Simulation of Vessel Collision Scenario Using Photogrammetry and 3D Laser Scanning-A Case Study at the Container Terminal

Sy Tien Do, Hiep Hoang, Nhan Nguyen Trong Truong, and Dat Ho Quang Che

Abstract Currently, transportation on the waterway in Vietnam is being increased considerably to meet the booming economy's demand. There are many river ports and seaports constructed within the two initial decades of the twenty-first century. The comprehensive studies of the ports system planning, hydrodynamic model for the channels were studied. However, specific research, such as inspection work after vessel collision is not yet fully estimated. This paper presents a study on the vessel collision of a container terminal located in Southern Vietnam. The inspection work was carried out by using innovative survey technologies, namely, 3D laser scanning, and photogrammetry. The simple-to-use process for simulation of vessel collision was then proposed. The evaluation and testing of structural components and operating equipment will then be performed meticulously.

Keywords 3D laser scanning · Vessel collision · Photogrammetry · Container terminal · Simulation

1 Introduction

Mekong delta is the biggest delta in Vietnam, which contains a dense network of about 2,360 rivers. In which, the waterway transportation in both cases of inland waterway and international waterway is mainly distributed in the four river systems, namely, Dinh An, Soai Rap, Sai Gon-Vung Tau, and Cai Mep-Thi Vai. There is approximately 41% of the country's total inland waterway freight has been transported from the Mekong Delta region and Ho Chi Minh City through the Soai Rap, and Cai Mep-Thi

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Vai rivers [1]. Due to the booming economy of Viet Nam, vessel transportation and the number of ports has been rapidly increased, which leads to the risk of vessel collisions with the ports that may occur frequently. In reality, during the period from 2015 to 2019, three collisions between vessels and wharf occurred in the Cai Mep-Thi Vai river, namely, the Phu My Port, Cai Mep International Terminal (CMIT), and SP-SSA International Container Terminal (SSIT). For surveying the collision scene, the traditional method using the camera, Vernier calipers, geodetics equipment was applied, e.g. Phu My Port, Cai Mep International Terminal (CMIT) [2, 3].

Recently, 3D laser scanning technology has been widely applied to many different professions. Based on the laser technology platform, it enables us to accurately collect an enormous number of measurable data points of visible objects within a short period [4]. Along with the common application of Building Information modeling (BIM) in the construction industry, the data of 3D laser scanning has also been transferred into BIM models, herein, called Scan-to-BIM [5]. For construction BIM, Faro showed that 3D laser scanning can be used for the survey, supervising construction, as-built documentation, and facility management. One of its widespread applications is the reconstruction of Heritage buildings by combining with the Photogrammetry method [6, 7]. This combination technique also appears in the monitoring of terrain surveys or geotechnical issues [8]. In addition, it has been served regularly in road safety and accident reconstruction [9, 10]. For the Maritime industry, 3D laser scanning and Photogrammetry technique have been commonly used for modeling the ship or vessel hull [11, 12]. Although 3D laser scanning has many such applications, its applications are not yet popular in Vietnam, especially in the Coastal and Marine works.

This study aims to investigate the damaged mechanism of the wharf using 3D laser scanning and photogrammetry techniques at a site of the Cai Mep-Thi Vai river. A simple-to-use process for application of scan-to-BIM into investigation work of damaged wharf caused by Vessel collision is then proposed. This process is expected to contribute a guideline for Port and Coastal engineers to collect the precise field data for inspection work of Vessel collision.

2 Literature Review

2.1 The 3D Laser Scanning Technique

The 3D scanning technique was firstly developed in the 1960s to accurately capture visible objects [13]. However, it has just only got popular in engineering during the last two decades of the twentieth century. From 1993 to 1994, the first 3D scanners were commercially produced by REPLICA and Cyra Technologies. Currently, there are several companies such as Faro, Leica, and Trimble that have been entering this market for distribution strategy besides pioneering their products.

The 3D laser scanning technology uses the laser to capture objects' surfaces for creating the model containing countless points called "Point cloud" [13]. A point cloud is a set of data points in a 3D coordinate system (x, y, z), commonly contained color parameters. Depending on the aptitude of the scanners and measurement method, the measurement accuracy is commonly less than 10 mm. Based on the website of Leica Geosystem and the datasheet of Leica P50 and Leica RTC360, the accuracy of the Leica-P50 scanner and Leica-RTC360 scanner is 3 mm and 1.9 mm (Leica RTC360 3D Reality Capture Solution), respectively. Also mentioned by FARO and Stormbee corporations on their website and datasheet, the accuracy of the Faro S350A on the tripod provided by FARO and combined with UAV Stormbee of Stormbee corporation is 1.0 mm (Faro - Focus Laser Scanner) and less than 20 mm, respectively.

2.2 Photogrammetry Technique

Photogrammetry is the science or art of obtaining reliable measurements by means of photographs. The term photogrammetry was developed from the Greek words phos or phot, which refers to light, gramma, which means something is drawn or written, and metrein, the noun of measure. In detail, the visible objects are firstly captured in lots of images. Based on the similarity and overlapping density between the captured images, the 2D or 3D digital model of objects is then created. Herein, the digital data points within the images' overlapping zone can be assigned 3D coordinates by using the collinearity equation defining the relationship between object and image coordinates [14]. The first generation called Plane Table Photogrammetry was developed in the nineteenth century by several authors. Therein the measurements were made on a map on a table. Since the twentieth century, the second and third generation has been developed using the Analog and Analytical technique, respectively. Analog Photogrammetry uses mechanical, optical, and electrical components for re-creating the measurable 3D model in 3D space. Whereas, in Analytical Photogrammetry, the 3D modeling is mathematical (not re-create) and the measurements are made in 2D images assisted with digital processing. The latest generation is Digital photogrammetry, is being used popularly since the first decade of the twenty-first century. The principle of this method bases on Analytical Photogrammetry and digital images are used to process it. The way photogrammetric procedures are implemented from the traditional plane table photogrammetry into Analog photogrammetry, through analytical photogrammetry into Digital photogrammetry.

Nowadays, photogrammetry is considered the best technique for the processing of image data, being able to deliver at any scale of application accurate, metric, and detailed 3D information with estimates of precision and reliability of the unknown parameters from the measured image correspondences (tie points).

3 Research Methodology

3.1 Process Description

The inspection of the damaged wharf includes the estimation of working conditions of structural units and equipment operating on the wharf. Herein, the Ship to Shore Container Crane is commonly operated on the wharf of the container terminal. For the first issue, the existing condition of damaged structures needs to be investigated; and then, vessel collision should also be re-simulated to provide the scenarios for structural analysis. To solve the second issue, the displacement of the rails shall be estimated. Therefore, the two research problems, namely, simulation of vessel collision and checking displacement of rails are given in this study.

The workflow for simulation of vessel collision was developed. In which, the field data collection is firstly conducted to provide the input data for the simulation process. At the incident scene, the damaged objects such as structural components of the wharf and equipment operating on the wharf shall be recorded by cameras. Afterward, the characteristics and navigation history tracks of an induced collision vessel, the as-built report of the damaged wharf, technical specification, and warranty information of equipment shall also be collected.

After completing the field data collection, the wharf and vessel shall be re-built as the 3D digital models. Herein, the scanned data from 3D laser scanners and 3D BIM model-based on as-built drawings shall be combined to create the 3D digital model of the wharf, whereas the 3D digital model of the damaged vessel is re-built by using the Photogrammetry technique. It is worth noting that the point cloud data and 3D BIM models must use the same landmark coordinates system.

3.2 Simulation of the Vessel Collision with the Wharf

The simulation of the vessel collision process is implemented based on the 3D digital models of the vessel and wharf. According to navigation history tracks, the speed of the vessel and its collision direction is firstly estimated. The vessel is then slowly moved how its laceration fully penetrates the wharf-damaged area. It means that the surface of the laceration touched that of the damaged area modeled by point cloud data. Also, the structural components and the operating equipment are estimated by combined BIM and Photogrammetry technique.

3.3 Checking Displacement of Rails

The 3D-BIM model of rails is reconstructed using as-built drawings first. Along with that, the existing rails are also scanned by 3D laser scanning technology. Based on the scanning data and the as-built 3D BIM model, the displacement of the rails shall be analyzed by specialized Scan-to-BIM software called Cyclone 3DR of Leica.

4 A Case Study in a Container Terminal

4.1 Site Description

SP—SSA International Container Terminal (SSIT) located in the downstream area of Nga Tu ditch, in Phuoc Hoa commune, Tan Thanh district, Ba Ria—Vung Tau province, Southern Viet Nam. It was designed for capable of accommodating vessels of up to 160,000 DWT (for maximum vessels of 80,000 DWT at present). Since 2014, it has been put into operation and the total cargo throughput reached 200,000 TEU/ year in 2018.

In the early afternoon of June 05, 2019, the bulk carrier with partially loaded 57,000 DWT moved on Vung Tau—Thi Vai Channel (Cai Mep area) and struck to SSIT Wharf. This vessel firstly collided with the barge mooring at the berth and then struck to the berth. The main characteristics of the vessel are given in Table 1. Therein, the vessel is a bulk carrier with it weighs approximately 50,000 DWT in case of the full-load capacity.

After the collision, the damaged components of the wharf are presented in Fig. 1a and 1b. On the top side and front view of the wharf, the broken concrete zones on the desk topping, beams, fender block, and three damaged fenders were observed. Whereas, one fallen pile, one cracked pile, three damaged fenders were also detected on the bottom of the wharf. Additionally, their locations on the wharf are schematized in Fig. 2. Herein, a fallen pile located at the axis of A46, which is denoted as Pile (A46), and the other cracked pile located at the axis of B46-1 also denoted as Pile (B46-1) is shown in Fig. 3a and 3b.

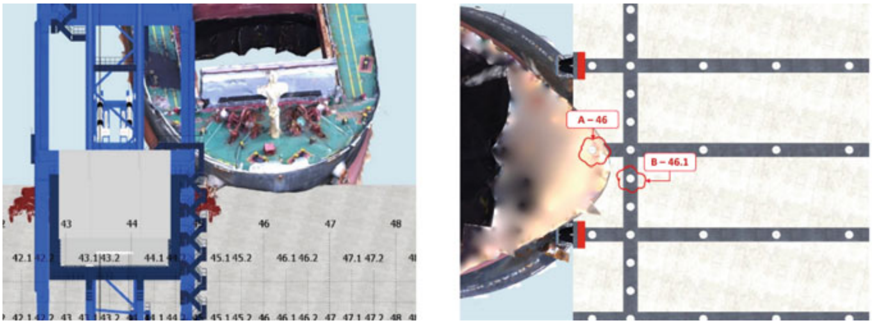
Table 1 The characteristics of vessel involved in the accident

Symbol	Unit	Vessel involved in the accident
L_{OA} (length overall of ship)	m	189.99
L_{BP} (Length between perpendiculars)	m	185.00
B_M (width)	m	32.26
D_V (depth of vessel)	m	18.00
C_C (cargo capacity)	DWT	58,414
D_L (Loaded draff)	m	13.067

(a) The scene of vessel collision (b) The damaged wharf

Fig. 1 Photos of collision

Fig. 2 Front view of the collision area

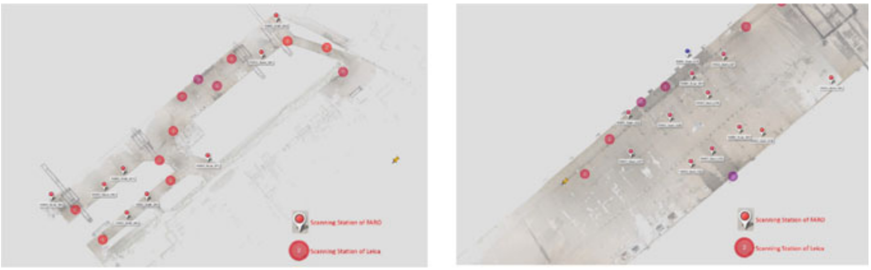


(a) Top view of the collision (b) Bottom view of the collision

Fig. 3 Simulation of vessel using photogrammetry method

4.2 *Reconstruction of the Accident Using 3D Laser Scanning and 3D Photogrammetry*

The investigation of wharf-damaged structures was firstly conducted using a 3D laser scanner. This device is named Focus Laser Scanner version S350A developing by



(a) The whole wharf (b) Incident area

Fig. 4 Laser scanning layout

FARO company. By using the laser technique, the S350A Focus enables capturing complex objects fast, straightforward, and highly accurate with a measurement range up to 350 m. At the site collision, 32 scanning stations were conducted within the incident area and 57 scanning stations were then implemented for the whole wharf. After scanning, the existing objects were digitized as billion points, which are called point clouds. Herein, each point contains the coordinate, elevation, and color. The scanning layout and scanned results are given in Fig. 4a and 4b. For the rails of the STS crane, the Leica-RTC360 was selected. Herein, the Leica-RTC 360 can quickly make 3D reality capture with a measuring rate of up to 2 million points per second and complete the colored 3D in under 2 min. The range accuracy of Leica RTC 360 is 1.0 mm + 10 ppm, moreover, it also contains the automated target less field registration (based on VIS technology) and the double scanning regime which denoise automatically the effect of moving objects on scanned data. Hence, this device is suitable for scanning in detail the components required strictly for their displacement. The scanners were located on both sides of the rails to scan the whole surface of the rails. In fact, there is a total of 24 scanning stations of Leica-RTC 360 were conducted.

A great number of digital photos of the vessel involved in the collision were captured by the Canon 6D Mark II camera. The camera was located at fixed positions on the wharf, barges moving around the damaged vessel, and on the damaged vessel. Based on the digital pictures, the 3D digital model of the vessel was then created by using Reality Capture software. Along with that, the Autodesk software, which is named Revit version 2020, was used to create the wharf's 3D-BIM model. Additionally, the AutoCAD 3D version 2020 and Leica 3DR version 2020 were applied to estimate the rails' displacement.

Fig. 5 The predictive scenario of vessel cooling

5 Results and Discussion

5.1 Vessel Collision Scenarios

The 3D digital model of the damaged vessel and the 3D-BIM as-built model of the wharf combined with the point cloud model. Based on the navigation history tracks, the speed, and incense moving of the vessel were determined. Then, using these calculated parameters, the re-modeled vessels were slowly moved into the wharf. This process was manually implemented using Autodesk Revit 2020 and Autodesk Navisworks 2020 software. In which, the vessel was firstly touched on the pile A46, thereafter, continue hit to the wharf. The collision stages are then predicted in Fig. 5. Herein, the vessel impacts concentrated force on Pile and Superstructure and their magnitude shall be estimated in accordance with AASHTO (2017).

5.2 Checking of the Deflection of the Rails of STS Crane

The dimensions of the rails of the STS crane, including the elevation on top of the rails, were selected from the as-built drawings of the rail's installation reports. Subsequently, the as-built model was carried out using these dimensions. For tracking of defection, point clouds obtained by the Leica-RTC360 scanner were firstly processed by Leica 3DR software for making the level contour lines of rails. Thereafter, these results were combined with the as-built model of rails. Consequently, the gap between those is the deflection of rails. It should be noted that the as-built model and point cloud data were assigned with the same coordinate system. Therein, the coordinate system was measured from the permanent control points, which are the base points to accurately refer to any existing locations. The establishing coordinate system from permanent control points determines the exact of the point cloud model.

The result of the comparison between the scanned data and the as-built model at a typical cross-section of rails is as shown in Fig. 6. In which, the baseline (grey line) of the rail is the measured line obtained from points cloud data. And then, the gap between the baseline and the as-build model is shown through the red and navy-blue regions. Herein, the red and navy-blue color represents the inward and outward displacement of the measured line compared with the as-built one, respectively.

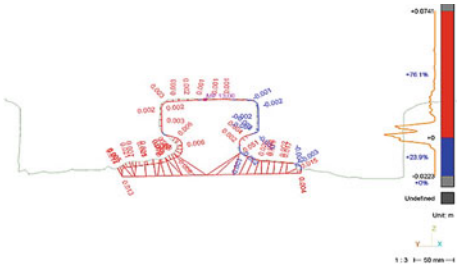


Fig. 6 Deviation of as-built model and mesh model

6 Conclusions

By using a 3D laser scanner from FARO, the actual size of components was captured with an accuracy of up to 2 mm. The deformation of STS crane rails after a collision could be checked by using point cloud data obtained from the 3D laser scanners and the as-built drawings. Accordingly, these results would be used for the estimation of STS crane working conditions. The collision scenario was reliably simulated by combining 3D laser scanning, photogrammetry, and as-built drawings. Accordingly, these results would probably be provided the rational calculation scheme for the wharf structures inspection.

In conclusion, the BIM process should be applied from the initial stage of the Port construction process. In which, the 3D laser scanning technology is recommended for digitizing as-built buildings, structures, or industrial facilities through the whole project stages.

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