NATIONAL TRANSPORTATION SAFETY BOARD
Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594

August 27, 2019

MATERIALS LABORATORY STUDY REPORT Report No. 19-043

A. ACCIDENT INFORMATION

Place	:	Miami, FL
Date	:	March 15, 2018
Vehicle	:	FIU UniversityCity Pedestrian Bridge
NTSB No.	:	HWY18MH009
Investigator	:	Robert Accetta (HS-20)

B. COMPONENTS EXAMINED

Selected surfaces on Member 12 and the deck under Member 11.

C. DETAILS OF THE STUDY

Flat areas were observed on the deck surface that was under Member 11 and on the bottom of Member 12 where it met the deck surface. A discussion of these areas is given in a Turner-Fairbank Highway Research Center (TFHRC) Factual Report entitled, “Concrete Interface Under Members 11 and 12”, dated October 19, 2018.

The location of the flat area on the deck surface under Member 11 is shown in Figures 1 and 2. Yellow dashed lines indicate a lip on the surface that was consistent with the edge of a cold joint. A portion of this area was sectioned and removed from the deck surface, as shown in Figure 3. The largest pieces separated from the deck were numbered 1, 2, and 3.

The bottom of Member 12 is shown in profile in Figure 4 and perpendicular in Figure 5. The yellow dashed line in Figure 4 highlights the straight plane of the flat area observed. Figure 5 shows that the flat area on Member 12 was only a portion of the cold joint and was irregular in shape.

The extracted portion of the deck under Member 11 and the entirety of the bottom of Member 12 were examined at TFHRC. Post-collapse damage was observed on portions of the flat surfaces, thus subsequent evaluation was performed on a best effort basis on undamaged areas.

There are two methods within the concrete construction community that are widely used to characterize concrete surfaces. The first method is ICRI 310.2R-2013, *Selecting and Specifying Concrete Surface Preparation*, International Concrete Repair Institute, Inc., St. Paul, MN, 2013. This method utilizes a set of concrete surface profile chips with varying levels of distress to use as a comparison tool for evaluating surface preparation only in a qualitative manner.

The second method follows ASTM E965-15, *Standard Test Method for Measuring Pavement Macrotexture Depth Using a Volumetric Technique*, ASTM International, West Conshohocken, PA, 2015. This method involves spreading a known volume of sand over the concrete surface to form a circle until all sand has settled in the surface cavities, with the roughness then calculated from the diameter of the circle. While this method results in quantifying the roughness of the surface, it does not directly measure surface roughness specifically. Moreover, this method was deemed unusable in the present evaluation due to the configuration of the specimens and the small size of the available surfaces.

There is no industry standard that specifies a direct method for quantitatively measuring the surface roughness of concrete.

Additional challenges to the measured surface characterization included that the post-collapse forensic evaluation was limited due to structural damage and availability of surfaces clearly identified as in the region of interest. Thus, although the surface area tested was atypical for a traditional evaluation of surface roughness, the testing documented in this report provided the best opportunity to quantify the flat areas observed on the structure in the location between Members 11 and 12.

Pieces 1, 2, and 3 on the deck and all the flat area under Member 12 were scanned using a 2G Robotics ULS-100 short-range laser scanner with a class 3R laser. An exemplar photo of a laser scan of the flat area on the bottom of Member 12 is shown in Figure 6. The laser determined the height of the surface at each positional coordinate on a specified grid.

The average scan resolution for the Member 11 pieces was 0.3 mm (0.012 in) by 0.5 mm (0.020 in) in the X and Y directions. The scan resolution for the height data was approximately 0.1 mm (0.004 in). The number of sampling points for Piece 1 was 211,744; for Piece 2 was 122,913; and for Piece 3 was 149,592.

The scan resolution for Member 12 was 0.5 mm (0.020 in) by 1.0 mm (0.039 in) in the X and Y directions, and 0.1 mm (0.004 in) in height, resulting in 109,605 total sampling points.

Because standards for this type of testing have not been established, a MatLab® (The MathWorks, Inc., Natick, Massachusetts) program was coded to quantify the surface roughness of the flat areas using the scan data[1]. The program used the following general procedure:

- Import the scan data (i.e., read in the X, Y, and Height values of each point from the three-dimensional point cloud). (Figure 7)
- Tessellate the point cloud (i.e., create a three-dimensional, unstructured, triangular surface mesh, without gaps or coincident features). (Figure 8)
- Remove extreme outliers from the data set (i.e., remove points far above or far below the target cold joint region).
- Section the tessellated surface mesh with parallel planes to extract point profiles needed to calculate surface roughness parameters. Each edge of the triangular surface mesh that intersects a cutting plane is used to calculate the corresponding surface height (via linear interpolation). (Figure 9)
- Remove run-on and run-off points along each point profile. The respective run-on/run-off points are discarded from the beginning/end of each scan to prevent edge effects from biasing the surface roughness calculations. The run-on and run-off lengths were sample-specific.
- Calculate the centerline for each extracted point profile. The centerline is a straight line that divides equal areas above (defined by the centerline to surface peak distance times the incremental distance along the surface) and below (defined by the centerline to surface valley distance times the incremental distance along the surface). (Figure 10)
- Calculate the mean profile depth (MPD) from the centerline in segment lengths of 50 mm (about 2.0 in.) when at least two adjacent 50 mm segment lengths are present.[2] (Figure 11)
- Average all MPDs across the scanned surface to calculate the arithmetic mean roughness value (S_a) for the target cold joint areas. (Figure 12)

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[1] The calculations developed in the code were based on the following sources: ISO 4287:1997, *Geometrical Product Specifications (GPS) – Surface Texture: Profile Method – Terms, Definitions, and Surface Texture Parameters*, International Organization for Standardization, Geneva, Switzerland, April 1997; ASTM E1845-15, *Standard Practice for Calculating Pavement Macrotexture Mean Profile Depth*, ASTM International, West Conshohocken, PA, 2015; and *Machine Design: An Integrated Approach, 2nd Edition*, Prentice-Hall, Inc., Upper Saddle River, NJ, 2000, p. 447.

[2] The evaluation length measured for surface roughness profiles has been defined as a multiple of the desired surface roughness profile amplitude by both American Concrete Institute methodology and in ISO specifications. Due to the limited amount of measurable surface in this specific case, 50 mm was chosen in order to gather a larger amount of data for evaluation.

The average S_a for the flat areas evaluated on both the Member 11 pieces as well as the Member 12 surface was approximately 1 mm (0.04 in), as measured in the partially damaged post-collapse condition.

The surface roughness on the FIU build plans was not specified for the surface between the deck and the bottom of the truss members on sheets B-37, B-38, and B-41. The surface roughness was specified as “proposed construction joint (CJ) shall be roughened to an amplitude of ¼” [0.25-in] prior to casting back span” on pylon diaphragm dimensions and reinforcement sheets B-24B and B-25. AASHTO LRFD Bridge Design Specifications defines surface roughness as “normal-weight concrete placed against a clean concrete surface, free of laitance, with surface intentionally roughened to an amplitude of 0.25 inch” (Section 5.8.4.3).

Adrienne V. Lamm
Materials Engineer

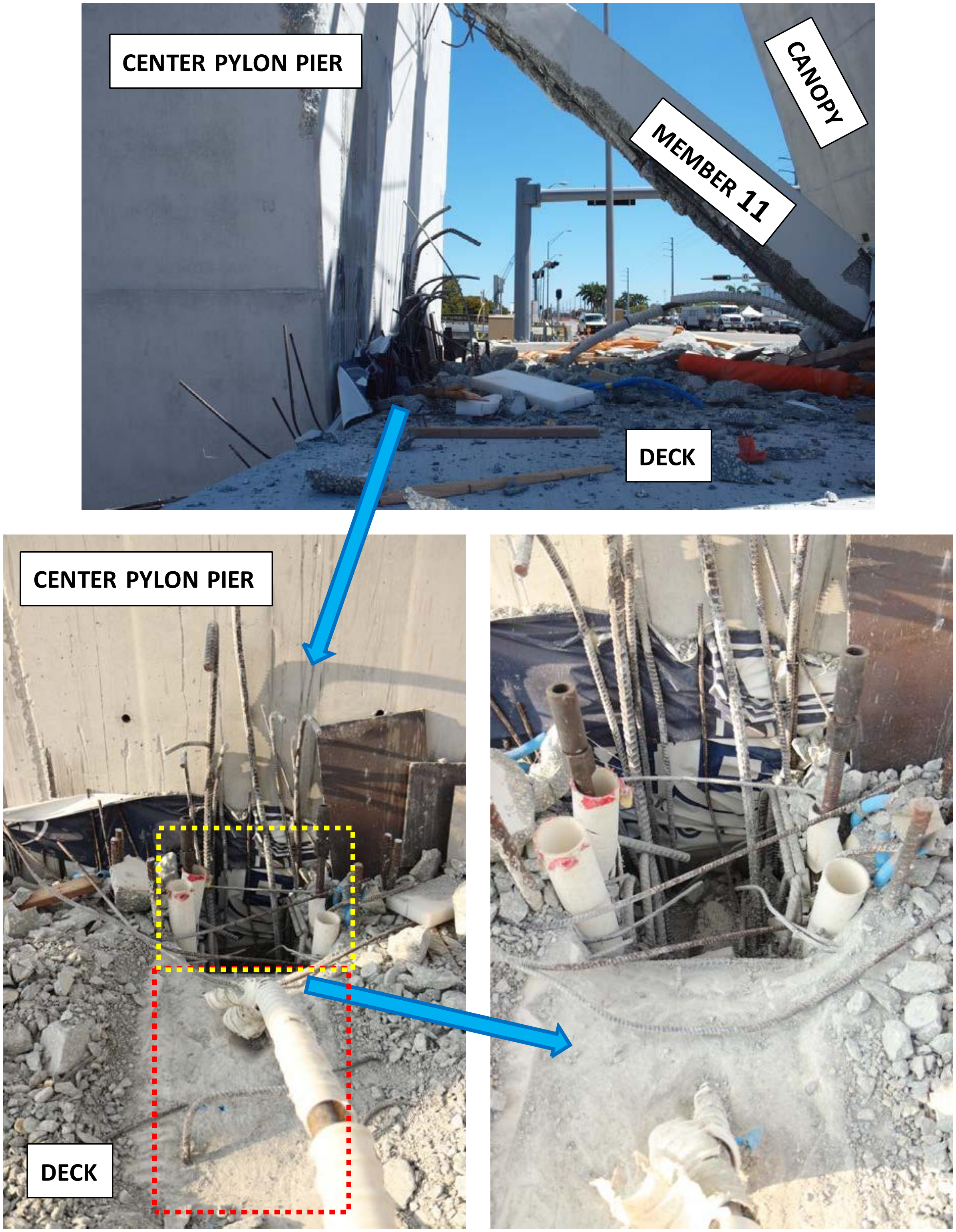

Figure 1: On-scene photos of the deck surface. The red box outlines the flat area on the deck surface under Member 11. The yellow box outlines where Member 12 was located.

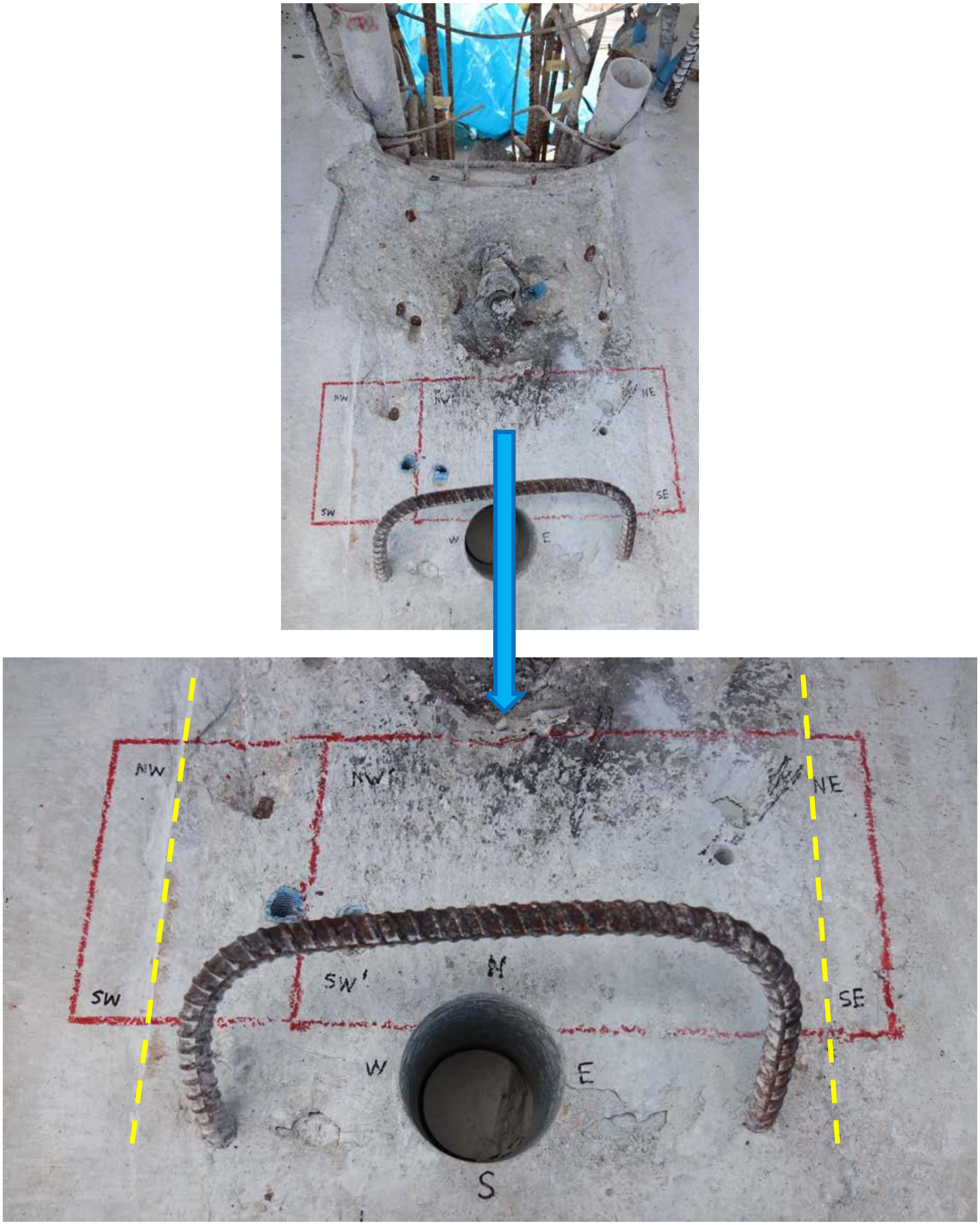

Figure 2: Close-up photos of the deck surface under Member 11. The yellow dotted lines indicate the edges of the cold joint.

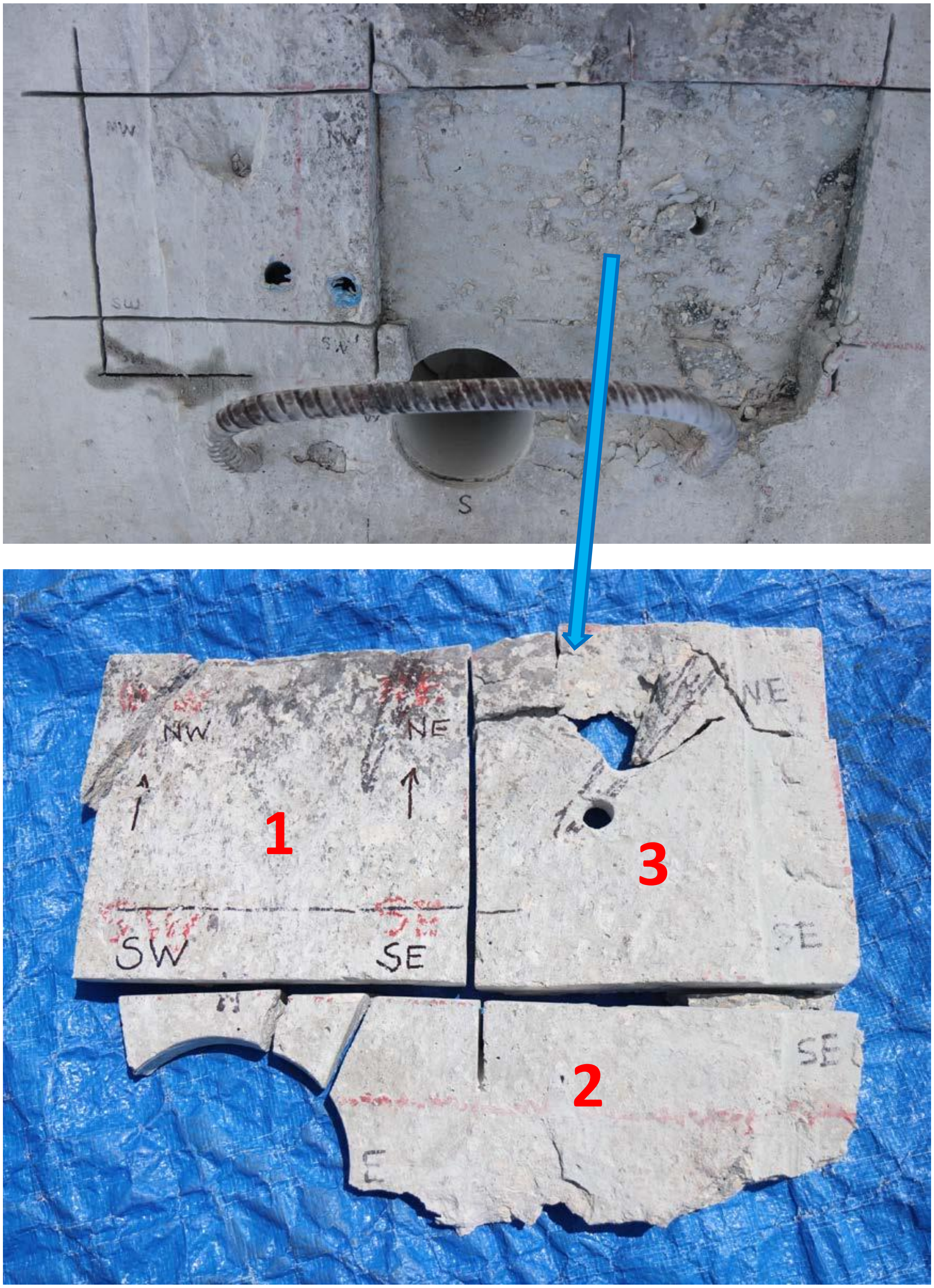

Figure 3: Close-up photos showing the portions of the deck surface under Member 11 that were sectioned for further analysis.

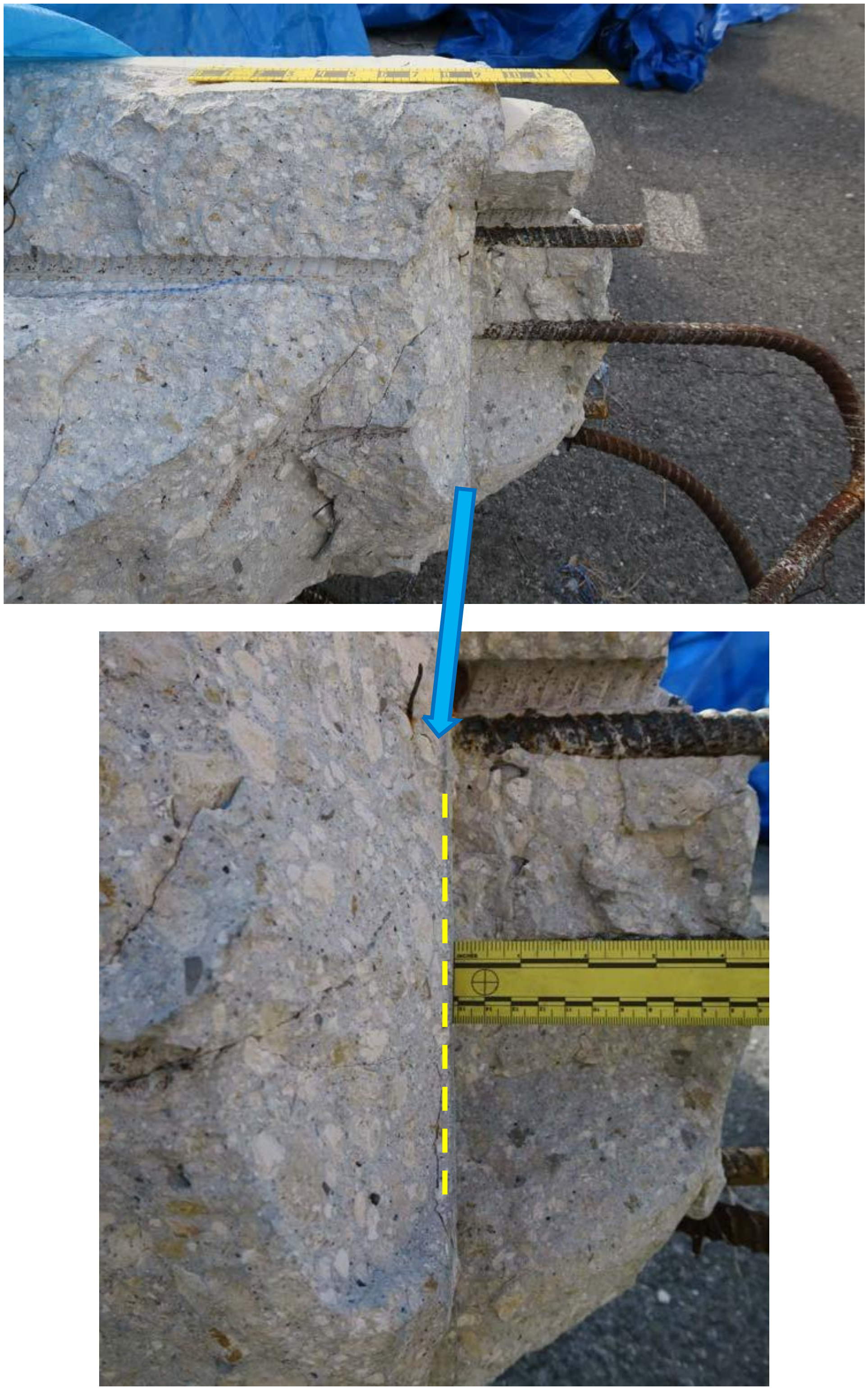

Figure 4: Macro photos of the bottom of Member 12 viewed in profile. The yellow dotted line indicates the straight plane of the flat area observed.

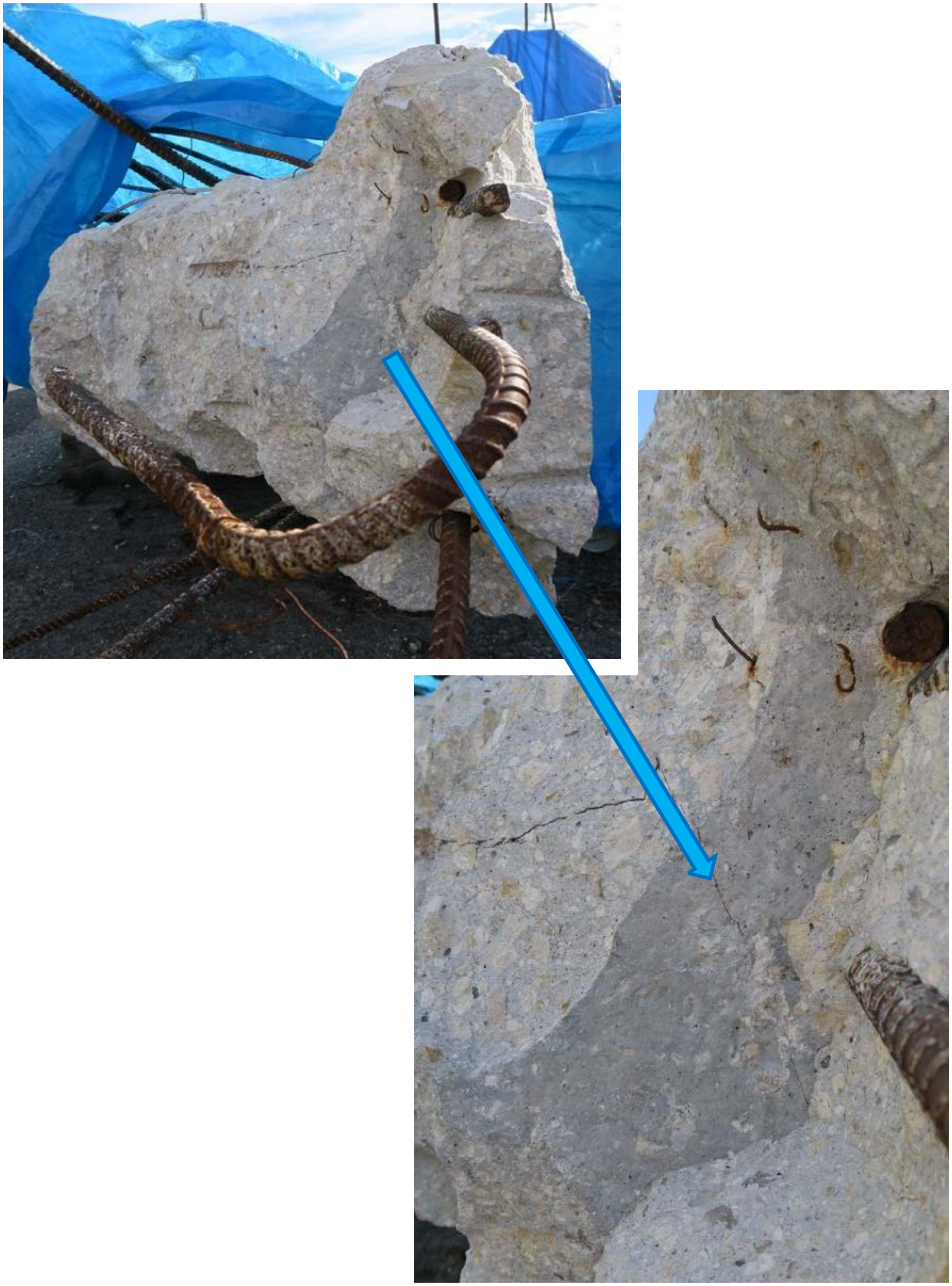

Figure 5: Macro photos of the bottom of Member 12 viewed perpendicular. The flat area observed was irregular in shape.

Figure 6: Macro photos of a laser scan of the flat area on the bottom of Member 12. The green line in the bottom image is the laser projected onto the surface.

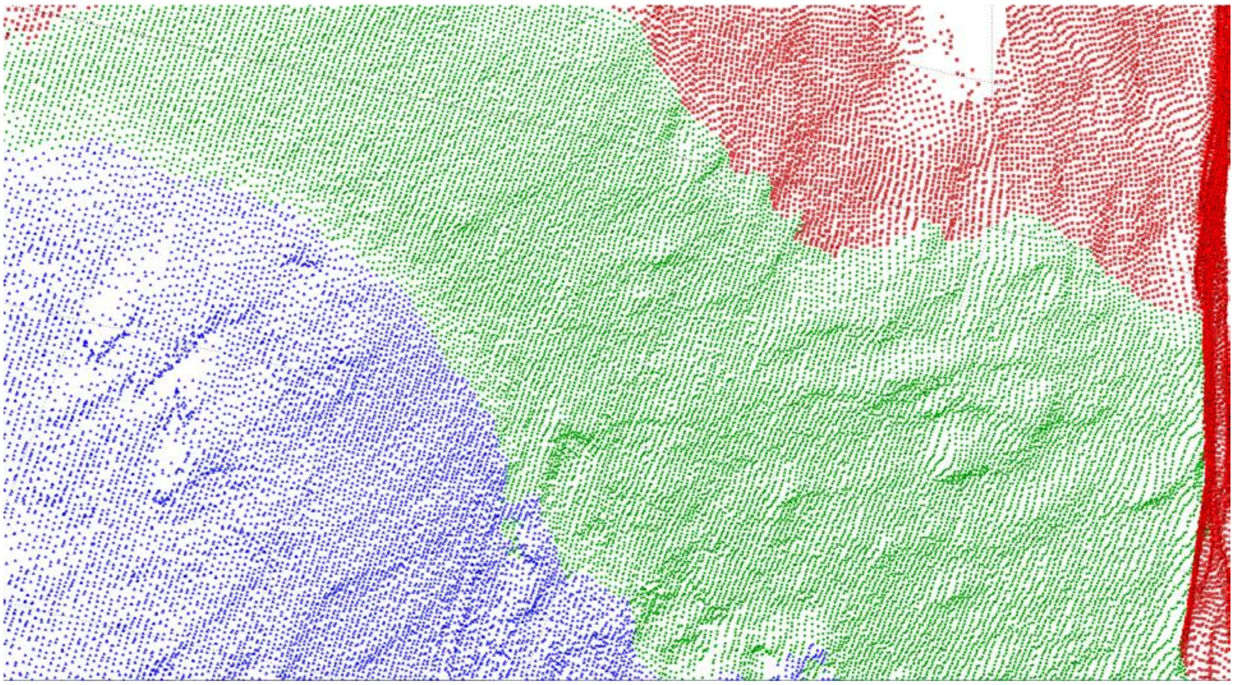

Figure 7: Subset of Member 12 point cloud obtained from digital scan (height not to scale).

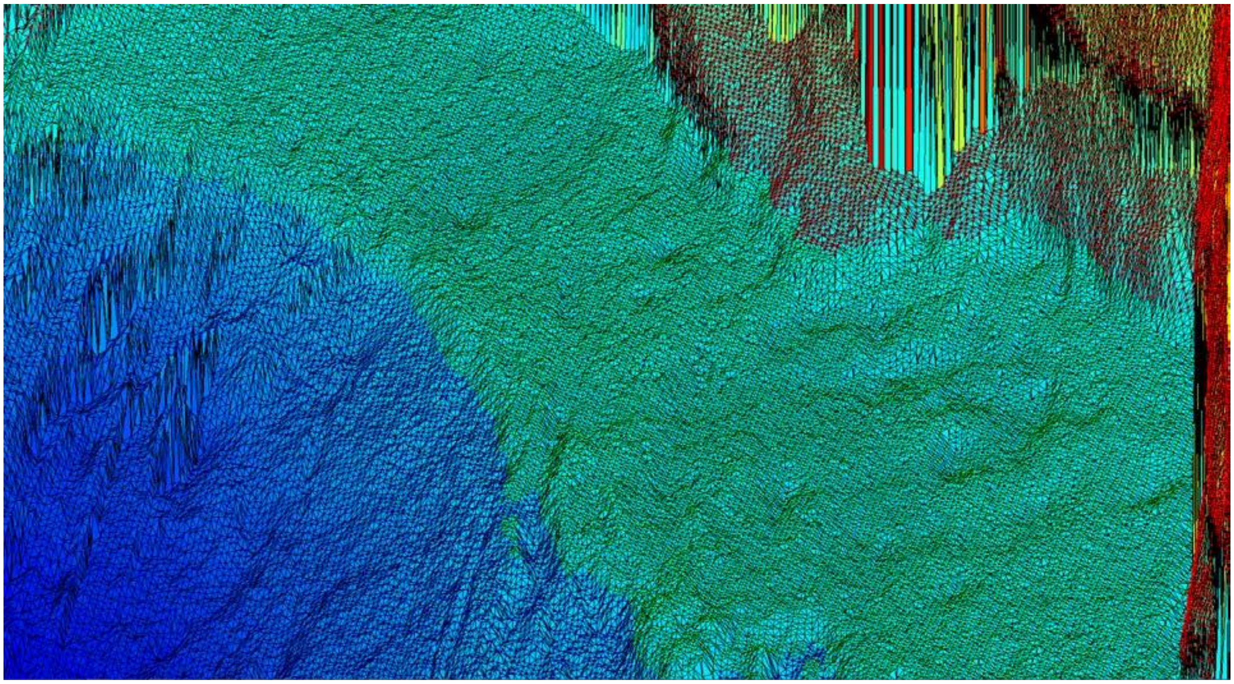

Figure 8: Subset of surface tessellation of Member 12 point cloud (height not to scale).

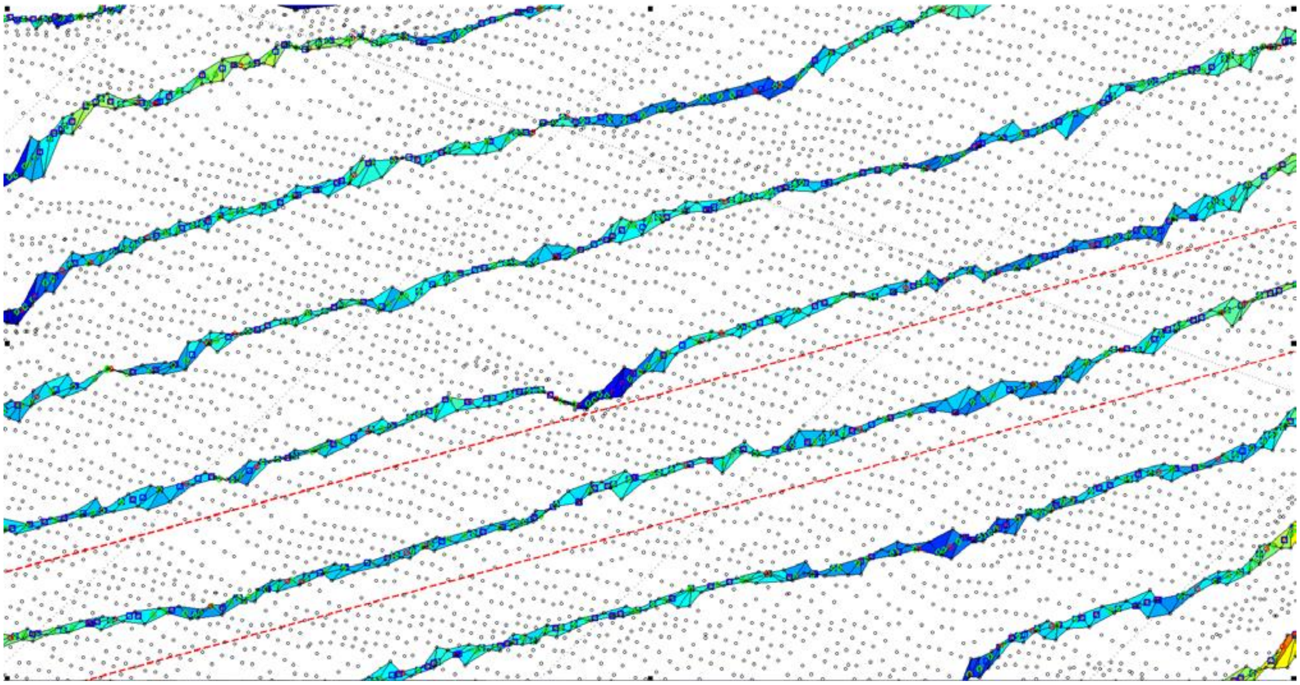

Figure 9: Exemplar intersection triangles and interpolated heights for subset of Member 12 point cloud (results shown for portions of nine parallel cutting planes).

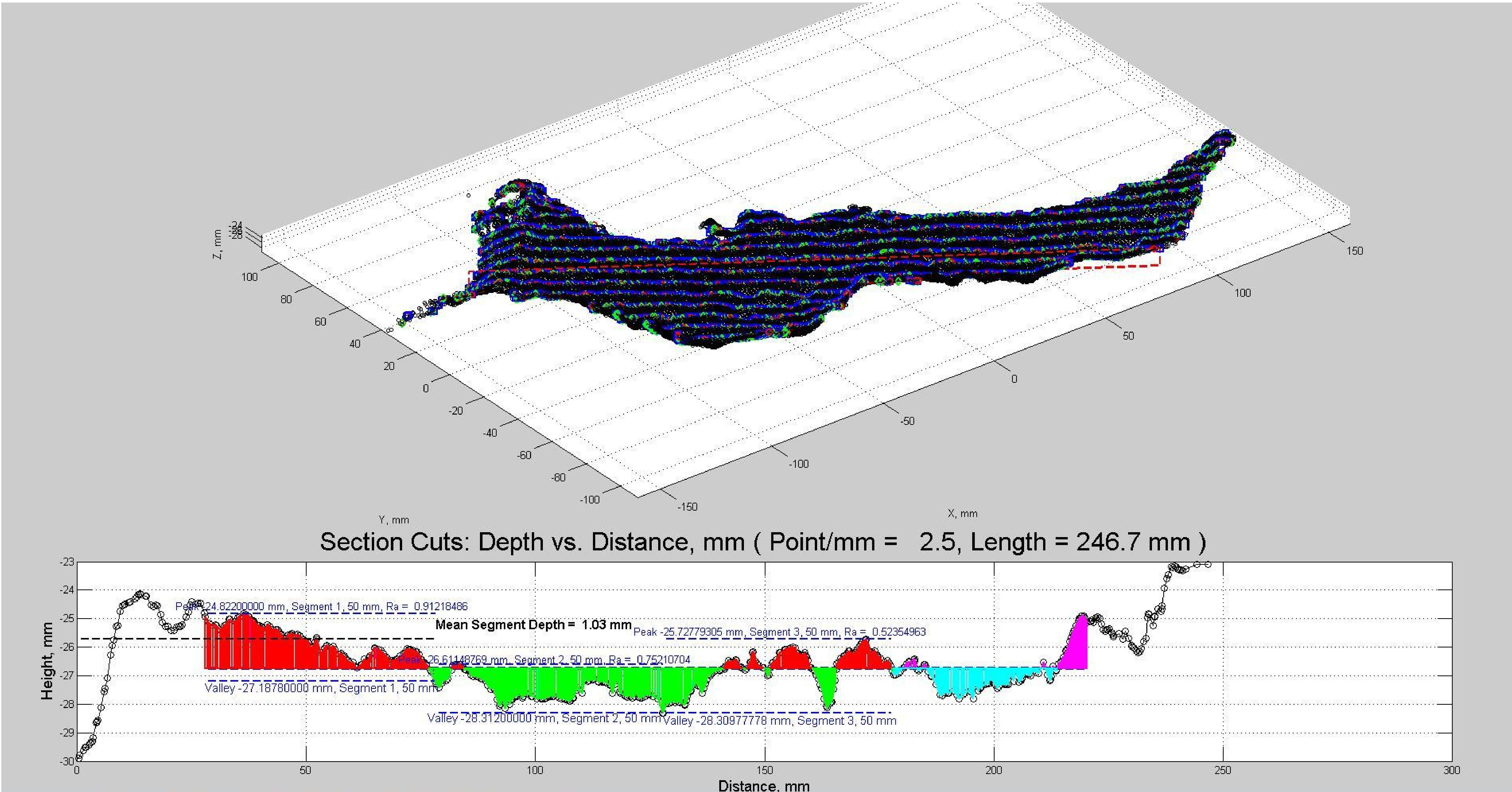

Figure 10: Exemplar section cut and MSD calculation #1 for Member 12.

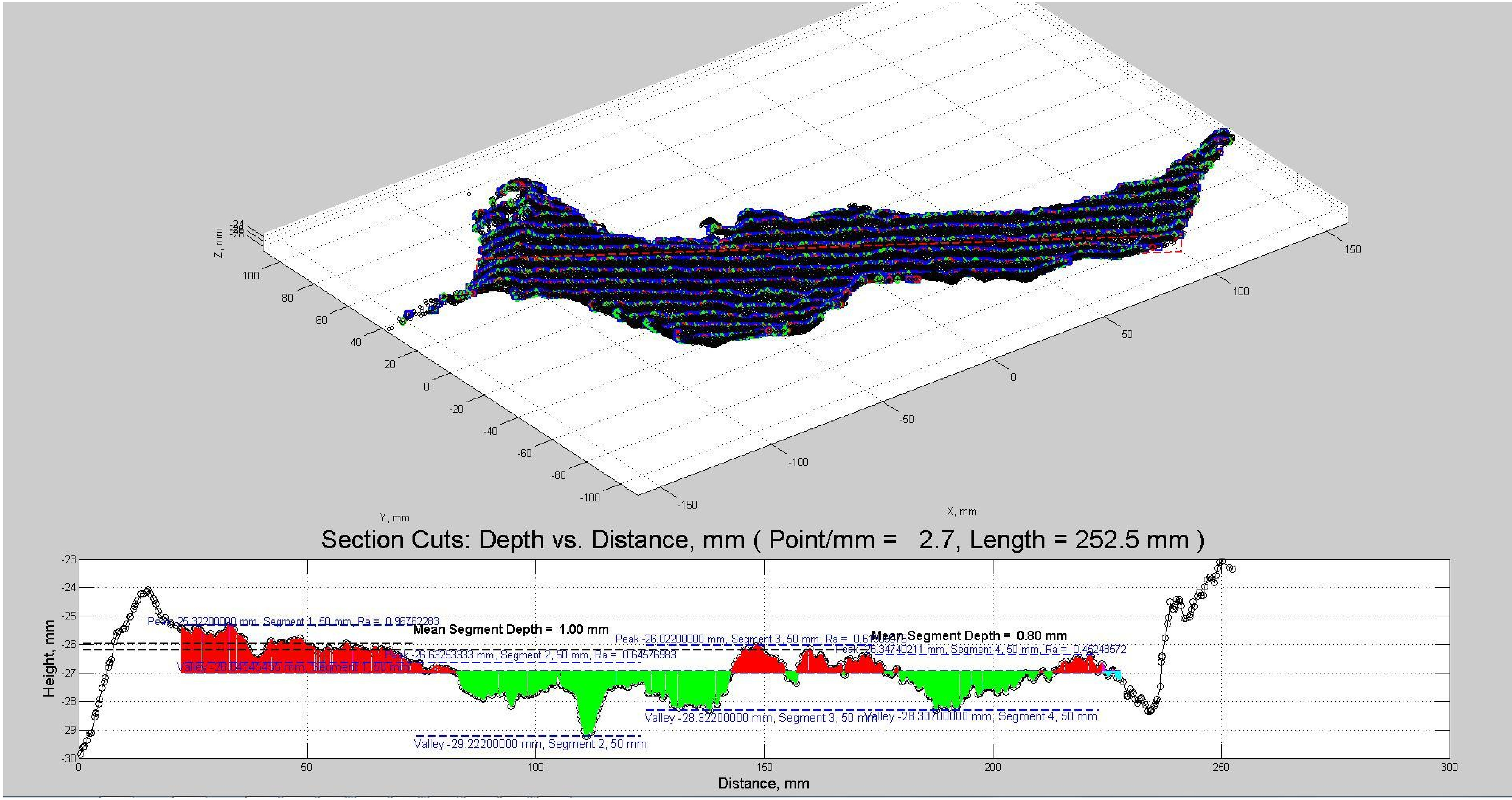

Figure 11: Exemplar section cut and MSD calculation #2 for Member 12.

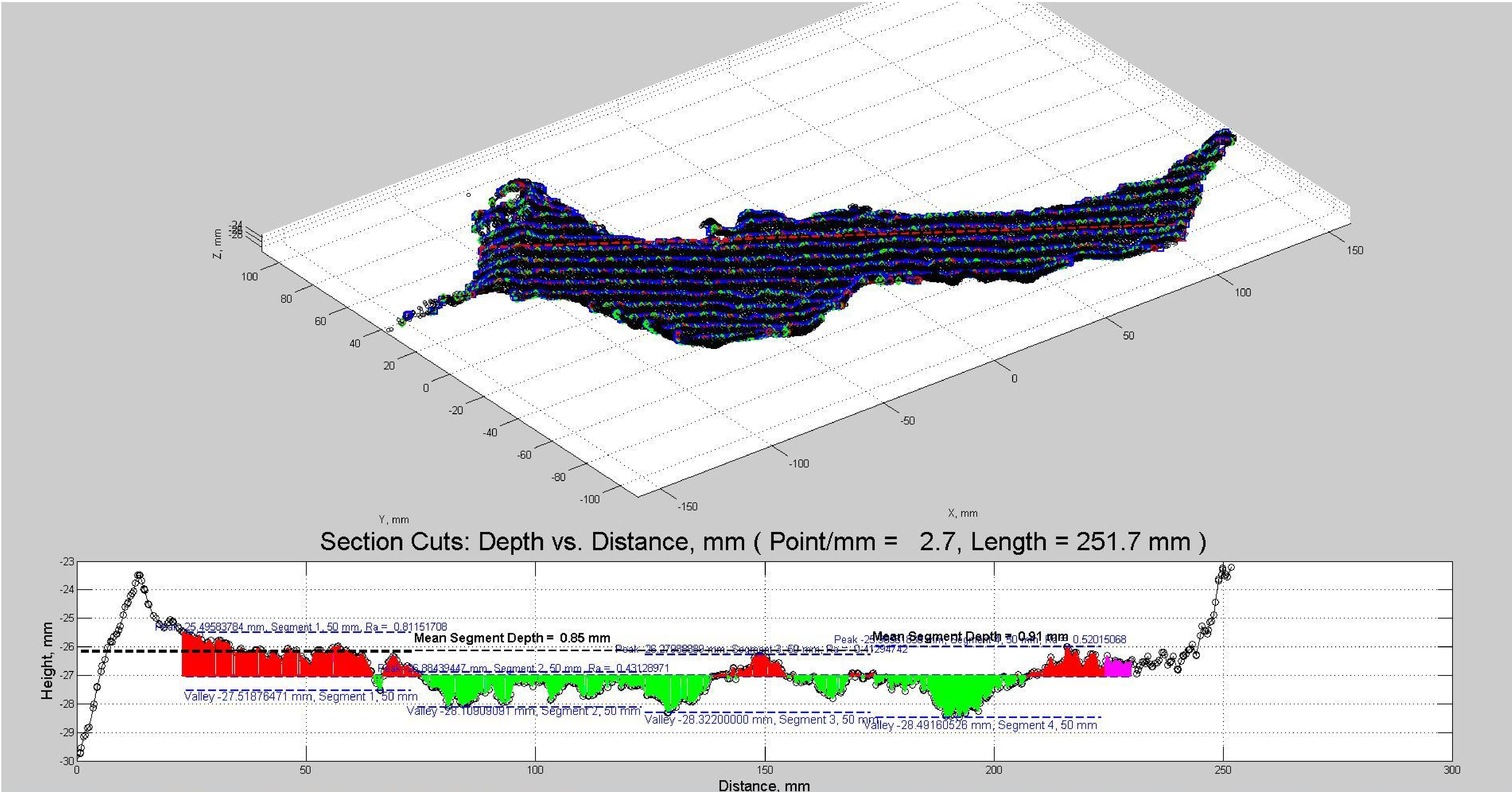

Figure 12: Exemplar section cut and MSD calculation #3 for Member 12.