Surveying the Barham Bridge Using 3D Laser Scanning

Leigh Finlay
Sinclair Knight Merz
lfinlay@globalskm.com

ABSTRACT

The Spatial Division of Sinclair Knight Merz (SKM), along with Astute Surveying and Roads and Maritime Services (RMS) surveyors, has recently completed an ambitious project to survey and document a 109-year old heritage-listed bridge at Barham over the Murray River in south-western NSW for planned upgrade, remediation and ongoing maintenance programs for the RMS South Western Region. The project demonstrates the use of dynamic and diverse technologies to allow stakeholders, far remote from the site, to make confident decisions based on quality data that is available at their fingertips. Using survey tools that captured the bridge and surrounds completely has provided the ability to future 'data mine' critical information from the captured data to allow intelligent decision making in relation to ongoing planning, remediation and maintenance programs without the need to undertake costly and time-consuming revisits to the bridge site. SKM's innovative approach to overcome the deficiencies of a traditional survey approach and deliver within an acceptable time frame was to implement a program involving the following technologies: (1) Terrestrial Laser Scanning (TLS) to capture the critical elements of the bridge structure, (2) Mobile Laser Scanning (MLS) for acquisition of underneath bridge structure and river banks from a boat in addition to capturing the adjacent road corridors from a vehicle, (3) bathymetry (depth sounding) of the Murray River bed to identify underwater structure and definition of the river bed upstream and downstream of the bridge, and (4) traditional field survey for establishing and confirming the existing survey control network on which the 3D laser scanning and bathymetry would be based in addition to providing independent calibration and quality control for the MLS and TLS datasets. This collaborative approach, combined with the application of state-of-the-art technologies, has not only provided an easily accessible and extremely useful dataset for RMS, but also helped introduce the concept and the benefits of fit-for-purpose spatial information within the wider RMS group. Since the completion of the Barham Bridge project, SKM and Astute Surveying have teamed together to supply similar services to RMS on four other bridge sites in the Hunter and mid-coast regions of NSW.

KEYWORDS: *Laser scanning, bathymetry, data mining, bridge survey.*

1 INTRODUCTION

Barham is a small town on the southern New South Wales (NSW) border, around 823 km south-west of Sydney. Its Victorian twin town of Koondrook is joined to Barham by a steel and wooden truss bridge, designed by NSW Public Works engineer E.M. De Burgh. It is a lift span bridge containing a central section that lifts up to let river traffic through. Members of the Sinclair Knight Merz (SKM) survey group were teamed up with Astute Surveying and Roads and Maritime Services (RMS) surveyors to conduct a survey to collect information relating to the bridge for heritage documentation, remediation upgrade and ongoing maintenance work.

The difficulties in surveying a bridge that was built 109 years ago are numerous. The measurement of different types of materials, which have settled, corroded and been replaced, as well as getting clear and visible access to the required parts of the bridge, and safety of personnel working near water, at heights and with constant traffic, made the project challenging but rewarding for the team involved. The remoteness of the bridge in relation to both the RMS and SKM offices meant that certain techniques were used to help engineers and planners using the data from a remote environment, hundreds of kilometres away, with complete confidence.

1.1 History

The area around Barham was developed into grazing country from 1840 onwards, and with the development of the large stations came a need to move goods and stock across the river and down to Melbourne, being the closest port, or to Adelaide via paddle steam. Much of this trade was done by paddle steamers, but the movement of stock created the need for bridges over the Murray. The Barham Koondrook Bridge was one of twelve bridges built across the Murray around the time. It replaced a ferry system that had been in place since 1884.

The Barham Koondrook Bridge was completed in 1904 and is composed of a lift span in the centre with two De Burgh composite trusses on either side connecting the lift span with the river banks (Figure 1). Originally the lift span was so well balanced that the bridge could be raised and lowered by a single person by means of a gear system. It was built by Sir John Monash who went on to become commander of Australian forces in World War I. The lift towers were raised by 2 metres in 1925 to allow for larger water craft to pass under its span. In 2012, the NSW and Victorian governments set aside funds for the restoration of the bridge, to ensure its continued operation into the future. This work involved, among other things, the replacement of bearings, gears and wires on the lift span, as well as some abutment work.

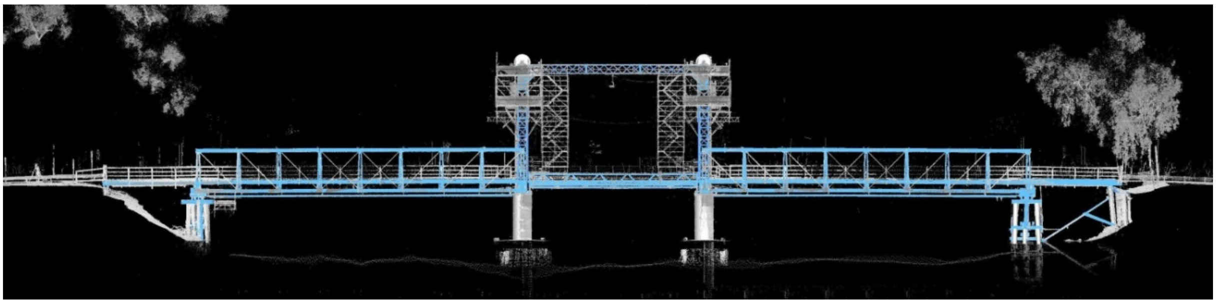

Figure 1: Point cloud and bathymetry data with 3D modelling of Barham Bridge.

1.2 The Project

SKM’s Spatial Division, along with Astute Surveying and RMS surveyors, has recently completed an ambitious project to survey and document the 109-year old heritage-listed Barham Koondrook Bridge over the Murray River in south-western NSW for planned upgrade, remediation and ongoing maintenance programs for the RMS South Western Region**.** The project demonstrates the use of dynamic and diverse technologies to allow stakeholders, far remote from the site, to make confident decisions based on quality data that is available at their fingertips. By using survey tools that captured the bridge and surrounds completely, facilitating the ability to future ‘data mine’ critical information from the captured data to allow intelligent decision making in relation to ongoing planning, remediation and

maintenance programs without the need to undertake costly and time-consuming revisits to the bridge site.

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2 SOLUTION

2.1 Control Network and Datums

Before starting any survey, a local control network needs to be established. RMS is continually monitoring the Barham Koondrook Bridge as part of an ongoing maintenance program and has a series of stable marks surrounding the bridge. Before each monitoring exercise the control is checked and re-established, which was performed by Chris Miller from RMS in the days leading up to SKM's arrival at site and also assisted SKM survey teams in the following day's during the project execution. The monitoring has been going on for many years and the network was originally set up in an Integrated Survey Grid (ISG) datum. Due to the low scale factor involved, it was chosen to adopt this network and datum for the project. It should be noted that most bridge surveys are done in a plane datum, due to their limited length and need for accuracy.

2.2 Terrestrial Laser Scanning

To capture all of the components on the bridge, from the wooden trusses to the gearing at the top of the lift spans, a Leica HDS 7000 phase-based terrestrial laser scanner was used. Under typical conditions, these instruments are able to produce results of better than 3 to 5 mm for horizontal and level position.

A reflectorless total station has the advantage of not relying on the use of a reflector to capture features. This means that points on the bridge structure that are inaccessible can be captured for position and height by simply pointing at the feature to be captured and recording the measured data. Figure 2 illustrates the instruments used for this project.

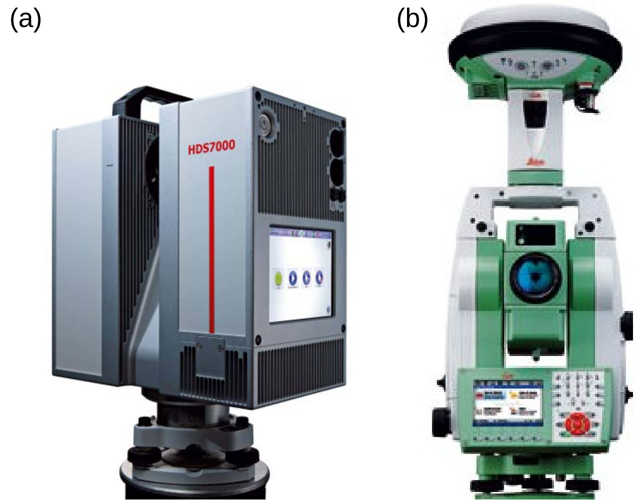

Figure 2: (a) Leica HDS 7000 laser scanner and (b) Leica total station.

The 3D scanner can be positioned anywhere adjacent to or within the site. The HDS scanners have a full 360-degree field of operation in the horizontal plane and 310-degree field of view in the vertical. Thus the operator can be specific in determining the limits of the scan and the operator can determine the density (resolution) of the 3D point cloud that is about to be observed. A minimum of three targets is placed within the scanned area, and these can be tripod-mounted or stick-on targets. The targets are also located by total station from the control network to derive 3D coordinates of the target points. These targets are also included in the 3D scan of the subject area and also very accurately scanned individually as a target control point after the initial scan. SKM more recently has successfully enhanced the registration process by also using common features within individual scans as part of the registration process to give a more robust solution to the merged dataset. The field process is illustrated in Figure 3.

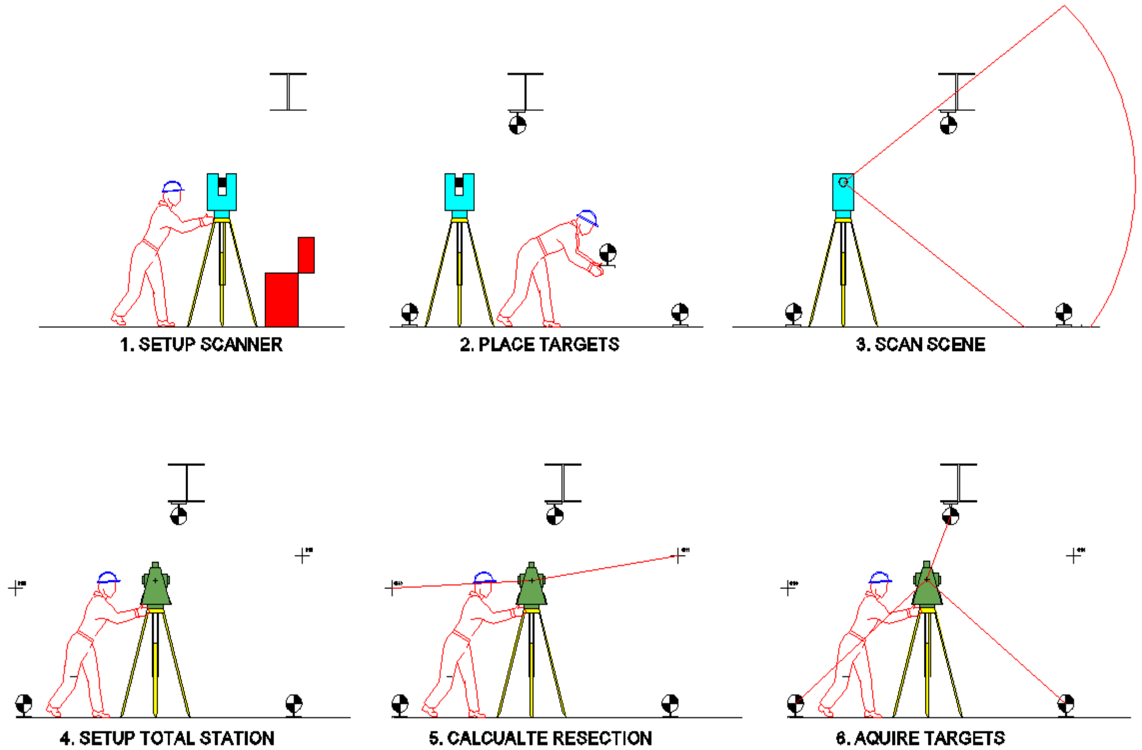

Figure 3: Field process.

The 3D software can then process the scans to link the point cloud to the control network, thus each of the thousands of points observed in the scan has individual xyz coordinates. Multiple scans from different viewpoints using the same targets allow the scan to be merged into a seamless 3D point cloud which is a true representation of the structure and features that have been scanned. Each scan can vary from 10 to 30 minutes depending upon the field of view including the target location; however many millions of points are captured. This is both quicker and far more detailed and efficient than traditional survey methods.

32 scans of the bridge were taken. 12 on the deck and approaches, 10 from scaffolding erected on the top of the lift span and 10 from the banks and piers in the middle of the river, taking two days. The scanning made every attempt to capture all elements of the bridge for later modelling (Figure 4).

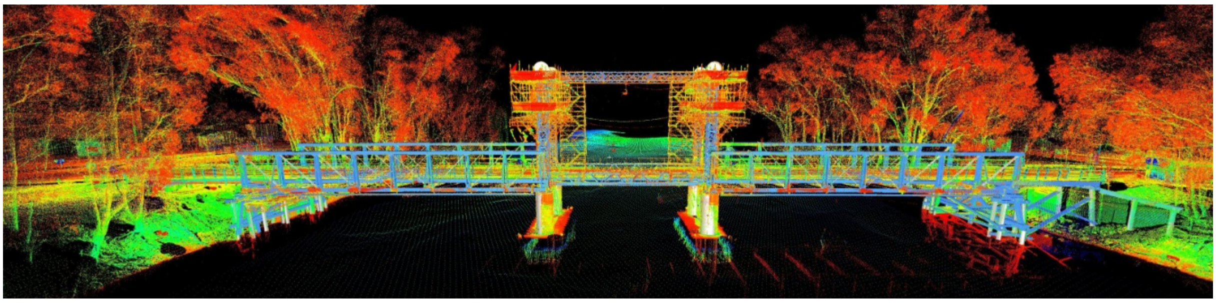

Figure 4: Barham Bridge scan data.

The underside of the bridge presented a challenge, as depending on the level of the river, access to the underside was always going to be a problem. Some concepts were brainstormed in the office, such as using a upside-down tripod, some sort of arm that could be lowered off the side of the bridge, or attaching the scanner to parts under the bridge with a specially made ‘claw’. The claw is a special mounting tool that can clamp to objects and was used for two of the scans, attached to the wooden abutment (Figure 5).

Figure 5: Laser scanner mounted using the ‘claw’.

With the high rainfall of the previous summers and the water-level controlling weir system that is on the Murray in that area, it was always going to be a gamble as to how much of the underside of the bridge it would be possible to acquire. It transpired that the water level was such that scans could be taken from the water’s edge with little foliage obstruction and from the river’s piers. Access to the piers was enabled by a boat which was being used for bathymetric surveys at the time.

Often a true colour point cloud is requested by clients, and in this case due to the picturesque nature of the area and bridge, it was decided to perform colour photography from each scan location. The photos were taken with a camera mounted on a special mount, which places the focal point of the camera at the scanner's aperture location. Using a wide-angle fisheye lens, 18 photos were taken which were then combined into a spherical panorama, and then 'burnt' onto the point cloud data (Figure 6).

Figure 6: Coloured point cloud data.

Leica TruView software (free ware) is an additional useful tool in that it too can be rotated and zoomed in a similar fashion to the point cloud data allowing a full detailed image of the roads and adjacent street furniture and building structures to be viewed by planners, engineers and designers to get a detailed understanding of the features of the structure (Figure 7).

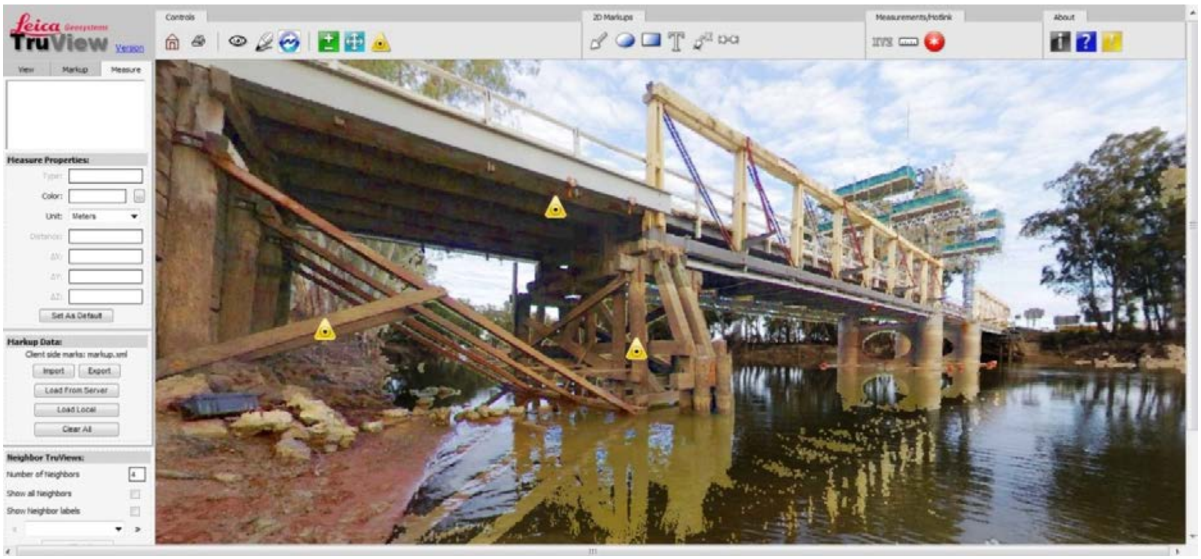

Figure 7: Leica TruView of Barham Bridge.

The resulting point cloud data can be modelled using various applications within both Cyclone and CloudWorx. The data can be easily exported to both AutoCAD and Microstation CAD packages. Sections and elevation drawings can be easily determined by sectioning the resulting point clouds. Individual structures can be quickly converted into models for export

into CAD applications. The advantage is that each structure is fully detailed and located in its true position in three dimensions. Another advantage of this methodology is that in capturing the whole structure, areas or items that may not be evident now as being critical to the design, but are later identified as being required, are captured as part of the process. This can negate the need to revisit the site for further survey as is often the case in using traditional survey data capture methods.

The fact that the data can be captured quickly and accurately and in such detail, without the need to place survey personnel on the structure, remove many of the Work Health and Safety (WHS) issues that would be applicable using traditional survey techniques. In essence, the above methodology represents the most complete solution to the capture and presentation of the existing structures. It removed the guesswork as to which are the important features to locate because with the scanner every detail within the scanner's range is located.

2.3 Bathymetric Survey

To provide RMS with a complete picture of the bridge and its surroundings, Ben Gray from Astute Surveying was engaged to provide bathymetric modelling of the river bed. Ben's boat is equipped with a multi-beam echo sounder and side-beam sonar and is certified as a bathymetric survey vessel. The position of the boat is positioned by a Real Time Kinematic (RTK) Global Positioning System (GPS) receiver, connected to a base station on the shore, supplemented with an Inertial Measurement Unit (IMU) to compensate for the pitch, roll and yaw of the boat.

The bathymetric survey (Figure 8) was completed over a couple of hours. It involved first measuring the with the multi-beam echo sounder which points downwards, and them using the side-beam sonar to get the areas close to the bank where it was too shallow for the boat to operate. The survey was made more difficult by the low water level of the river, making snags and hidden logs a real danger to both survey and nautical equipment. Careful navigation of the river was necessary to ensure that data was captured in these areas, even though access was quite limited.

Figure 8: Bathymetric survey.

As the name suggests, multi-beam hydrographical surveying uses a Multi-Beam Echo Sounder (MBES) to generate multiple sound beams through water. These beams are aligned perpendicular to the hydrographical survey vessel in a swath or fan shape. It is possible to

generate between 120 and 420 beams 14 times per second. This method of surveying can achieve what is known as 'full bottom coverage'. The amount of coverage per transect is also related to the depth of water and can be calculated by multiplying the depth of water by approximately 2.5. Therefore, the deeper the water the more river bed can be surveyed more efficiently. This makes the MBES ideal for larger survey areas and deeper waters.

2.4 Mobile Laser Scanning

SKM is one of only a few companies that own and successfully operate a mobile laser scanner. A vehicle-mounted Riegl VMX-250 consisting of two 3D laser scanners supplemented by the on-board navigation system including a GPS receiver, a fibre optic gyro based IMU which takes into account roll, pitch and yaw, and velocities in x, y and z axes. The IMU and the latest Direct Inertial Aiding (DIA) to assist in areas of poor GPS reception were deployed to scan the existing road pavements, adjacent road furniture, vegetation and river embankments in far greater detail and much quicker than achievable by traditional survey methods.

Two mobile scan sorties were performed for the Barham Bridge project. The first was a standard vehicle-mounted scan where the scanner was used to scan the approaches to the bridge and surrounding cross streets out to a distance of 600 m. While conventionally this would be a large area to capture using traditional survey methods, the capture of the laser scan point cloud was done in just over one hour. The advantage of using the mobile scanner to capture the information was RMS had mentioned they were only interested in the immediate approach to the bridge, but might be interested in expanding the survey further out in the future. By capturing the data while on site, the actual survey strings that RMS use in the MX program can be extracted as needed any time in the future, and the data could be extracted in less time than it would take for an RMS surveyor to drive to the site and back.

The second sorties were performed by mounting the mobile laser scanner on the back of the bathymetric survey boat, for scanning the banks of the river and to provide infill data under the bridge structure that could not be captured from the terrestrial laser scanners located on the river banks or bridge piers (Figure 9). Survey of river banks can be difficult due to excessive vegetation caused by the continual water supply. Lines of sight are limited, and the terrain is generally steep and tough-going for any surveyor. Most of the time, the best that can be extracted is a top and bottom of bank, while the area between may undulate significantly.

Figure 9: Equipment mounted on the bathymetric survey vessel.

By mounting the mobile scanner on the back of a boat, the banks were captured from the water side of the bank, as opposed to the landward side. This gives an aspect that is rarely captured using conventional survey techniques, without the surveyors getting their boots wet. The surveyors operating the scanner had difficulties getting the IMU initialised, and originally had initialised the machine while the boat was mounted on the trailer, but due to tree cover at the boat ramp degrading the GPS, the initialisation had to be performed out in the river. This involved doing fast turns, loops and accelerations on the boat, i.e. 'circle work' and there where quite a number of odd looks from the spectators on the bank.

There was difficultly placing control markers for the mobile laser scan to tie to, so the scan processors came up with the novel idea of using the terrestrial scan data and beams on the underside of the bridge to tie the trajectory down to achieve the required accuracy.

2.5 Work Health and Safety

The main risks associated with the project were traffic, water, height and remoteness (Figure 10). A risk assessment was conducted before leaving the office, with controls and measures outlined in a job safety and environment analysis. Signs were placed to alert motorists crossing the bridge that people were working in the area, and spotters and good communication plans were outlined at the start of each day and at the different work areas. When working on the boats, near the banks or on the piers, all personnel were required to wear life jackets, and all persons involved were competent swimmers.

Figure 10: Working close to water.

At all times the work was able to be performed from safe areas on scaffolding or behind rails on the bridge deck, but a working-at-heights kit was on standby if needed. The remoteness of the site meant that long travel was required. A travel plan was formed, with breaks and driver changes every two hours, and the travel was split into two days to limit fatigue. Each morning, a quick and informal toolbox talk was conducted to outline the day's work and give the personnel time to assess risks and hazards that could not be identified from the office.

3 DATA PROCESSING

The scan datasets needed to be first registered and tied down before the extraction could begin. The terrestrial data needed to be extracted from the compressed format, then have the targets identified in the cloud, spherical panoramas needed to be stitched together and applied to the scan cloud positions, and then the separate clouds tied together and combined into one

usable overall cloud (Figure 11). The mobile scan data needed to be uncompressed and have a processed trajectory applied to it, then tied down using the control points, and exported to a cloud extraction package (Figure 12). The results of the individual movements for each run and the overall residuals are reported out to identify any outliers which may require further attention as part of the full calibration report and residual check (Figure 13).

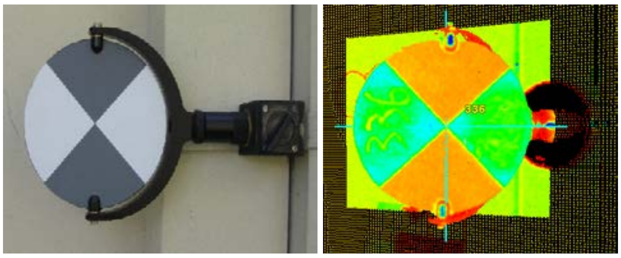

Figure 11: Black and white target photo and laser scan.

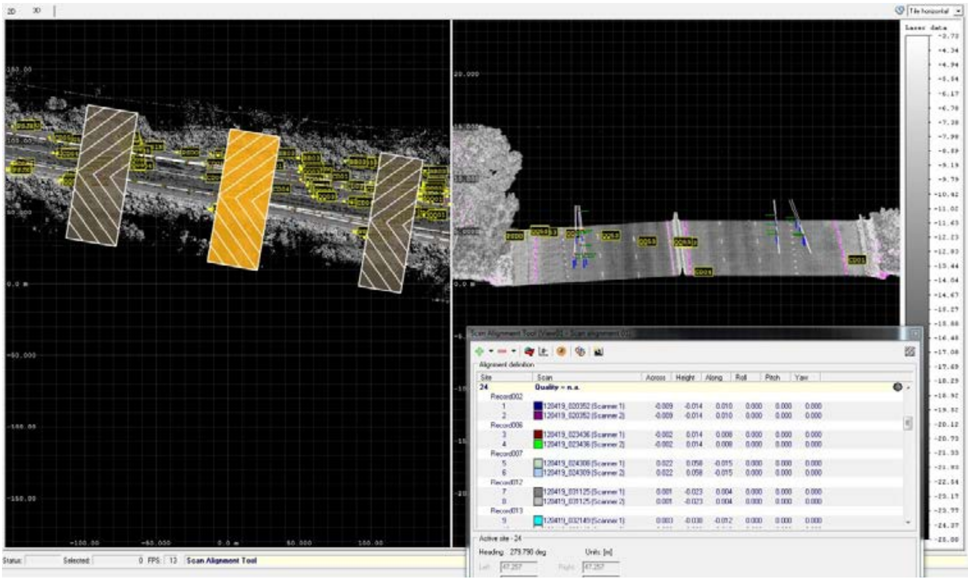

Figure 12: Scan alignment view with relative shifts per run.

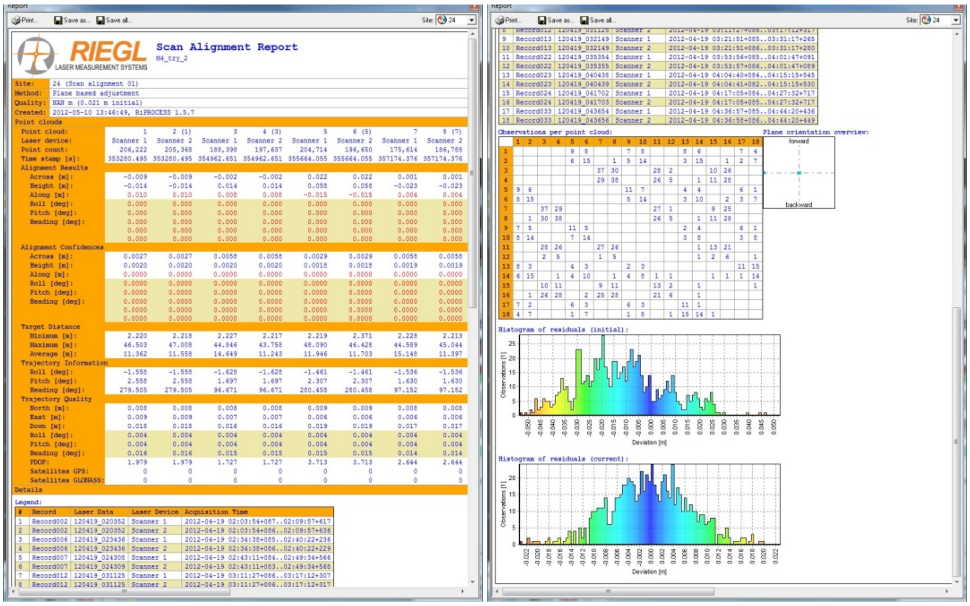

Figure 13: Scan alignment report showing shifts and residuals between runs.

The bathymetric data needed to be uncompressed and then tied together. The data related to obstacles in the river was removed and the resulting data sub-sampled down to a usable grid size. Then it was converted to the plane ISG grid system and imported into 12d software where a Digital Terrain Model (DTM) of the river bed was created. This was subsequently contoured and merged with the river bank DTM allowing cross sections to be extracted at required locations (Figure 14).

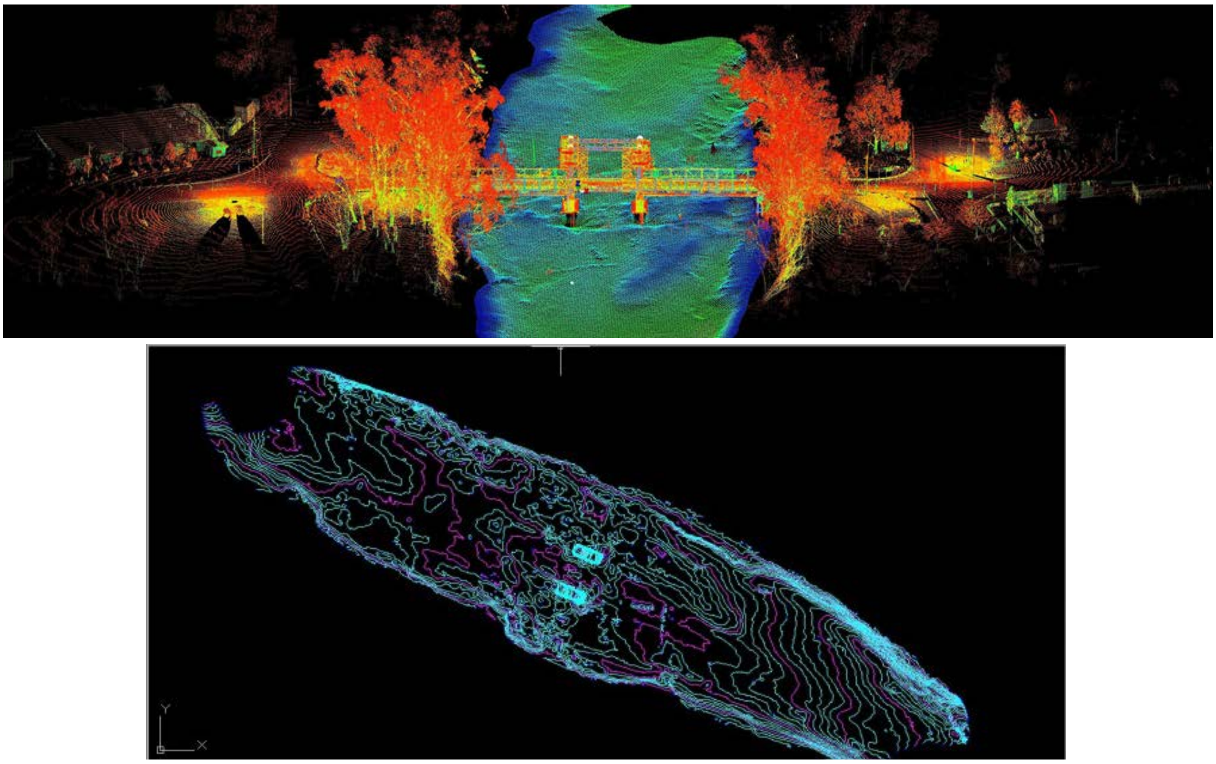

Figure 14: Bathymetry data of the river bed (top) and contours (bottom).

3.1 Extraction

With all types of point cloud capture, one of the main costs to projects is the extraction of usable data from the cloud. With terrestrial scanners, extraction can take a minimum of 3 times the amount of time spent in the field. The advantage is that the data can be 'farmed' out to many users to extract data, i.e. the data captured in the field by the one piece of equipment can be used simultaneously by many users in the office. In this case, three scan processors were used to extract the data from the bridge and surrounds. One processor was working on the lift span, the second on the truss spans, and the third on extracting conventional survey data on the deck, along the banks and in the approaches to the bridge.

The extraction was performed mainly using the Leica Cyclone and CloudWorks packages. Specialist parts tables are used to apply real shapes to the components of the bridge (Figure 15). As the bridge is over 100 years old and the specialist steel parts for the bridge where constructed at the Euston foundry, as well as the standard components being designed using out-dated British standard sections, special parts tables needed to be created. Another problem was created by the upgrade in 1925, which used a different parts table, after which, as structural members have been replaced since, more modern parts tables have been used. SKM has collected a significant library of old parts tables from steel manufactures that apply to existing structures in Australia, and it is common to find structures that are a conglomerate of different manufactures and sizes. In this bridge, some of the girders were of a size that was

not in any existing parts table, but by checking the old plans with assistance from RMS bridge engineers their correct size was able to be established.

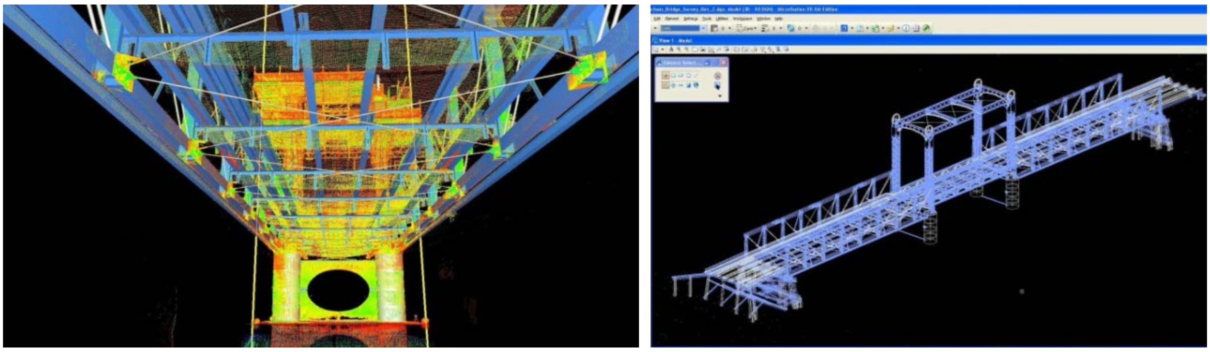

Figure 15: Modelling of steel beams.

The wooden components of the bridge also created challenges for the modellers (Figure 16). In an attempt to try and get the beams to conform to standard inch sizes, wooden beam parts tables were established. The problem with this was over the hundred years the beams had shrunk, warped, and were probably not originally hewn to a fine tolerance, meaning fitting them to standard tables was difficult. In critical areas, some beams had to be re-examined in the cloud and converted to their actual size, and represented with a twist or warp in the beam. The end result of all this modelling was a 3D model in AutoCAD, which was then dimensioned and projected into plan and sectional views.

Figure 16: 3D modelled beams from point cloud data.

Using a specialist program that has been developed in-house, known as Virtual Surveyor for AutoCAD, the standard detail strings that are used in MX were extracted over the deck, approaches and river banks. This involved loading the cloud and identifying features both in plan view as well as in profile to assign the correct height. This was combined with the specific required bridge features, translated from the 3D model into an MX format, which is the standard deliverable required by RMS (Figure 17).

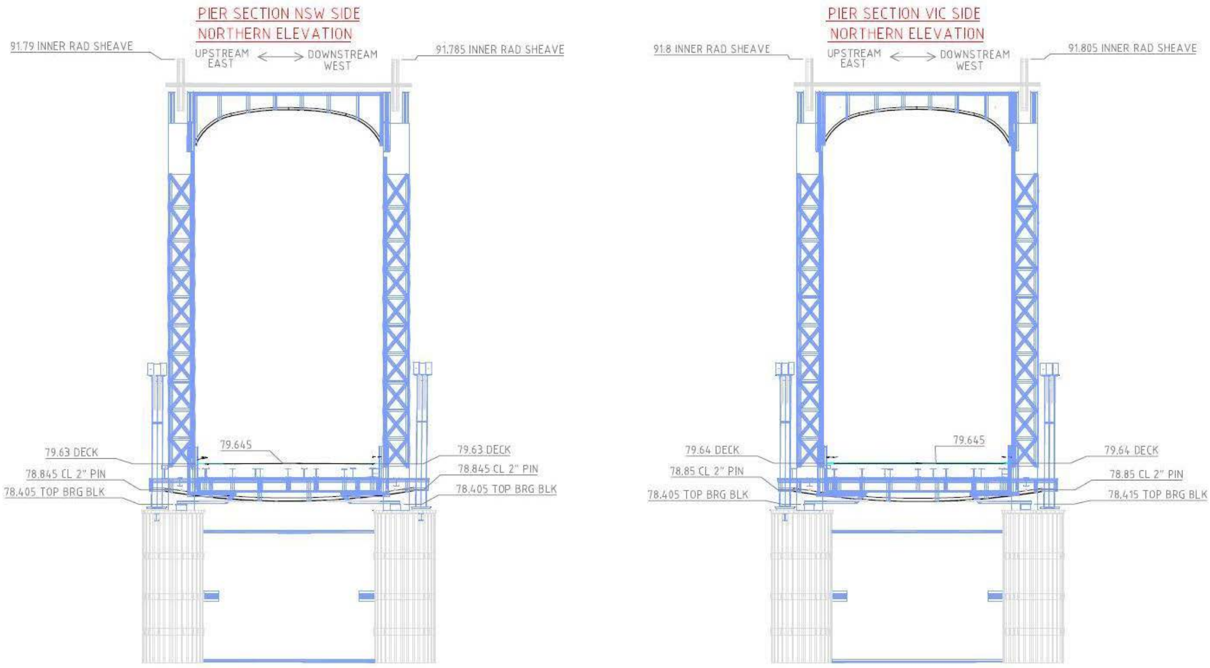

Figure 17: Sections extracted from 3D models.

4 CONCLUDING REMARKS

The difficulty of access to an old structure located a long way from any client office, with very few accurate existing plans posed a significant challenge to deliver a cost-effective and long-term solution to the ongoing maintenance of a critical heritage bridge linking two towns and providing a vital transport link between two states. Previous efforts had necessitated numerous long trips back to the site by both survey teams and engineers to continually seek spatial data to adapt solutions to maintain this vital structure without compromising its significant heritage value. There are hundreds of similar bridge structures throughout NSW and other states in Australia.

The solution proposed by SKM and Astute Surveying removed many of the risks that have been inherent in the practices to date. The approach from SKM and Astute Surveying to the requested services and project needs is a complete departure from what has been traditionally undertaken in previous surveys on these bridge structures. The proposed solution was up until recent years not even possible but typifies the rapid technical advances that are now a reality within the spatial industry. As early adopters of 3D laser scanning technology, especially MLS, SKM recognised that there are now different platforms (other than land-based methods) that can deliver data solutions when combined with other survey technologies, such as bathymetry and TLS, that were unthinkable as little as five years ago. The approach and acceptance by clients can change the paradigm of how the spatial industry can solve a multitude of technical challenges across multiple industry sectors. The project outlined in this paper is just one very small example.

ACKNOWLEDGEMENTS

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