# Proposed Use of V-STARS for Heavy Engineering

## 28 February 2001

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# Introduction

The following report is a summary of the V-STARS work carried out at the Kawada facility in Takamatsu, Japan. One measurement was undertaken using the V-STARS E3 camera system.

The measurement involved the determination of some key dimensions on a large (12m) bridge section. The objectives are outline below in the requirements section.



*V-STARS with E3 camera.*

# Requirements

**Object 1 – Bridge Section**
The following requirements were stipulated.
1. Measure targets at predefined locations.
2. Determine dimensions
3. Compare measured data to nominal data.



*Bridge Section*

## Documentation

The following documentation is included in this report for this measurement.

- A report outlining methodology and results.

## Measurement Procedure

# Targeting

In order to meet the measurement objectives outlined earlier it was necessary to target the object. In general, targets are placed on points or surfaces that are of interest. For surfaces, strips of retro-reflective tape of variable pitch and dot size are commonly used. They are relatively cheap, disposable and easy to apply. To coordinate tooling datums such as bushed holes or button datums, tooling targets are used. These come in a variety of shank and dot sizes. They are also available in variable orientations. For this measurement, there were no bushed holes to measure. Individual targets were placed at key points on the object. Individual targets were also placed on the main surface to define the plane.

To automate the measurement process it was necessary to add "coded" targets to the object. These targets are automatically detected and help the software determine the location and orientation of the camera at the time the photo was taken. They also help tie the entire object into a uniform coordinate system.
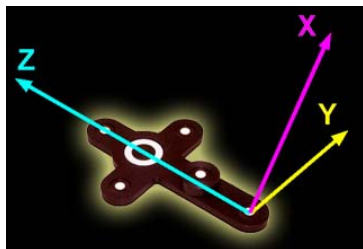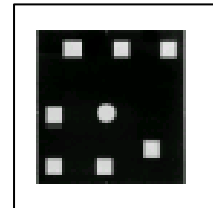


The initial coordinates system and scale is determined via the AutoBar. The AutoBar used by the V-STARS system is a fixture with five targets arranged in the form of a cross. The target's known coordinates are used by the AutoMatch procedure to determine the camera's orientation relative to the AutoBar. The AutoBar is securely attached on or near the measured object, preferably in a highly visible location. The AutoBar's default coordinate system has its origin at Target 1 at the bottom of the AutoBar. The positive Z-axis goes through Target 3 at the top of the bar. The positive X-axis is up out of the AutoBar. The diagram on the left shows both the AutoBar and its coordinate system

To scale a photogrammetric measurement, there must be at least one known distance. Normally this distance comes from a calibrated coded graphite scale bar or invar scale bar (Refer to adjacent image). Typically multiple scales are used for redundancy. Two scale bars were used to complete this measurement.



*Invar Scale Bar Kit*

Some of the key targeting features are shown in the image below: -
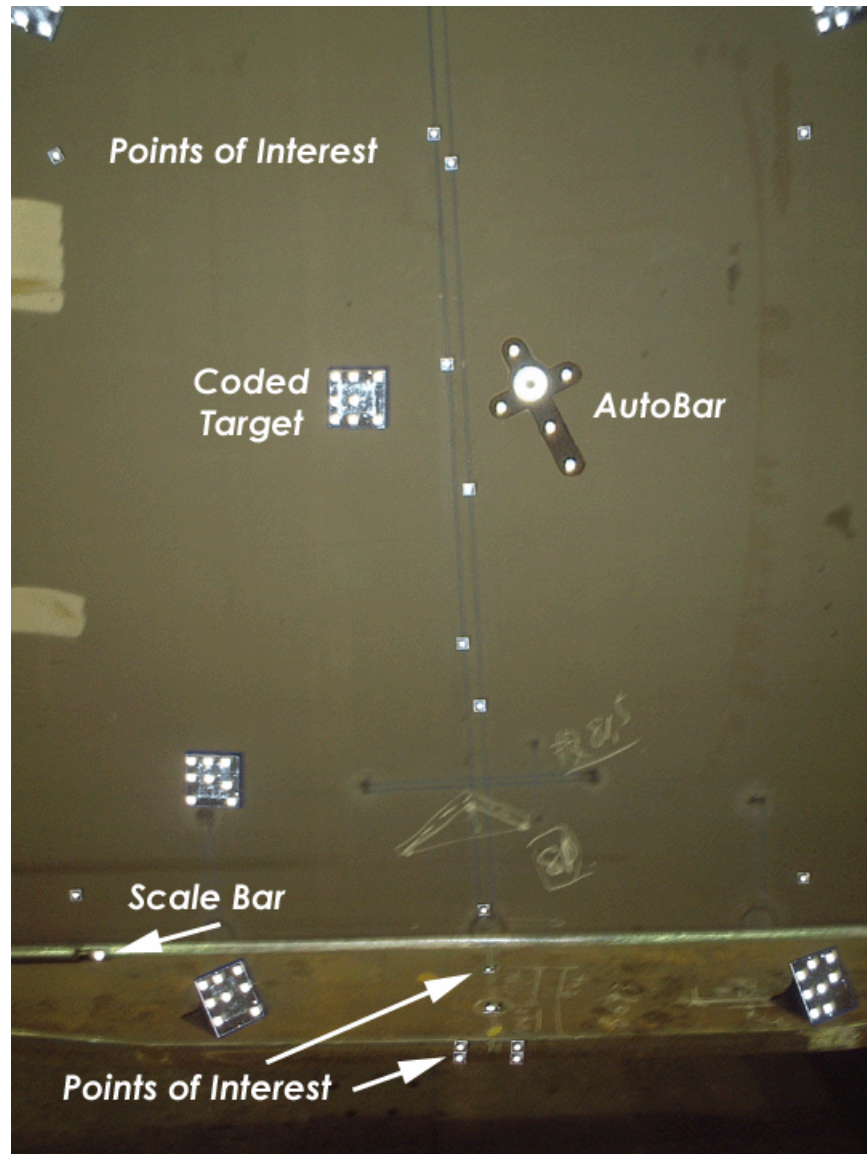


## Photography

The photography is carried out once the object targeting is completed. Put simply, the aim of the photography is to record each of the targeted points in as many images as possible from as wide a range of angles as possible. To improve the accuracy of the measurement, generally photos are taken both close to the ground and from an elevated position. A total of 70 photographs were taken of the object. The number of photos taken depends on the complexity of the measurement and accuracy requirements. In this case, the photography was

rather complicated by the restricted set back distance. It was also complicated by the need to measure points on the rear face of the plate.
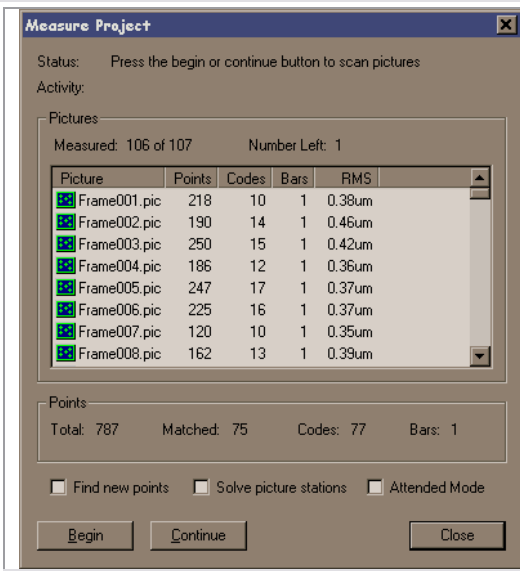
The photography for the object was completed in approximately 10 minutes. Camera station locations for the measurement are shown in the diagram below. Also shown is a sample intersection pattern for a point. Each of the green lines represents an observation to that point from the corresponding camera station.
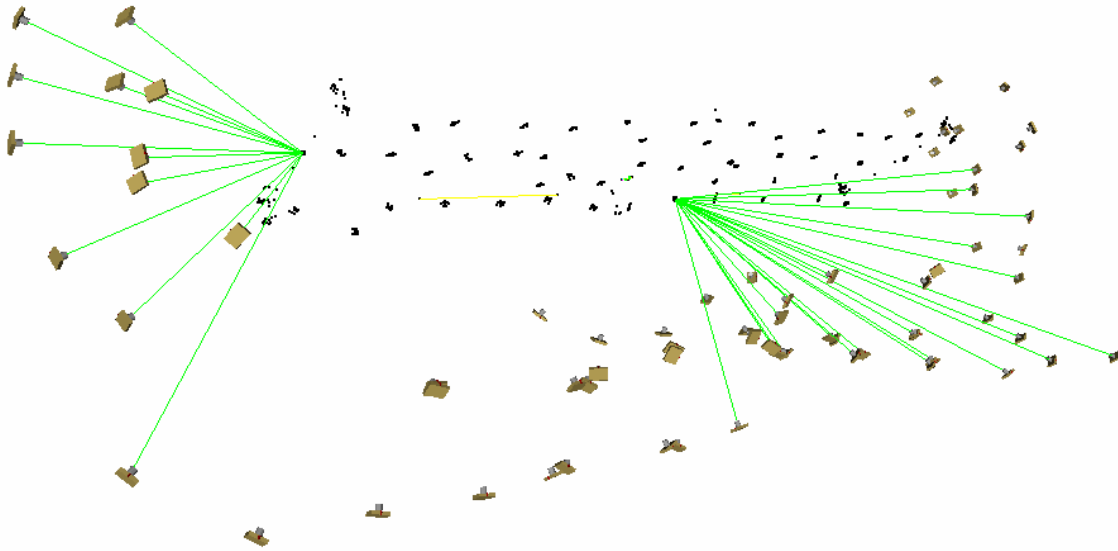
## Processing

Once the photography has been completed the images are transferred to the system laptop. The images are stored on an IBM MicroDrive hard drive and V-STARS accesses these images directly from the drive.

Almost all of the measurement process is automated. The images are processed and the coordinates extracted by the "AutoMeasure" command. A typical AutoMeasure dialog box is shown on the right. The AutoMeasure command will open each of the images, determine the camera location, find new target points and finally adjust all the measurements in the "Bundle Adjustment". At the conclusion the user is left with the XYZ coordinates for all the target points in the network. The AutoMeasure procedure is very powerful as it allows the user to continue working while it processes the data. It also means that relatively unskilled workers can be used to process the data.

**Measure Project**

Status: Press the begin or continue button to scan pictures

Activity:

Pictures

Measured: 106 of 107          Number Left: 1

| Picture | Points | Codes | Bars | RMS |
|---|---|---|---|---|
| Frame001.pic | 218 | 10 | 1 | 0.38um |
| Frame002.pic | 190 | 14 | 1 | 0.46um |
| Frame003.pic | 250 | 15 | 1 | 0.42um |
| Frame004.pic | 186 | 12 | 1 | 0.36um |
| Frame005.pic | 247 | 17 | 1 | 0.37um |
| Frame006.pic | 225 | 16 | 1 | 0.37um |
| Frame007.pic | 120 | 10 | 1 | 0.35um |
| Frame008.pic | 162 | 13 | 1 | 0.39um |

Points

Total: 787      Matched: 75      Codes: 77      Bars: 1

☐ Find new points    ☐ Solve picture stations    ☐ Attended Mode

[Begin]    [Continue]                    [Close]

*Typical AutoMeasure Dialog*

The AutoMeasure routine will assign random labels to the points it finds. These labels start with the key word "Target" followed by a number. If specific labeling is required the random labels can be easily changed to labels defined by the user. This is possible in both the picture view and the graphical 3D view. For this particular project it was necessary to re-label the points so that analysis could be simplified.

Seen below is an image taken as part of the object measurement.
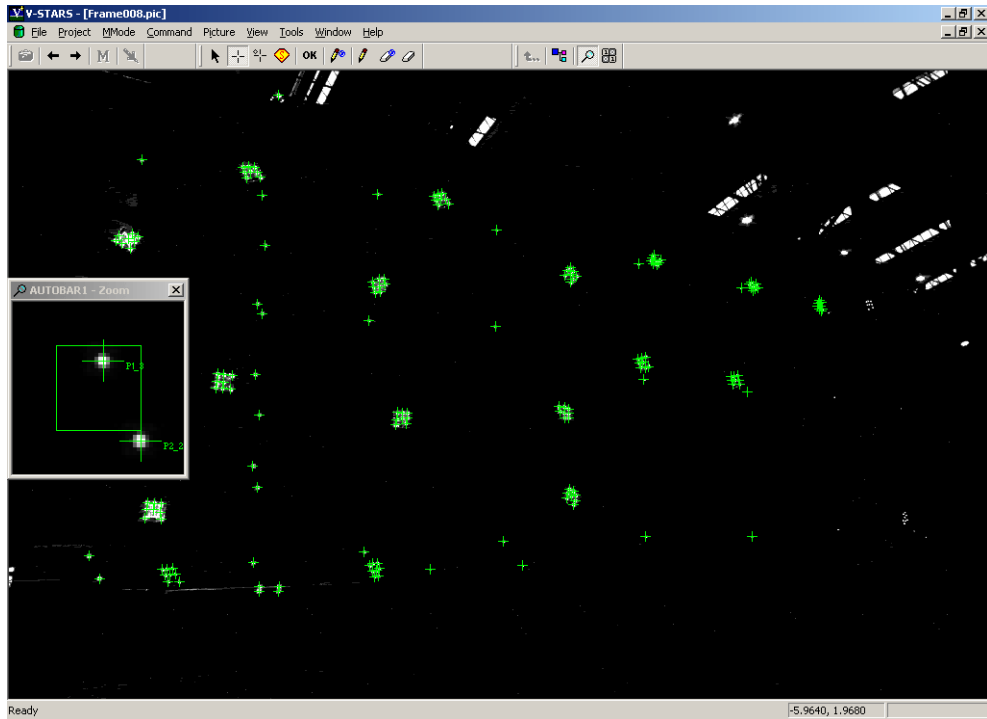
The green crosses represent points that have been located in this particular image. Note that the image appears a little dark and difficult to see. This is intentional as the best photogrammetric measurements are made on images that have dark backgrounds and bright targets. One of these targets is shown in the zoom window in the corner. If the scale bar is visible then a yellow line will be drawn between the two end points.

# Results

## Statistics

The following is a summary of the measurement statistics from the measurement of the object.

| | | |
|---|---|---|
| No. of photos | 70 | |
| No. of points | 512 | |
| No. of scales | 2 | |
| Scale Agreement | 0.048mm | |
| Accuracy RMS(mm) X,Y,Z | X | 0.039 |
| | Y | 0.029 |
| | Z | 0.031 |

A typical point listing is shown below.

This point data can be analyzed within the V-STARS' SOLIDS module, easily exported to almost any CAD platform or other analysis program.

# Point Cloud

The point cloud showing all the points generated is shown below.
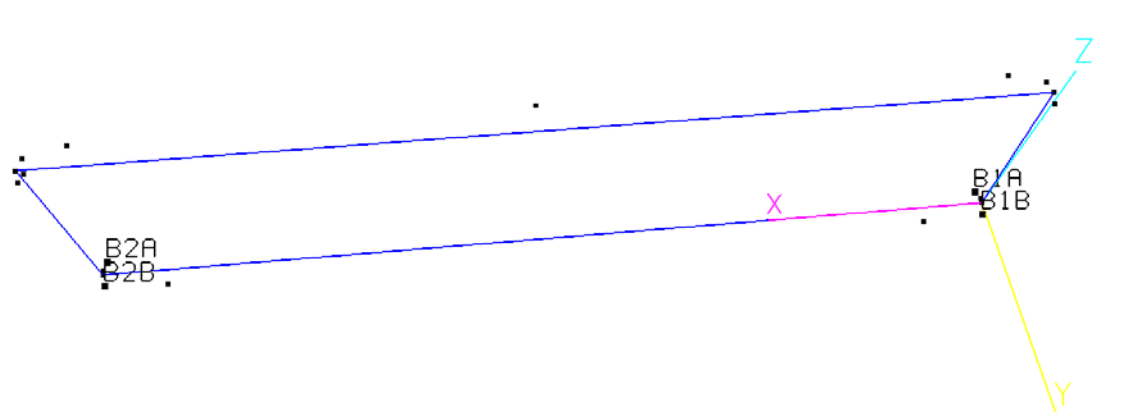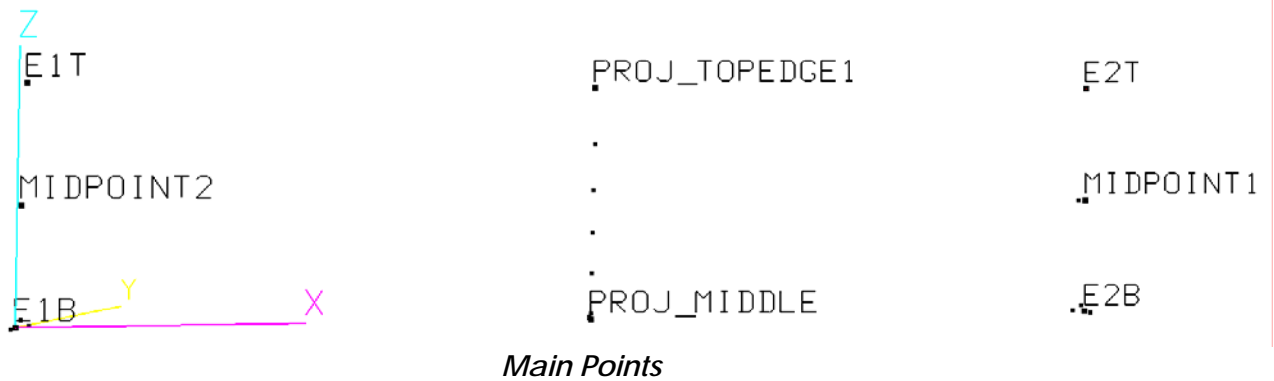


The point cloud showing all the points of interest is shown below.

# Numbering Guide

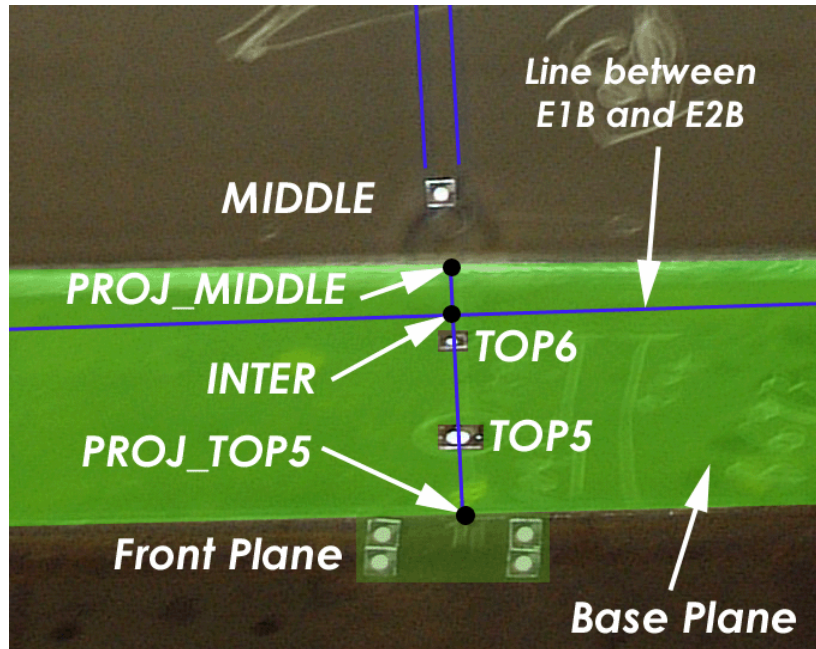The numbering used is shown in the images below



E1T        PROJ_TOPEDGE1        E2T

MIDPOINT2        MIDPOINT1

E1B        PROJ_MIDDLE        E2B

*Main Points*



*Points used to construct the "Base Plane"* (B1A, B1B, B2A, B2B, TOP5 and TOP6)

*Points in the Middle of the Plate*

# Alignment

Typically one of the last tasks is alignment into the coordinate system of the object being measured. There are two basic types of alignment. The first is a simple Axis or 3-2-1 alignment. This alignment is based on three points – an origin, an axis point and a third point to define the plane in which the axis lies. The second type of alignment uses point correspondence from a known alignment (such as the CAD model) to transform the data into that coordinate system. This is a "best-fit" solution and is preferred as it involves greater redundancy.

In this project two alignments were carried out. The first of these was a simple Axis alignment through the points E1B (Origin), E2B (X-Axis) and E1T (XZ Plane). The second alignment was a simple transformation using the four points E1B, E2B, E1T, and E2T. These points were compared to the nominal data for the points. The alignment produced the following results.

These results indicate a high level agreement to the nominal data. The most significant error seems to be in the Y direction. This indicates a twisting in the section.

# Analysis

SOLIDS is the geometric analysis module of V-STARS. For example, consider a simple function like determining the distance between two points. Computing the point-to-point distance is as simple as highlighting the two points and pressing "d". The results appear on the screen and are written to a report file.

Calculation of the Best-fit plane is also very simple. The plane points are highlighted and the "P" key is pressed. The plane dialog is shown in the adjacent image. The dialog gives you a few options and reports the results of the operation.

Similarly, best-fit lines, circles, spheres etc. can also be calculated. SOLIDS also has the ability to measure between objects. For example, by selecting a point and a plane the normal distance can be computed. This makes SOLIDS a very useful analysis tool.

For this measurement, distances between the points were determined, planes calculated, and plane to plane relationships determined.

**Plane Parameters**

Name: NewPlane12

A: -0.0008
B: -0.0039
C: 1.0000
D: 16.3405

Rejection Limit: 0.0040
Final RMS: 0.0011
Points Accepted: 8
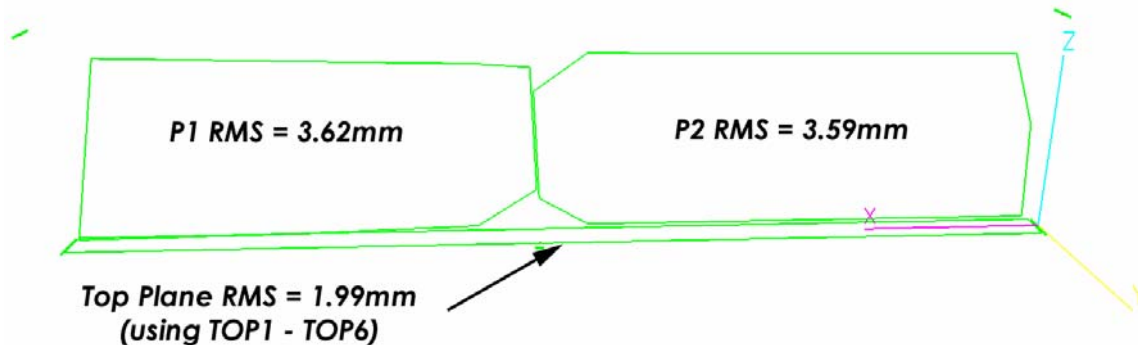Points Rejected: 0

☐ Create Template          Offset: ☐

| Label | Residuals |
|-------|-----------|
| ✚ CODE118 | 0.0017 |
| ✚ NUGGET118_1 | 0.0004 |
| ✚ NUGGET118_9 | 0.0001 |
| ✚ NUGGET118_14 | 0.0011 |

OK          Cancel

*Typical Plane Dialog*

# Numerical Results

## Planes



P1 RMS = 3.62mm          P2 RMS = 3.59mm
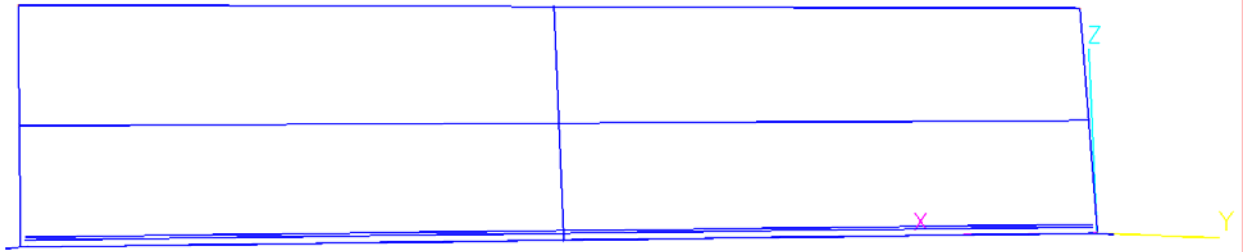
Top Plane RMS = 1.99mm
(using TOP1 - TOP6)

* TOP1 – TOP4 are the same as B1A, B1B, B2A and B2B
Angle between Plane P1 and Plane P2 = 178.27°
Angle between Plane P1 and Top Plane = 89.24°
Angle between Plane P2 and Top Plane = 89.10°

# Distances



Distances between points. (mm)

| Start | End | Nominal | V-STARS | Tape |
|---|---|---|---|---|
| E1B | E1T | 2500.00 | 2502.76 | 2502 |
| E2B | E2T | 2500.00 | 2502.19 | 2502 |
| E1B | E2B | 11410.00 | 11412.69 | 11412 |
| E1T | E2T | 11410.00 | 11412.72 | |
| W1B | W2B | 11325.22 | 11328.92 | 11328 |
| PROJ_MIDDLE | PROJ_TOP5 | | 342.32 | |
| PROJ_MIDDLE | INTER | | 73.43 | |
| TOP6 | PROJ_TOP5 | | 244.60 | |
| E1B | PROJ_MIDDLE | | 5875.02 | |
| PROJ_MIDDLE | E2B | | 5538.62 | |
| B1B | B2B | 11320.22 | 11321.07 | |
| B1A | B2A | 11329.96 | 11331.93 | |

# Time Summary

| | |
|---|---|
| Targeting | 15 minutes |
| Photography | 10 minutes |
| Processing | 10 minutes |
| Analysis | 35 minutes |
| **Total** | **70 minutes** |

## Concluding Remarks

The measurement undertaken has shown that V-STARS with the E3 system can be a very powerful measurement tool. The results of the measurement were very accurate and more importantly were produced quickly.