 2024
Approved by Coordinator	Prof. Cédric Pradalier (CNRS) Signature:
Declaration	Any work or result described therein is genuinely a result of the BUGWRIGHT2 project. Any other source will be properly referenced where and when relevant.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 871260

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ABBREVIATIONS

AR	Augmented Reality
AUV	Autonomous Underwater Vehicles
CS	Classification Society
CVSS	Common Vulnerability Scoring System
DSS	Decision Support System
IW	Integration Week
KPI	Key Performance Indicator
MAV	Micro Aerial Vehicles
RIT	Remote Inspection Techniques
ROV	Remotely Operated Vehicle
UWB	Ultra-wide-band
VR	Virtual Reality

REFERENCED DOCUMENTS

1. BUGWRIGHT2 Grant Agreement (GA) Number 871260

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HISTORY OF CHANGES

Date	Written by	Description of change	Approver	Version No.

Executive summary

This document aims at evaluating the developed BUGWRIGHT2 components to increase confidence on the platforms. This report focuses on identifying the field tests performed on other WPs for the robotic platforms and all developed modules. Most importantly, this deliverable will evaluate the developed platforms following the stakeholders' requirements and Key Performance Indicators (KPIs) defined in task 1.1. Finally, this task collects the performance of the large-scale pilot and the appreciation of the end-users, among others classification societies, ship owners, shipyards, captains. The resulting analysis is a major evaluation criterion for the BUGWRIGHT2 project.

The document is divided into four main parts. The first one is related to the BUGWRIGHT2 platforms. A brief description of the technologies and the developments beyond the state-of-the-art is presented. Then the next section summarises the tests carried out in the corresponding work packages where the platforms have been developed. The third section evaluates the platforms according to predefined indicators and requirements. The fourth section aims at evaluating the end users' appreciation through a survey that investigates among others the ease of use, efficiency, effectiveness and accuracy. Finally, the practical applicability and robustness of the developed solutions within real-world maritime environments are discussed.

I. Introduction

The main scope of WP9 is the integration and evaluation of the components developed in the tasks of WP1 to WP8 into a large-scale pilot. As a final part of the WP and the whole project, T9.4 aim is to perform the overall evaluation of the robotic platforms and the large-scale pilot. In line with this objective, T9.4 established a methodology for the evaluation of both qualitative and quantitative measures for the evaluation of the platforms' performance.

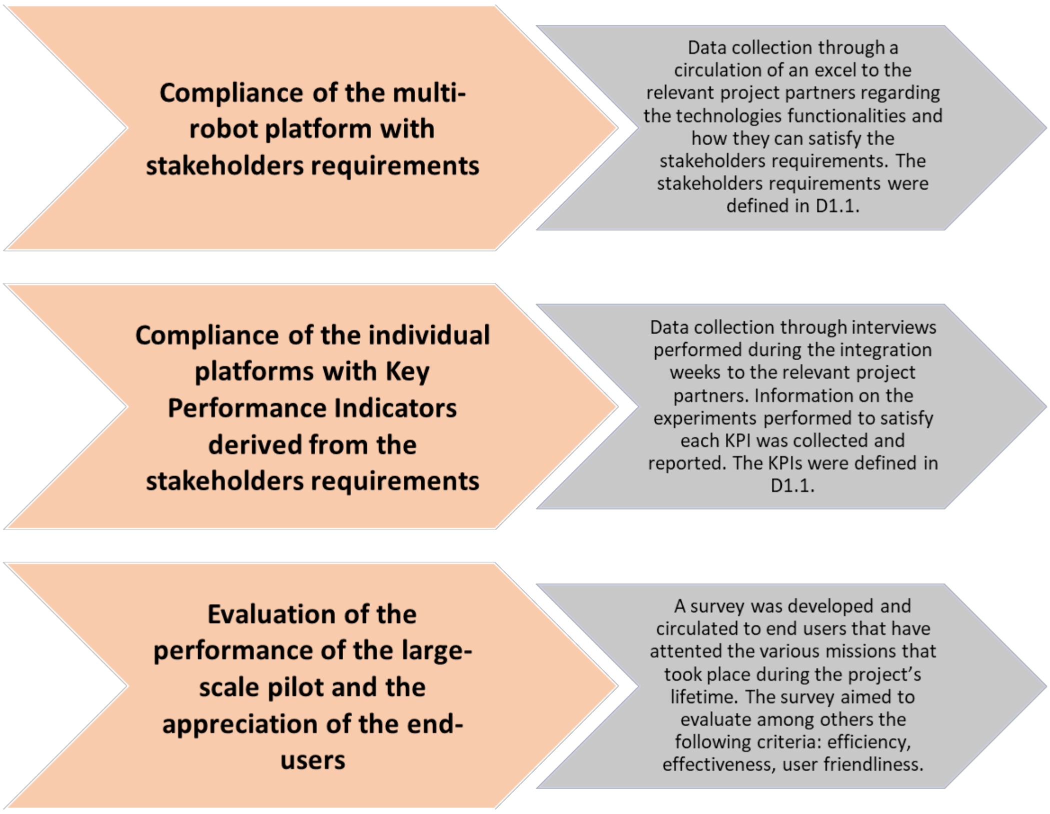
A three steps methodology is followed for the evaluation, as depicted in Figure 1.

First part of the evaluation process is the compliance of the multi-robot platforms with the stakeholders' requirements as identified in D1.1. A list of requirements (

Table 4) from all stakeholder perspective was derived, where the owner of the requirement is stated while each user need is split in “mandatory” - stressing the necessity to be satisfied - and “optional”, or in other words a “nice to have” functionality. The requirements are derived from the following perspectives: ship-owners / managers requirements, service provider requirements, hull Survey Standardization, legal framework, as well as reporting requirements.

For the following step of the evaluation process, the compliance of the Key Performance Indicators (KPIs) is assessed, as defined in the project proposal and later adjusted in D1.1 of the individual platforms. The KPIs are focused on high-level technical requirements on the overall multi-robot platform as well as on specific requirements of each robot and of the pilot. The KPIs are given in Table 5 to Table 11. A quantitative or qualitative metric is provided to facilitate the assessment of the KPIs.

The final step of the evaluation process is the performance assessment of the large-scale pilot and the appreciation of the end users. For this reason, a survey was created, individualised for each end user, that assesses among other the time efficiency, user friendliness and accuracy of the platforms.



Compliance of the multi-robot platform with stakeholders requirements

Data collection through a circulation of an excel to the relevant project partners regarding the technologies functionalities and how they can satisfy the stakeholders requirements. The stakeholders requirements were defined in D1.1.

Compliance of the individual platforms with Key Performance Indicators derived from the stakeholders requirements

Data collection through interviews performed during the integration weeks to the relevant project partners. Information on the experiments performed to satisfy each KPI was collected and reported. The KPIs were defined in D1.1.

Evaluation of the performance of the large-scale pilot and the appreciation of the end-users

A survey was developed and circulated to end users that have attented the various missions that took place during the project’s lifetime. The survey aimed to evaluate among others the following criteria: efficiency, effectiveness, user friendliness.

Figure 1: Evaluation process

II. Robotic platforms

BUGWRIGHT2 aim was to bridge the gap between the current and desired capabilities of ship inspection and service robots by developing and demonstrating an adaptable autonomous robotic solution for servicing ship outer hulls. For this purpose, a multi-robot platform was developed, which requires a minimal user intervention to perform a visual and acoustic inspection, detecting defects (corrosion patches etc.), cleaning surfaces and performing thickness measurements. The information gathered by the multi-robot platform with the assistance of virtual reality technologies is integrated into a real-time visualisation decision support user interface. The objective of BUGWRIGHT2 is to demonstrate to the community of end-users that autonomous inspection of hull state and hull cleaning is not only possible, but also fast and valuable, with minimal human intervention and without requiring time in dry-dock.

The robotic platforms considered in the project are: a) autonomous Micro Aerial Vehicles (MAV), b) Autonomous Underwater Vehicles (AUV), c) magnetic-wheeled crawlers (the first in the world wireless crawler, which brings new possibilities for hull inspection) operating also under water. During the project's duration, significant advances have been made to reach the desired capabilities for ship inspections. The main novelties achieved are discussed in the following paragraph.

The MAV performs an autonomous survey collecting survey data including a 3D mesh of the ship. One of the main novelties is that the mesh, the ultra-wide-band (UWB) tag's location and Augmented Reality (AR) tag's location are all located in the same global frame. The overall goal of the robot localisation in this project was to have all mobile systems working in a common reference frame. Since every platform type has its own unique actuator types and configuration, the consortium developed inner control loops to control the platforms actuators. This autonomous localisation with global referencing UWB anchor-position on the pier and ship supports the end-user during the initialisation process and removes the requirement of the end-user to manually place the UWB anchors. In addition, the globally referenced UWB anchors are further used as a reference for the magnetic crawlers. The data from the robots are visualised in a common user interface with the support of the AR and mission commands are sent to the individual agent. In addition, the robotic platforms can be remotely controlled at a conveniently high level through a VR environment for a unifying control framework. The overall goal of the unified robot control interfaces is to be able to create a unique interaction framework that can define missions or tasks for the BUGWRIGHT2 platforms to perform the overall inspection task. The unified interfaces also enable such a framework to receive data from all platforms, to coherently display the inspection process and to define actions based on the received data during runtime. Therefore, from the derived 3D mesh a mission is planned on the same frame and communicated to the crawlers, which as a result follows a navigation path. The thickness measurements made by the crawlers are also localised and reported to the 3D mesh. Furthermore, for close-up inspection, a swarm of drones is utilised to cover the area of interest and take close-up pictures. The pictures taken and their exact location are then reported on the interface. Finally, for the underwater drones, in the BUGWRIGHT2 project an autonomous coverage of the ship is achieved and globally localised images and sonar scans are collected.

III. Pilots and Experimental activities

The following sections present a summary of all the experiments and field tests performed by the various partners during the project's duration. Several experimental activities have been performed both on an actual vessel and on the mock-up to assess the platforms. It may be remarked here, that even though the tests were curtailed due to the pandemic situation in the first years of the project, attempts were made to overcome this hindrance and resume with the necessary testing. Information was collected regarding the date, location and description of the experiments and their results. The listed data facilitate the evaluation process of the platforms.

1. Individual experiments

In Table 1, a comprehensive list of all the experiments performed throughout the project's duration is presented. A brief description of each testing is included on the table for the purposes of this deliverable; however, more details can be found on each relevant deliverable.

Table 1: Individual experiments within the project life

#	Date	Location	Ship type/surface	Robotic platform	Participants	Experiments description
1	Sep-20	Perama, Greece	Small Vessels	ROV	GLM	Trial Inspection
2	Sep-20-Apr-22	Trondheim, Norway	Not applicable	RON	NTNU	Tests in water to find the correct sensor setup for the project
3	Jan-21	Perama, Greece	Small Vessels	ROV	GLM	Trial Inspection
4	Apr-21-Sep-22	Greece	Cargo Holds	Crawler	GLM	Conducting measurements in the context of a survey at different internal parts of a ship. (number of tests: 4)
5	May-21-Sep-21	Trondheim, Norway	Not applicable	ROV	NTNU	Autonomy in open water, follow autonomously simple paths created by user
6	Sep-21-Mar-22	Trondheim, Norway	Hull	ROV	NTNU	Testing on detection of defects while inspecting
7	nov-21	Bazancourt, France	Storage tank	Magnetic crawler	RBP, CNRS	Testing of 3D localisation with Leica total station
8	Dec-21	Lisbon, Portugal	Not applicable	Magnetic crawler	UT, AASA	Process of thickness measurement and user interface demands
9	Jan-22	Portugal	Steel vessel in the inclined plane	Magnetic crawler	AASA, RBP	Experimental inspection
10	feb-22	Bazancourt, France	Storage tank	Magnetic crawler	RBP, CNRS	Testing of 3D localisation with Leica total station
11	Spring 2022	Greece	Cargo Holds	Crawler	GLM	Testing basic parameters (electronics, power supply,

						kinematic, alignment of shafts and remote operation) of robot on the floor
12	Summer 2022	Greece	Cargo Holds	Crawler	GLM	Magnetic crawler evaluation in a test facility (check magnetism, kinematics, control and endurance on a vertical surface)
13	Summer 2022	Greece	Cargo Holds	Crawler	GLM	Conducting failure scenarios such as motor deactivation and dropping from different heights, at the structure (mock-up) for different magnetic crawler designs.
14	Summer 2022	Greece	Cargo Holds	Crawler	GLM	Testing of water flow and pressure to confirm that turbo nozzles would not damage the paint on the structure (mock-up)
15	Summer 2022	Greece	Cargo Holds	Crawler	GLM	Cleaning different adhesive materials (concrete, 3M adhesive and 3M collar) without damage the paint of the structure (mock-up)
16	Summer 2022	Greece	Cargo Holds	Crawler	GLM	Operation underwater at real conditions with Q = 50 l/min and p > = 200 bar, respectively, similar to the experiment conducted in the test facility. The actual results met the expectations.
17	Summer &Autumn 2022	Greece	Cargo Holds	DJI and Helios drones	GLM	Conducting measurements in the context of a survey at different external parts of the structure (mock-up).

18	May-22-Nov-22	Trondheim, Norway	Hull	ROV	NTNU	Autonomous inspection of ship hull. Autonomous navigate around the hull and adapt to its shape while at the same time estimate it using sonar data
19	Sep-22	Spain	Not applicable	Drone	UIB	Mission planning for drone test
20	Sep-22	Metz and Bazancourt, France	Storage tank	Magnetic crawler, VR	RWTH, UT CNRS, RBP	Integration with the user interface
21	Oct-22	Concarneau, France	Fishing vessel	Magnetic crawler	CNRS, RBP	Collect data to build a 3D model of ship
22	Oct-22	Klagenfurt, Austria	Ferry boat	AUV	NTNU, UNI-KLU	Improvement of the localisation system based on the MaRS framework
23	nov-22	Klagenfurt, Austria	Not applicable	MAV	UIB, UNI-KLU	Integration of all the motion estimation modules into the visual inspection-oriented UIB drone; evaluate the vision-based odometer and the laser-based odometer and their fusion through MaRS
24	nov-22	Piraeus, Greece	Not applicable	VR	RWTH,UT	HoloLens virtual world alignment tests
25	Jan-23	Trondheim, Norway	Hull	ROV	NTNU	Point specific inspection. Focus the inspection on the most important parts like the propeller, chest gratings, keels, etc. to model them.
26	mar-23	Metz, France	Not applicable	Crawler, VR	RWTH, UT, CNRS	Integration between the crawler and user interface
27	apr-23	Trondheim, Norway	Not applicable	ROV	NTNU	Automatic summary generation based on the operation data

28	Sep-23	Lisbon, Portugal	Fleet support vessel	Magnetic Crawler & EMAT sensors	CETIM	Angular scanning for ultrasonic imaging of reflectors (edge, weld, stiffener). Linear scans to detect defects (loss of thickness, impact, etc.).
29	Sep-23	Lisbon, Portugal	Fleet support vessel	MAV	UIB	Testing the autonomous navigation and inspection data collection capabilities the drone. Assisted flight to cover ship from end to end. Initialisation of the localisation framework.
30	Sep-23-Mar-24	Lyon & Metz, France	Ground surface	Magnetic Crawler	INSA, CNRS	Testing autonomy of a fleet of crawlers for surface inspection
31	Jan-24	Lisbon, Portugal	Door of dry dock	Magnetic Crawler	AASA	One day training with a crawler. Experimental inspection, data collection and evaluation of the thickness measurement.
32	Mar-24	Piraeus, Greece	Mock up	Magnetic Crawler	INSA	Testing autonomy of a fleet of crawlers for surface inspection

2. Experimental inspections and trainings

A core element of the Large-Scale Pilot Integration is the field trials of the robotic platform, performed by the service provider (GLM). GLAFCOS employed all the platforms in regular commercial activities to evaluate the system's performance and demonstrate their abilities to the shipping community.

GLAFCOS personnel was trained to familiarise with the platforms, before going onboard and perform inspections with the use of the platforms of the project. Training was made in the periods Aug-20 to May-22 in Perama using different platforms (ROV, Crawler, MAV). It should be underlined that these field trials satisfied all the necessary safety and quality requirements of an onboard survey as defined by Classification Societies and IACS rules.

Table 2: Experimental inspections within the project life

#	Mission type	Date	Location	Ship type/surface	Technologies	Partner	Participants
1	Class Audit BV	Dec-20	Syros, Greece	Cargo Holds, Ballast Tanks	MAV, AUV, Crawler, ROV	GLM	• Class surveyors • Ship-owners' Superintendent engineer • Ship Officers
2	Onboard inspection & Class Audit ABS	Jan-21	Vattika, Greece	Cargo Holds, Ballast Tanks	MAV, ROV, Crawler	GLM	• Class surveyors • Ship-owners' Superintendent engineer • Ship Officers
3	Onboard inspection	May-21	Syros, Greece	Cargo Holds, Ballast Tanks	MAV, AUV, Crawler	GLM	• Class surveyors, • Ship-owners' Superintendent engineer, • Ship Officers
4	Onboard inspection & Class Audit DNV	Jul-21	Perama, Greece	Decks, Outer Hull, Underwater	MAV, ROV, Crawler	GLM	• Class surveyors • Ship-owners' Superintendent engineer • Ship Officers
5	Onboard inspection & Class Survey	Sept-21	Bakar, Croatia	Cargo Holds, Ballast Tanks	UAV, Crawler	GLM	• Class surveyors • Ship-owners' Superintendent engineer • Ship Officers
6	Onboard inspection & Class Survey	Apr-22	Ploce, Croatia	Cargo Holds, Ballast Tanks	UAV, Crawler	GLM	• Class surveyors • Ship-owners' Superintendent engineer • Ship Officers
7	On board inspection &	Aug-22	Papilas Shipyards S.A, Greece	Small vessels Yaught	Crawler, Drone, ROV	GLM	• Class surveyors • Ship-owners' Superintendent engineer • Ship Officers

	Class Audit RINA						

3. Integration Weeks

The Integration Weeks (IW) served as pivotal milestones within the BUGWRIGHT2 project framework, facilitating the real-world testing and integration of developed platforms across diverse maritime settings. These weeks encapsulate the culmination of collaborative efforts aimed at advancing robotic platforms and associated modules, aligning with the project's overarching objectives and KPIs.

DESCRIPTION OF INTEGRATION WEEKS

Integration Weeks represent intensive periods of field testing conducted in various maritime environments, showcasing the adaptability and performance of robotic platforms amidst real-world challenges. Each Integration Week corresponds to a distinct location and entails targeted testing scenarios tailored to assess specific functionalities and system capabilities. During these Integration Weeks, the project team converges at designated sites, bringing together a comprehensive suite of robotic platforms, including MAVs, AUVs, and Crawlers. These platforms are deployed across a spectrum of ship types and surfaces, ranging from the developed mock-up at Greece and research vessels to cargo holds and ballast tanks, encompassing diverse operational contexts and challenges encountered within the maritime domain.

Table 3: Integration weeks

#	Date	Location	Ship type/surface	Robotic platform	Participants
IW1	May-22	Perama	Mock-up	MAV, AUV, Crawler	All partners
IW2	Jun-22	Trondheim	Control room for multi-vehicle operation, dummy offshore platform and 36m long research vessel Gunnerus	MAV, AUV, Crawler	All partners
IW3	Nov-22	Piraeus	Hull, Underwater, mock-up	MAV, AUV, Crawler	All partners
IW4	Jun-23	Porto	Barge	MAV, AUV, Crawler	All partners
IW5	Set-23	Lisbon	Hull	MAV, AUV, Crawler	All partners
IW6	Mar-24	Perama	Cargo Holds	MAV, AUV, Crawler	All partners
IW6	Mar-24	Perama	Hull, Underwater	MAV, AUV, Crawler	All partners

The Integration Weeks schedule was meticulously structured, encompassing a sequence of tasks and scenarios designed to evaluate the performance of developed components against predefined benchmarks and KPIs. From Perama to Trondheim, and from Lisbon to Porto, each location offers unique test environments, fostering iterative refinement and validation of robotic systems in response to evolving project requirements and end-user feedback. At each Integration Week, a meticulously planned agenda guided the execution of experiments and tests, aligning with the objectives and aspirations of project partners. The agenda was crafted to elucidate the rationale behind each test, delineating the specific outcomes and insights sought by individual partners. This collaborative approach fosters transparency and synergy, ensuring that the collective efforts converge towards the overarching goals of the project. Partners contributed distinct perspectives and expertise, shaping the trajectory of experimentation and driving innovation within the maritime robotics domain. The following list highlights the experimentation focus and objectives pursued by partners during Integration Weeks:

- Perama (May-22, Nov-22, Mar-24): Hosted a spectrum of experiments targeting mock-up environment at Perama in Greece, cargo holds, and underwater hulls. Partners aimed to validate system robustness, assess manoeuvrability in confined spaces, and refine sensing capabilities for inspection tasks.
- Trondheim (Jun-22): Partners focused on multi-vehicle operations within a controlled environment, leveraging a dummy offshore platform and the research vessel Gunnerus. Experimentation centred on coordination algorithms, communication protocols, and adaptive control strategies.
- Porto (Jun-23): Emphasized testing scenarios tailored to barge environments, emphasizing navigation in open waters, obstacle avoidance, and collaborative task execution. Partners sought to enhance platform autonomy, optimize energy efficiency, and mitigate operational risks.
- Lisbon (Sep-23): Prioritized hull inspection and navigation challenges, encompassing scenarios prevalent in maritime operations. Partners explored novel sensing modalities, navigation algorithms, and human-robot interaction paradigms to streamline inspection workflows and enhance situational awareness.

Throughout each Integration Week, the collective pursuit of experimentation and innovation fostered a dynamic ecosystem of learning and discovery. Partners collaborated closely, sharing insights, challenges, and best practices, thus enriching the collective knowledge base and driving continuous improvement within the project framework.

IV. Robotic platforms evaluation

1. Compliance with requirements

BUGWRIGHT2 aims to bridge the gap between the current and desired capabilities of ship inspection and service robots by developing and demonstrating an adaptable autonomous robotic solution for servicing ship outer hulls. These services are in line with the objective of the project to demonstrate to the community of end-users that autonomous hull state inspection and cleaning is possible, fast and valuable, with minimal human intervention and without requiring time in dry-dock. For this reason, a list of requirements was composed in D1.5 with the requirements of the relevant stakeholders and end users. As part of the evaluation process of the platforms in

Table 4, it is explained how these requirements were achieved throughout the project life. First, according to the D1.5 the requirements are described including the owner of each requirement and whether the compliance is optional or mandatory. At a second stage it is demonstrated how each requirement was achieved in the project and the justification is supported with the relevant experiments listed in Table 1. It is evident that all the requirements set by the stakeholders were achieved.

Table 4: Compliance with stakeholders' requirements

#	Description of requirement	Owner of requirement	Status (optional or mandatory)	Compliance with requirement	Experiments from Table 1
1	Spot potential hull integrity problems at an early stage and minimize operational downtime	Ship Owner/Manager	Mandatory	During the project life various trial inspections in presence of classification societies were performed (see also Table 2) that confirm the ability of the platforms to spot potential hull integrity problems. In addition, to manage identifying hull integrity defects detection testing were performed. An algorithm for a fleet of crawlers for inspection was developed and tested to inspect efficiently the ship hull. Finally, missions were planned and executed for the drone visual inspection and a 3d model of the ship was derived that facilitates the detection of defects and minimises operational downtime.	17,18,6,25,28,1,3,9,30, 32,19,4,23,21,29
2	Full coverage of critical parts of hull plating and visible parts of propulsion/steering system for inspection and cleaning	Ship Owner/Manager & Class society	Mandatory	Specific experiments were performed to showcase that the platforms can perform inspection on specific critical parts such as propeller, chest, keels etc.	17,25
3	Able to provide underwater service within ship port stay time limits	Ship Owner/Manager	Mandatory	The autonomous underwater inspections were planned and executed with the ROV (using sonar data) that demonstrated an efficient underwater inspection. The crawler was also tested for inspection on real underwater operational conditions.	16,2,5,18

#	Description of requirement	Owner of requirement	Status (optional or mandatory)	Compliance with requirement	Experiments from Table 1
4	Ensure reliable data streams and full information coverage	Ship Owner/Manager	Mandatory	The data from all the platforms are integrated on the UI for a holistic full information coverage. Various experiments were executed to demonstrate this integration with the UI. The reliability of the data streams was ensured with various failure scenarios testing that were performed.	13,26,20
5	Potential integration with ship maintenance software (PMS) for recording due maintenance job orders	Ship Owner/Manager	Optional	In the framework of our research project, we have developed a database dedicated to ship maintenance. Its primary objective is to gather and provide easy access to data concerning ship inspections. The database furnishes outputs pertinent to vessel maintenance and the necessary actions to be taken. Given that accurate data and decisions must be drawn from comprehensive information, this can be achieved through a structured methodology involving both the database and a Decision Support System (DSS)	WP8
6	Assess severity and assist owner's surveyor in the decision for an on-spot repair or cleaning while ship is afloat	Ship Owner/Manager	Mandatory	Both the ROV, drone and crawler were tested on detecting defects and the latter also on thickness measurements. Experiments were also performed to ensure that these data from all the platforms are integrated on the UI for a holistic full information coverage that assists the surveyor in the decisions for an on-spot repair or cleaning of the hull. In addition, the platforms were tested on real operational conditions to simulate the real conditions of ship afloat.	6,8,16,20,26
7	BUGWRIGHT2 underwater system	Ship Owner/Manager	Mandatory	Concerning the ROV inspection, it aligns with the requirement as it has been deployed in ports (Integration weeks). However,	

#	Description of requirement	Owner of requirement	Status (optional or mandatory)	Compliance with requirement	Experiments from Table 1
	should consider restrictions imposed by port authorities and comply with the harbour water quality regulations securing effective filtering of the removed fouling.			it's important to note that the ROV is tasked with inspection rather than cleaning the vessel's biofouling. As for the hull-cleaning crawler, its use within ports is not feasible due to regulatory constraints. Consequently, offshore experiments were conducted to validate its efficacy in hull cleaning	
8	Provide underwater measurement of hull roughness	Ship Owner/Manager & Service Provider	Optional	In light of the Integration weeks, it's evident that there were very few dry-docked ships, thus underwater measurements of hull roughness were not carried out. This is further supported by the test outcomes. However, images of the underwater hull were taken to conceptualize the DSS related to biofouling.	
9	Operate at least in the same environmental conditions as those assumed for the inspection of a human surveyor in person	Service Provider	Mandatory	During the project life various trial inspections in presence of classification societies were performed (see also Table 2) that ensure that the inspections with the platforms can be performed on similar to real conditions. In addition, specifically surveys on open water and under real underwater conditions were demonstrated. Finally, it was demonstrated that the drones flying on real operational conditions can achieve coverage of the ship hull from one end to the other.	5,16,29

#	Description of requirement	Owner of requirement	Status (optional or mandatory)	Compliance with requirement	Experiments from Table 1
10	Provide visual information with level of detail, colour, contrast, brightness etc. sufficient for detecting and ranking defects in a way that is comparable to the information available to the surveyor when operating in person. Where data collection from optical devices is considered, devices should be capable of capturing in high definition both video images and still images	Service Provider & Class society	Mandatory	It was also demonstrated that the platforms can provide details on all the critical parts of the hull. Specifically, the crawler was tested to detect defects with linear scans and to perform angular scanning for ultrasonic imaging. A 3D model is also developed from the drone's inspection (including all the defects visualised). All the collected data are integrated on the UI to facilitate the surveyor. RINA surveyors reviewed the results (March 2024) and confirmed that the level of detail and the quality of the information derived from the platforms are up to the required standards as they are defined on the remote service guidelines. Especially for the underwater drone the quality of the video is higher than what is provided by traditional devices.	21,26,28,25,23,20,29

#	Description of requirement	Owner of requirement	Status (optional or mandatory)	Compliance with requirement	Experiments from Table 1
11	Provide measurement data, e.g. steel plate thickness, at least with the same accuracy and for the same locations as in traditional surveys, as described in the relevant rules and guidelines	Service Provider & Class society	Mandatory	Experiments were performed with measurements internal and external following the guidelines. In addition, RINA has provided the relevant rules and guidelines for the thickness measurements to the relevant partners. RINA surveyors reviewed the results (March 2024) and confirmed that the measurements follow the guidelines. A detailed comparison was performed between the measurements taken by the crawler and the traditional inspection devices, and it is evident that the measurements are identical (Annex).	4,17, 31
12	The time required for a complete scan of the space to be inspected should be compatible with the time constraints of a typical class survey	Service Provider & Class society	Mandatory	The use of multiple crawlers and of a 3D model developed for external inspection demonstrated the benefits of the platforms for an efficient inspection. Experimental surveys were performed, and RINA surveyors participated an inspection with the robots (March 2024) and confirmed that it is compatible with the time constraints of a typical class survey.	1,3,5,7,9,10,30,32,29
13	The power source should be such to allow effective performance of assigned tasks.	Service Provider & Class society	Mandatory	Experiments were performed to test various basic parameters of robots among others the power supply, demonstrating that they allow an effective performance of the assigned tasks.	11

#	Description of requirement	Owner of requirement	Status (optional or mandatory)	Compliance with requirement	Experiments from Table 1
14	Utilize different types of cleaning methods depending on hull coating type and condition as well as on the marine fouling type and degree	Service Provider	Mandatory	Methods to clean different adhesive materials without damaging the hull were demonstrated.	15
15	Integration with fleet operational database of the ship management company to retrieve information (vessel particulars, historical data of sister, statistics etc.) to be correlated with data captured by BUGWRIGHT2 system necessary for condition	Service Provider	Mandatory	The database established as part of the project is fed with data provided by ship owners regarding their vessels (including vessel information and structural components) as well as the maintenance history of these vessels (previous maintenance records). As a result, it effectively integrates and correlates both historical and new data from the BUGWRIGHT2 robotic platforms.	

#	Description of requirement	Owner of requirement	Status (optional or mandatory)	Compliance with requirement	Experiments from Table 1
	assessment procedure				
16	The decision-making procedure shall evaluate and utilize appropriately defined metrics	Service Provider	Optional	The Decision Support System (DSS) utilizes both quantitative and qualitative metrics to inform decisions concerning vessel maintenance. These metrics were determined by incorporating rules and regulations from classification societies, as well as insights derived from tests conducted as part of the project.	
17	Should facilitate external and internal examination, including close-up surveys and gauging	Class society	Mandatory	A 3D model is also developed from the drone's external inspection (including all the defects visualised). Experiments for the localisation of the crawler were performed to localise the crawler on the developed 3D model. This allowed to operate the crawler with the VR. Therefore, the examination and gauging are facilitated. A variety of experiments were performed to improve the localisation system and its integration with the VR (HoloLens alignment tests) both for the crawler and the AUV. Measurements in the context of a survey were demonstrated with the crawler both on internal and external parts of the ship. The underwater inspection around the hull was also achieved with the ROV using sonar data.	7,10,4,17,19,22,23,28,18,29, 24, 31
18	Provide the survey results normally obtained by the	Class society	Mandatory	An automatic summary is generated based on the operation data according to classification requirements, guidelines and checklists of the CS that were provided to the partners. RINA	27,8

#	Description of requirement	Owner of requirement	Status (optional or mandatory)	Compliance with requirement	Experiments from Table 1
	Surveyor. Results obtained should be acceptable by an attending Surveyor			surveyors reviewed the results (March 2024) and confirmed that the results follow the format of the results provided by the surveyor and would be acceptable by an attending surveyor. However, in many cases a post processing is required. In addition, for the crawler, the shipyard reviewed the automated report with the derived results and confirmed that they follow the end user's requirements.	
19	The use of BUGWRIGTH2 system may be restricted or limited where there is a record or indication of abnormal deterioration or damage	Class society	Mandatory	All robotic developers have taken into consideration high-level safety commands that cease operation and initiate a return to base when the platforms are malfunctioning. It's noteworthy that in "from the self platforms" like Deep Trekker and DJI drones, these features have been built in.	
20	Should be capable of operation within an enclosed space	Class society	Mandatory	It was demonstrated that the crawler can effectively operate in closed areas performing the required operations.	4

#	Description of requirement	Owner of requirement	Status (optional or mandatory)	Compliance with requirement	Experiments from Table 1
21	For in water survey and concerning methods of localization on the plating, System should make use where necessary of permanent markings on the plating at selected points.	Class society	Mandatory	Experiments were performed to identify the most fitting sensors for the underwater localisation and ensure that the ROV is following the path provided by the user.	5, 2
22	BUGWRIGHT2 data recording and classification should comply with standardized format of reporting	Class society	Mandatory	An automatic summary of the inspection is generated according to classification requirements, guidelines and checklists of the CS that were provided to the partners. RINA surveyors reviewed the results (March 2024) and confirmed that the results follow the format of the results provided by the surveyor and would be acceptable by an attending surveyor.	27,8
23	Potential of fill in automatically reports with necessary input avoiding manual data entry	all	optional	The automated generation of data was demonstrated for all platforms.	27,8

2. Compliance with Key Performance Indicators

The robotic platforms of BUGWRIGHT2 are being evaluated through Key Performance Indicators (KPIs) which reflect on quantitative terms the level of compliance with the various stakeholders' requirements. Individual interviews have been implemented for the acquisition of data from the relevant partners in to evaluate the aforementioned KPIs. The data that can support the evaluation of the platforms are related with experiments that have been performed throughout the project's duration.

Table 5: KPIs for Aerial Platforms from D1.1

#.	KPI	Metric	Owner of KPI	Compliance with KPI
1	*Stable flight around the inspected structure*	*Position keeping accuracy better than 50cm with less than 5kts of wind.*	UIB	Tested on a laboratory level. The tests performed show a per-axis average accuracy of 8 cm (X), 10 cm (Y), 6 cm (Z), while the average total error is 15 cm. These results come from flight sessions with winds of 3.89 - 5.83 knots (2-3 m/s) and 9.72 - 11.66 knots (5-6 m/s).
2	*Sufficient flight autonomy*	*Flight autonomy above 10 minutes.*	UIB	Test flights typically take 3-4 minutes. A fully charged battery usually covers 3 test flights. In any case, one of the tests carried out during the Lisbon field trials covered the full vessel end to end (140.6 m in length) with one single flight, taking a time of 3 min and 7 sec.
3	*Observation of the structure in sufficient detail*	*Projection of processed pixels on the surface < 2mm (subject to change depending on working distance for optimum 3D reconstruction).*	UIB	The differences between a Leica TS model of the test vessel and the 3D model produced by means of the data collected by the drone were on average between 5 and 10 cm.
4	*Precise localisation of the acquired data*	*Drone pose estimation around 20-25 cm, 3-5 degrees.*	UIB	The drone's position accuracy was evaluated at 3.5 cm on average (with a standard deviation of 21 cm). Regarding drone's orientation, i.e. yaw, the evaluation indicates 0.5 degrees of error on average.
5	*Safe operation*	*Safe/successful mission execution close to the hull with autonomous obstacle avoidance.*	UIB	The drone is fitted with collision detection and avoidance functionalities. Besides, a safe distance is defined before flight so that onboard control prevents the platform from colliding with the surface under inspection, even intentionally.

#.	KPI	Metric	Owner of KPI	Compliance with KPI
6	*Survey in less time than a port stay*	*Coverage of at least $600m^2$/drone within one battery charge. Coverage of a full hull (aerial part) with a sufficient number of robots (e.g. 2-3).*	UIB	An end-to-end flight was performed with less than one battery charge, with an average reconstruction error between 5 and 10 cm. The length of the test vessel was 140.6 m and the time taken to cover the full vessel was 3 min and 7 sec.
			Lakeside Labs	A multi-robot flight was performed with 3 drones with less than one battery charge that demonstrated a full hull coverage in 10 to 15mins.

Table 6: KPIs for crawlers from D1.1

#	KPI	Metric	Owner of KPI	Compliance with KPI
1	*Safe operation, without tether entanglement*	*Autonomous operation with negative and positive obstacles larger than 3cm. Proper handling of angle discontinuities up to 5 degrees. Entanglement avoidance for positive obstacles higher than 5 cm.*	INSA, CNRS	The NC-AMAPF algorithm to plan multi-robot coverage paths avoiding tether entanglements was developed and successfully tested with modified Turltlebot robots (emulating crawlers). Different scenarios with several robots and several obstacles (with varying size and shape) have been tested. In beginning 2024, the algorithm will be tested with crawler robots in Metz (CNRS partner) and in the mock-up at Piraeus port (March 2024).
2	*Precise localisation of the acquired data*	*Crawler localisation better than 10 cm globally, 5 cm with respect to the current plate.*	CNRS	The precise localisation has been tested and demonstrated within the required range (*10 cm globally, 5 cm with respect to the current plate)* on a static object. It has also been demonstrated on the ship hull and less than 20cm accuracy was achieved.

3	*Sufficient observation density*	*100 measurement points per* m^2*, where deemed necessary by the surveyors.*	RBP, CNRS	It has been demonstrated that the crawler can attain 1 measurement per every cm.
4	*Measurement accuracy*	*Acquired measurements have to be accurate in comparison to ones taken with traditional devices*	GLM, RINA, AASA	The measurements obtained are identical to those obtained through traditional inspection methods due to adherence to standardization rules set forth by Classification Societies. A detailed comparison was performed between the measurements taken by the crawler and the traditional inspection devices, and it is evident that the measurements are identical (Annex). The only difference lies in the manner of control. In traditional methods, control is exercised directly by the surveyor.
5	*Survey in less time than a port stay*	*Complete coverage of one side of a 200 m hull (aerial part) with sufficient resolution in less than 4 hours with 4 crawlers.*	RBP, CNRS	It is demonstrated that one crawler can cover at least 12m/min with a sufficient resolution of 3-5 points per plate (acceptable by Classification standards). Therefore, more than 200m hull can be covered by a crawler in less than 4 hours with sufficient resolution.
			GLM	The process is significantly faster with robots, especially when considering the time required for scaffolding setup. While we don't have precise quantitative data, it is at least twice as fast with robots.

Table 7: KPIs for underwater platform from D1.1

#	KPI	Metric	Owner of KPI	Compliance with KPI
1	*Stable navigation around the hull*	*Position keeping accuracy better than 50cm with less than 0.25 m/s of current*	NTNU	It has been tested and demonstrated that the AUV can keep the position accuracy below 50cm with less than 0.25m/s current.
			GLM	The stable navigation around the hull ensures position-keeping accuracy better than 50cm, even under currents of less than 0.25 m/s. This performance has been confirmed through rigorous testing and trials.
2	*Sufficient operational autonomy*	*Flight autonomy above 2 hours*	NTNU	It has been demonstrated that the AUV can operated in autonomy for the required timeframe. However, there are challenges with the battery after 1 hour of continuous operation. In addition, it has been demonstrated that a sequence of 15 mins operation without recharging or restarting the robot is optimal to maintain accuracy.
3	*Hull observation in sufficient details*	*Projection of processed pixels on the surface < 2mm*	NTNU	Observation of sufficient detail is achieved comparable with the traditional inspection. The quality of the images depends on the distance from the ship hull.
			GLM	The hull observation meets the requirement for sufficient detail. Both video and image resolution are considered adequate, and the playback and zoom in/out functionalities provide an extensive level of inspection detail.

4	*Precise localisation of the acquired data*	*AUV pose estimation better than 10cm, 1 degree.*	NTNU	It has been demonstrated that the AUV can maintain an accuracy below 50cm under a 30mins mission. However, with increasing the duration of the operation there is a risk that the accuracy deteriorates.
			GLM	Ensuring precise localization of acquired data is paramount. Through rigorous testing, it has been established that operators must possess extensive training and experience to achieve accurate localization. Specialized training courses have been conducted to equip operators with the necessary skills for effective data acquisition
5	*Safe operation, without tether entanglement*	*Autonomous obstacle avoidance around the hull and in particular for objects larger than 3cm (cables)*	NTNU	Sonar is employed for detecting obstacles and for obstacle avoidance. In addition, a safe mode is in effect and has been demonstrated that asks the robot to stop and stay in the same position or sea bottom in case of an emergency (it is manually activated).
			GLM	In general, significant issues with obstacles were not encountered during all tests conducted. However, it is noteworthy that the inner hull environment presents greater challenges due to the presence of equipment and complex structural elements of the vessel. In instances where obstacles were encountered in this environment, the crucial role of operator experience was observed.

6	*Survey in less time than a port stay*	*Complete coverage of one side of a 200m-hull (underwater part) with sufficient resolution in less than 4 hours with 4 AUVs.*	NTNU	It has been demonstrated that the AUV manages to inspect with one robot under 15min one side of hull 40x4m. Therefore, it is easily achievable to achieve a complete coverage of one side of a 200m hull with 4 hours in less than 4 hours.
			GLM	Data collection for the survey has been completed. The duration of the survey process varies depending on the condition of the outer hull, as it may necessitate post-processing procedures.

Table 8: KPIs for pilot from D1.1

#	**KPI**	**Metric**	**Owner of KPI**	**Compliance with KPI**
1	*Large-scale pilots – from its inception, BUGWRIGHT2 is designed as a large scale pilot whose performances can be validated through extensive field testing on end users' sites with the support of inspection service providers offering initial services already within the project phase.*	*The BUGWRIGHT2 inspection services are offered to at least 20 vessels per year.*	GLM	Upon obtaining the platforms developed, particularly in the project's latter stages (second half of the project duration), all surveys were diligently completed, averaging around 20 per year. To do so, a total of 34 individual experiments and seven experimental inspections were undertaken throughout the project's duration. It's worth acknowledging that while this specific KPI initially appeared ambitious, it was eventually met.
2	*Complete value-chain validation – robot providers, inspection service providers, certification agencies, shipyards, harbours and ship owners*	*The BUGWRIGHT2 technology and processes are installed on the site of at least two end users.*	GLM/DAN/SBK	The validation process has been completed through the construction of a mock-up, specifically within the cargo hold, which forms a part of the vessel. This endeavour involved the participation of companies

	will be involved in the specification and evaluation of the system throughout the project to ensure that integration is focused on practical problems with a clear path to market and realistic market viability.			DANAOS and Starbulk. Additionally, validation occurred through visit to the shipyard in UPorto. These efforts ensure that all stakeholders, including robot providers, inspection service providers, certification agencies, shipyards, harbours, and ship owners, are actively engaged in specifying and evaluating the system throughout the project
3	*Legal insight, human factors and norms – In addition to technologists and industrials, BUGWRIGHT2 involves partners from the fields of maritime laws and workplace psychology to understand the conditions for its legal and social acceptance in the European workplace.* *Furthermore, the development of a strategy towards the evolutions of servicing rules will be conducted by WMU through its strong link to the International Maritime Organization.*	*Evaluation of distinct success factors for user acceptance, required knowledge and skills. Recommendations for HR managers.*	UT	A systems usability questionnaire was developed according to ISO9241 criteria for the system usability. This questionnaire was circulated for the evaluation of the success factor of user acceptance. It was completed by 6 people and a sufficient score (>68) was achieved.
		A strategy for the use of autonomous robots to meet international and European treaty inspection requirements is proposed.	WMU	A review of the regulatory framework was performed, and a draft regulatory blueprint was devised that can be exploited by regulatory bodies, as well as national and international agencies that deal with remote inspection techniques in Europe and across the world. Furthermore, a report with recommendations for the reform and the progressive development of relevant norms and policy advice concerning autonomous robotics regulation and standards was delivered. Both these reports contribute towards to the strategy for the use of autonomous robots to meet international and European treaty inspection requirements

4	*Dissemination and Exploitation – in addition to the experimental commercial offering, we aim at a strong dissemination strategy through publications in conferences and journals, presentations in professional fairs as well as a video coverage that explains the project in plain language.*	*Given the size and strength of the consortium, it should be possible to aim for 30 journal publications within the project lifetime. Through the large-scale pilot, 80 potential customers have been acquainted with the experimental service.*	WMU and all partners	Various scholar publications and webinars were delivered throughout the project life. In addition, 80 interviews with maritime authorities, classification societies, industry experts and port authorities were performed to develop a blueprint and guidelines

Table 9: KPIs for inspection technologies from D1.1

#	**KPI**	**Metric**	**Owner of KPI**	**Compliance with KPI**
1	*Precise ultrasonic localisation on a plate*	*Relative localisation better than 5cm on a plate with less than 5 measurements points, at most 1s per measurement.*	CETIM	The overall acquisition time is nearly 25 minutes (could be reduced to 3 minutes). The reflectors (edges, welds, stiffeners) are accurate to within a few tens of mm. A comparison with actual reflector positions was performed both on a mock up and an actual use case.
			CNRS	It has been demonstrated that 1s per measurement was achieved with high precision trackers.

2	*Damage detection for thickness losses*	*Detection of thickness loss > 0.1mm, in areas larger than 10x10cm (precision of a standard UT device). Some Influential Parameters such as metallurgical properties, plate roughness, coupling and temperature can impact the global measure exactness. Under the review of CETIM, a +/- 0.15mm global exactness with a 90% confidence may be adequate with the field parameters.*	CETIM	Measurements on artificial defects simulating corrosion thickness losses indicate that detection of thickness loss > 50%, in areas larger than 10x10cm.
			RBP	The precision of the crawler is verified under EN15317 standards.
3	*Visual detection of damages*	*Detection of visually detectable damage larger than 1x1cm (e.g. rust patch, pitting), from the air or underwater*	UIB	Tests show the capability of detecting defects as small as approx. 2-3 cm in size. This has been achieved by means of a 2 Mpx camera equipped with a 3.5 mm focal length lens.
			NTNU	An openly available dataset with damages (corrosion, cracks, paint peel) on ship parts has been developed that assists on the detection of damages and then at a second stage the surveyor can review the images that were detected.

4	*Visual detection of fouling*	*Detection of visual fouling thicker than 5mm over a 10x10cm patch.*	NTNU	An openly available dataset with fouling on ship parts has been developed that assists on the detection of fouling and then at a second stage the surveyor can review the images that were detected.

Table 10: KPIs for VR from D1.1

#	KPI	Metric	Owner of KPI	Compliance with KPI
1	*Demonstrating remote VR interface*	*Remote VR interaction is demonstrated to 20 experts.*	UT	Both the original prototypes have been demonstrated by experts and the final VR interface was reviewed by end user experts. (exceeding the 20 in total)
2	*Usability of user interface*	*The user interface quality is evaluated with a usability rate (SUS) score above 68.*	NTNU	A score above 68 was estimated for the prototype.
3	*Rendering performance*	*The rendering performance is above 60 frames per seconds.*	RWTH	The tests executed indicate that depending on the headset the performance ranges from 72-90 frames per second.

Table 11: KPIs for decision support system from D1.1

1	KPI	Metric	Owner of KPI	Compliance with KPI
1	*Ensure user acceptance*	*Evaluation of distinct success factors for user acceptance, required knowledge and skills. Recommendations for HR managers.*	GLM	GLM has successfully obtained certifications from Classification Societies and gathered valuable feedback from our market clients, both of which have significantly contributed to ensuring user acceptance.
2	*Database capacity*	*Database structure and capacity shall be adequate to hold data for a time period of at least 10 years to facilitate time history analysis and prediction.*	GLM	The database structure and capacity have been configured to support data storage for a duration exceeding 10 years, facilitating robust time history analysis and prediction functionalities.
3	*Database performance*	*Transaction completeness time shall be lower than 2 standard deviations from the average baseline value.*	GLM	The database facilitates automation of specific elements and enables bulk data import. Moreover, it supports interconnection with data from robotic platforms via Python code. This strategy significantly reduces the time needed for data entry and processing compared to conventional hard copy methods.
4	*Data management system security*	*System must be ranked in the lower severity range according to the Common Vulnerability Scoring System.*	GLM	To ensure compliance with the requirement for the data management system to be ranked in the lower severity range according to the Common Vulnerability Scoring System (CVSS), a cohesive strategy for database security and protection has been devised. This strategy encompasses various measures, including robust identity management with secure access controls, protection of privileged access, data encryption, asset management for

				security visibility, thorough threat detection and incident response procedures, comprehensive vulnerability management practices, endpoint security measures, reliable backup and recovery mechanisms, and governance structures to establish roles, responsibilities, and standards for database management.
5	*Predictive maintenance reliability*	*The success rate of the decision support system in defect detection and identification shall be higher than 80%.*	GLM	The Decision Support System (DSS) leverages advanced technology and analytical tools to seamlessly integrate inspection data and identify areas requiring maintenance. By combining detection results with vessel-specific background knowledge, including model, class, fleet, and owner information, the DSS aims to enhance the success rate of defect detection and identification. Additionally, the intuitive and interactive 3D interface enhances visualization, contributing to the system's effectiveness in achieving a success rate of over 80% in defect detection and identification for predictive maintenance reliability.
6	*AR performance*	AR shall have at least three (3) attributes to support maintenance	Aachen	The AR supports maintenance with the following attributes: the live sonar sensor data from the drones, log of every defect highlighted, potential defect localisation on the ship hull, visualisation of the measurements, capability to plan robot missions for inspection in critical areas.

3. Evaluation of user-interface and Data Visualisation

For the evaluation of the user-interface and data visualisation RWTH and UT have performed a series of tests, and the detailed description can be found in WP7 deliverables. Specifically for the User Interface, the focus has been on the evaluation of the UI regarding the affective, cognitive and behavioural user responses as well as the system usability. For this reason, various tests have been made in various stages of the UI development to satisfy these requirements that can be found in Table **12**.

Table 12: User Interface (UI) evaluation

#	Requirement	Test description	Date of test
1	Analysis of current task and person-related characteristics for the human-robot team and identification of affective, cognitive, and behavioural demands and support needs for inspectors in human-robot teams	Qualitative video-supported interview series to analyse current and anticipate prospective ship hull inspection	Apr-Jun 20
2		Online end-user "Persona" workshop with GLM	Jun 21
3		On-site work analysis at AASA	Dec 21
4	System Usability	Initial UI draft presentation and formative evaluation at AASA	Dec 21
5		UI draft presentation and formative evaluation	May 22
6		Task-specific (i.e., planning, monitoring, make annotations) UI prototype presentation and formative evaluations by potential users within the consortium	Jun 22
7		Formative evaluation and testing of User Interface (UI) prototype	Nov 22
8		Internal UI development and testing (focus VR application)	Jan& Feb 23
9		Summative evaluation of the functional prototype with end-users	Sep 23

V. End-users’ appreciation

Understanding the perspectives and experiences of end-users is pivotal in evaluating the effectiveness and practicality of the implemented solution developed during the BUGWRIGHT2 project. End-users, ranging from shipowners and captains to shipyards and surveyors, provide invaluable insights into the real-world application of the developed technologies and methodologies. This section delves into the appreciation received from these key stakeholders, shedding light on their feedback and perceptions regarding the project's outcomes.

1. Criteria for appreciation

Appreciation from end-users encompasses various criteria that gauge the utility, efficiency, and effectiveness of the solutions provided. Feedback from shipowners, captains, shipyards, and surveyors is vital for assessing different aspects of the project, including accuracy, user-friendliness, acceptance, and efficiency. This subsection delineates the specific criteria used to evaluate the project's outcomes as perceived by the diverse array of end-users involved in the maritime industry:

- Feedback from shipowners and captains with focus on accuracy of results.
- Feedback from shipyards (AASA) for the crawler measurements.
- Feedback from surveyors with focus on user friendliness, acceptance, efficiency, etc.

The exact questionnaire that was circulated to each end user can be found in the Annex.

- Do the BUGWRIGHT2 systems provide a full coverage of the critical parts of hull plating and visible parts of propulsion/steering system for inspection?
- Do the BUGWRIGHT2 systems have a user-friendly interface?
- Do the BUGWRIGHT2 systems minimize operational downtime of the inspection?
- Is the time required for a complete scan of the space to be inspected compatible with the time constraints of a typical class survey?
- Do the BUGWRIGHT2 systems ensure reliable data streams and full information coverage?
- Do the BUGWRIGHT2 systems operate at least in the same environmental conditions (wind, rain etc) as those assumed for the inspection of a human surveyor in person?
- Do the BUGWRIGHT2 systems facilitate external examination, including close-up surveys and gauging?
- Do the BUGWRIGHT2 systems have any limitations to operate in the shipyard (permission issues, compatibility issues, elements that could limit their accuracy)?
- Do the BUGWRIGHT2 systems provide visual information with level of detail, colour, contrast, brightness etc. sufficient for detecting and ranking defects in a way that is comparable to the information available to the surveyor when operating in person.
- Are the results provided the same as normally obtained by the surveyor? Do they comply with standardized format of reporting?
- Do the BUGWRIGHT2 systems provide measurement data, e.g. steel plate thickness, at least with the same accuracy and for the same locations as in traditional surveys?
- Are the BUGWRIGHT2 systems easy to use/accessible?
- Do the crawlers of BUGWRIGHT2 provide measurement data, e.g. steel plate thickness, at least with the same accuracy and for the same locations as in traditional surveys?
- Do the BUGWRIGHT2 systems assist in the decision for an on-spot repair or cleaning while ship is afloat?
- Do the BUGWRIGHT2 systems minimize the inspection total time compared to the traditional process since the inspection can take place without the surveyor present and in the most convenient location and time for the ship’s operation?
- Do the BUGWRIGHT2 systems minimize the inspection total cost compared to the traditional process since the inspection can take place without the surveyor present and in the most convenient location and time for the ship’s operation?
- Do the BUGWRIGHT2 systems require special training to be used?

2. Results from end-users’ appreciation survey

Conducting thorough surveys among end-users provides invaluable insights into their perceptions and experiences regarding the implemented solutions. This section presents the results derived from the comprehensive appreciation survey administered to shipowners, personnel onboard, shipyards, and surveyors. The findings encapsulate the diverse perspectives and feedback received, shedding light on the strengths, areas for improvement, and overall impact of the project from the standpoint of its end-users.

In total, 16 questionnaires were completed for the evaluation of the platforms from relevant end users that experienced the platforms. The findings in Figure 2 are summarised for all end users. In the rest of the chapter the analysis of the survey findings is done per end user according to interviews made during the completion of the questionnaires.

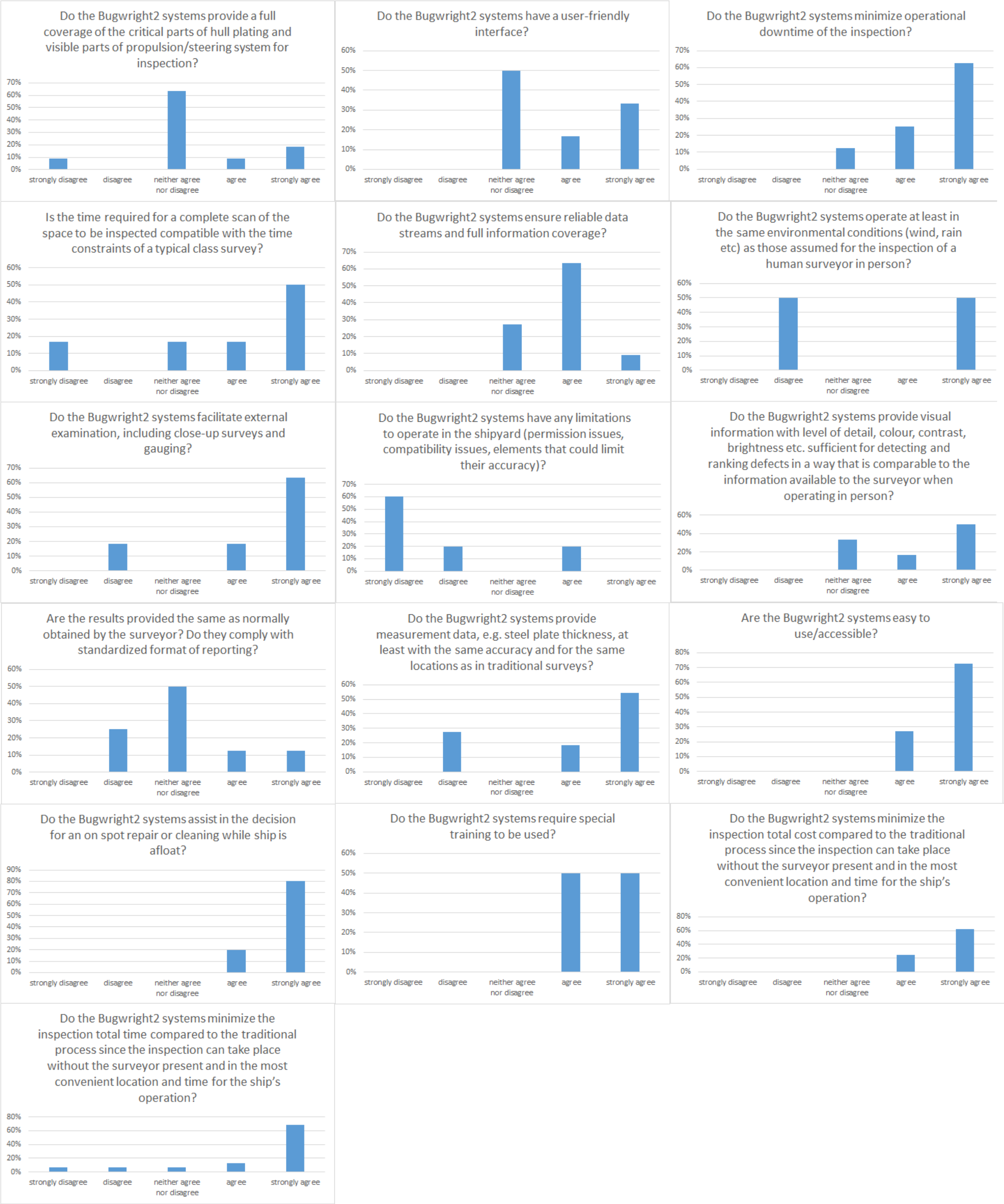


Figure 2: Survey findings

Ship owners and personnel onboard

There was a unanimous consensus from the shipowners and the personnel onboard that the operational time is minimised due to the lack of scaffolding. The minimisation of inspection time due to the use of the robots has a direct effect to increasing the assets availability along with the fact that the BUGWRIGHT2 systems assist in the decision for an on-spot repair or cleaning while the ship is afloat. This increased availability is translated to cost savings. However, neither the inspection service cost nor the robots cost is accounted but there is a trade-off with the maximisation of the operational time.

Regarding the data streaming and full coverage information, the survey participants agreed that there is a reliable stream of information, however there were some concerns that the data transmission from the platforms to the database was not always stable.

A full coverage of the critical parts of the hull was agreed however, there were concerns it might not cover all the appendices. It looks like the platforms have the capacity to make the inspection at the propulsion and steering systems, but during the BUGWRIGHT2 project it wasn’t evidently presented.

Finally, regarding the report derived from the platforms it was claimed that the technology readiness to deliver a report of equal value as a standard report with a traditional survey is not very high. In addition, the automated report is not still validated and in general data collected should be further elaborated to comply with the standardized format of reporting.

Class/Flag Surveyors

It was unanimously agreed that the platforms provide visual data useful for serving the inspection scope with quality close to the traditional and in some cases even better. For example, during the underwater inspection the robots were able to reach and illuminate dark and remote surfaces, thus facilitating the inspection. However, there were some concerns that the platforms could fail to use the distinct measuring techniques needed for the inspection of propulsion and steering systems.

Regarding the time of the inspection, all participants agreed that it is compatible with the time of a typical survey. However, the output of the survey is ambiguous regarding the minimisation of the time compared to the traditional survey. There is a consensus regarding the time efficiency of the underwater survey, as it appears very likely to minimize the time of inspection. Close up inspection can be also minimised in open areas of the ship. Nevertheless, for the complex structured areas and special areas of interest there are concerns that it would be difficult to complete a thorough visual assessment at the less time than the traditional inspection.

The robots have some limitations on operation in extreme conditions. Strong winds or a heavy rain will affect the drones, while a person can still complete the survey. Despite these limitations, the robots are exceeding the operational conditions that humans can withstand for example for underwater surveys and inside cargo holds.

Another limitation is regarding the reporting. It derived from the survey that the platforms need to be post processed to comply with the standardized format of reporting.

It is a consensus that the visual information provided by the platforms has sufficient level of detail, colour, contrast, brightness for detecting and ranking defects in a way that is comparable to the information available to the surveyor when operating in person. Furthermore, there are post – processing tools that can provide better information and details for defects. The defect detection software, once the input data is available, will provide output in the form necessary to locate the defect. However, as mentioned previously the visual detail is not sufficient for thorough examination of complex structures.

A big part of the survey includes the thickness measurements on suspected areas. Regarding the thickness measurement the crawlers provide measurements with sufficient accuracy. However, gauging appears to be difficult, without human intervention, in areas that are corroded. There were concerns regarding the accuracy of the measurements compared to the traditional surveys in the corroded areas. Even for a skilled person sometimes it is hard to take a thickness measurement, it might be needed to try 2-3 times on the same point to get a measurement with the existing equipment.

Finally, regarding the interface of the platforms there were some comments that they appear like mature prototypes rather than market products. However, there was a unanimous consensus that the platforms are very user friendly, and no substantial training is required for their use. The platforms provide autonomous behaviours to the operator and when requested they capture pictures, videos and take measurements. The communication with the vehicles is done through a VR interface and a joystick. These features make the platforms control easier for a non-expert.

Shipyard

In terms of usability, once the equipment and user manual are read, the user can control the crawler and make accurate thickness measurements, but some IT skills and UT knowledge are required, especially for non-experts. However, the platform is very user friendly.

The accuracy of the measurements is as precise as the traditional devices. A comparison of the measurements made with the traditional devices and the crawler is reported on the Annex. Overall, the measurements of A scan were accurate. The difference of the thickness measurements from the crawler to the traditional method was in average 0,1 mm. It was also found that there is a higher standard deviation of thickness measurement for the crawler compared to the traditional method.

Overall, the costs of the inspection and the operational downtime of the crawler compared to the traditional process are lower because scaffolding is eliminated in most cases. The time of preparation with the traditional method is longer than the time of preparation with the crawler in dry dock door because of scaffolding installation (one day). In case of floating dock, the difference of the time preparation between the traditional method and the crawler is smaller because of the wall's height. A lifeline is easy to place in dry dock and in floating dock. In addition, it was quite user friendly to get the crawler working, placing it on the plate to take the measurements. However, in some cases the operation had to be stopped to refill the reservoir of the crawler. The number of the technicians is the same in both methods. The crawlers do not have yet the autonomy to undertake the planned route without the help of at least two technicians. The time of the data transmission (Excel sheet) in the crawler is quicker than the traditional method. Another final benefit regarding the operation is that the crawler can be used while the ship is sailing.

In addition, on surfaces without corrosion (painted and with low rugosity), it was possible to obtain measurements quickly, but in some cases, it was required to adjust the A scan parameters to get a measurement, losing time compared to the traditional method. On surfaces with corrosion (with imperfection on the paint and with higher rugosity), it was more difficult to get measurements, more time was required, and in some cases it was impossible to get the measurement.

As it is evident from the analysis in the Annex in B Scan, the inspection is quicker than the traditional methods, but the post processing requires some extra time, and the standard deviation is higher than in A scan. In good surfaces the results are better, and less time is needed for the post processing, in comparison to a rusty surface, that requires more time to get the best B Scan graph possible.

When the plates thickness changes through the entire surface, a partial calibration is required to be carried out: the crawler is collected and calibrated, then placed at the exact same place as before. In the traditional method, it will also be necessary to calibrate the devices used, but the technicians can use the standard without leaving the inspection area. This can lead to some time inefficiencies.

Although the gauging pattern was previously defined, the crawler requires the user intervention to be implemented (during measurement). It would be useful to have a space to identify the plates that are measured in the same report, because in the drydock door there were many different plates with different thickness. Post processing is required to allocate the measurement made by the crawler to the exact location on the plate for the report. In situ reporting does comply with the standardization, but the final official reporting requires post processing to fit a standard format.

One of the crawler’s limitations is that the localisation is not fully automated. The crawler is not yet integrable with other equipment, like the Micro-Aerial Vehicles or the laser that are used to scan the hull for localisation purposes. In addition, it is challenging to get the precise localisation, because only the distance based on the movement of wheels (rotation) is available, giving only an approximate indication of the position in the plate. Furthermore, in corroded surfaces the crawler does not provide a full coverage of the surface. The crawler camera has a low definition, thus providing poor visual information, that is not sufficient for detecting defects when compared to the information available to the surveyor operating in person. The crawler does not have systems to assist in the decisions on-spot repair or cleaning while the ship is afloat.

Finally, some general comments regarding the crawler are that it is not affected by external conditions, it showed a good performance in wind and rain. In addition, there were no permission issues for the operation of the crawler in the shipyard. However, there might be some limitations on the acceptance of the crawler use in the shipyard due to the possibility of damaging the hull coating. In some cases, scratching of the plate has been observed.

VI. Impact of the findings

The impact of the findings extends beyond theoretical conclusions, encompassing tangible outcomes derived from field tests and certifications obtained by GLF through the project. The culmination of rigorous field tests serves as a testament to the practical applicability and robustness of the developed solutions within real-world maritime environments. GLF's certification acquired through the project underscores the validation and recognition of its capabilities in implementing innovative technologies and methodologies. These certifications not only affirm GLF's adherence to industry standards but also enhance its credibility and market competitiveness.

1.1. Certifications

The certification process, a crucial aspect of the subtask Class Certification, has been diligently completed to secure certification from pertinent classification societies such as Bureau Veritas (BV), Der Norske Veritas (DNV), American Bureau of Shipping (ABS) and RINA, as it can be seen in Figure 3. This rigorous process underscores the service provider's proficiency in managing and executing visual assessments of ship structures using RIT and ROV techniques, in accordance with the stringent requirements of the Classification Society.

A pivotal facet of the certification procedure entailed the meticulous submission of documentation that comprehensively addresses specific prerequisites outlined by the Class. These documents encompass a spectrum of essential entities including Company Outline (Policy & Code of Conduct, Company Description, Services, Organization Chart, Management Structure), Personnel Competency and Training, Description of Equipment, Guide for Operators (Monitoring and Maintenance, Activities prior to operation, Checklists, Operation Plan, Environmental Awareness Rules, Operational Restrictions, Operational Safety Rules, Activities after operation, Storage Data), Training Programs (Theory, Practical Training, Completion of Training, Re-examination & recertification), Checklists and record formats for recording results of the services, Quality Manual and Documented Procedures (Documented Procedures, Maintenance and control of documents, Update, establishment, and issuance of documents, Use and control of documents), Customer Claims Record, and Corrective Actions.

These certifications obtained by GLM are of paramount significance for the successful execution of field trials utilizing the project's robotic platforms, as mandated in WP9, Task 9.2.

RINA Services S.p.A.
Via Corsica, 12 - 16128 Genova
Tel. +39 010 53851
Fax +39 010 5351000

CERTIFICATE OF APPROVAL
OF SERVICE SUPPLIER

CERTIFICATE NO. SSU012322XH

This is to certify that

GLAFCOS MARINE LTD.
45, FRAGIADON STR.
185 37 Piraeus GREECE

Has been approved in compliance with the
RINA "RULES FOR THE CERTIFICATION OF SERVICE SUPPLIERS"
for the supply of the following services to ships and other units classed by RINA:

Q - Survey using Remote Inspection Techniques (RIT) as an alternative means for Close-up Survey of the structure of ships and mobile offshore units

Date of the audit: 04 Aug 2022
Issued in PIRAEUS
on 14 Feb 2023

This Certificate is valid from the date of the audit until 03 Aug 2025

This certificate consists of this sheet plus an attachment.

This is an electronically signed document and does not require a handwritten signature.
Andreas PAPALIMNEOS
RINA Services S.p.A.

Certificate Number 21-4602856-A
Effective Date 06-April-2021
Expiry Date 05-April-2024
ABS Port Office Piraeus
Company's Website www.glafcos-marine.com

CERTIFICATE OF
Recognized Service Supplier

This is to certify that

Glafcos Marine Ltd.

located at

45, Fragiadon Street, GR 185 37, Piraeus, Greece

having been audited by ABS and having given a satisfactory practical demonstration of the service listed below, is recognized by ABS as a Service Supplier to provide services which ABS Surveyors may rely on to make decisions affecting classification or statutory surveys.

Remote Inspection Techniques as An Alternative Means for Close-up Survey of Ships and Mobile Offshore Units

Attached Certificate Appendix provides specific scope of approval, authorized personnel, manufacturer authorizations, and subcontractors.

It is the responsibility of the Service Supplier to employ, train and qualify persons in the service provided. If the service requires approval from manufacturers, the Service Supplier is responsible to maintain contact with the manufacturer and maintain any service manuals up to date. Where required by the category of service, the Service Supplier shall provide valid evidence that it is authorized or licensed by the equipment manufacturer to service the makes and models of equipment for which approval is sought. If approval from the manufacturer is not attained, a surveyor must be present at time of survey to continue work. Alternatively, current written instructions from the flag state are to be obtained to continue work without the surveyor present. Service Suppliers must present photo identification, evidence of qualification and authorizations from manufacturers, as applicable, at the time of service.

The ABS office issuing this certificate is to be kept updated with changes to the management of the company, employees, equipment and models on the authorization list and any changes made.

Alexandros Mylonas, Surveyor

CLS-SFM-00040 Rev.25 Page 1 of 3

DNV

APPROVAL OF SERVICE SUPPLIERS

Certificate No:
AOSS0000JDH

This is to certify that

Glafcos Marine Ltd.

Piraeus, Greece

is granted acceptance for
Survey using remote inspection techniques (RIT) as an alternative means for close-up survey of the structure of ships and mobile offshore units , in accordance with Class Programme DNVGL-CP-0484.

This service supplier certificate will be accepted for use with all rule sets published by DNV.
See the following page(s) for details regarding application.

This Certificate is valid from **2021-11-04** to (inclusive) **2024-11-03**.

This Certificate is issued on **2021-11-23.**

for DNV

This document has been digitally signed and will therefore not have handwritten signatures
Demenopoulos, Nikolaos-Evgenios
Surveyor

This Certificate may be withdrawn if:
1. The service provided has been improperly carried out or the results improperly reported.
2. The surveyor has found any deficiencies in the accepted operating systems of the service supplier.
3. The firm has failed to inform of any major changes having effect on the quality of the service rendered.
4. The conditions listed in the certificate are changed and/or are not fulfilled.

BUREAU VERITAS

ATTESTATION

No. LPR0/SKO/202107053258 PM

Issued within the scope of the Bureau Veritas Marine & Offshore General Conditions
Délivrée dans le cadre des Conditions Générales de Bureau Veritas Marine & Offshore

Certification of a Firm engaged in
Survey using Remote Inspection Techniques (RIT)
as an alternative means to close-up survey

This is to certify that:

Company: **GLAFCOS MARINE LTD.**
Company address: 45, Fragiadon Street,
185 37 PIRAEUS
GREECE

is certified by the Society to perform and report surveys using Remote Inspection Techniques (RIT) as an alternative means for close-up surveys, in presence of surveyors of the Society, of the structure of ships and mobile offshore units classed with the Society, within the scope of the Rules, Part A.

Type of RIT used: Crawler, UAV (Aerial drone), ROV (Underwater drone)

This certification remains valid until : 28 December 2023 **

and may be renewed for a further period of 3 years, subject to satisfactory renewal audit. This certification is given subject to maintenance of original standards and ability of this firm, together with keeping informed the Society of any change in the information originally supplied.

At: Piraeus on 5 July 2021

Spyros KONT[illegible]LIS
By order of the Secretary

** Not later than 3 years after the date of evaluation

The latest published Rules of the Bureau Veritas Marine & Offshore and the General Conditions therein are applicable.

Ad NE1537

Figure 3: Service suppliers certifications

1.2. Field tests

The integration of field test results and GLF's certification into the project's findings amplifies its significance and relevance within the maritime sector. It demonstrates the project's capacity to translate research outcomes into actionable solutions that address practical challenges faced by stakeholders. This holistic approach underscores the transformative potential of the project's findings, catalysing positive change and fostering innovation within the maritime industry.

VII. Conclusion

The aim of this deliverable was to evaluate the platforms developed in the BUGWRIGHT2 project. First, a very thorough list of the experiments that have been carried out during the process was presented. Then the platforms evaluation according to the stakeholders' requirements and the KPIs identified in WP1 was successfully achieved. Finally, the end users' appreciation for the large-scale pilot was collected and demonstrated through a dedicated survey. On top of this analysis, the tangible outcomes derived by the field tests and certifications obtained by GLF through the project provide a testament to the practical applicability and robustness of the developed solutions. Therefore, the analysis performed in this deliverable should be considered as the quantification of the expected BUGWRIGHT2 benefits by the implementation of these platforms in the shipping market.

ANNEXES

Survey

Questionnaire for end users' acceptance

Ship-owners+ personnel onboard

Focus on accuracy and results and time efficiency.

a) Do the BUGWRIGHT2 systems provide a full coverage of the critical parts of hull plating and visible parts of propulsion/steering system for inspection?

strongly disagree	disagree	neither agree nor disagree	agree	strongly agree

b) Do the BUGWRIGHT2 systems minimize operational downtime of the inspection?

strongly disagree	disagree	neither agree nor disagree	agree	strongly agree

c) Do the BUGWRIGHT2 systems minimize the inspection total time compared to the traditional process since the inspection can take place without the surveyor present and in the most convenient location and time for the ship's operation?

strongly disagree	disagree	neither agree nor disagree	agree	strongly agree

d) Do the BUGWRIGHT2 systems minimize the inspection total cost compared to the traditional process since the inspection can take place without the surveyor present and in the most convenient location and time for the ship's operation?

strongly disagree	disagree	neither agree nor disagree	agree	strongly agree

e) Do the BUGWRIGHT2 systems assist in the decision for an on spot repair or cleaning while ship is afloat?

strongly disagree	disagree	neither agree nor disagree	agree	strongly agree

f) Do the BUGWRIGHT2 systems facilitate external examination, including close-up surveys and gauging?

strongly disagree	disagree	neither agree nor disagree	agree	strongly agree

g) Do the BUGWRIGHT2 systems ensure reliable data streams and full information coverage?

strongly disagree	disagree	neither agree nor disagree	agree	strongly agree

h) Are the results provided the same as normally obtained by the surveyor? Do they comply with standardized format of reporting?

strongly disagree	disagree	neither agree nor disagree	agree	strongly agree

Class/Flag Surveyors

User friendliness, acceptance, efficiency

a) Do the BUGWRIGHT2 systems provide a full coverage of the critical parts of hull plating and visible parts of propulsion/steering system for inspection?

strongly disagree	disagree	neither agree nor disagree	agree	strongly agree

b) Do the BUGWRIGHT2 systems minimize operational downtime of the inspection?

strongly disagree	disagree	neither agree nor disagree	agree	strongly agree

c) Do the BUGWRIGHT2 systems minimize the inspection total time compared to the traditional process since the inspection can take place without the surveyor present and in the most convenient location and time for the ship's operation?

strongly disagree	disagree	neither agree nor disagree	agree	strongly agree

d) Is the time required for a complete scan of the space to be inspected compatible with the time constraints of a typical class survey?

strongly disagree	disagree	neither agree nor disagree	agree	strongly agree

e) Do the BUGWRIGHT2 systems ensure reliable data streams and full information coverage?

strongly disagree	disagree	neither agree nor disagree	agree	strongly agree

f) Do the BUGWRIGHT2 systems operate at least in the same environmental conditions (wind, rain etc) as those assumed for the inspection of a human surveyor in person?

strongly disagree	disagree	neither agree nor disagree	agree	strongly agree

g) Do the BUGWRIGHT2 systems facilitate external examination, including close-up surveys and gauging?

strongly disagree	disagree	neither agree nor disagree	agree	strongly agree

h) Do the BUGWRIGHT2 systems provide visual information with level of detail, colour, contrast, brightness etc. sufficient for detecting and ranking defects in a way that is comparable to the information available to the surveyor when operating in person.

strongly disagree	disagree	neither agree nor disagree	agree	strongly agree

i) Are the results provided the same as normally obtained by the surveyor? Do they comply with standardized format of reporting?

strongly disagree	disagree	neither agree nor disagree	agree	strongly agree

j) Do the BUGWRIGHT2 systems provide measurement data, e.g. steel plate thickness, at least with the same accuracy and for the same locations as in traditional surveys?

strongly disagree	disagree	neither agree nor disagree	agree	strongly agree

k) Are the BUGWRIGHT2 systems easy to use/accessible?

strongly disagree	disagree	neither agree nor disagree	agree	strongly agree

l) Do the BUGWRIGHT2 systems require special training to be used?

strongly disagree	disagree	neither agree nor disagree	agree	strongly agree

m) Do the BUGWRIGHT2 systems have a user-friendly interface?

strongly disagree	disagree	neither agree nor disagree	agree	strongly agree

Shipyards

Crawlers' measurement accuracy

a) Are the BUGWRIGHT2 systems easy to use/accessible?

strongly disagree	disagree	neither agree nor disagree	agree	strongly agree

b) Do the crawlers of BUGWRIGHT2 provide measurement data, e.g. steel plate thickness, at least with the same accuracy and for the same locations as in traditional surveys?

strongly disagree	disagree	neither agree nor disagree	agree	strongly agree

c) Are the results provided the same as normally obtained by the surveyor? Do they comply with standardized format of reporting?

strongly disagree	disagree	neither agree nor disagree	agree	strongly agree

d) Do the BUGWRIGHT2 systems minimize operational downtime of the inspection?

strongly disagree	disagree	neither agree nor disagree	agree	strongly agree

e) Do the BUGWRIGHT2 systems have any limitations to operate in the shipyard (permission issues, compatibility issues, elements that could limit their accuracy)?

strongly disagree	disagree	neither agree nor disagree	agree	strongly agree

f) Do the BUGWRIGHT2 systems minimize the inspection total time compared to the traditional process since the inspection can take place without the surveyor present and in the most convenient location and time for the ship's operation?

strongly disagree	disagree	neither agree nor disagree	agree	strongly agree

g) Do the BUGWRIGHT2 systems minimize the inspection total cost compared to the traditional process since the inspection can take place without the surveyor present and in the most convenient location and time for the ship's operation?

strongly disagree	disagree	neither agree nor disagree	agree	strongly agree

Thickness Measurements at Arsenal do Alfeite, SA with the ALTISCAN crawler

INTRODUCTION

This part of the Annex aims at evaluating the performance during field tests using the real robotic platform – magnetic-wheeled crawler, by the end-user Arsenal do Alfeite, SA (AASA).

To perform an analysis of the performance of ultrasound thickness measurements carried out with the crawler we took a comparative approach with the standardized ultrasound thickness measurement method, which is referred to, in this document, as the traditional method and ultrasound thickness measurements carried out by the magnetic-wheeled crawler, which is referred to, in this document, as the Altiscan.

The ultrasound thickness measurements carried out by the magnetic-wheeled crawler can be represented through A scan or B scan. The A scan representation, which is common when using the impulse-echo technique, is also obtained by the traditional method. The B scan representation is common in automatic equipment, with the results displayed in a continuous way.

The location of measurements on the structure inspected in both traditional and Altiscan methods is approximated by external reference points, such as welds or connections.

Given that the type of the surface to be tested may have an influence on the performance of the thickness measurement test, we carried out the tests on two types of surfaces. On the dry dock door, painted with low roughness and no corrosion, and on the floating dock, which has an old paint scheme, areas with corrosion and high roughness.

The tests were carried out by NDT technicians certified at least level 2 in ultrasound thickness measurements and validated by an NDT technician certified in ultrasound level 3, metallic materials sector.

The collected data and the performance expectations of crawler will permit the appreciation and resulting analysis of the end-user AASA.

Based on the testing and operated by training personnel, the AASA provide feedback on the usability of the technology.

THICKNESS MEASUREMENT OF DRYDOCK DOOR – A SCAN

PHOTOS OF DRYDOCK DOOR

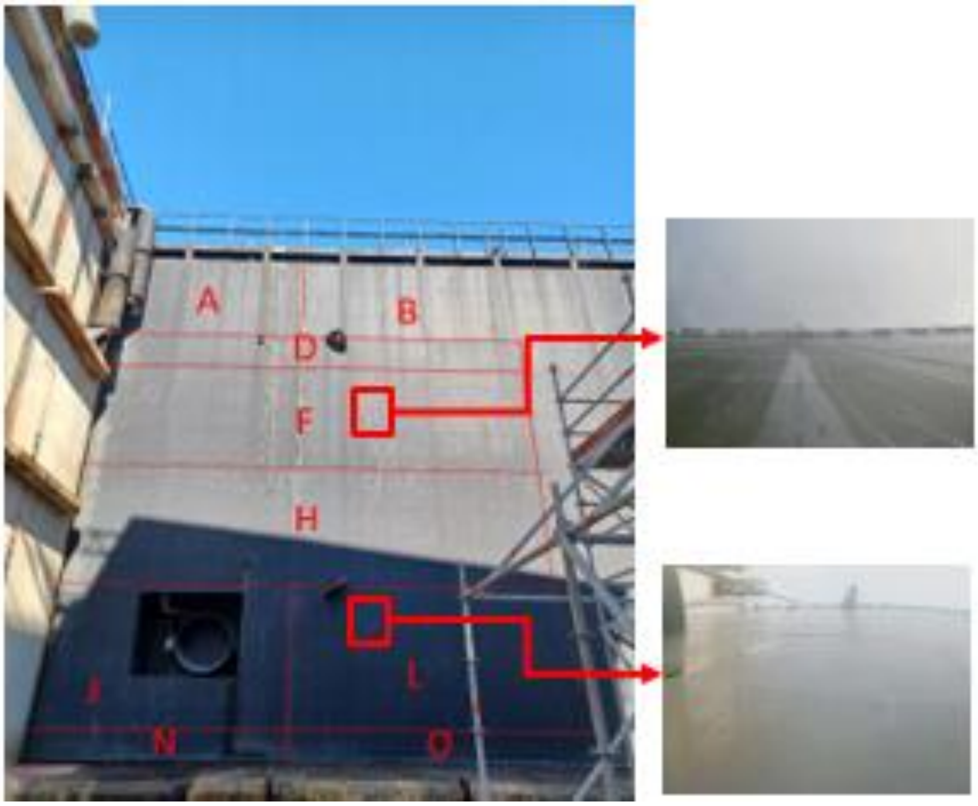


Figure 4: Dry dock door and respective inspection plates (Left)

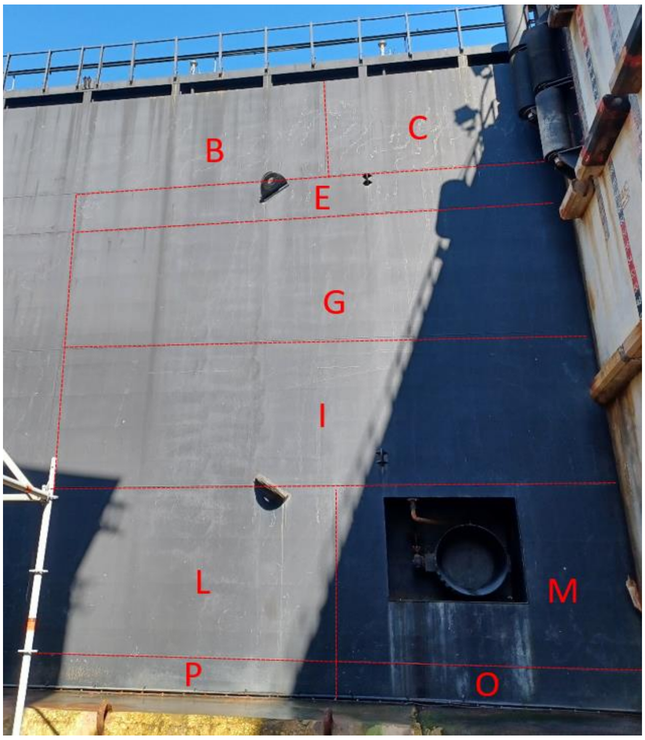


Figure 5: Dry dock door and respective inspection plates (Right)

Table 13: Nominal Values of dry dock door plates

Plate	Nominal Thickness (mm)	Acceptable Minimum thickness (mm) - 10%
A	8,00	7,20
B	8,00	7,20
C	8,00	7,20
D	10,00	9,00
E	10,00	9,00
F	10,00	9,00
G	10,00	9,00
H	10,00	9,00
I	10,00	9,00
J	12,00	10,80
L	12,00	10,80
M	12,00	10,80
N	12,00	10,80
O	12,00	10,80
P	12,00	10,80

MEASURED PARAMETERS

Table 14: Range of Measured parameters in Drydock

	Minimum	Maximum
Rugosity	8 µm	23 µm
Coating Thickness Measure	400 µm	600 µm

TRADITIONAL METHOD – 1ST TEST

Table 15: Measured Thickness Values on all plates with traditional method (results are in mm)

Plate A

Distance (m)	4,70			
2,75	8,30	8,20	8,30	8,30
	8,50	8,50	8,60	8,50
	8,50	8,30	8,50	8,30

Plate B

Distance (m)	10,00								
2,50	7,40	7,50	7,50	7,40	7,50	7,50	7,60	7,60	7,60
	7,50	7,50	7,50	7,50	7,60	7,60	7,60	7,70	7,60
	7,40	7,30	7,40	7,40	7,30	7,40	7,60	7,60	7,50

Plate C

Distance (m)	4,70			
2,75	8,20	8,20	8,10	8,20
	8,50	8,50	8,40	8,50
	8,30	8,20	8,30	8,00

Plate D

Distance (m)	9,40								
0,90	10,40	10,20	10,00	10,10	10,10	10,00	10,00	10,00	10,00
	10,10	9,90	10,10	9,90	9,90	9,80	9,70	9,70	9,80

Plate E

Distance (m)	9,40							
0,90	10,30	10,40	10,20	10,20	10,20	10,20	10,00	10,00
	10,50	10,40	10,20	10,20	10,20	10,20	10,10	10,10

Plate F

Distance (m)	9,40								
2,50	10,00	10,00	10,00	10,10	10,20	10,40	10,5	10,6	10,50
	10,30	10,30	10,30	10,50	10,60	10,60	10,70	10,80	10,70
	10,10	10,30	10,30	10,40	10,60	10,60	10,70	10,80	10,60
	10,00	10,00	10,00	10,10	10,40	10,30	10,50	10,60	10,50

Plate H

Distance (m)	9,40									
2,40	10,00	10,00	10,00	10,00	9,90	9,70	10,00	10,00	10,20	10,20
	10,30	10,20	10,20	10,20	10,10	10,30	10,20	10,30	10,50	10,50
	10,30	10,30	10,20	10,20	10,20	10,20	10,20	10,30	10,40	10,40
	10,00	10,00	10,00	10,00	10,00	10,10	10,20	10,10	10,10	10,10

Plate I

Distance (m)	9,40							
2,40	10,20	10,30	10,30	10,20	10,30	9,90	10,10	10,10
	10,50	10,60	10,50	10,50	10,40	10,40	10,50	10,50
	10,40	10,50	10,60	10,40	10,50	10,40	10,10	10,20

Plate J

Distance (m)	4,70				
2,50	12,20	12,10			12,20
	12,10	12,00			12,10
	11,70	11,70	12,00	12,00	11,90

Plate L

Distance (m)	10,00								
2,50	12,30	12,20	12,20	12,10	12,00	12,10	12,00	11,90	12,00
	12,30	12,10	12,10	12,00	12,10	12,00	12,10	12,00	11,90
	12,00	11,90	11,90	11,80	12,00	12,10	12,00	11,90	12,00

Plate M

Distance (m)	4,70				
2,50	12,20			12,10	12,00
	12,20			12,00	12,00
	12,00	12,00	11,80	11,90	11,70

Plate N

Distance (m)	4,60				
0,90	12,70	12,70	12,60	12,70	12,80

Plate O

Distance (m)	10,00								
0,90	12,90	12,90	12,50	12,60	12,70	12,70	12,60	12,50	12,80

Plate P

Distance (m)	4,70				
0,90	12,60	12,60	12,70	12,70	12,80

GAUGE PATTERN OF ALTISCAN'S MEASUREMENTS – 1ST TEST

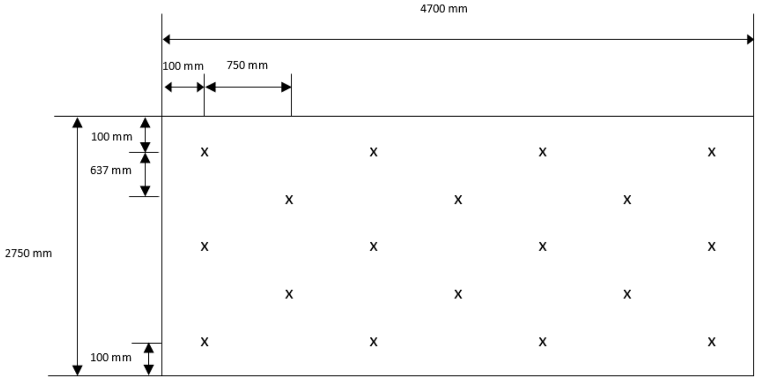


Figure 6: Plate A

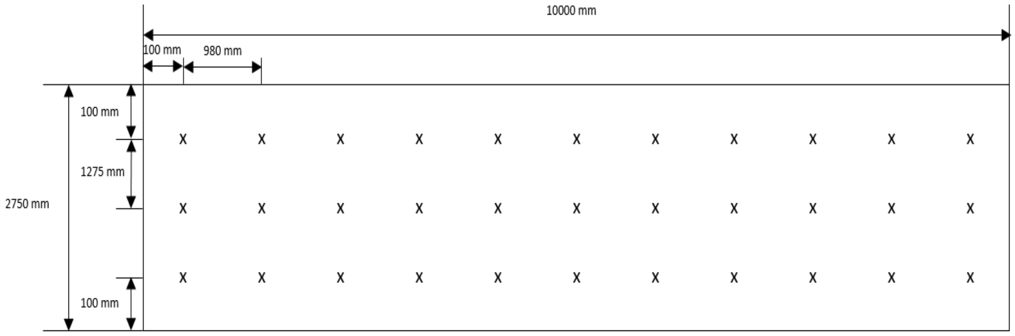


Figure 7: Plate B

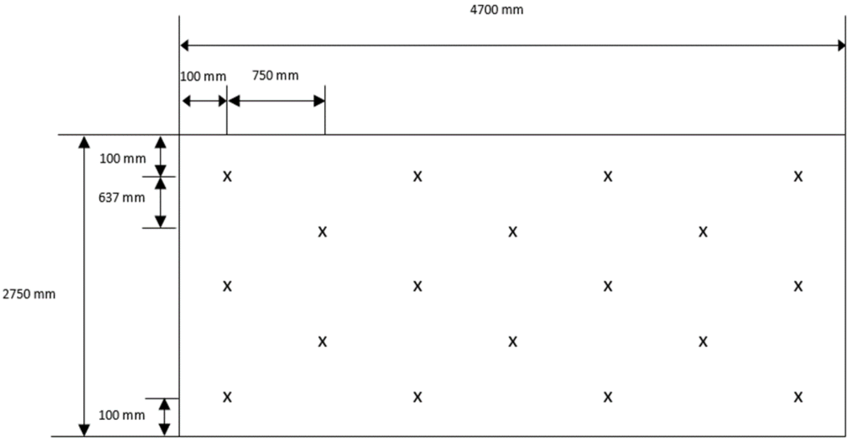


Figure 8: Plate C

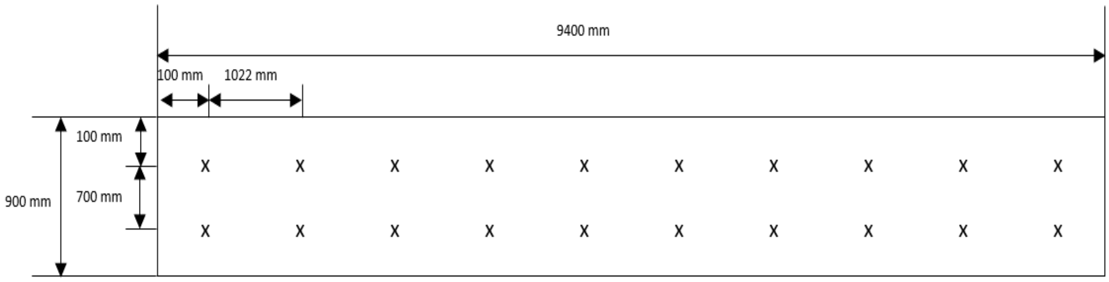


Figure 9: Plate D

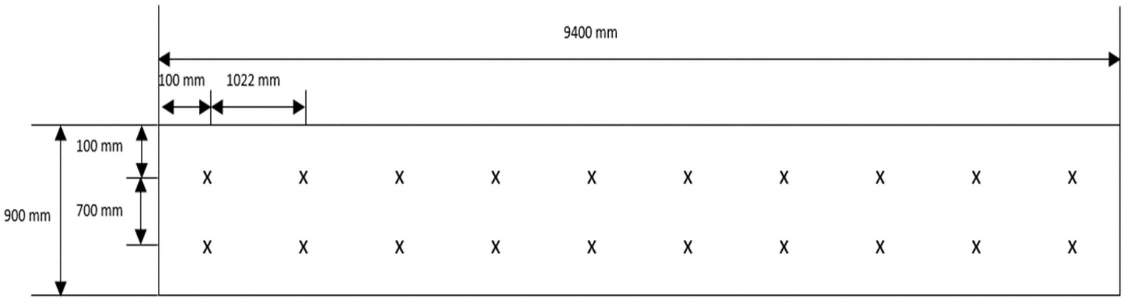


Figure 10: Plate E

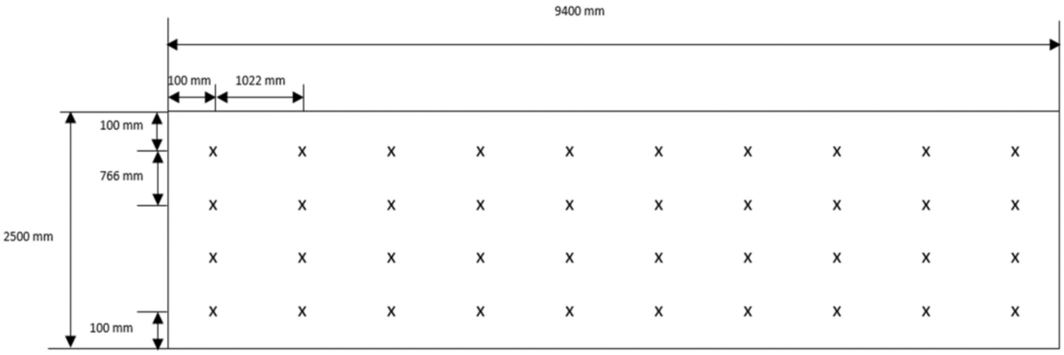


Figure 11: Plate F

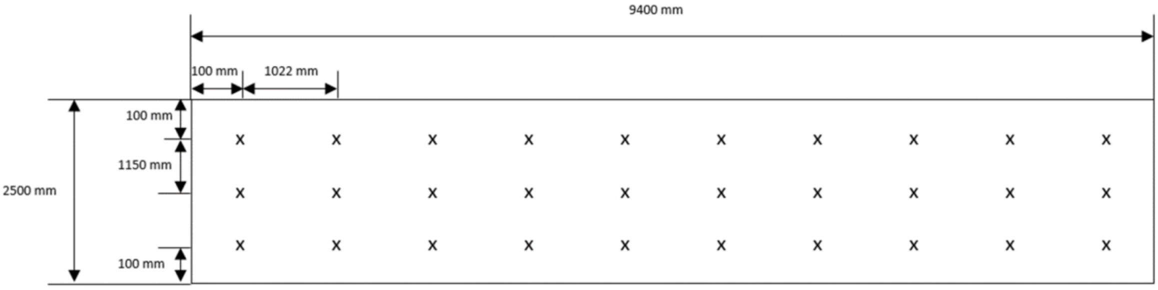


Figure 12: Plate G

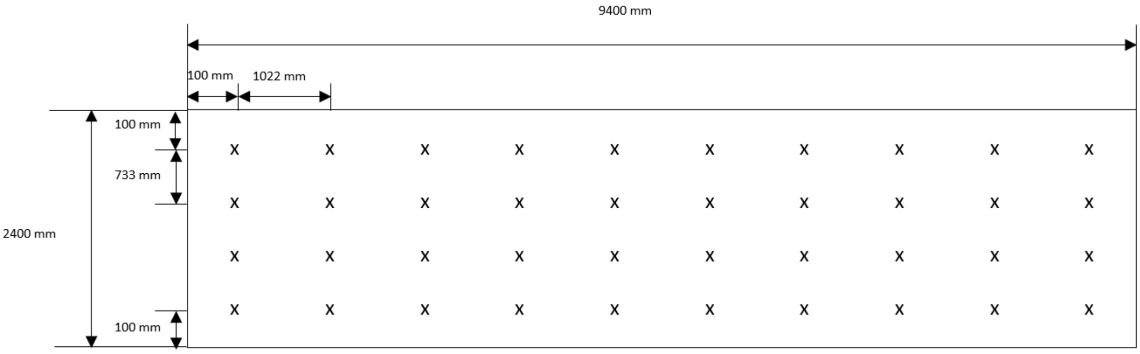


Figure 13: Plate H

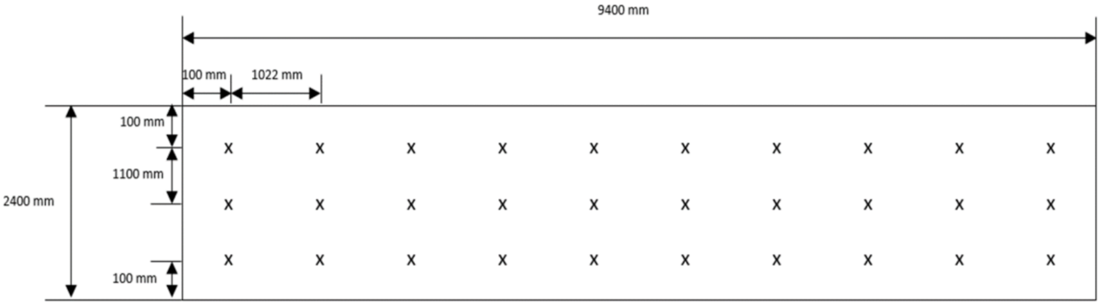


Figure 14: Plate I

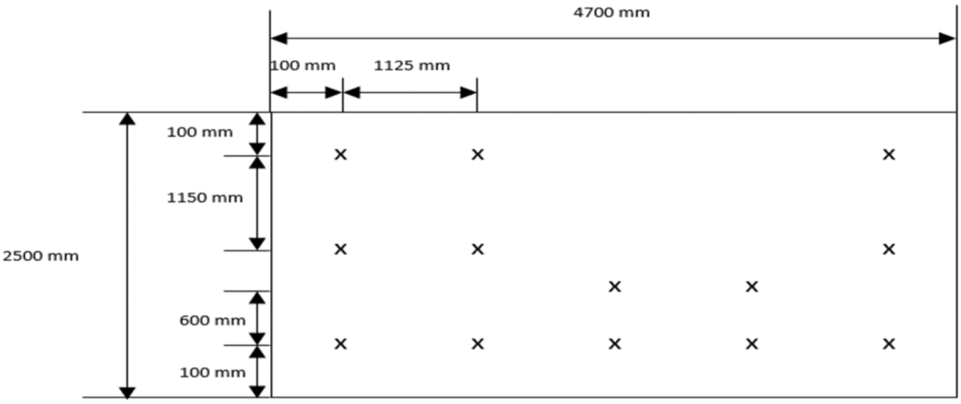


Figure 15: Plate J

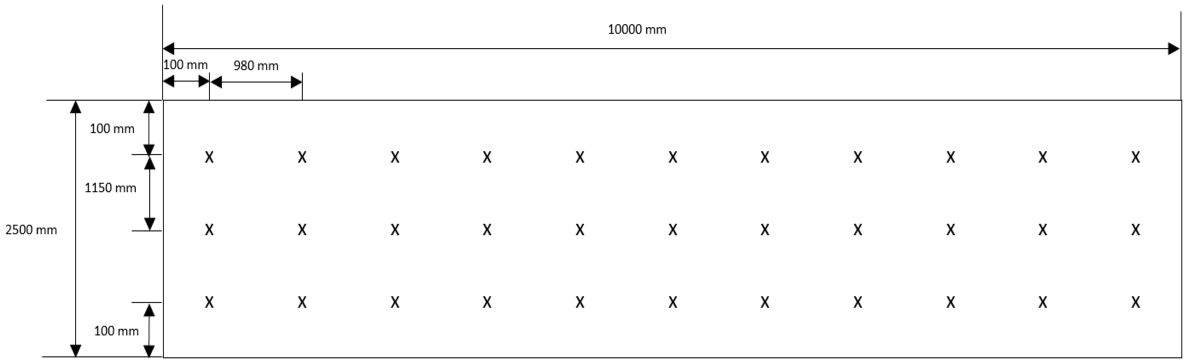


Figure 16: Plate L

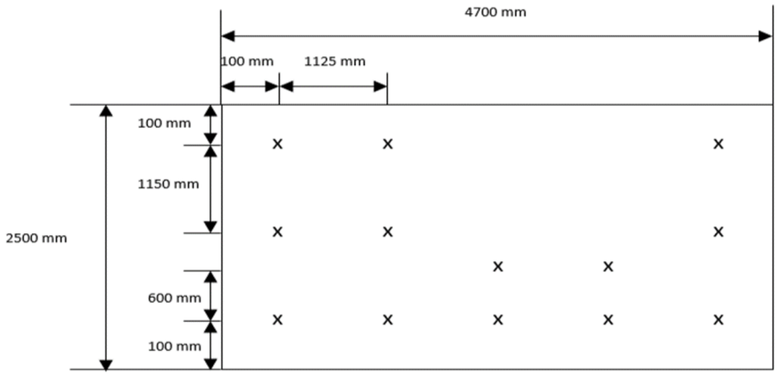


Figure 17: Plate M

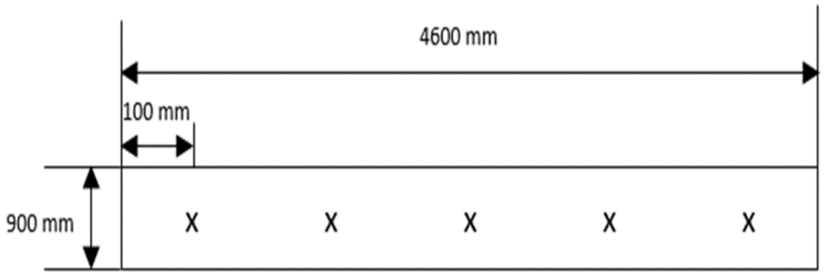


Figure 18: Plate N

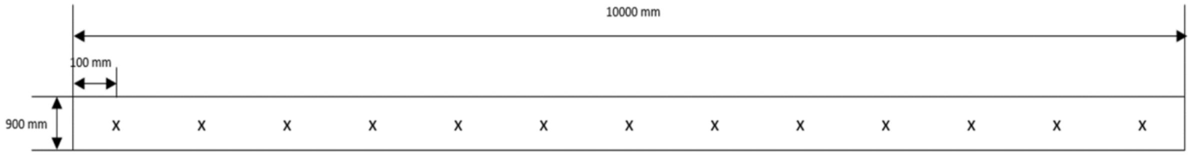


Figure 19: Plate O

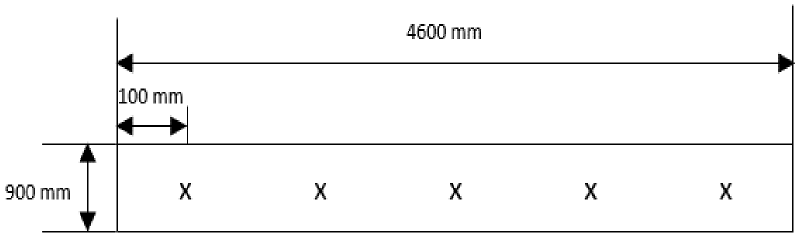


Figure 20: Plate P

MEASUREMENTS WITH ALTISCAN – 1ST TEST

Table 16: Measured Thickness Values on all plates with Altiscan (results are in mm)

Plate A

Distance (m)	4,70						
2,75	8,20		8,10		8,20		8,10
		8,20		8,50		8,30	
	8,40		8,40		8,30		8,30
		8,40		8,50		8,50	
	8,20		8,10		8,50		8,20

Plate B

Distance (m)	10,00										
2,5	7,40	7,30	7,30	7,40	7,20	7,40	7,60	7,40	7,60	7,60	7,40
	7,30	7,50	7,40	7,40	7,40	7,20	7,50	7,50	7,60	7,60	7,30
	7,30	7,30	7,20	7,40	7,20	7,20	7,40	7,40	7,40	7,40	7,20

Plate C

Distance (m)	4,70						
2,75	8,10		8,00		8,00		8,10
		8,30		8,20		8,30	
	8,30		8,30		8,30		8,30
		8,20		8,20		8,40	
	8,10		8,10		8,00		8,20

Plate D

Distance (m)	9,40									
0,90	10,10	10,20	10,10	10,00	10,20	9,90	9,90	9,70	9,80	10,20
	10,20	10,20	10,10	10,00	10,20	9,70	9,60	9,80	9,80	9,80

Plate E

Distance (m)	9,40									
0,90	10,30	10,30	10,30	10,00	10,10	10,00	9,90	10,10	9,90	9,90
	10,40	10,30	10,40	10,00	10,20	10,30	10,30	10,40	10,00	10,00

Plate F

Distance (m)	9,40									
2,50	10,00	10,00	10,20	10,30	10,30	10,20	10,50	10,60	10,30	10,40
	10,40	10,20	10,50	10,70	10,60	10,70	10,60	10,70	10,70	10,50
	10,40	10,30	10,50	10,30	10,50	10,50	10,50	10,40	10,70	10,30
	10,10	10,00	10,20	10,30	10,20	10,50	10,20	10,30	10,50	10,30

Plate G

Distance (m)	9,40									
2,50	10,20	10,10	10,00	10,10	10,30	10,30	10,20	10,00	10,00	10,40
	10,40	10,50	10,50	10,60	10,40	10,50	10,50	10,20	10,50	10,60
	10,10	10,20	10,20	10,50	10,30	10,30	10,20	10,30	10,40	10,20

Plate H

Distance (m)	9,40									
2,40	10,10	9,80	10,20	10,00	9,50	9,70	9,90	9,80	10,00	10,00
	10,50	10,40	10,40	10,30	10,50	10,10	10,30	10,00	10,20	10,60
	10,40	10,40	10,40	10,30	10,50	10,40	10,10	10,20	10,20	10,50
	10,20	10,20	10,00	10,30	9,80	10,10	10,20	10,30	10,40	10,40

Plate I

Distance (m)	9,40									
2,40	10,00	10,10	10,20	10,20	10,20	10,00	10,00	10,20	10,30	9,90
	10,30	10,40	10,60	10,50	10,50	10,30	10,50	10,30	10,20	10,30
	10,20	10,10	10,30	10,50	10,50	10,10	10,30	10,10	10,00	10,00

Plate J

Distance (m)	4,70				
2,50	11,70	11,70			11,70
	11,90	12,10	12,10	12,50	12,40
	11,80	12,70	11,70	12,00	12,20

Plate L

Distance (m)	10,00												
2,50	12,00	12,00	11,80	11,70	11,70	11,50	11,70	11,60	11,60	11,60	11,60	11,50	11,50
	12,50	12,30	12,30	12,20	12,00	12,00	12,20	11,90	11,70	11,90	11,80	11,80	11,80
	11,90	11,70	11,90	12,10	11,60	11,80	12,00	11,50	11,70	11,60	11,60	11,50	11,60

Plate M

Distance (m)	4,70				
2,50	11,70			11,60	11,60
	12,20	12,00	11,90	11,90	11,90
	11,80	11,70	11,60	11,70	11,60

Plate N

Distance (m)	4,60				
0,90	12,70	12,60	12,50	12,50	12,60

Plate O

Distance (m)	10,00												
0,90	12,90	12,90	12,70	12,60	12,50	12,50	12,50	12,50	12,60	12,50	12,70	12,70	12,60

Plate P

Distance (m)	4,70				
0,90	12,50	12,60	12,60	12,50	12,60

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under Grant Agreement No. 871260

STATISTIC DATA PER PLATE – 1ST TEST

Table 17: Traditional Method Statistic Data

Statistic Data Plate A			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
8,40	8,20	8,60	0,13

Statistic Data Plate B			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
7,50	7,30	7,70	0,10

Statistic Data Plate C			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
8,28	8,00	8,50	0,16

Statistic Data Plate D			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
9,98	9,70	10,40	0,18

Statistic Data Plate E			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
10,21	10,00	10,50	0,14

Statistic Data Plate F			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
10,38	10,00	10,80	0,26

Statistic Data Plate G			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
10,45	10,20	10,70	0,13

Statistic Data Plate H			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
10,15	9,70	10,50	0,16

Statistic Data Plate I			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
10,35	9,90	10,60	0,18

Statistic Data Plate J			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
12,00	11,70	12,20	0,17

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 871260

Statistic Data Plate L			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
12,04	11,80	12,30	0,12

Statistic Data Plate M			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
11,99	11,70	12,20	0,15

Statistic Data Plate N			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
12,70	12,60	12,80	0,07

Statistic Data Plate O			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
12,69	12,50	12,90	0,15

Statistic Data Plate P			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
12,68	12,60	12,80	0,08

Table 18: Altiscan Statistic Data

Statistic Data Plate A			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
8,30	8,10	8,50	0,15

Statistic Data Plate B			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
7,38	7,20	7,60	0,13

Statistic Data Plate C			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
8,19	8,00	8,40	0,12

Statistic Data Plate D			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
9,98	9,60	10,20	0,20

Statistic Data Plate E			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
10,16	9,90	10,40	0,18

Statistic Data Plate F			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
10,39	10,00	10,70	0,20

Statistic Data Plate G			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
10,30	10,00	10,60	0,18

Statistic Data Plate H			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
10,19	9,50	10,60	0,25

Statistic Data Plate I			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
10,24	9,90	10,60	0,18

Statistic Data Plate J			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
12,04	11,70	12,70	0,32

Statistic Data Plate L			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
11,81	11,50	12,50	0,25

Statistic Data Plate M			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
11,78	11,60	12,20	0,18

Statistic Data Plate N			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
12,58	12,50	12,70	0,07

Statistic Data Plate O			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
12,63	12,50	12,90	0,14

Statistic Data Plate P			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
12,56	12,50	12,60	0,05

Table 19: Average Measurements per thickness

Average measurements on plates with a thickness of 8 mm

Traditional Method (mm)	Altiscan (mm)
8,06	7,96

Average measurements on plates with a thickness of 10 mm

Traditional Method (mm)	Altiscan (mm)
10,25	10,21

Average measurements on plates with a thickness of 12 mm

Traditional Method (mm)	Altiscan (mm)
12,35	12,23

Table 20: Maximum Measured Values per thickness

Maximum measured thickness in plates with 8 mm

Traditional Method (mm)	Altiscan (mm)
8,60	8,50

Maximum measured thickness in plates with 10 mm

Traditional Method (mm)	Altiscan (mm)
10,80	10,70

Maximum measured thickness in plates with 12 mm

Traditional Method (mm)	Altiscan (mm)
12,90	12,90

Table 21: Minimum Measured Values per thickness

Minimum measured thickness in plates with 8 mm

Traditional Method (mm)	Altiscan (mm)
7,30	7,20

Minimum measured thickness in plates with 10 mm

Traditional Method (mm)	Altiscan (mm)
9,70	9,5

Minimum measured thickness in plates with 12 mm

Traditional Method (mm)	Altiscan (mm)
11,70	11,5

Table 22: Standard deviation values per thickness

Measurements standard deviation of the 8 mm plate

Traditional Method (mm)	Altiscan (mm)
0,13	0,13

Measurements standard deviation in 10 mm thickness

Traditional Method (mm)	Altiscan (mm)
0,17	0,20

Measurements standard deviation in 12 mm thickness

Traditional Method (mm)	Altiscan (mm)
0,13	0,17

In general, the standard deviation of measurements collected by Altiscan is higher than the measurements collected with traditional method. This is due to the adjustments needed in A scan menu in each measurement.

The average measurements are identical both in traditional method and Altiscan, proving that the Altiscan have a good performance since the traditional method is carried out using a standardized method and executed by certified technicians.

GAUGE PATTERN OF 2ND TEST IN DRY DOCK (A SCAN)

The 2nd test was carried out with a tighter mesh.

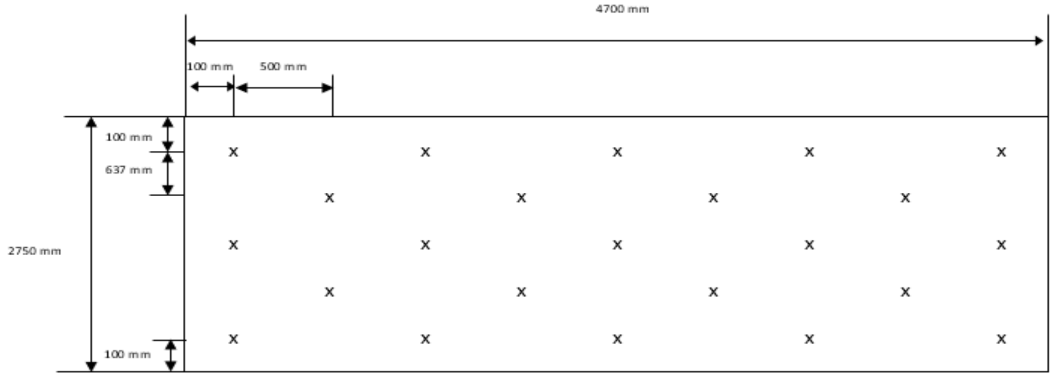


Figure 21: Plate A (2nd test)

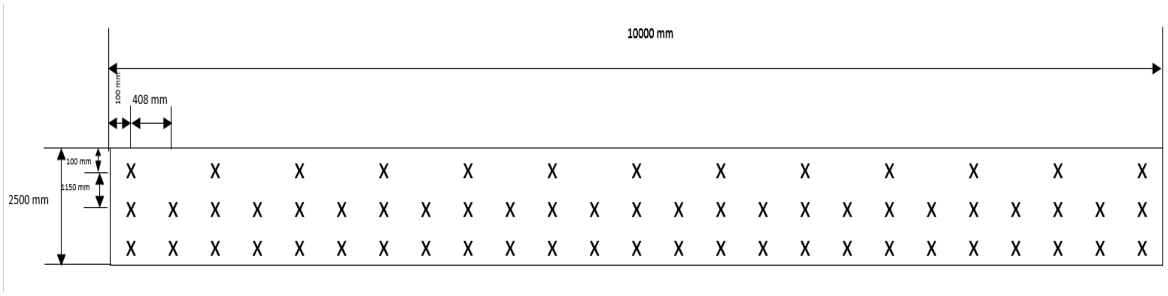


Figure 22: Plate B (2nd test)

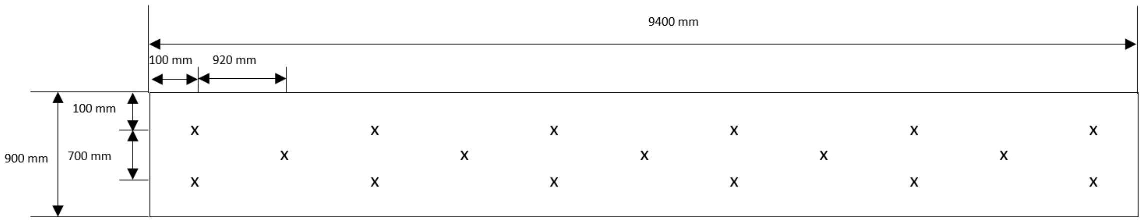


Figure 23: Plate D (2nd test)

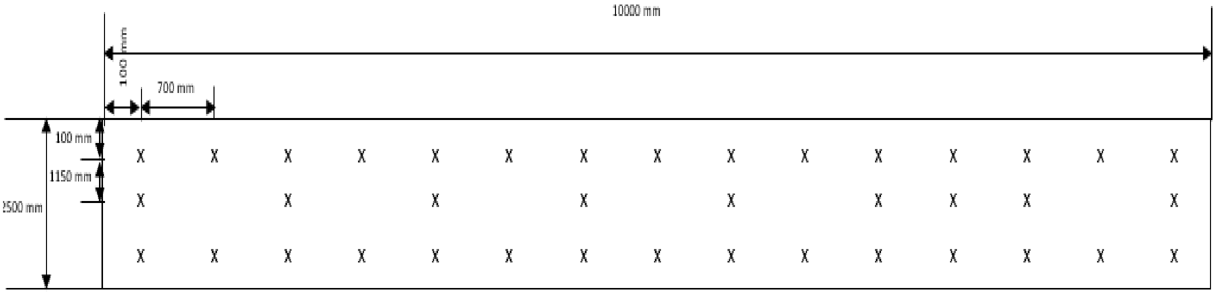


Figure 24: Plate F (2nd test)

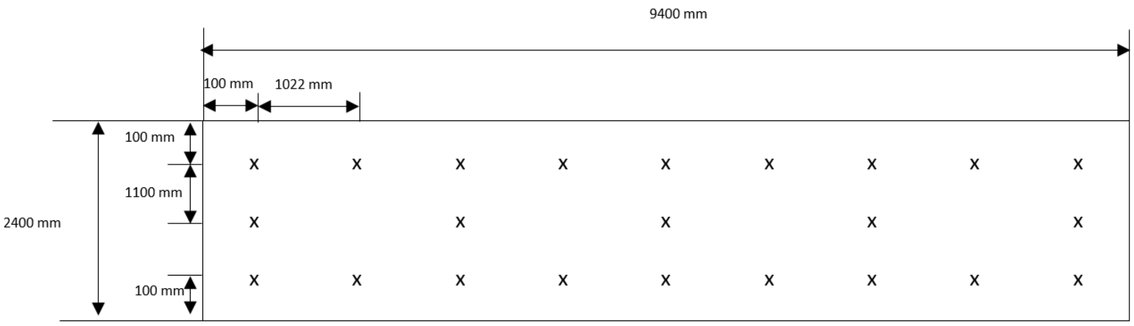


Figure 25: Plate H (2nd test)

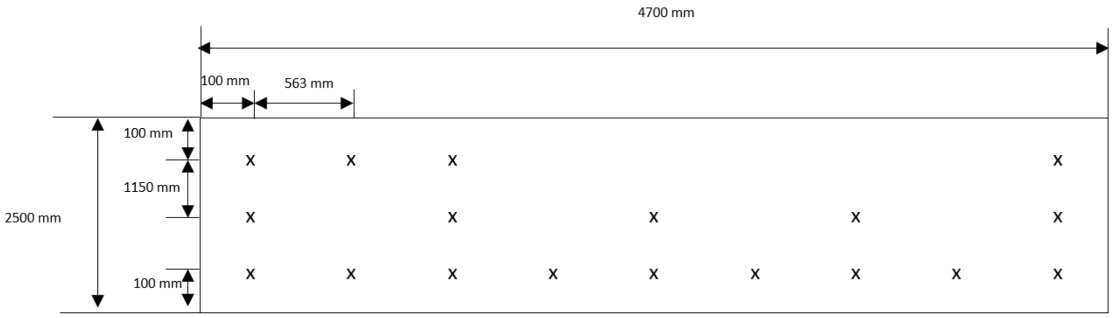


Figure 26: Plate J (2nd test)

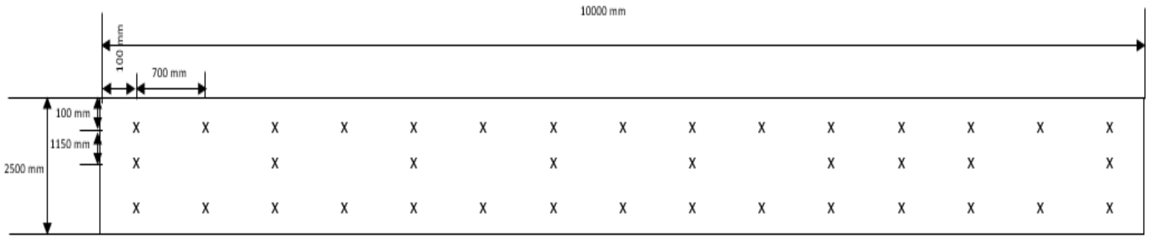


Figure 27: Plate L (2nd test)

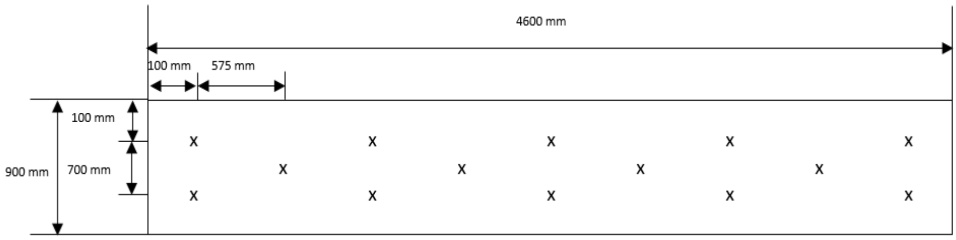


Figure 28: Plate N (2nd test)

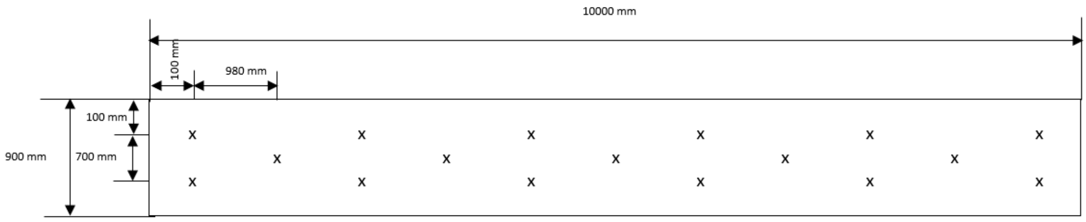


Figure 29: Plate O (2nd test)

MEASUREMENTS WITH ALTISCAN IN DRYDOCK –2ND TEST

Table 23:- 2nd Test with Altiscan in drydock (results are in mm)

Plate A

Distance (m)	4,70								
2,75	8,00		8,20		8,30		8,20		8,30
		8,30		8,40		8,50		8,40	
	8,50		8,50		8,50		8,40		8,50
		8,20		8,30		8,40		8,40	
	8,10		8,20		8,20		8,20		8,30

Plate B

Distance (m)	10,00																								
2,50	7,30		7,40		7,40		7,30		7,30		7,30		7,40		7,60		7,50		7,30		7,40		7,60		7,50
		7,40		7,40		7,50		7,40		7,50		7,50		7,50		7,50		7,30		7,50		7,50		7,50	
	7,40		7,50		7,40		7,40		7,40		7,50		7,60		7,60		7,50		7,50		7,60		7,60		7,50
		7,30		7,40		7,40		7,30		7,20		7,40		7,50		7,60		7,30		7,40		7,50		7,60	
	7,30		7,30		7,30		7,20		7,30		7,20		7,40		7,40		7,50		7,20		7,40		7,40		7,50

Plate D

Distance (m)	9,40										
0,90	10,2	-	10,2	-	10,2	-	10,1	-	10,2		9,9
	10	10,1	9,9	10	9,9	10	9,9	9,9	9,6	9,80	10,5

Plate F

Distance (m)	9,40								
2,50	9,9	10,1	9,9	10	10	10,2	10	10,2	10,2
	10,1		10,2		10,2		10,2		10,4
	9,8	10,1	9,9	9,8	9,9	10	9,9	10,2	10

Plate H

Distance (m)	9,40								
2,40	9,8	10,2	9,9	10,1	9,8	10	9,9	10,1	9,9
	10,2		10,2		10,1		10,1		10,1
	9,9	10,1	9,9	9,9	9,8	9,9	9,9	10,1	9,7

Plate J

Distance (m)	4,70								
2,50	11,70	12,00	12,00						11,70
	12,00		12,00	12,00	11,80		12,00		12,20
	11,70	11,80	11,60	11,70	11,70	11,80	11,30	11,90	11,80

Plate L

Distance (m)	10,00														
2,50	11.9	12.2	12.0	12.0	11.9	12.0	11.7	12.0	11.7	12.0	11.7	11,50	11,50	12.0	11.7
	12.2		12.1		12.1		12.0		12.0		12.0	11,80	11,80		12.0
	11.9	12.2	11.8	12.0	12.0	11.9	11.6	11.9	11.6	12.2	11.6	11,50	11,60	12.2	11.6

Plate N

Distance (m)	4,60								
0,90	12.7	-	12.6	-	12.6	-	12.6	-	12.6
	12.5	12.6	12.5	12.6	12.5	12.5	12.5	12.5	12.6

Plate O

Distance (m)	10,00										
0,90	12,9		12,7	12,9	12,6	12,6	12,6		12,6	12,6	12,5
	12,8	12,7	12,7		12,5		12,5	12,9	12,8		12,6

MEASUREMENTS STATISTIC DATA WITH ALTISCAN –2^{ND} TEST

Table 24: 2nd Measurements Statistic Data in each plate

Statistic Data Plate A			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
8,32	8,00	8,50	0,14

Statistic Data Plate B			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
7,42	7,20	7,60	0,11

Statistic Data Plate D			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
10,02	9,60	10,50	0,20

Statistic Data Plate F			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
10,05	9,80	10,40	0,15

Statistic Data Plate H			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
9,98	9,70	10,20	0,14

Statistic Data Plate J			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
11,83	11,30	12,20	0,20

Statistic Data Plate L			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
11,88	11,50	12,20	0,21

Statistic Data Plate N			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
12,56	12,50	12,70	0,06

Statistic Data Plate O			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
12,68	12,50	12,90	0,14

GLOBAL STATISTIC ANALYSIS – 2ND TEST

Table 25: Average Measurements per thickness in 1st and 2nd test

Average thickness on plates with a thickness of 8 mm

Altiscan - 1st test (mm)	Altiscan - 2nd test (mm)
7,96	7,86

Average thickness on sheets with a thickness of 10 mm

Altiscan - 1st test (mm)	Altiscan - 2nd test (mm)
10,21	10,02

Average thickness on sheets with a thickness of 12 mm

Altiscan - 1st test (mm)	Altiscan - 2nd test (mm)
12,23	12,24

Table 26: Maximum Measured Values per thickness 1st and 2nd test

Maximum measured value in 8 mm thickness

Altiscan - 1st test (mm)	Altiscan - 2nd test (mm)
8,50	8,50

Maximum measured value in 10 mm thickness

Altiscan - 1st test (mm)	Altiscan - 2nd test (mm)
10,70	10,50

Maximum measured value in 12 mm thickness

Altiscan - 1st test (mm)	Altiscan - 2nd test (mm)
12,90	12,90

Table 27: Minimum Measured Values per thickness 1st and 2nd test

Minimum measured value in 8 mm thickness

Altiscan - 1st test (mm)	Altiscan - 2nd test (mm)
7,20	8,00

Minimum measured value in 10 mm thickness

Altiscan - 1st test (mm)	Altiscan - 2nd test (mm)
9,50	9,60

Minimum measured value in 12 mm thickness

Altiscan - 1st test (mm)	Altiscan - 2nd test (mm)
11,50	11,30

Table 28: Standard deviation values per thickness in 1st and 2nd test

Measurements standard deviation in 8 mm thickness

Altiscan - 1st test (mm)	Altiscan - 2nd test
0,13	0,14

Measurements standard deviation in 10 mm thickness

Altiscan - 1st test (mm)	Altiscan - 2nd test (mm)
0,20	0,16

Measurements standard deviation in 12 mm thickness

Altiscan - 1st test (mm)	Altiscan - 2nd test (mm)
0,17	0,15

The measurements collected in the 2nd test by the Altiscan have a lower standard deviation than the 1st test, due higher number of measurements. In average, the thickness measurement is higher in the 1st test.

In overall, the thickness measures of A scan were accurate. The difference of thickness measure from the crawler to the traditional method was in average 0,1 mm.

There is a higher standard deviation of thickness measure in crawler than in traditional method.

THICKNESS MEASUREMENT OF DRYDOCK DOOR – B SCAN

PHOTO OF DRYDOCK DOOR AND B SCAN INSPECTION LINES

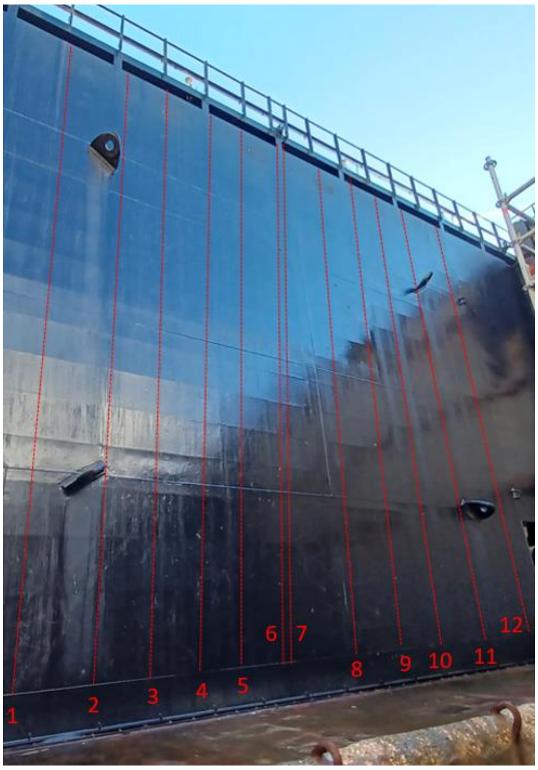


Figure 30: Drydock Door and Inspection lines

B SCAN RESULTS OBTAINED WITH ALTISCAN DATAREPORT SOFTWARE (RESULTS IN MM)

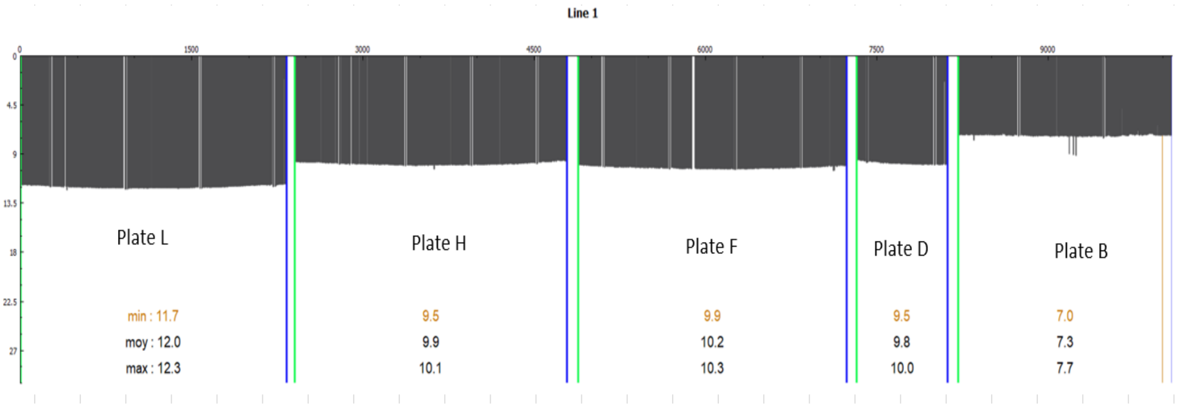


Figure 31: Line 1

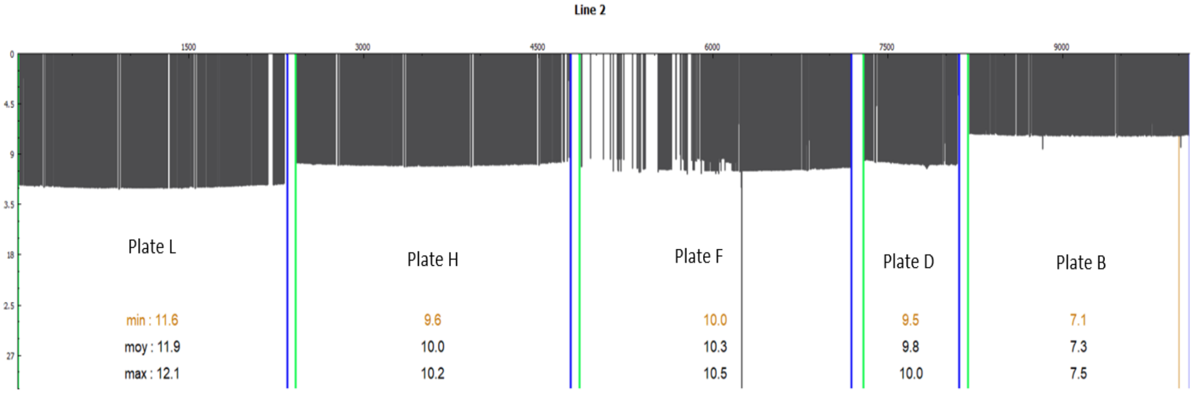


Figure 32: Line 2

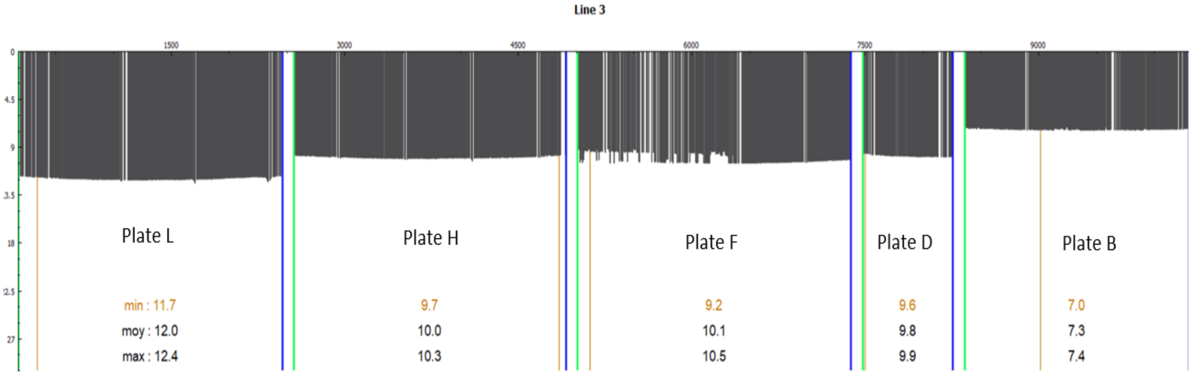


Figure 33: Line 3

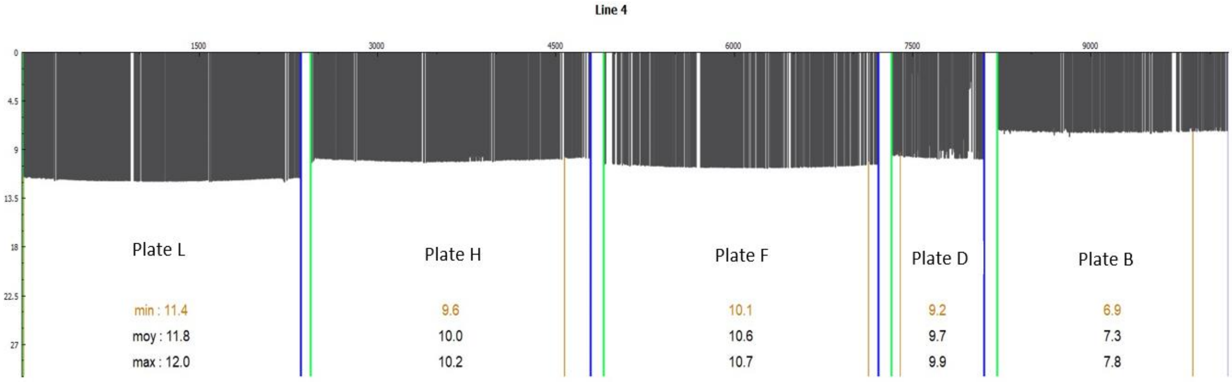


Figure 34: Line 4

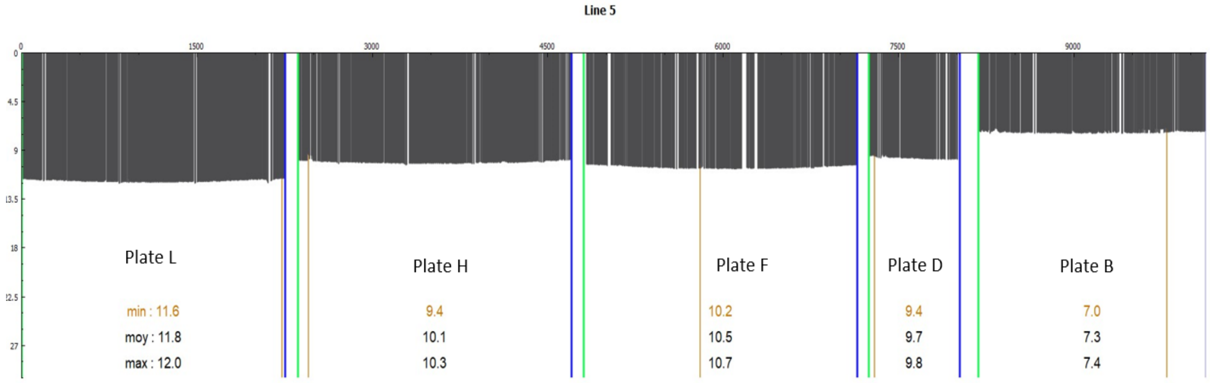


Figure 35: Line 5

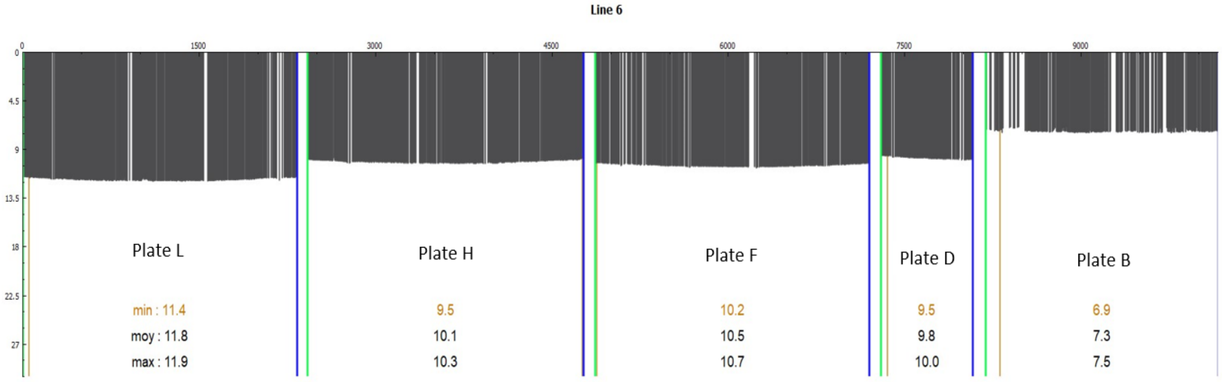


Figure 36: Line 6

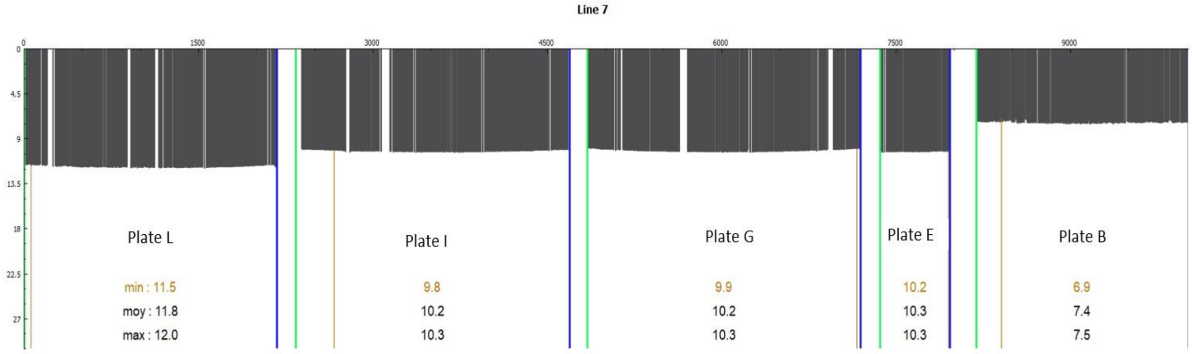


Figure 37: Line 7

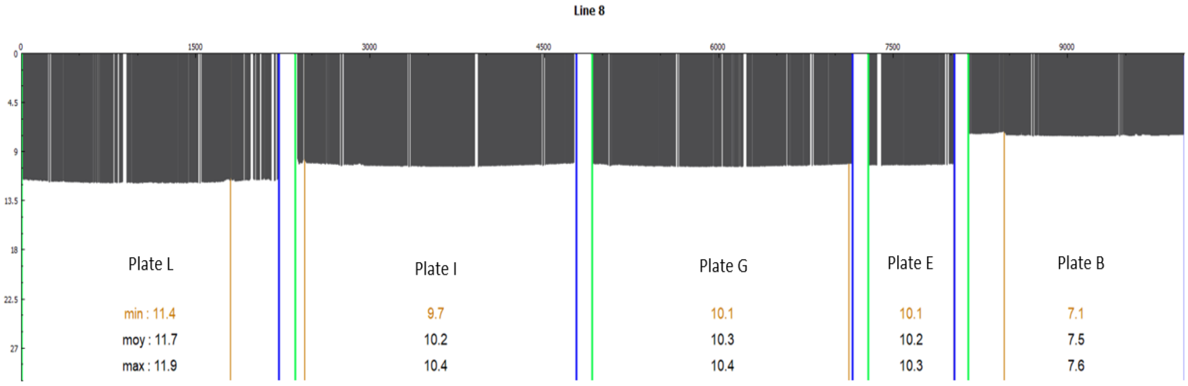


Figure 38: Line 8

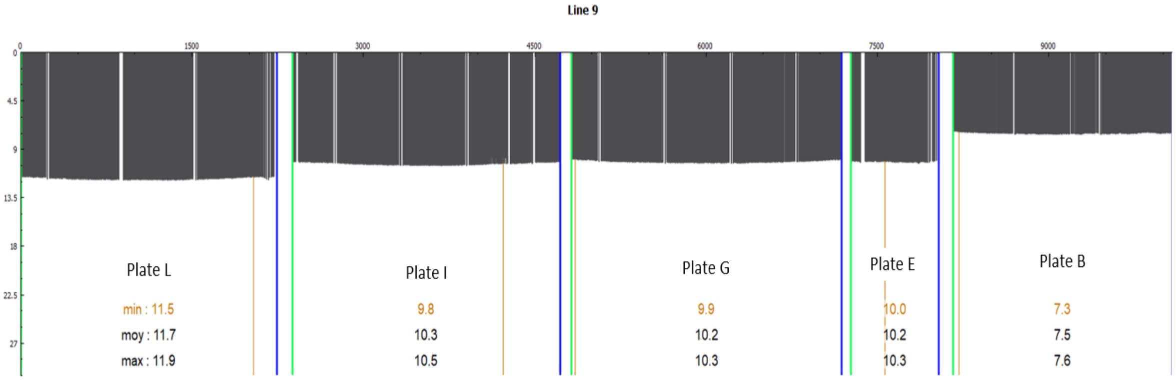


Figure 39: Line 9

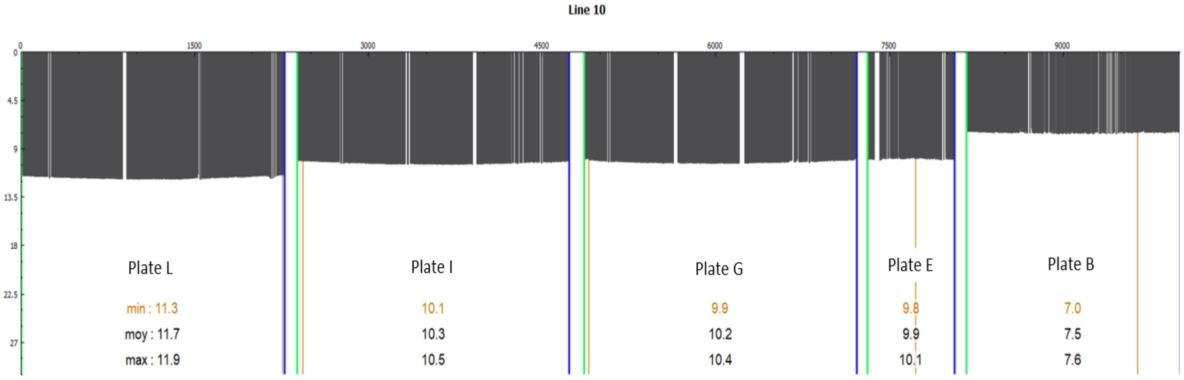


Figure 40: Line 10

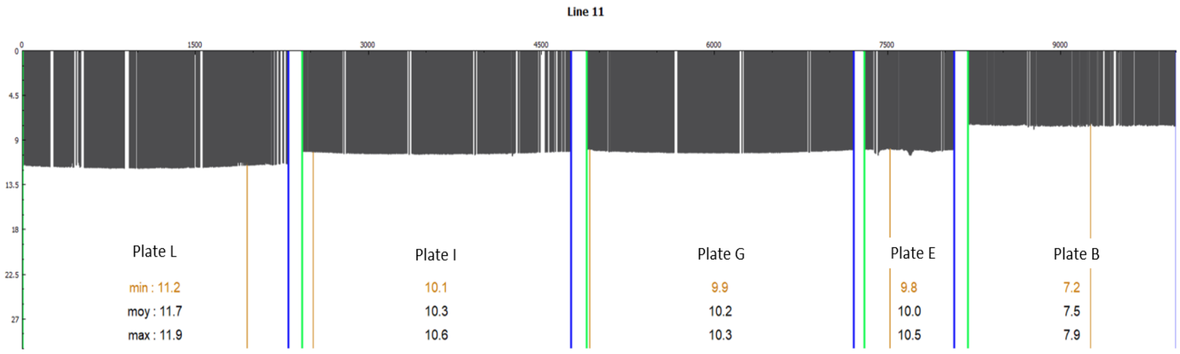


Figure 41: Line 11

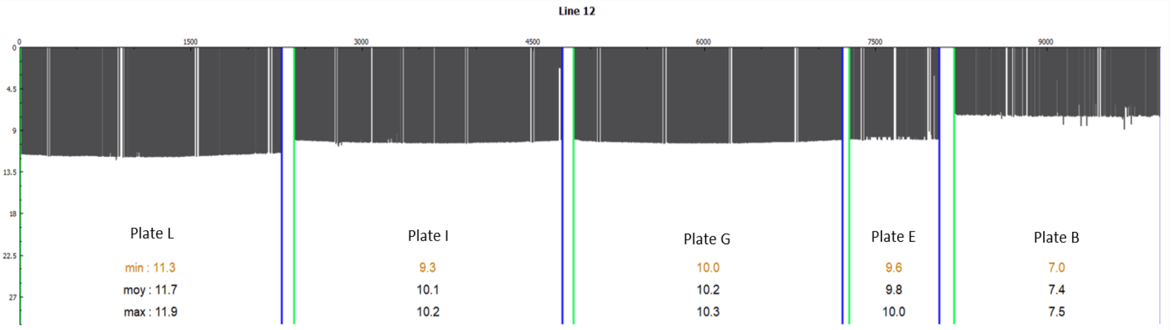


Figure 42: Line 12

STANDARD DEVIATION

Table 29: Measurements Standard deviation with B Scan

Measurements Standard Deviation	
Nominal thickness	**Standard Deviation**
8 mm plate	1,16 mm
10 mm plate	1,01 mm
12 mm plate	1,79 mm

In B Scan, we can do an inspection more quickly, but it can consume some time in post processing and the standard deviation is higher than in A scan.

The good preparate surfaces (low rugosity) are important to have a better result, and it need less time to do the post processing.

THICKNESS MEASUREMENT OF FLOATING DOCK – A SCAN

PHOTO OF FLOATING DOCK

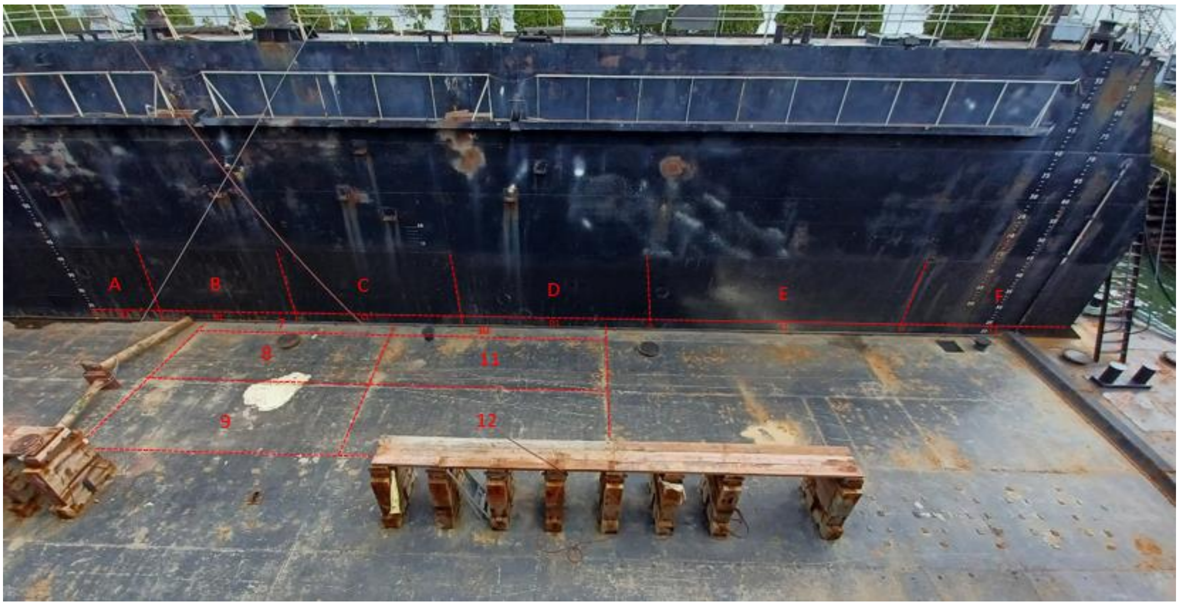


Figure 43: Floating Dock Port View

Figure 44: ALTISCAN photo of floating dock lateral surface

Figure 45: ALTISCAN photo of floating dock lateral and bottom surface

Figure 46: Floating Dock Starboard view

MEASURED PARAMETERS

Table 30: Range of measured parameters in Floating Dock

	Minimum	**Maximum**
Rugosity	45 µm	75 µm
Coating Thickness Measure	280 µm	700 µm

TABLES OF NOMINAL VALUES

Table 31: Nominal Thickness of lateral plates

Plate	Nominal Thickness (mm)	Acceptable Minimum thickness (mm) - 10 %
A	12,50	11,25
A1	14,00	12,60
B	12,50	11,25
B1	14,00	12,60
C	12,50	11,25
C1	14,00	12,60
D	12,50	11,25
D1	14,00	12,60
E	12,50	11,25
E1	14,00	12,60
F	12,50	11,25
F1	14,00	12,60

Table 32: Nominal Thickness of base plates

Plate	Nominal Thickness (mm)	Acceptable Minimum thickness (mm) - 10 %
1	15,50	13,95
2	15,50	13,95
3	15,00	13,50
4	15,50	13,95
4a	15,50	13,95
5	15,50	13,95
6	15,00	13,50
7	15,00	13,50
8	14,00	12,60
9	14,00	12,60
10	15,00	13,50
11	14,00	12,60
12	15,00	13,50

TRADITIONAL METHOD

Table 33: Thickness Measurements of lateral Plates with Traditional Method (results are in mm)

Plate A

Distance (m)	2,30			
1,6	11,80	11,80	11,30	11,60
	12,30	12,50	11,90	11,70
	12,40	12,10	12,30	11,80
	12,40	11,30	11,70	12,10

Plate A1

Distance (m)	2,30			
0,4	13,60	13,30	13,40	13,20

Plate B

Distance (m)	3,70					
1,6	12,40	12,80	13,10	13,30	13,00	13,20
	13,20	14,10	13,40	13,40	13,10	13,60
	12,60	13,00	13,40	13,30	13,20	13,40
	12,20	12,00	12,20	12,00	12,10	12,00

Plate B1

Distance (m)	3,70					
0,4	13,80	13,70	13,60	13,50	13,60	13,50

Plate C

Distance (m)	4.50							
1,6	12,60	12,60	12,60	12,50	12,40	12,50	12,60	12,90
	13,00	13,20	13,00	13,00	12,90	13,20	13,40	13,30
	12,80	12,80	12,60	12,80	12,70	12,80	13.0	12,80
	12,00	11,40	11,70	12,60	11,70	11,80	11,40	11,50

Plate C1

Distance (m)								
0,4	13,60	13,40	13,60	13,60	13,60	13,60	13,40	13,40

Plate D

Distance (m)	5,30								
1,6	11,40	12,00	11,80	11,80	11,70	12,40	11,80	12,00	11,60
	12,70	12,60	12,50	12,60	12,40	12,30	12,60	12,80	12,90
	12,70	13,00	12,90	12,80	12,50	12,30	13,10	13,20	12,70
	11,60	10,70	12,60	12,40	12,40	12,00	12,20	12,50	12,60

Plate D1

Distance (m)	5,30								
0,4	13,80	14,00	13,80	13,60	13,60	13,80	14,00	14,00	13,90

Plate E

Distance (m)	6,70									
1,6	11,50	12,40	12,80	12,30	11,60	11,80	11,00	11,60	11,20	11,10
	12,00	12,00	12,20	12,00	12,30	12,00	12,10	12,10	11,40	11,80
	12,80	12,30	12,60	12,00	12,10	12,00	12,10	12,30	12,10	11,70
	12,20	12,00	11,80	11,40	12,80	12,80	11,80	11,,9	11,80	11,50

Plate E1

Distance (m)	6,70									
0,4	13,80	14,00	13,80	14,10	13,90	14,10	14,10	13,90	14,10	14,10

Plate F

Distance (m)	4.50							
1,6	11,50	11,60	11,60	12,20	11,30	11,30	11,00	11,30
	12,20	12,80	11,60	11,80	11,80	11,70	11,60	12,30
	11,90	11,70	11,90	11,80	11,80	11,80	11,40	11,40
	12,80	11,40	11,30	11,60	11,70	11,40	11,10	11,00

Plate F1

Distance (m)								
0,4	14,20	14,20	14,10	13,30	14,10	14,00	14,00	14,00

GAUGE PATTERN OF LATERAL PLATES

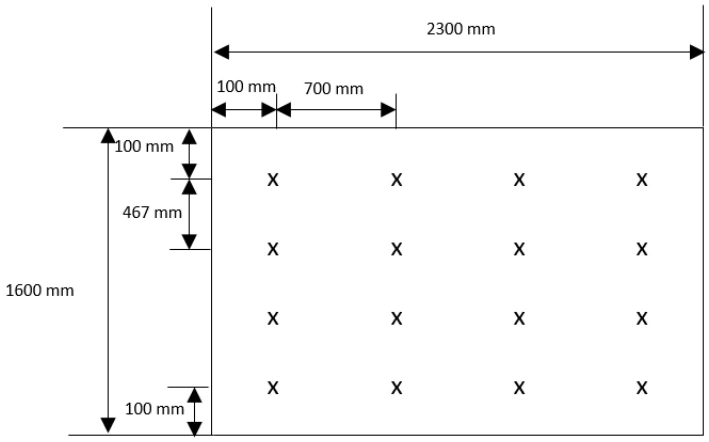


Figure 47: Plate A

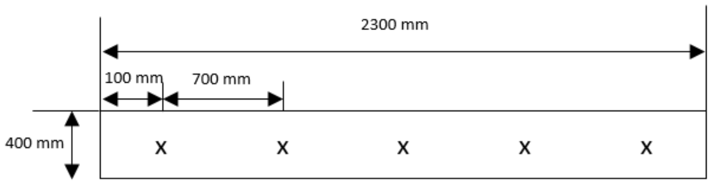


Figure 48: Plate A1

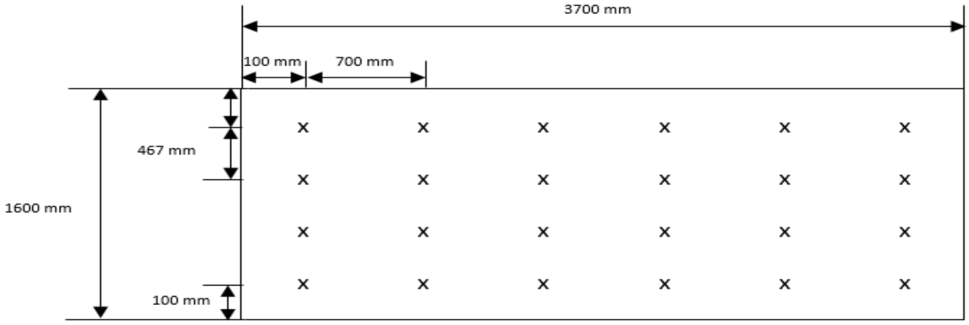


Figure 49: Plate B

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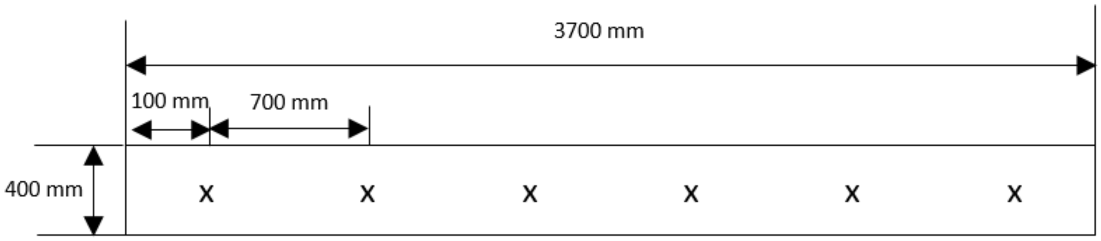

Figure 50: Plate B1

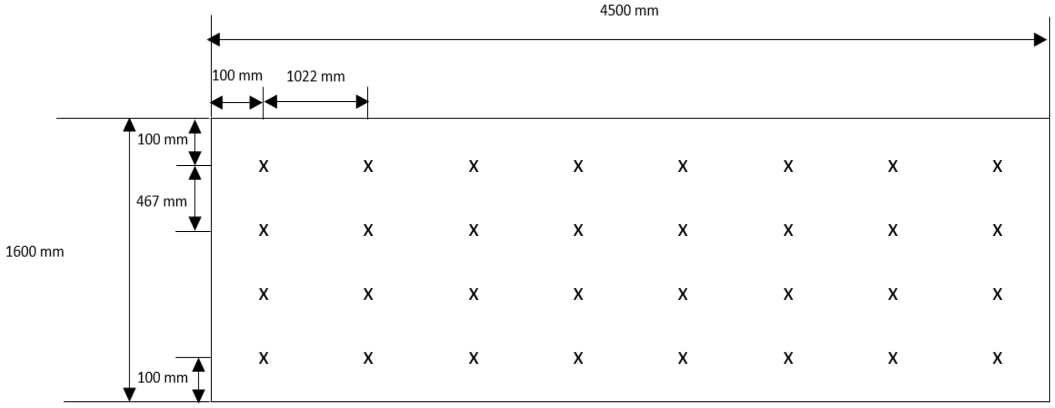

Figure 51: Plate C

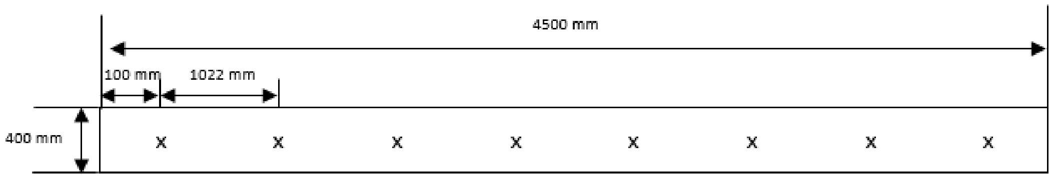

Figure 52: Plate C1

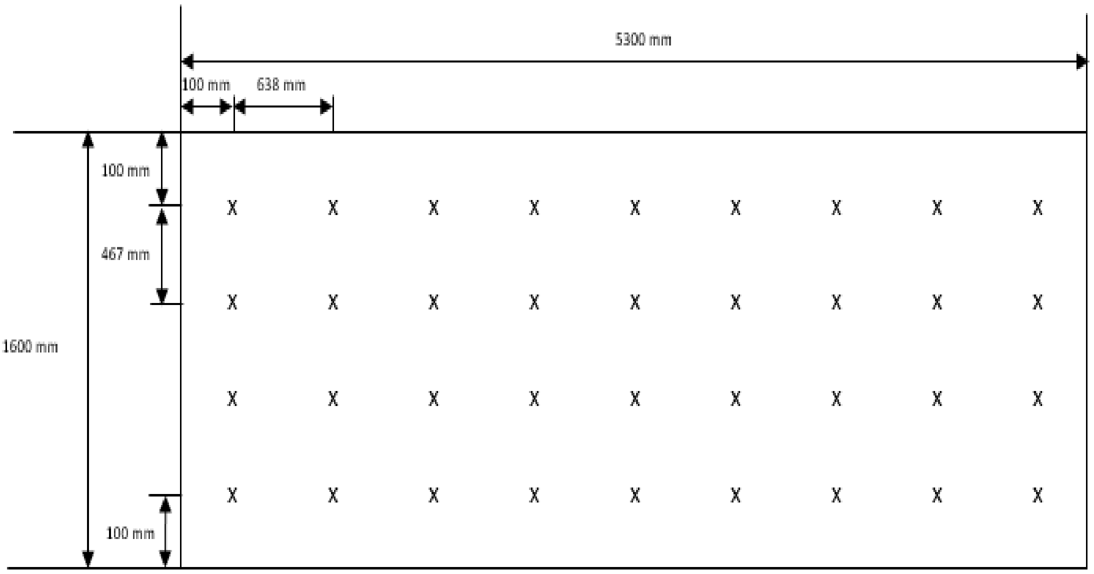

Figure 53: Plate D

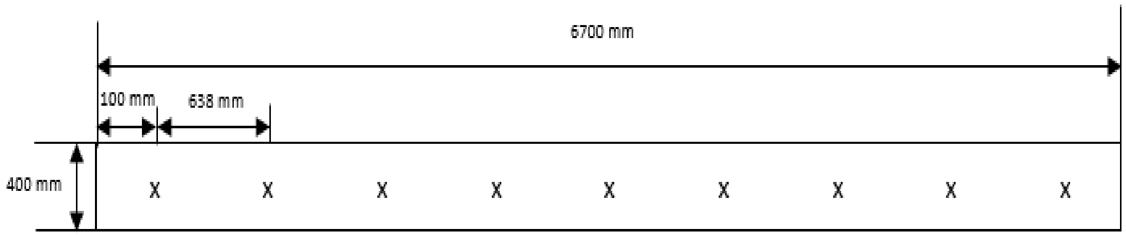

Figure 54: Plate D1

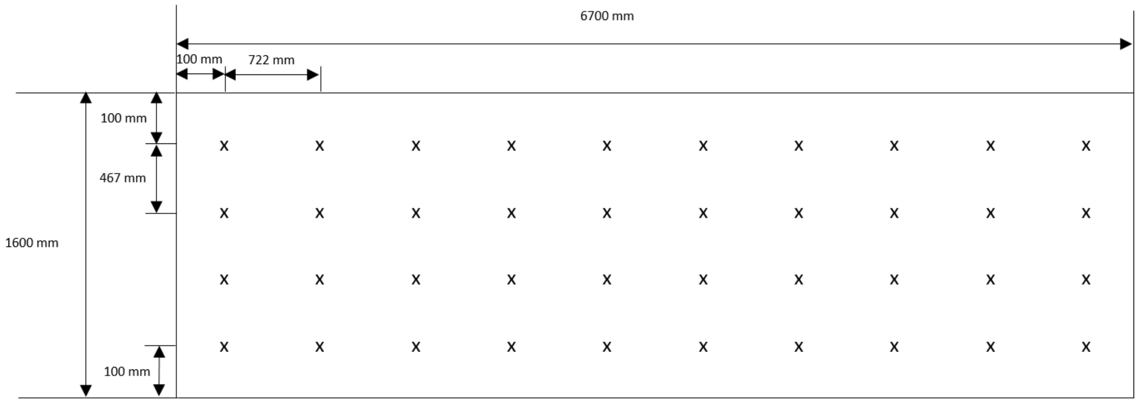

Figure 55: Plate E

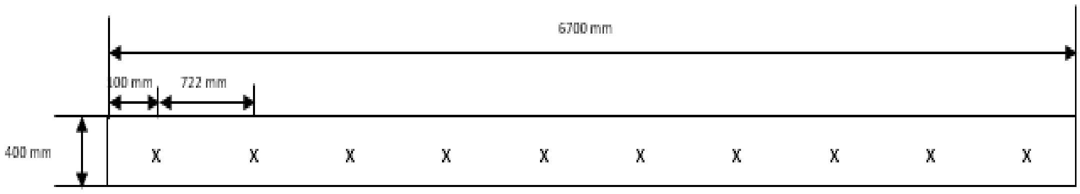

Figure 56: Plate E1

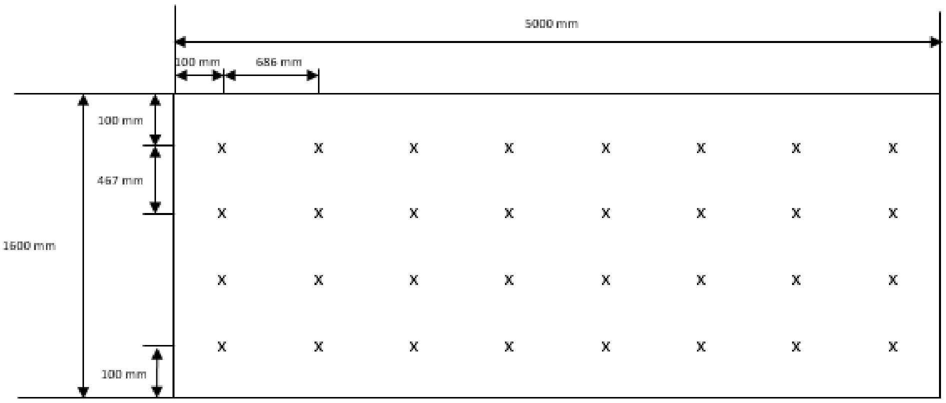

Figure 57: Plate F

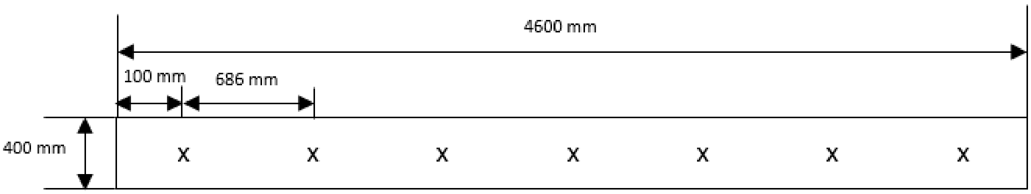

Figure 58: Plate F1

MEASUREMENTS WITH ALTISCAN ON THE LATERAL SURFACE (A SCAN)

Table 34: Thickness Measurements of lateral Plates with Altiscan (results are in mm)

Plate A

Distance (m)	2,30			
1,6	11,60	12,00	11,70	11,80
	12,10	12,50	12,00	12,20
	11,80	11,70	12,20	11,70
	12,20	11,60	12,50	11,30

Plate A1

Distance (m)	2,30			
0,4	13,60	13,50	13,30	13,40

Plate B

Distance (m)	3,70					
1,6	🟨	🟨	13,20	13,50	13,30	13,60
	13,60	13,60	13,80	13,40	12,80	13,50
	13,10	13,50	🟨	13,70	13,20	13,70
	12,60	12,40	12,70	11,90	12,00	🟨

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Plate B1

Distance (m)	3,70					
0,4	14,10	13,60		13,30	13,20	

Plate C

Distance (m)	4.50							
1,6	13,00	12,60	12,70	12,70	12,70	12,70	13,10	12,70
	13,30	13,40	13,20	12,80	12,90	13,30	13,20	13,50
	12,90	12,70	12,30	12,60	13,00	13,00	13,40	13,20
	12,20	10,50	11,20	11,60	11,90	11,60	11,70	12,90

Plate C1

Distance (m)								
0,4	14,00		13,70	13,70	13,40		13,50	13,80

Plate D

Distance (m)	5,30								
1,6	11,50	12,00	12,20	11,80	10,20		12,50	12,20	
	12,60	12,50	12,50		12,70		12,70	13,20	12,60
	12,70	12,80	12,90	12,80	12,80	12,20	12,80	12,70	12,10
	11,50	10,00	12,60	12,60	13,00	12,20	12,70	13,10	13,00

Plate D1

Distance (m)	5,30								
0,4	13,60	13,80	13,90	14,00	13,70	14,10	14,00	14,10	14,00

Plate E

Distance (m)	6,70									
1,6	12,60	12,60	🟨	🟨	12,30	12,70	🟨	11,70	11,20	10,70
	12,30	12,60	🟨	11,60	12,30	12,30	11,60	12,40	11,60	11,90
	12,80	12,70	12,10	12,00	12,30	🟨	11,80	11,90	12,40	12,00
	12,60	12,70	🟨	🟨	12,20	11,50	12,20	11,80	12,90	11,70

Plate E1

Distance (m)	6,70									
0,4	13,90	13,80	13,20	13,80	13,90	13,90	13,80	14,20	14,10	14,00

Plate F

Distance (m)	4.50							
1,6	11,70	12,00	11,80	12,10	11,50	11,50	11,40	11,60
	12,00	12,40	11,90	11,90	11,80	12,10	11,50	11,70
	11,40	11,50	12,00	12,20	12,00	12,30	11,40	11,30
	12,30	11,60	11,70	11,90	12,20	11,30	11,20	11,00

Plate F1

Distance (m)	4,60							
0,4	13,80	14,20	14,30	13,80	14,10	13,90	14,00	13,70

The Altiscan was unable to measure in the fields marked in yellow.

TRADITIONAL METHOD AND ALTISCAN STATISTIC DATA ON THE LATERAL PLATES (A SCAN)

Table 35: Lateral Plates Statistic Data (Traditional Method)

Statistic Data Plate A			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
11,94	11,30	12,50	0,38

Statistic Data Plate A1			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
13,38	13,20	13,60	0,17

Statistic Data Plate B			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
12,92	12,00	14,10	0,59

Statistic Data Plate B1			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
13,62	13,50	13,80	0,12

Statistic Data Plate C			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
12,55	11,40	13,40	0,56

Statistic Data Plate C1			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
13,53	13,40	13,60	0,10

Statistic Data Plate D			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
12,34	10,70	13,20	0,53

Statistic Data Plate D1			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
13,83	13,60	13,60	0,16

Statistic Data Plate E			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
11,98	11,00	12,80	0,45

Statistic Data Plate E1			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
13,99	13,80	14,10	0,13

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Statistic Data Plate F			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
11,68	11,00	12,80	0,43

Statistic Data Plate F1			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
13,99	13,30	14,20	0,29

Table 36: Lateral Plates Satistic Data (Altiscan)

Statistic Data Plate A			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
11,93	11,30	12,50	0,34

Statistic Data Plate A1			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
13,45	13,30	13,60	0,13

Statistic Data Plate B			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
13,16	11,90	13,80	0,57

Statistic Data Plate B1			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
13,55	13,20	14,10	0,40

Statistic Data Plate C			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
12,64	10,50	13,50	0,70

Statistic Data Plate C1			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
13,68	13,40	14,00	0,21

Statistic Data Plate D			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
12,37	10,00	13,20	0,73

Statistic Data Plate D1			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
13,91	13,60	14,10	0,18

Statistic Data Plate E			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
12,12	10,70	12,90	0,50

Statistic Data Plate E1			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
13,86	13,20	14,20	0,27

Statistic Data Plate F			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
11,76	11,00	12,40	0,36

Statistic Data Plate F1			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
13,98	13,70	14,30	0,21

GLOBAL STATISTIC DATA OF LATERAL PLATES THICKNESS

Table 37: Average Thickness Measurements in port side plates

Average measurements on plates with a thickness of 12,5 mm

Traditional Method (mm)	Altiscan (mm)
12,23	12,33

Average measurements on plates with a thickness of 14 mm

Traditional Method (mm)	Altiscan (mm)
13,72	13,74

Table 38: Maximum Thickness Measurements in port side plates

Maximum measured value on plates with 12,5 mm thickness

Traditional Method (mm)	Altiscan (mm)
14,10	13,80

Maximum measured value on plates with 14 mm thickness

Traditional Method (mm)	Altiscan (mm)
14,20	14,30

Table 39: Minimum Thickness Measurements in port side plates

Minimum measured value on plates with 12,5 mm thickness

Traditional Method (mm)	Altiscan (mm)
10,70	10,00

Minimum measured value on plates with 14 mm thickness

Traditional Method (mm)	Altiscan (mm)
13,20	13,20

Table 40: Standard deviation per thickness in port side plates

Measurements standard deviation on plates with 12,5 mm thickness

Traditional Method (mm)	Altiscan (mm)
0,49	0,53

Measurements standard deviation on plates with 14 mm thickness

Traditional Method (mm)	Altiscan (mm)
0,16	0,23

In general, the standard deviation of measurements collected by Altiscan is higher than the measurements collected with traditional method due to the corrosion of the lateral surface of the floating dock.

TRADITIONAL METHOD ON BOTTOM SURFACE

Table 41: Thickness Measurements of base Plates with Traditional Method (results are in mm)

Plate 1

Distance (m)	5,7				
2,2	15,60	15,40	15,60	15,60	15,00
	15,80	15,20	15,00	15,80	15,40
	15,80	15,10	15,10	15,00	15,60

Plate 2

Distance (m)	5,7				
2,2	15,80	15,30	15,30	15,50	15,00
	14,30	16,00	15,90	16,00	15,20
	13,60	13,80	14,90	15,40	15,60

Plate 3

Distance (m)	5,7			
0,486	14,60	12,00	13,00	10,00

Plate 4

Distance (m)	7,00									
2,2	14,60	13,80	14,60	14,40	14,80	14,20	14,10	14,20	14,00	13,90
	14,20	14,70	15,20	15,30	13,80	15,00	14,20	14,20	15,40	12,60
	13,80	14,00	14,20	14,20	13,50	12,60	12,60	14,60	14,30	14,20

Plate 4a

Distance (m)	0,6
2,2	15,60
	15,20
	15,00

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Plate 5

Distance (m)	7,0									
2,2	13,40	15,30	14,90	13,70	14,50	13,00	12,00	15,00	15,00	15,40
	15,50	13,00	14,00	15,40	15,10	9,60	14,50	15,60	15,50	15,40
	14,00	14,30	15,30	14,60	14,40	14,40	13,90	14,50	14,60	13,90

Plate 6

Distance (m)	7,0									
0,486	14,40	14,30	14,00	14,00	14,20	14,40	14,30	14,40	14,40	14,50

Plate 7

Distance (m)	5,7							
0,486	14,60	15,10	14,50	14,50	14,80	14,60	14,60	14,60

Plate 8

Distance (m)	5,7							
2,2	12,80	13,40	14,20	12,80	14,20	13,00	12,70	13,40
	13,60	14,00	14,10	14,00	14,20	14,20	14,00	14,20
	13,60	13,60	13,90	13,80	14,00	13,90	13,70	13,90

Plate 9

Distance (m)	5,7							
2,2	14,10	14,00	14,00	14,00	13,90	13,80	13,90	13,40
	14,00	14,10	14,00	13,90	14,00	14,00	13,90	14,20
	13,80	13,80	13,80	13,60	13,50	13,70	13,70	13,90

Plate 10

Distance (m)	5,7							
0,486	14,30	14,60	14,10	14,10	13,70	14,60	14,60	14,40

Plate 11

Distance (m)	5,7							
2,2	13,40	14,10	13,30	13,40	14,00	14,00	14,20	13,80
	14,40	14,60	14,60	14,60	14,60	14,00	14,40	14,40
	14,00	14,70	14,20	14,30	14,00	14,00	13,60	14,00

Plate 12

Distance (m)	5,7							
2,2	15,50	15,60	15,40	15,70	14,60	14,90	14,90	14,80
	15,90	15,90	15,70	16,00	15,40	14,60	15,70	15,40
	15,60	15,80	15,30	15,70	15,60	15,50	15,20	15,40

GAUGE PATTERN OF ALTISCAN MEASUREMENTS ON BOTTOM PLATES

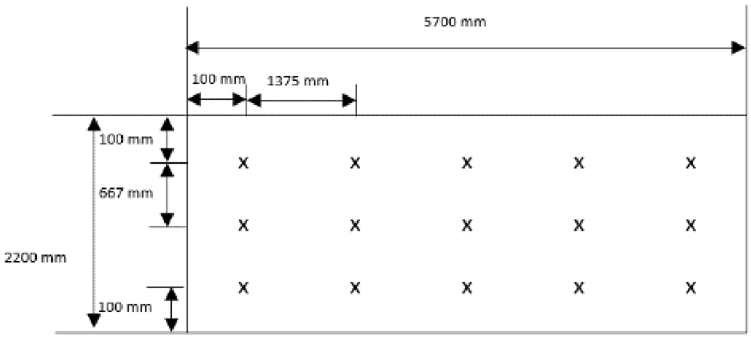

Figure 59: Plate 1

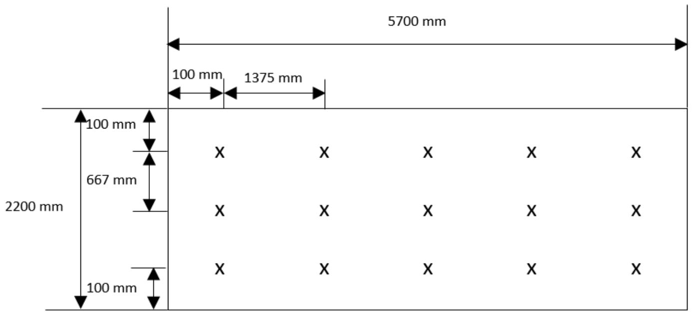

Figure 60: Plate 2

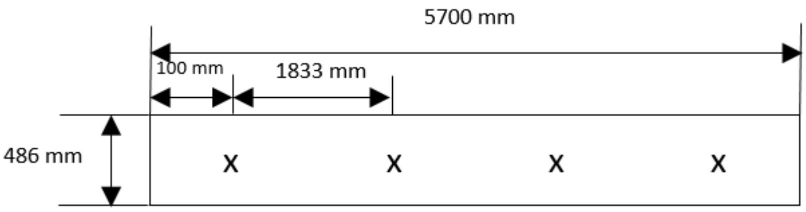

Figure 61: Plate 3

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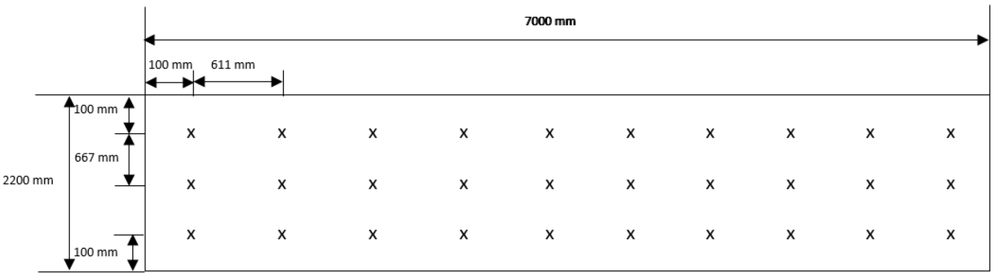

Figure 62: Plate 4

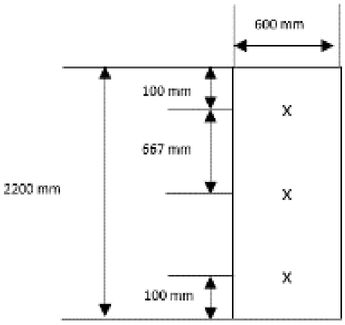

Figure 63: Plate 4a

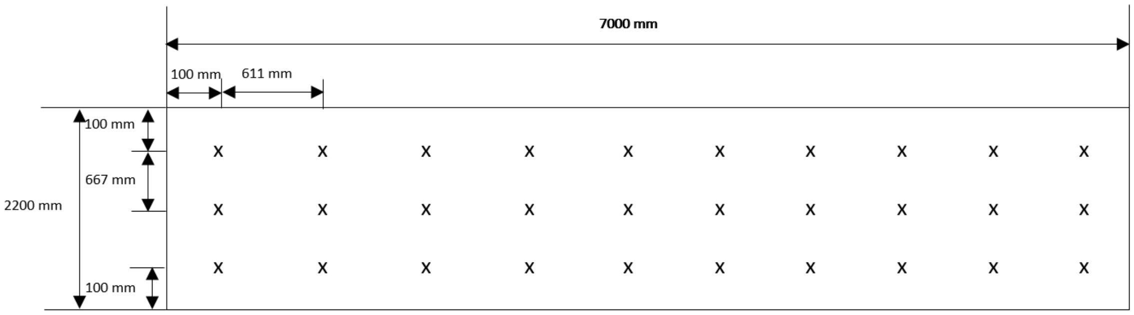

Figure 64: Plate 5

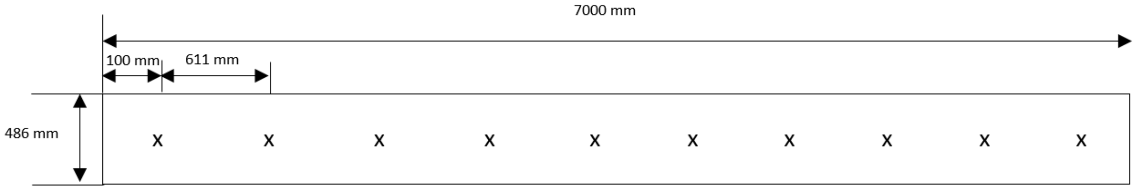

Figure 65 :Plate 6

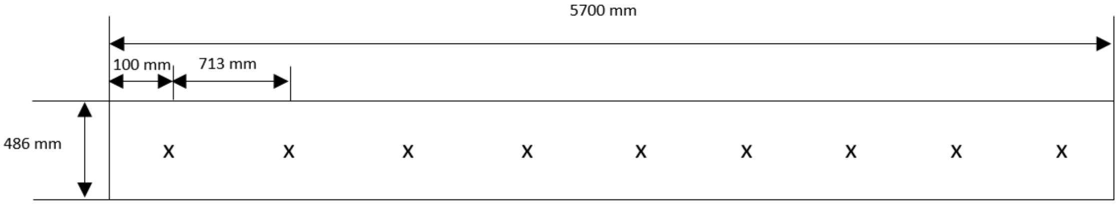

Figure 66: Plate 7

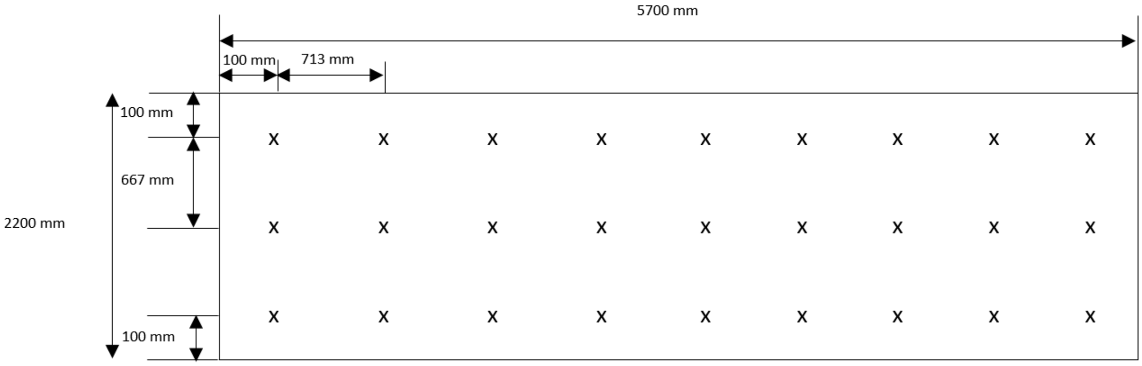

Figure 67: Plate 8

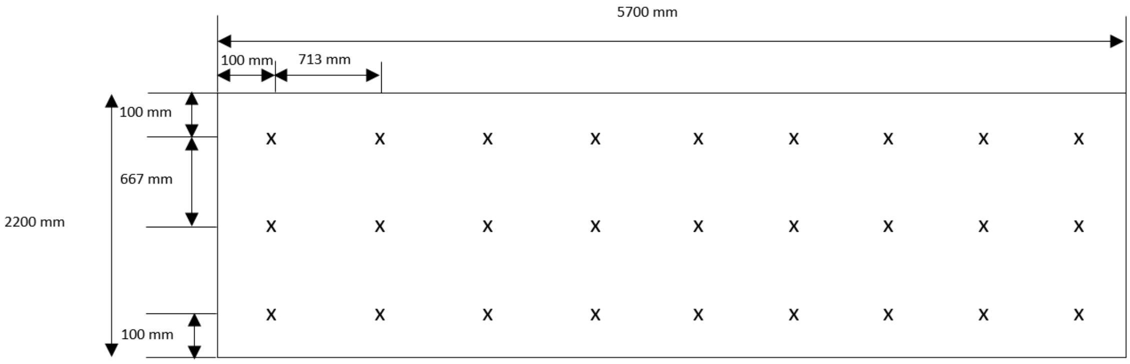

Figure 68: Plate 9

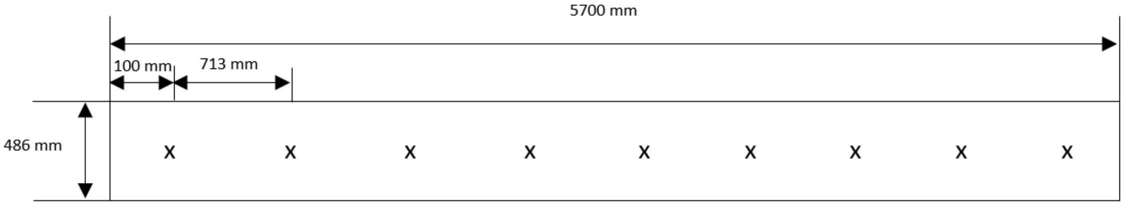

Figure 69: Plate 10

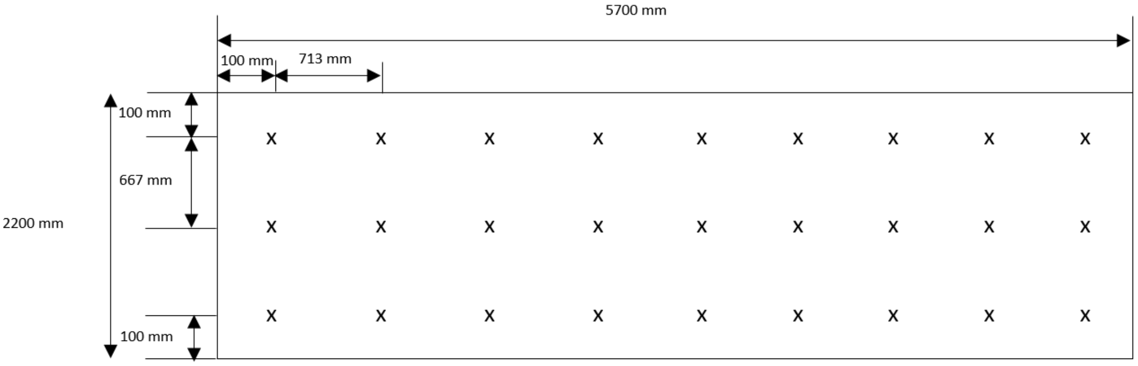

Figure 70: Plate 11

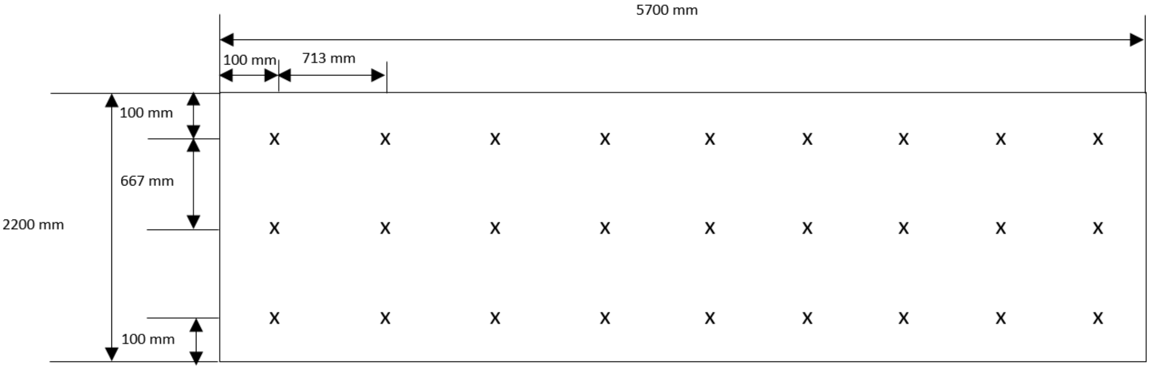

Figure 71: Plate 12

MEASUREMENTS WITH ALTISCAN ON BOTTOM SURFACE (A SCAN)

Table 42: Thickness Measurements of base Plates with Altiscan (results are in mm)

Plate 1

Distance (m)	5,7				
2,2	15,60	15,00	15,40	15,50	15,50
	15,80	15,00	15,80	15,40	15,50
	15,50	15,00	15,10	14,90	15,50

Plate 2

Distance (m)	5,7				
2,2	15,70	14,50	15,30	15,80	15,50
	14,00	15,90	15,90	15,90	15,10
	13,30	14,50	15,60	🟨	15,00

Plate 3

Distance (m)	5,7			
0,486	14,40	11,60	11,80	9,20

Plate 4

Distance (m)	7,00									
2,2	14,70	14,00	14,70	14,80	15,10	14,20	14,20	14,70	14,70	12,00
	13,80	14,80	14,90	15,20	15,50	15,30	🟨	🟨	15,30	12,40
	13,80	14,10	14,50	14,20	🟨	12,60	12,70	14,80	14,60	13,60

Plate 4a

Distance (m)	0,6
2,2	15,70
	15,50
	15,20

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Plate 5

Distance (m)	7,0									
2,2	14,10	15,10	15,00	14,00	15,30	13,20	11,80	14,80	14,40	15,00
	15,00	13,50	14,00	15,70	15,20	9,90	14,90	15,60	15,50	14,70
	14,20	14,80	15,30	14,20	14,20	14,20	14,30	14,80	14,30	14,30

Plate 6

Distance (m)	7,0									
0,486	14,70	14,10	14,30	13,80	14,60	15,00	14,40	14,40	14,60	14,10

Plate 7

Distance (m)	5,7							
0,486	14,70	14,50	14,60	15,00	15,00	14,50	14,30	15,20

Plate 8

Distance (m)	5,7							
2,2	13,10	12,50	12,90	13,00	13,90	13,20	12,90	13,40
	14,00	14,20	14,00	13,70	14,10	14,20	13,80	14,10
	13,80	13,50	13,80	13,20	13,70	13,80	13,80	13,70

Plate 9

Distance (m)	5,7							
2,2	13,80	13,90	14,00	13,90	13,90	13,80	13,80	13,90
	14,00	13,80	14,00	13,80	13,80	13,80	13,90	13,60
	13,80	13,80	14,10	13,60	13,80	13,50	13,80	13,40

Plate 10

Distance (m)	5,7							
0,486	14,30	14,20	13,90	14,10	13,80	14,80	14,40	14,60

Plate 11

Distance (m)	5,7							
2,2	13,20	14,60	🟨	13,60	13,60	14,00	14,30	14,20
	14,20	14,60	14,20	14,50	14,60	14,70	14,30	14,50
	14,30	14,50	13,70	14,30	13,80	13,80	13,90	14,10

Plate 12

Distance (m)	5,7							
2,2	15,50	15,50	15,00	15,70	13,80	14,70	15,20	15,00
	15,90	15,60	15,70	16,00	15,30	14,70	15,20	15,30
	15,60	15,60	15,30	15,80	15,50	15,30	15,30	15,50

The Altiscan was unable to measure in the fields marked in yellow.

TRADITIONAL METHOD AND ALTISCAN STATISTIC DATA - BOTTOM (A SCAN)

Table 43: Base Plates Statistic Data (Traditional Method)

Statistic Data Plate 1			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
15,40	15,00	15,80	0,31

Statistic Data Plate 2			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
15,17	13,60	16,00	0,75

Statistic Data Plate 3			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
12,40	10,00	14,60	1,93

Statistic Data Plate 4			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
14,17	12,60	15,40	0,70

Statistic Data Plate 4a			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
15,27	15,00	15,60	0,31

Statistic Data Plate 5			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
14,32	9,60	15,60	1,24

Statistic Data Plate 6			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
14,29	14,00	14,00	0,17

Statistic Data Plate 7			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
14,66	14,50	15,10	0,20

Statistic Data Plate 8			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
13,72	12,70	14,20	0,48
Statistic Data Plate 9			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
13,88	13,40	14,20	0,19

Statistic Data Plate 10			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
14,30	13,70	14,60	0,32

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Statistic Data Plate 11			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
14,11	13,30	14,70	0,40

Statistic Data Plate 12			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
15,42	14,60	16,00	0,40

Table 44: Base Plates Statistic Data (Altiscan)

Statistic Data Plate 1			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
15,37	14,90	15,80	0,29

Statistic Data Plate 2			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
15,14	13,30	15,90	0,80

Statistic Data Plate 3			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
11,75	9,20	14,40	2,13

Statistic Data Plate 4			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
14,27	12,00	15,50	0,92

Statistic Data Plate 4a			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
15,47	15,20	15,70	0,25

Statistic Data Plate 5			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
14,38	9,90	15,70	1,16

Statistic Data Plate 6			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
14,40	13,80	15,00	0,35

Statistic Data Plate 7			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
14,73	14,30	15,20	0,31

Statistic Data Plate 8			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
13,60	12,50	14,20	0,47
Statistic Data Plate 9			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
13,81	13,40	14,10	0,16

Statistic Data Plate 10			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
14,26	13,80	14,80	0,34

Statistic Data Plate 11			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
14,15	13,20	14,70	0,39

Statistic Data Plate 12			
Mean (mm)	**Minimum (mm)**	**Maximum (mm)**	**Std. Deviation (mm)**
15,33	13,80	16,00	0,47

GLOBAL STATISTIC DATA

Table 45: Average Thickness Measurements in bottom plates

Average Methods on sheets with a thickness of 14 mm	
Traditional Method (mm)	Altiscan (mm)
13,90	13,85
Average Methods on sheets with a thickness of 15 mm	
Traditional Method (mm)	Altiscan (mm)
14,21	14,09
Average Methods on sheets with a thickness of 15,5 mm	
Traditional Method (mm)	Altiscan (mm)
14,87	14,92

Table 46: Maximum Thickness Measurements in bottom plates

Maximum measured value 14 mm plate	
Traditional Method (mm)	Altiscan (mm)
14,70	14,70
Maximum measured value 15 mm plate	
Traditional Method (mm)	Altiscan (mm)
16,00	16,00
Maximum measured value 15,5 mm plate	
Traditional Method (mm)	Altiscan (mm)
16,00	15,90

Table 47: Minimum Thickness Measurements in bottom plates

Minimum measured value 14 mm plate

Traditional Method (mm)	Altiscan (mm)
12,70	12,50

Minimum measured value 15 mm plate

Traditional Method (mm)	Altiscan (mm)
10,00	9,20

Minimum measured value 15,5 mm plate

Traditional Method (mm)	Altiscan (mm)
9,60	9,90

Table 48: Standard deviation per thickness in bottom plates

Measurements standard deviation of the 14 mm plate

Traditional Method (mm)	Altiscan (mm)
0,36	0,34

Measurements standard deviation of the 15 mm plate

Traditional Method (mm)	Altiscan (mm)
0,60	0,72

Measurements standard deviation of the 15,5 mm plate

Traditional Method (mm)	Altiscan (mm)
0,66	0,69

In the bottom surface, the standard deviation is higher than the standard deviation in lateral surfaces, due to the greater corrosion in the bottom surface of the floating dock.

THICKNESS MEASUREMENT OF FLOATING DOCK LATERAL SURFACE – B SCAN

PHOTO OF LATERAL SURFACE AND B SCAN INSPECTION LINES (PLATE F)

Figure 72: Floating Dock Lateral Surface and Inspection lines

B SCAN RESULTS OBTAINED WITH ALTISCAN DATAREPORT SOFTWARE

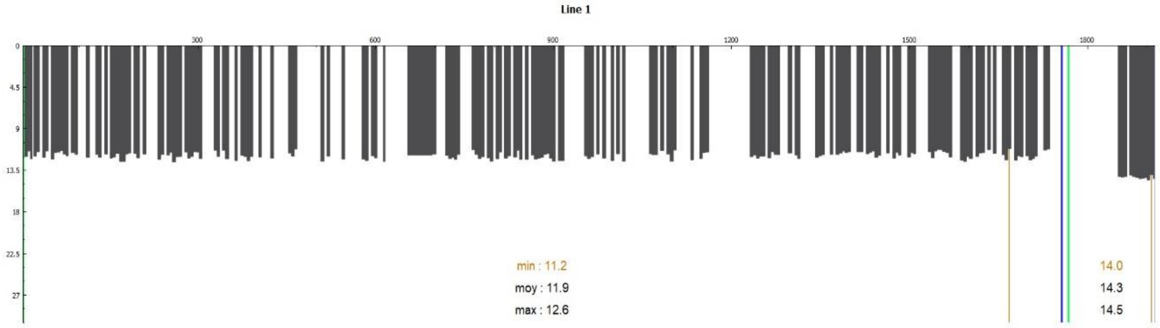

Figure 73: Line 1 B Scan of Plate F

Figure 74: Line 2 B Scan of Plate F

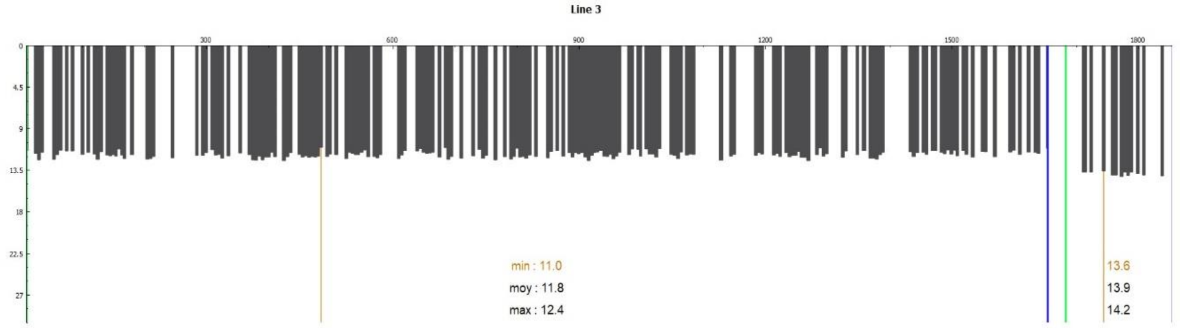

Figure 75: Line 3 B Scan of Plate F

The results are in mm.

STANDARD DEVIATION

Table 49: Measurement Standard deviation with B Scan

Measurements Standard Deviation	
Thickness	**Standard Deviation**
14,0 mm	1,80 mm
12,5 mm	1,11 mm

In rusty surface we can do B Scan inspection quickly, but it can consume more time in the post-processing to get the best B Scan graph possible.
The standard deviation of B Scan is higher than in A scan.

CONCLUSION

In terms of usability, once the crawler and user manual are read, the user can control the crawler and make accurate thickness measurements, but some IT skills and UT knowledge are required, especially for non-experts. However, the box with the crawler and the accessories and the tank of water is heavy and need at least two persons to carry out.

The crawler showed a good performance in working with difficult ambient condition like wind and rain.

The time of preparation thickness measure with traditional method is longer than the time of preparation thickness measure with the crawler because the need of scaffolding.

Although the gauging pattern is previously defined, the crawler needs the user intervention to be implemented. There could be an automatic way to adjust gates and gain without user intervention to get the most accurate thickness measurement possible, even with less experienced operators.

It needs the identification of the plates that are measuring in the report.

In the test realized on the crawler, wasn't needed scaffolding, lifeline was easy to place. Also, it was easy to get the crawler working and place it on the plate. The batteries have enough autonomy, and there are enough spare batteries inside the box.

On surfaces without corrosion, with paint and with low rugosity, it is possible to obtain measurements quickly, but in some cases, we need to adjust the A scan parameters to get a measure, losing time compared to the traditional method. Otherwise, on surfaces with corrosion, with imperfection on the paint and with higher rugosity, it is more difficult to get measurements than in traditional method and we also spend more time to measure, and in some cases, measurements were not able to be taken.

If the thicknesses of the plates were different through the entire surface, we will have time constraints due to the partial calibrations required to be carried out. The technician must collect the crawler and calibrate it, returning it to the same place where we stopped the measurements. In the case of the traditional method, it will also be necessary to calibrate, but the technician can use the standard without leaving his inspection area.

Time of the transmission of data in the crawler method is quicker than the traditional method. There aren't constraints in the data streaming from the crawler to the PC.

The format of report does not comply with standardized format of reporting.

The crawler camera provides a good orientation to the operator but has a low definition, not being sufficient for detecting defects comparable to the information available to the surveyor when operating in person.

Overall, the time of the inspection with the crawler, compared to the traditional process are lower because scaffolding is not needed. Although the number of technicians is the same in both methods.

REFERENCES

EN ISO 16809: Non-destructive testing – Ultrasonic thickness measurement

Altiscan user's manual V 1.4 - ROBOPLANET

User Manual Datascan V 2.1 - ROBOPLANET