CAIT-UTC-REG52

Bridge Deck Surface Profile Evaluation for Rapid Screening and Deterioration Monitoring

FINAL REPORT
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16. Abstract

The assessment of bridge deck condition demands the development of rapid and efficient diagnosis, prognosis, and repair techniques to safely and cost-effectively extend the life-cycle of our transportation infrastructure. Without the ability to identify and characterize deficiencies at their early stages, prognosis and various repair strategies simply cannot be brought to bear effectively. Therefore, there is a pressing need for the implementation of wireless, non-contact, or remote sensors that can provide rapid and cost-effective data. LiDAR sensors have the ability to capture dense point clouds that define the geometry of objects in a remote (non-contract) manner. This project evaluates the impact of capturing point cloud data of bridge deck top surfaces to enable a rapid screening method by identifying characteristics of early stage deterioration.

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Description of The Problem

The assessment of bridge deck condition demands the development of rapid and efficient diagnosis, prognosis, and repair techniques to safely and cost-effectively extend the life-cycle of our transportation infrastructure. Without the ability to identify and characterize deficiencies at their early stages, prognosis and various repair strategies simply cannot be brought to bear effectively. Bridge owners have begun to explore augmenting conventional assessment approaches with nondestructive evaluation (NDE), yet the primary barrier of contact structural evaluations is not simply cost but the disruption of traveling traffic.

Therefore, there is a pressing need for the implementation of wireless, non-contact, or remote sensors that can provide rapid and cost-effective data. Light Detection and Ranging (LiDAR) sensors have the ability to capture dense point clouds that define the geometry of objects in a remote (non-contract) manner. This project evaluates the impact of capturing point cloud data of bridge deck top surfaces to enable a rapid screening method by identifying characteristics of early stage deterioration. Ultimately, this screening method will allow bridge owners to rank their infrastructure and help prioritize their assets.

Bridge Deck Condition

The bridge deck condition rating, typically used for visual, hands-on assessment, is based on a scale from 0 to 9, representing a failed to excellent condition, respectively. This scale is in accordance with the guidelines in the *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges* provided by the Federal Highway Administration (FHWA), as shown below in Figure 1.

Code	Description
N	NOT APPLICABLE
9	EXCELLENT CONDITION
8	VERY GOOD CONDITION - no problems noted.
7	GOOD CONDITION - some minor problems.
6	SATISFACTORY CONDITION - structural elements show some minor deterioration.
5	FAIR CONDITION - all primary structural elements are sound but may have minor section loss, cracking, spalling or scour.
4	POOR CONDITION - advanced section loss, deterioration, spalling or scour.
3	SERIOUS CONDITION - loss of section, deterioration, spalling or scour have seriously affected primary structural components. Local failures are possible. Fatigue cracks in steel or shear cracks in concrete may be present.
2	CRITICAL CONDITION - advanced deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present or scour may have removed substructure support. Unless closely monitored it may be necessary to close the bridge until corrective action is taken.
1	"IMMINENT" FAILURE CONDITION - major deterioration or section loss present in critical structural components or obvious vertical or horizontal movement affecting structure stability. Bridge is closed to traffic but corrective action may put back in light service.
0	FAILED CONDITION - out of service - beyond corrective action.

Figure 1. General Condition Ratings provided by the FHWA.

When determining the rating of the structure, the *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges* provided by the Federal Highway Administration (FHWA) states that concrete decks are to be inspected for crackling, scaling, spalling, leaching, chloride contamination, potholing, delamination, and full or partial depth failures. Steel grid decks and Timber decks should also be inspected. For steel grids it is critical to inspect for broken welds, broken grids, section loss, and growth if filled grids from corrosion. Timber decks should be inspected for splitting, crushing, fastener failure, and deterioration from rot. When bridges are rated 0, 1, 2, 3, or 4, it is identified as a structurally deficient classification for that particular bridge. Though there may be other factors to consider and account for during inspection such as the condition of the wearing surface, curbs, sidewalks, bridge rail and protective system joints, they should not be considered in the overall deck evaluation. The scope of this project considers the evaluation of concrete bridge decks.

Conventional Evaluation and Assessment Methods

Chain dragging

One of the main traditional methods to inspect concrete decks for delamination is chain dragging. It is a simple method in which the inspector will drag heavy chains over the concrete deck creating a distinct sound over the areas with potential delamination. These areas are then marked and mapped for further evaluation. Typically, when this method is used, multiple chains can be incorporated to cover large areas quickly. However, this method is heavily reliant upon the inspector's expertise to distinguish the different sounds being produced, as high levels of background noise could difficult the evaluation. The test also causes a disruption of traveling traffic, as the lane under inspection must be closed. Figure 2 below shows an undergoing chain dragging test.

Figure 2. Chain Dragging Test (Source: www.researchgate.net).

Visual Inspection

Visual Inspection is one of the most common types of inspections done on bridges. This method includes looking over a structure through the naked eye of qualified inspectors, for defects on a bridge surface such as potholes, cracks, spalling, corrosion, joint condition, among others. Traditionally, this includes physically going out to the structure and visually inspecting it. Inspectors would sometimes require the use of bucket trucks to review the conditions underneath a bridge if needed. While more recently, the implementation of Remote Visual Inspection (RVI) is starting to be implemented. RVI includes the use of drones to safely reach hard-to-access areas on the structure.

Traditional visual inspection can only be conducted by certified inspectors with Federal Highway Administration (FHWA) approved comprehensive training courses. Some limitations to this method include controlling traffic, visual acuity, color vision, complexity, accessibility and cost. Traffic would need to be controlled on both sides of the bridge, especially if a bucket truck needs to maneuver on the structure. Visual acuity and color vision refer to the vision of the inspector(s) doing the evaluation, and how well they are able to see clearness and sharpness within a distance of 20 feet as well as color. The complexity, accessibility and cost of a structure's inspection is also a limitation since there may be areas that would be hard to access on the bridge and other alternatives, such as drones or using heavy equipment would be expensive to buy. In general, this method is highly reliable for identifying visible damage, however it does not allow for an adequate assessment of what occurs on the interior of the structure. Figure 3 below shows an example of a visual inspection of a bridge using a bucket truck.

Figure 3. Visual Inspection on a Bridge using a Snoops Truck.

Hammer sounding

A hammer sounding test provides a qualitative evaluation of the concrete in question. This non-destructive process involves hitting the concrete with the hammer and analyzing the sounds that it makes at different areas of the concrete. The higher pitched and stronger hammer vibrations, the stronger the concrete. The lower pitched and hollow sounding areas, more so described as a drum like sound, the weaker the concrete. This method works for finding voids and deformations at the top part of the concrete but is unable to determine the condition of the concrete deeper in the member. Another limitation to this method is being unable to find possible defects underneath overlays. Similar to chain dragging and visual inspection, the expertise of the inspector is key when assessing the deck. Figure 4 shows a typical diagram of how the hammer sounding test is performed to evaluate the condition of concrete.

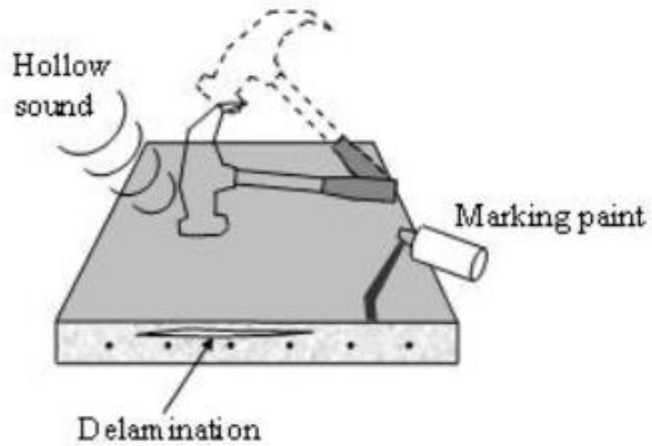


Figure 4. Hammer Sounding Test Diagram.

Modern Approaches – Non-Destructive Evaluation (NDE)

Important limitations of the aforementioned conventional assessment methods are the lack of spatial information, the time required to complete the assessment, and the subjective nature of the data. Capturing spatial information would enable a more accurate and objective mapping and quantification of the damaged areas. The implementation of modern NDE methods aid to ease some of the limitations of conventional inspection methods. Modern NDE digital data provides geometry information that maps the acquired information including depth of the damage found. The most common NDE used are presented next.

Ground Penetrating Radar (GPR)

A prevalent and common form of Non-destructive evaluation method for bridges is Ground Penetrating Radar. For this method, electromagnetic wave pulses are transmitted via an antenna which are then collected by a radar receiver to make an image of the subsurface features in a bridge deck or pavement. As the pulse encountered a discontinuity, they are reflected back which could indicate the presence of delamination. Therefore, GPR has been found useful for the evaluation of bridge decks on determining the depth of concrete and to spot the presence of potential deterioration (e.g. delamination). Figure 5 illustrates a GPR test being carried out in which it cannot be deployed by hand or push carts.

Figure 5. Ground Penetrating Radar Test.

Current GPR instrumentation, have the capacity of collecting data through a depth of up to 50 m (164 ft). In concrete bridge deck applications, GPR technologies are applied for collecting data 1 m (3.28 ft) into the surface. Figure 6 bellow, show the array of GPR applications and the frequency needed to achieve the required depths.

GPR Center frequency vs penetration depth [3]

Center Frequency (MHz)	***Depth of Penetration (m)***	***Typical Applications***
1600	0.5	Concrete Evaluation
900	1	Concrete Evaluation, Void Detection
400	4	Utility, Engineering, Environmental, Void Detection
270	6	Utility, Engineering, Geotechnical
200	7	Geotechnical, Engineering, Environmental
100	20	Geotechnical, Environmental, Mining
16 - 80	35 - 50	Geotechnical

Figure 6. GPR Frequency Vs. Penetration Depth

A shortcoming associated with GPR technology is the limitation of waves to penetrate through metal, blocking the possibility for detecting voids, delamination, or cracks under the rebars. On the other hand, this means that GPR is useful in determining the location of steel rebars within the deck.

Impact Echo (IE)

Impact Echo is an NDE technique that relies on the acoustical resonance of a material's internal flaws to detect subsurface delamination. In this test, a short impact is made on the deck which causes stress waves to progress through the material back and forth between the impacted and opposite surface, as well as internal flaws. A time domain and frequency domain will be acquired to analyze the data and discover any internal flaws such as delamination, cracks, voids, and honeycombing. Figure 7 below shows a typical procedure for the Impact Echo test.

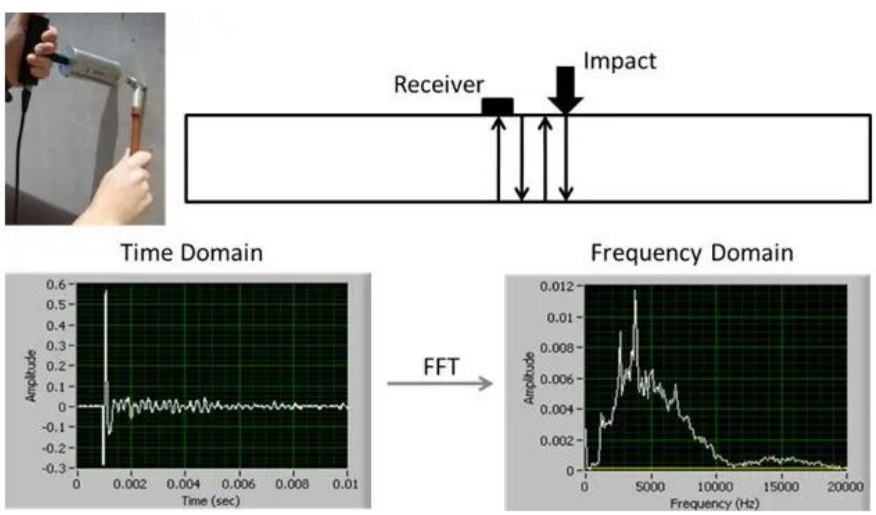


Figure 7. Impact Echo Test.

An important limitation of IE is that the technology fails to differentiate between air voids and delamination. For this reason, it is necessary to take data from multiple points to ensure sufficient information is collected, that properly reflects the condition stage of the elements.

Half Cell Potential (HCP)

Half Cell Potential is a method to determine the risk of corrosion or the presence of corrosion on the reinforcing steel in concrete. This method uses a reference electrode to compare to the reinforcing steel that is being tested to measure the potential difference between the two. From there, ASTM C876 provides the probability of steel corrosion activity based on the measured potential. Figure 8 shows the measurement set-up for a Half Cell Potential test, while Figure 9 shows the ASTM C876 table for the criteria for corrosion of steel in concrete.

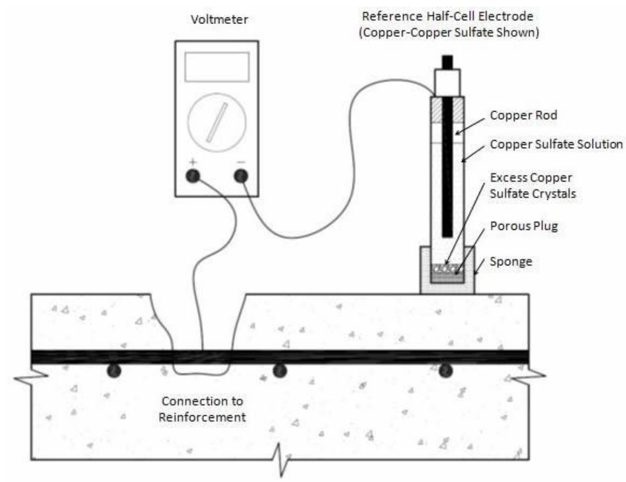


Figure 8. HCP Test Setting.

Copper/Copper sulfate	Silver/silver chloride / 4M KCl	Standard hydrogen electrode	Calomel	Corrosion condition
>-200 mV	> -106mV	> +116mV	> -126mV	Low (10% risk)
-200 to -350mV	-106 to -256mV	+116 to -32mV	-126 to -276mV	Intermediate risk
< -350mV	< -256mV	< -34mV	< -276 mV	High (<90% risk)
< -500mV	< -406mV	< -184mV	< -426 mV	Severe corrosion

Linear Polarization Resistance (LPR) Technique

Figure 9. ASTM C876 Criteria for Corrosion of Steel in Concrete.

Shortcoming associated with HCP are the potential fluctuation of results based on the presence of chlorine, moisture, oxygen, and temperature gradients within the concrete. Time consumption is another downside of HCP, since multiple data points must be collected in order to achieve a comprehensive map.

Electrical Resistivity (ER)

Electric Resistivity is defined as a material property that describes the strength of resistance to the flow of an electric current. This is important to the bridge inspection because the electrical resistance of the concrete is a controlling factor for the potential rate of corrosion. This test goes hand in hand with the above HCP test where they both test the possible rate of corrosion. An example of an ER test can be seen in the figure below. The higher the electrical resistivity of the concrete, the less likely the reinforcements are to corrode.

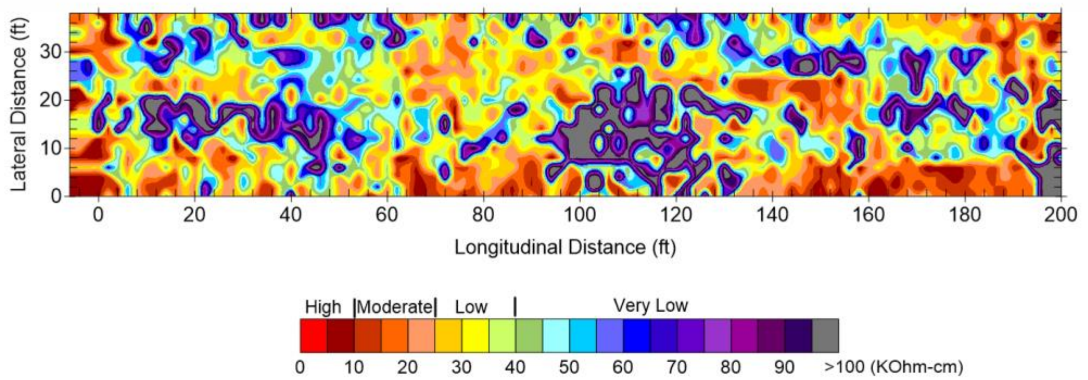


Figure 10. ER Data Sample.

An important limitation of ER, comes from the effects of water to cement ratio of the concrete tested. Higher w/c ratio results in high percentage of porosity, leading to lower electrical resistivity. These values are also affected by the incorporation of supplementary cementitious materials. Additionally, during the time of data collection, the presence of water must be considered when interpreting the final results, since the presence of water inside the concrete will reduce its porosity.

Point Cloud Data via LiDAR

Common LiDAR scanner operational mechanisms consist of the emission of light beams over a range of 300° vertically and 360° horizontally with a step sizes as small as 0.009° (1.57E-4 rad) at full resolution on both directions (vertical and horizontal rotation) to characterize its surroundings. These pulses travel from the scanner and bounce back once they reach a surface. Then, based on the phase shift of the pulses and the rotational angles (vertical and horizontal) of the scanner the point is registered on a global coordinate system (X, Y, Z) which is how different types of software are able to process and generate the 3D images. Figure 11 shows the operation of a typical LiDAR scanner.

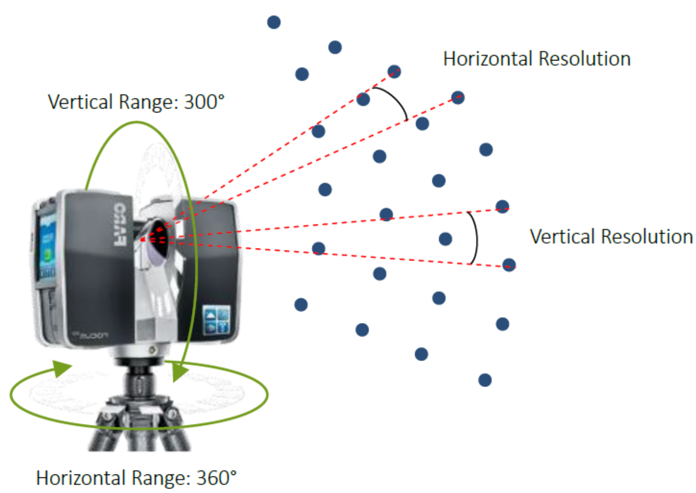
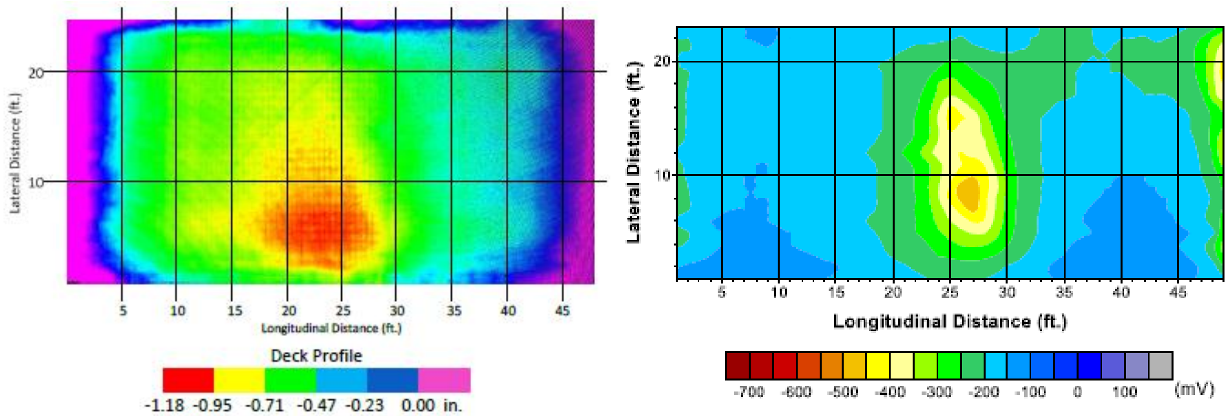


Figure 11. Principals of operation of a LiDAR scanner.

Limitations of LiDAR mainly fall on its inability to scan the interior of structures, which entails the performance of multiple scans depending on the application, and the level of details needed. The size of the data collected is also seen as a limitation, since the point cloud of each data set can vary between one and tens of gigabits.

Deck Top Surface Geometry Characteristics and Condition Stage

Recent studies have indicated a potential correlation between the deck's top surface geometry with its deterioration pattern and stage. A study performed by Dr. Trias on the comparison of the geometry information captured via LiDAR of the top surface of a bridge deck with its correspondent NDE data, presented clear evidence of connection. Figure 12 evidences the potential association between the geometry of the scanned deck and its deterioration pattern.



(a) (b)

Figure 12. (a) LiDAR data of deck surface; (b) Half Cell Potential data of deck after deterioration

Expanding on the information presented above, this project investigates how the geometry data captured via LiDAR of the top surface of bridge decks correlates with the deterioration conditions provided by FHWA's Long Term Bridge Performance InfoBridge data, and how can it help predict potential areas of early deterioration on newly constructed members.

Approach

To expand on the aformentioned knowledge, this project selects 8 bridges in the State of New Jersey to perform an analysis of their top surface geometry captured via LiDAR, and determine potential correlation with their current condition stage. For this, the research team will identify critical aspects of bridge deck deterioration as are rutting, spalling, low points on vertical curvature, and potholes.

Description of Structures

Bridge 0954163 - Baldwin Avenue over Conrail & Path:

Structure 0954163 is a two-span continuous steel girder bridge, located in Jersey City in Hudson County, NJ. The bridge was built in 1928, while the deck was reconstructed in 1990. It carries two traffic lanes, one on each side, with an ADT of 37,940 and a Truck ADT of 4% (2018). The bridge has a total length of 166 ft, the longer span being 71.9 ft long. It has a curb-to-curb width of 32.2 ft, and out-to-out width of 33.8 ft. The total area of the deck is 5609.9 sq.ft. with a skew angle of 14°. The deck condition rating for year 2022 is 4 (Poor).

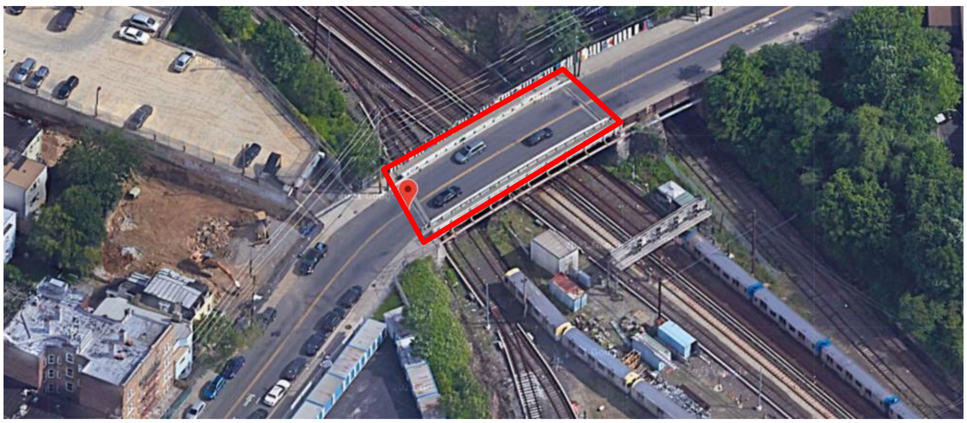


Figure 5. Structure 0954163 – Aerial View.

Bridge 0416151 - RT 73 & Ramp G over Route US 130:

Structure 0416151 is a two-span continuous concrete encased steel girder bridge, located in Pennsauken Township in Camden County, NJ. The bridge was built in 1930. It carries eight traffic lanes, four on each side, with an ADT of 54,495 and a Truck ADT of 4% (2019). The bridge has a total length of 148 ft, the longer span being 81 ft long. It has a curb-to-curb width of 100.4 ft, and out-to-out width of 134.5 ft. The total area of the deck is 19903.5 sq.ft. with a skew angle of 1°. The deck condition rating for year 2022 is 4 (Poor).

Figure 10. Structure 0416151 – Aerial View.

Bridge 361632N - Garden State Parkway NB over Interstate 163 Ramp NBX:

Structure 361632N is a two-span continuous steel girder bridge, located in Paramus Borough in Bergen County, NJ. The bridge was built in 2016. It carries three traffic lanes, with an ADT of 36,400 and a Truck ADT of 1% (2018). The bridge has a total length of 210 ft, the longer span being 112.9 ft long. It has a curb-to-curb width of 58.1 ft, and out-to-out width of 61.7 ft. The total area of the deck is 12951.1 sq.ft. with a skew angle of 22°. The deck condition rating for year 2022 is 8 (Very good).

Figure 6. Structure 361632N – Aerial View.

Bridge 18G0701 - S Main ST(CR533) over Royce Brook:

Structure 18G0701 is a two-span continuous steel girder bridge, located in Manville Borough in Somerset County, NJ. The bridge was built in 2019. It carries four traffic lanes, two on each side, with an ADT of 24,478 and a Truck ADT of 4% (2019). The bridge has a total length of 75.1 ft, the longer span being 35.1 ft long. It has a curb-to-curb width of 46.3 ft, and out-to-out width of 65.3 ft. The total area of the deck is 4905.2 sq.ft. with a skew angle of 9°. The deck condition rating for year 2022 is 9 (Excellent).

Figure7. Structure 18G0701 – Aerial View.

Bridge 0821155 - Tomlin Rd (CR 607) over I-295:

Structure 0821155 is a two-span continuous steel girder bridge, located in Greenwich Township in Gloucester County, NJ. The bridge was built in 1953. It carries two traffic lanes, one on each side, with an ADT of 1,086 and a Truck ADT of 3% (2018). The bridge has a total length of 159.1 ft, the longer span being 76.1 ft long. It has a curb-to-curb width of 29.9 ft, and out-to-out width of 41 ft. The total area of the deck is 6525.6 sq.ft. with a skew angle of 15°. The deck condition rating for year 2022 is 9 (Excellent).

Figure 9. Structure 0821155 – Aerial View.

Bridge 1317154 - RT 138 EB over Garden State Pkwy NB:

Structure 1317154 is a two span, steel girder bridge, located in Wall Township in Monmouth County, NJ. The bridge was built in 1974. It carries three traffic lanes, with an ADT of 30,130 and a Truck ADT of 5% (2019). The bridge has a total length of 194.9 ft, the longer span being 120.1 ft long. It has a curb-to-curb width of 42.3 ft, and out-to-out width of 50.9 ft. The total area of the deck is 9910.3 sq.ft. with a skew angle of 13°. The deck condition rating for year 2022 is 7 (Good).

Figure 11. Structure 1317154 – Aerial View.

Bridge 1816154 & Structure 1816155 - I-78 over North Branch Raritan River:

Structures 1816154 and 1856155 are twin bridges constructed by two span composite prestressed concrete girders, located in Somerset County, NJ. The bridges were built in 1965, and carry highway I-78 Eastbound and Westbound, respectively, on three traffic lanes each, with an ADT of 54,406 and a Truck ADT of 14% (2019). The bridges have a total length of 112.9 ft, the longer span being 53.1 ft long. The curb-to-curb width is of 50.9 ft, and out-to-out width of 56.1 ft. The total area of the deck is 6331.8 sq.ft. with a skew angle of 11°. The deck condition rating for year 2022 is 6 (Satisfactory) for structure 1816154, and 3 (serious) for structure 1816155.

Figure 8. Structure 1816154 (I-78 EB) & 181655 (I-78 WB) – Aerial View.

Evaluated Aspects

Making use of the point cloud data collected of each bridge deck, this project will evaluate the following aspects:

- Rutting percentage: Rutting will be expressed in percentage of area, in reference to the total area of the deck.
- Overall potholes percentage: Potholes will be expressed in percentage of area, in reference to the total deck area.

- Section loss at joint locations: Deck section loss at the location of joints will be expressed in percentage of area.
- Longitudinal curvature: The longitudinal curvature of each deck will be analyzed to find potential correlation between the presence of low points within the deck and the condition stage.
- Transverse curvature: To evaluate the transverse curvature of the bridge decks, the slope will be compared to the recommended 2% for proper water drainage.

Methodology

Data Collection

A Faro Focus terrestrial laser scanner was used by the research team for collecting the data of all bridge decks. A field visit was conducted to each bridge and positioning of the scanner and scans performed were determined based on the structure's span length, curb-to-curb dimension, obstructions, and traffic flow during scanning. As presented in Figure 13, the scanner was always located on the side of the road (shoulder or sidewalk) to avoid traffic disruptions.

(a) (b)

Figure 13. Typical location of scanner: (a) Scanner located on deck's shoulder; (b) Scanner located on sidewalk.

The scanner settings were not included as an evaluated variable. Given the large dimension of the object scanned, and the superposition provided by the execution of multiple scans, the scanner as set on fixed settings of resolution. The resolution chosen to execute all data collected for this project was 1/3, which represents an angular distance between points of 0.027 degrees. This resolution provides a distance between data points of 0.05 ft at a distance of 10 ft from the scanner. To provide a colored point cloud, some scans were performed using real-time photo collection.

Data Processing

For this project, the data processing method used to transform single scans into a combined point cloud and further dissemination of the data of each bridge deck, is a multi-step procedure that involves handling the data with three software: (1) Faro Scene, (2) CloudCompare, and (3) Microsoft Excel.

Faro scene is the software provided by the scanner manufacturer which is used to register or combine the single scans collected into a single point cloud. For this, an automatic registration provided by the software was selected, were the scans are compared based on their plan view and cloud-to-cloud distance. After each point cloud is generated, scene indicates the level of accuracy of the registration process. To increase the precision of the registration, a preprocessing is highly recommended, where each individual scan is cleaned by removing potential noise and unnecessary points that can interfere with the final registration. Figure 14 shows a typical processed point cloud data that resulted from the registration using Faro Scene. The boxes present in this figure indicate the location of each single scan performed to capture the entirety of the top surface of the bridge deck.

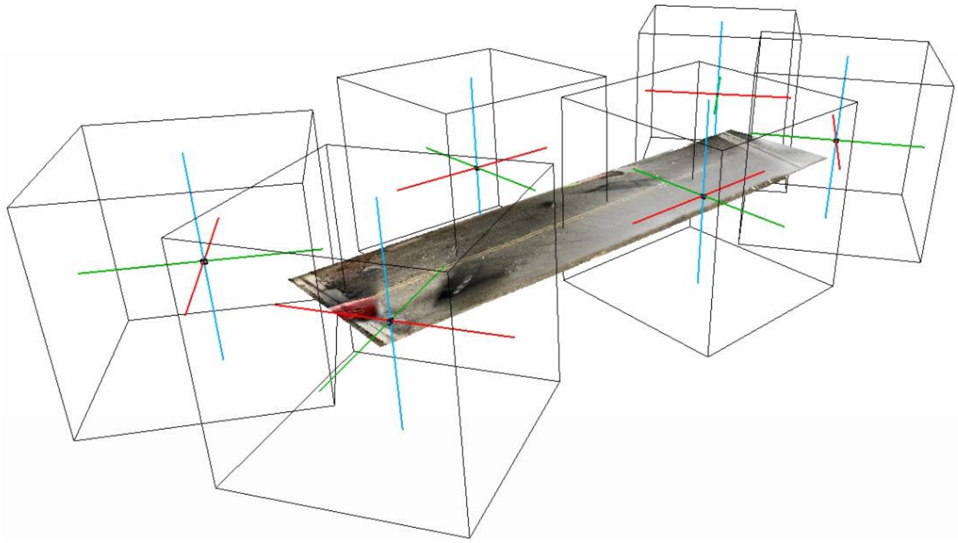


Figure 14. Processed point cloud of a bridge deck.

Once the point cloud of each deck is generated, CloudCompare is used to generate cross-sections on the longitudinal and transverse directions for further analysis. These cross-sections were then exported to Excel, to produce plots that allowed better visualizations of the slopes of the bridge deck surface and highlighted interest areas as low points or discontinuations which could indicate the presence of potholes.

Selection of Structures

The selection of bridge decks for the execution of this project was based on the ADT and deck condition reflected on the InfoBridge webpage. Additionally, the structures were classified as “training” or “predict” as they were to serve for train the assessment protocol, or to test the protocol, respectively.

The following table presents the summary information for the grid of structures used.

Table 1. Structure data and classification.

Structure Number	ADT	Deck Condition	Classification
0954163	37940	4	Training
0416151	54495	4	Training
361632N	36400	8	Predict
18G0701	24478	9	Predict
0821155	1086	9	Predict
1317154	30130	7	Training
1816154	54406	6	Predict
1816155	54406	3	Predict

Findings

Bridge 0954163 - Baldwin Avenue over Conrail & Path

Bridge 0954163 presented a rutting of approximately 36% of the total deck area. The arrows in Figure 15 indicate the presence of rutting on the scanned deck. While the grayed areas on Figure 16, represent the approximated rutting area on the deck. The percentage of rutting area was estimated by adding the grayed squares and dividing this amount by the total number of squares that cover the area of the deck, multiplied by 100. Figure 17 presents a plan view of the top surface of the deck as reference.

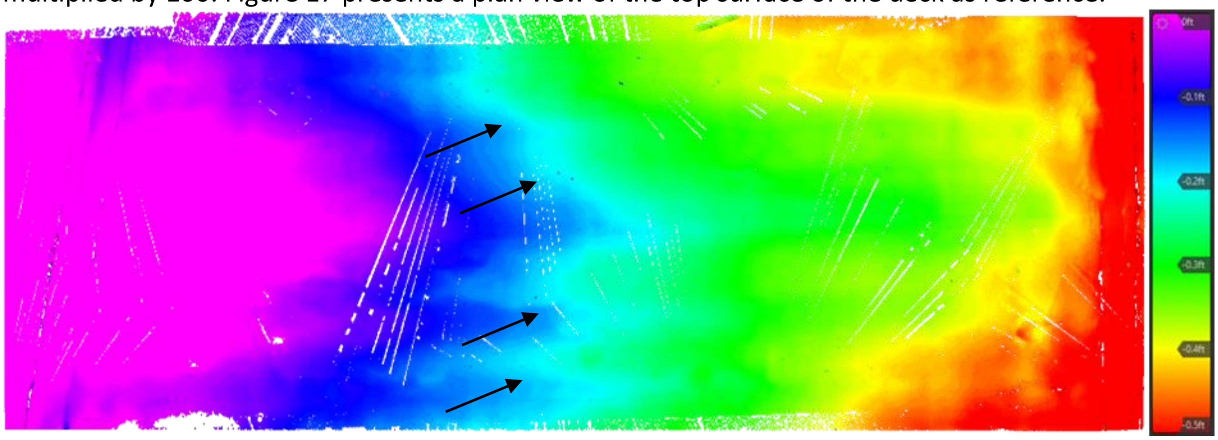


Figure 15. Structure 0954163 - Elevation map, evidence of rutting.

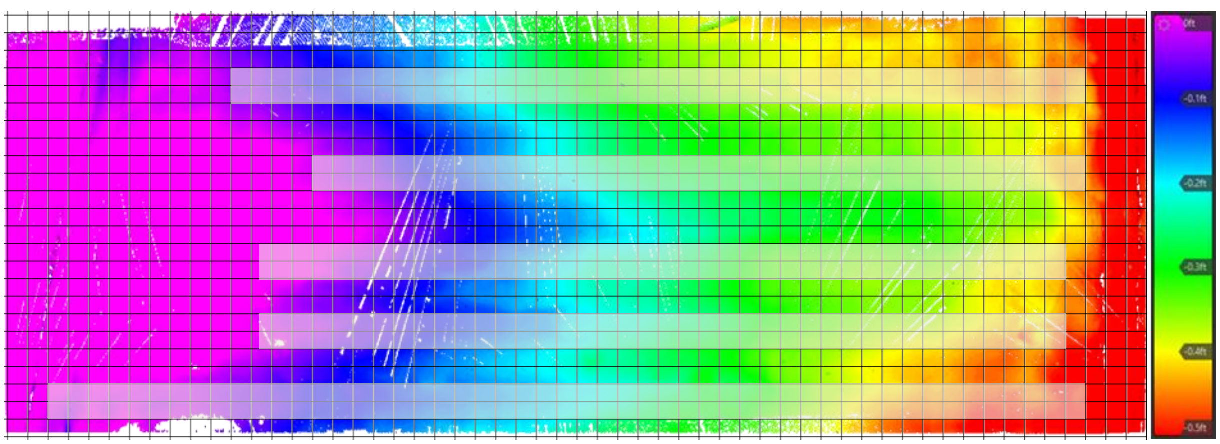


Figure 16. Structure 0954163 - Rutting areas on bridge deck.

Figure 17. Structure 0954163 - RGB image of the deck's top surface.

Cross sections along the transverse and longitudinal directions were generated by creating slices of the point cloud of the deck. The misalignment seen on the plan views do not represent deformations or potential errors, but variations in X or Y coordinate of the selected points. The location of each cross section is presented in Figure 18, where Long A, Long B, and Long C are the cross section on the longitudinal direction, while Trans Top, Trans Mid, and Trans Bottom are the cross sections on the transverse direction. While Figure 19 presents an approximate location of each of the aforementioned cross sections within structure 0954163.

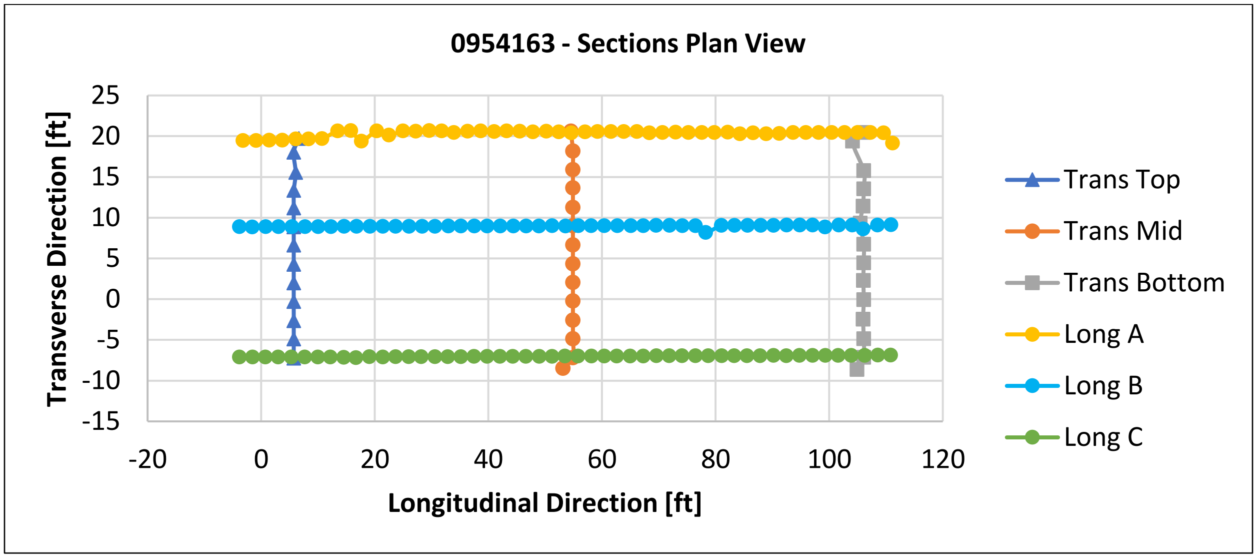


Figure 18. Structure 0954163 - Sections Plan View.

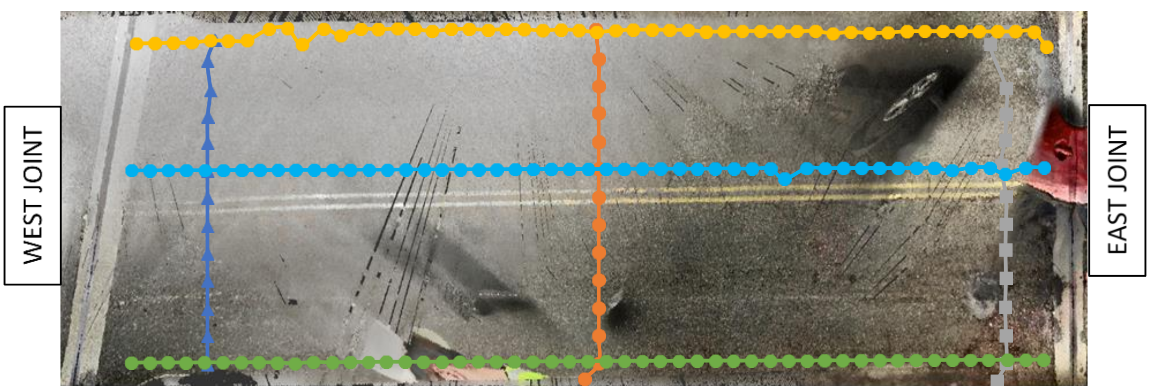


Figure 19. Structure 0954163 - Refence of cross section location.

The longitudinal cross sections generated for this structure show several low points as indicated in Figure 20, which are areas where water is more likely to sit for longer periods accelerating the damage of the reinforcing steel. Additionally, the longitudinal slope was estimated to be of 0.5% slowing the water drainage. From Figure 21, the transverse cross section slope is estimated to be between 0 to 0.8%, which is below the recommended 2%. The plan view presented on Figure 18 indicates the location of the longitudinal and transverse section within the deck.

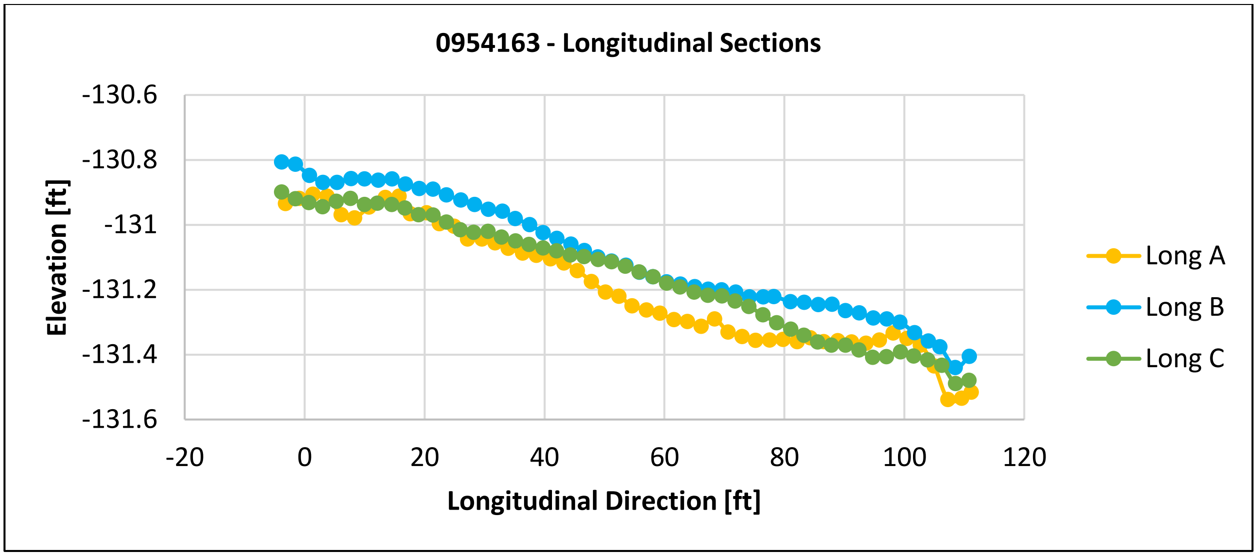


Figure 20. Structure 0954163 - Longitudinal Sections.

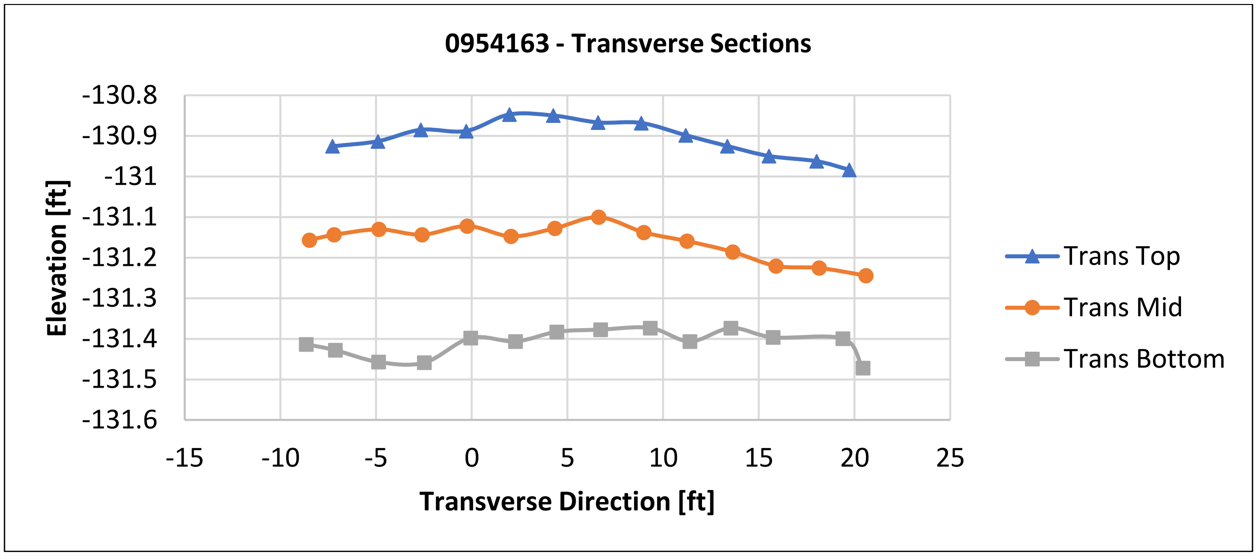
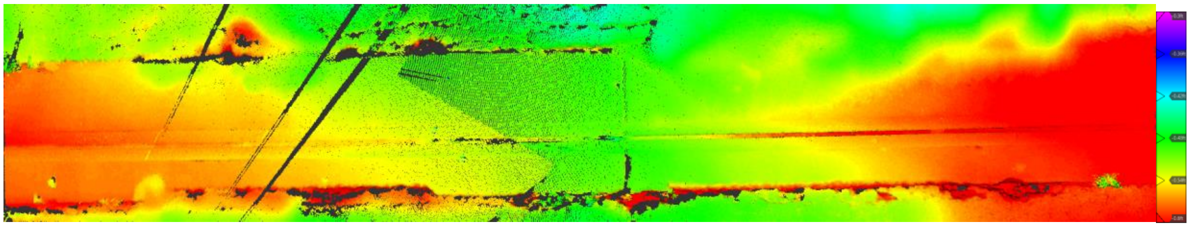
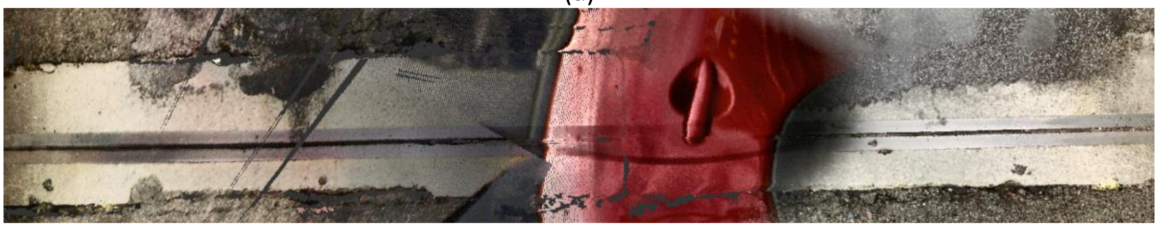


Figure 21. Structure 0954163 - Transverse Sections.

Additional analysis was performed at the location of the joints. LiDAR was capable of detecting the surface of the deteriorated joints. Figure 22 helps visualize the condition of the East joint and the surrounding area, while Figure 24 presents information for the West joint. The lines present on these and other images are originated due to the passing of cars/trucks during data collection, which generates a gap in the point cloud. Following the scope of work of this project, the analysis of the joints will be limited to measuring approximated area of damage. Following the same percent area estimation for calculating the presence of rutting, the East joint presented 18% of deteriorated area, as seen in Figure 23. Similarly, the West joint of the bridge deck presented 39% of deteriorated area, as seen in Figure 25.



(a)



(b)

Figure 22. Structure 0954163 - East joint: (a) Elevation, (b) RGB.

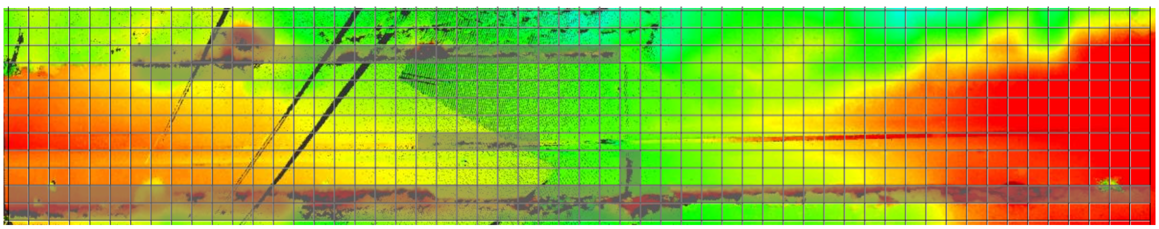
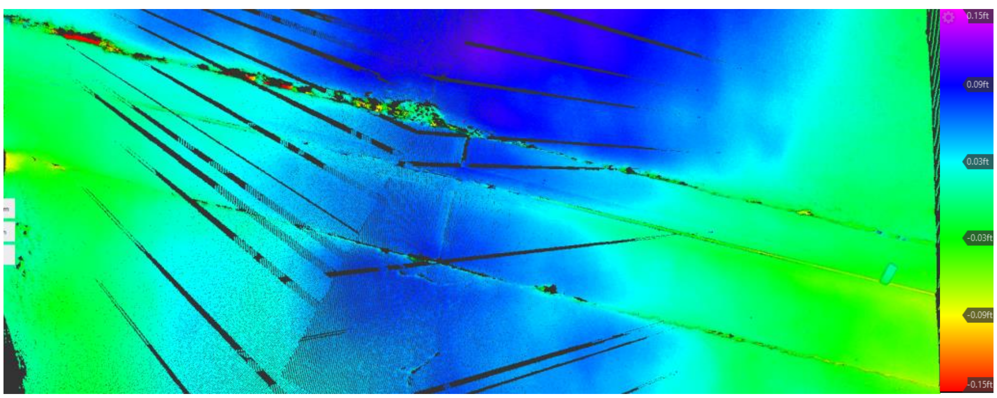
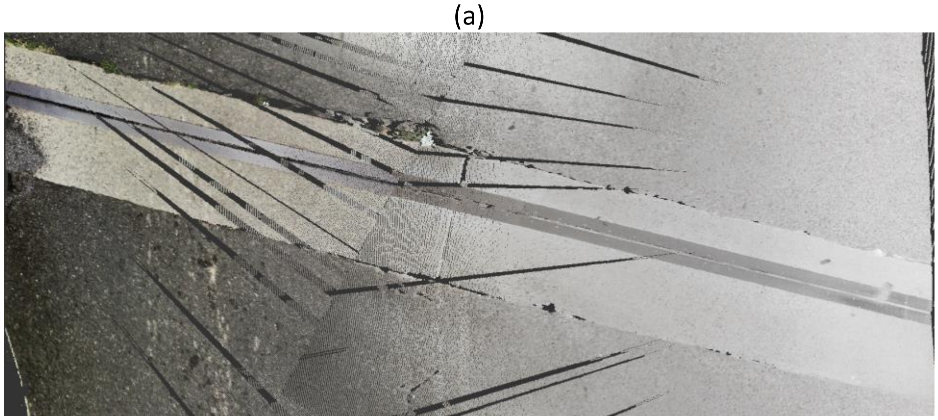


Figure 23. Structure 0954163 – Deteriorated areas of the East joint.



(a)



(b)

Figure 24. Structure 0954163 - West joint: (a) Elevation, (b) RGB.

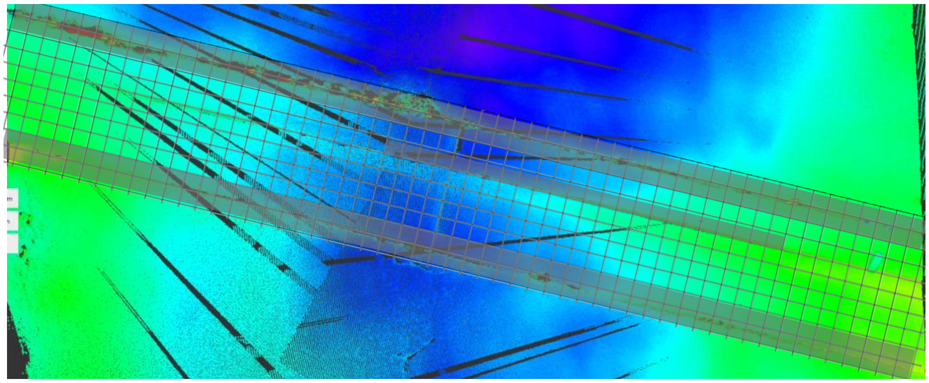


Figure 25. Structure 0954163 - Deteriorated areas of the West joint.

Bridge 0416151 - RT 73 & Ramp G over Route US 130

Bridge 0416151 presented large flat areas that are explained through Figure 26 and Figure 28. Where, Figure 26 represent the variation in elevation of the deck's top surface, while Figure 28 highlights the areas considered flat, since the variation in elevation or slope is inexistent. Figure 27 presents an RGB view of the deck's top surface. The presence of flat areas within the deck affects how the water runs off the structure. In these areas water is more likely to sit and percolate inside the deck, increasing the risk for corrosion of the reinforcing steel.

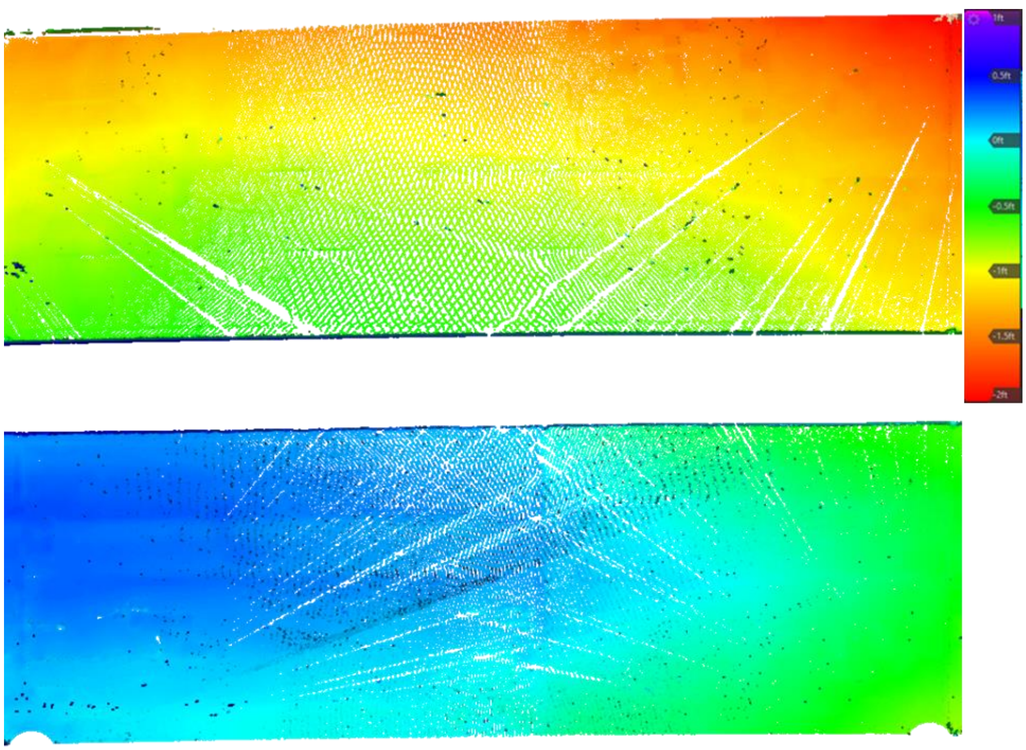


Figure 26. Structure 0416151 - Elevation map.

Figure 27. Structure 0416151 - RGB image of the deck's top surface.

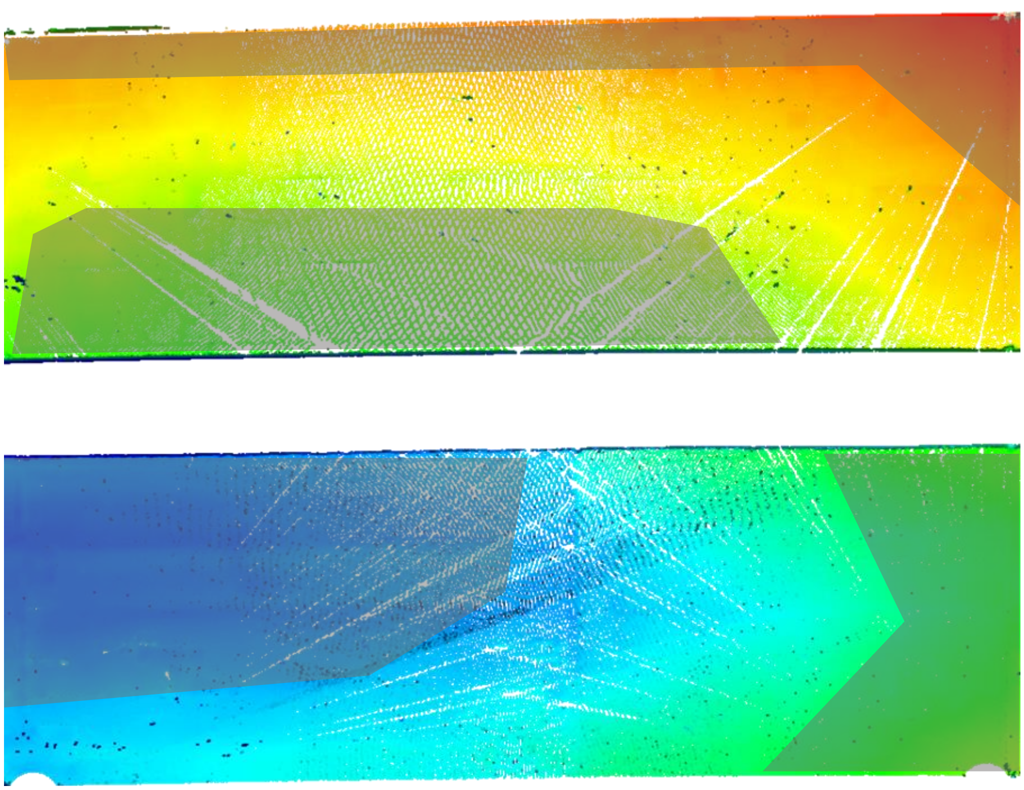


Figure 28. Structure 0416151 - Deck flat areas (Grayed).

The plan view presented on Figure 29 indicates the location of the longitudinal and transverse section within the deck, where Long A, Long B, Long C, and Long D are the cross section on the longitudinal direction, while Trans Top, Trans Mid, and Trans Bottom are the cross sections on the transverse direction. From Figure 31 and Figure 32 the longitudinal and transverse cross sections were estimated to be between 0 and 0.6%, which difficult proper water drainage. Figure 31 also indicates the presence of low points. Figure 30 presents an approximate location of each of the aforementioned cross sections within structure 0416151.

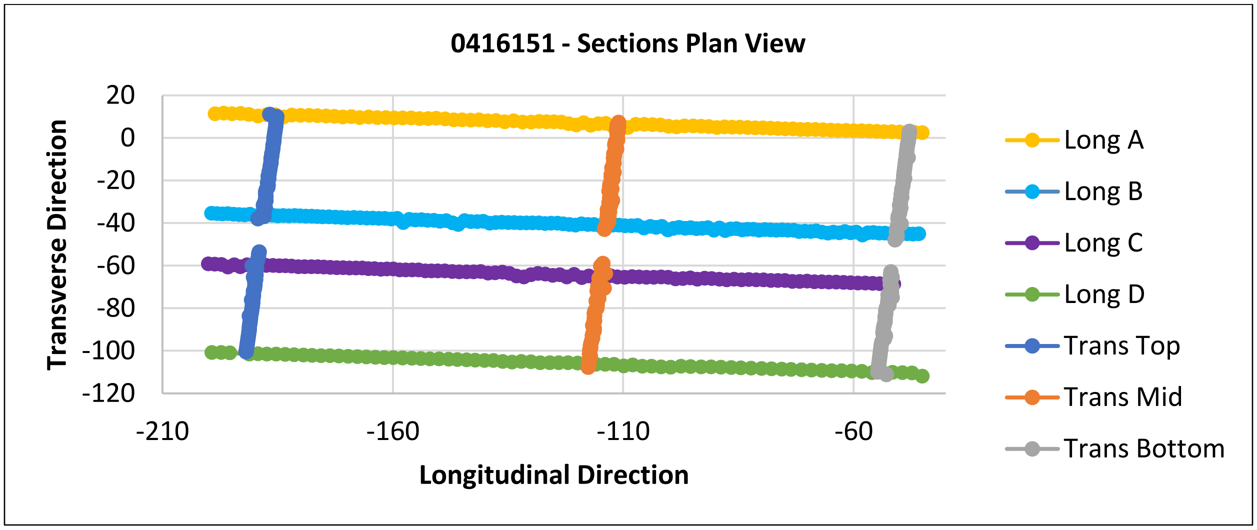


Figure 29. Structure 0416151 - Sections Plan View.

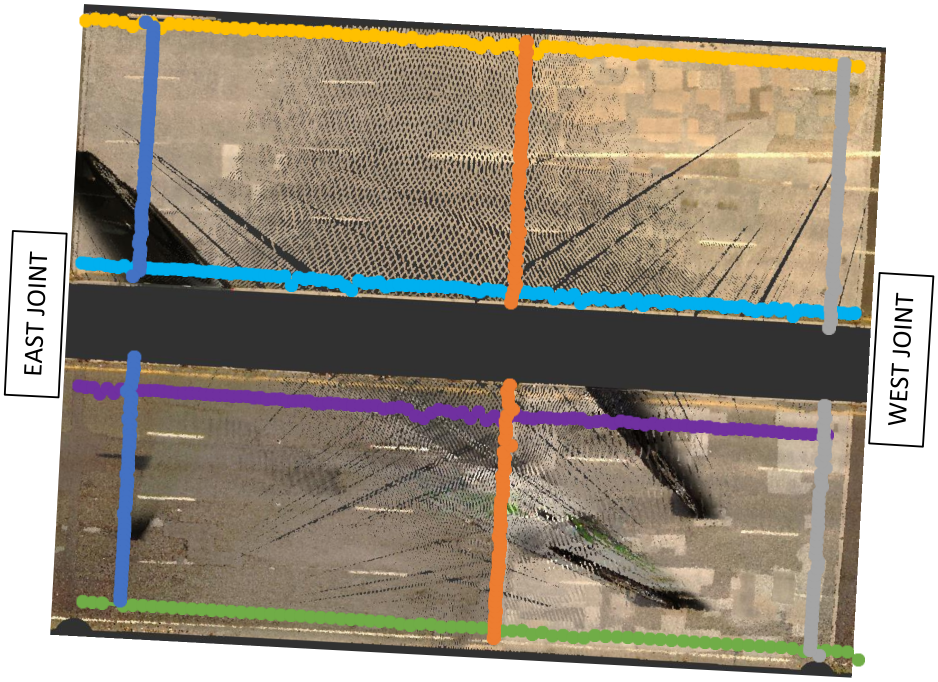


Figure 30. Structure 0416151 - Refence of cross section location.

The peaks present of Figure 31 and Figure 32, represent the potential presence of irregularities on the deck's surface, e.g. small potholes. The noticeable gap found on Figure 32, is due to the presence of a barrier.

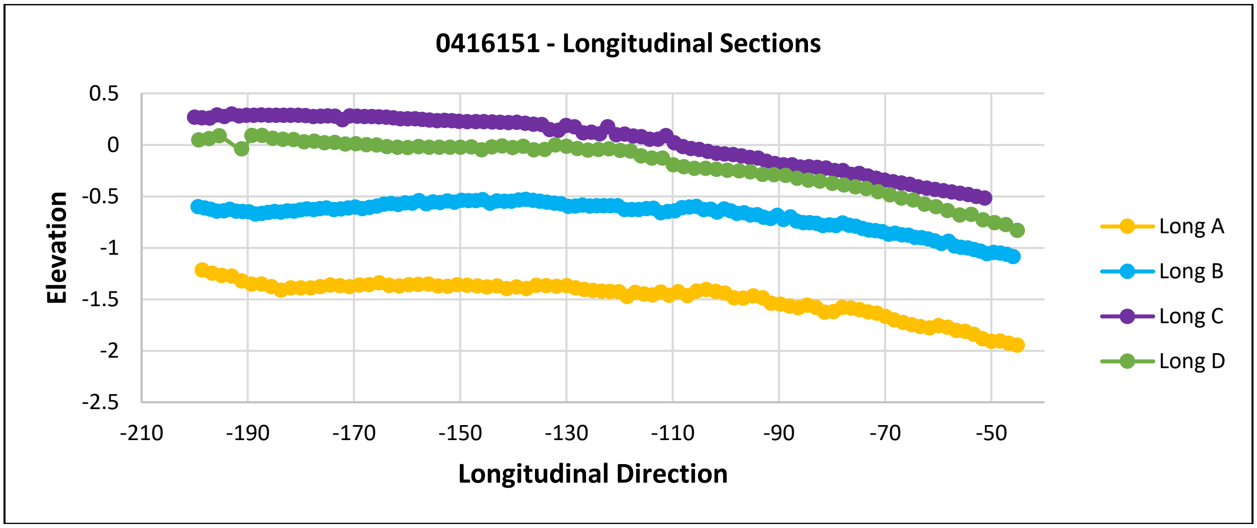


Figure 31. Structure 0416151 - Longitudinal Sections.

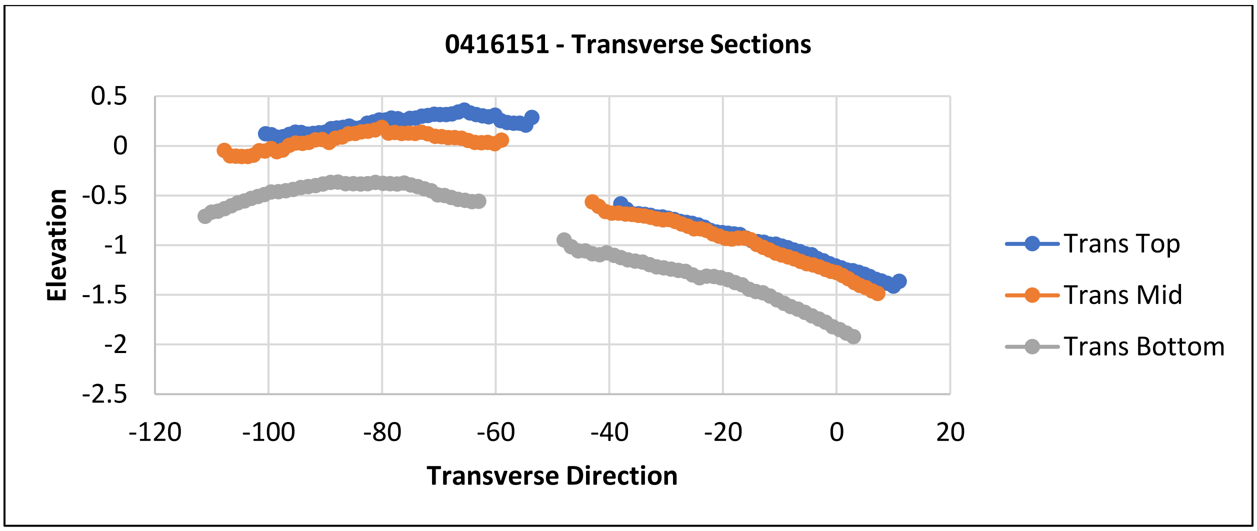


Figure 32. Structure 0416151 - Transverse Sections.

Bridge 361632N - Garden State Parkway NB over Interstate 163 Ramp NBX

The elevation map presented in Figure 33, combined with the longitudinal slope estimated from Figure 37 which was estimated to be between 1 to 1.5%, indicate the presence of proper surface conditions for water to run off the deck without difficulty. Moreover, the transverse slope estimated from Figure 38 was found to be approximately 2%. Structure 361632N does not present clear evidence of potential areas susceptible to early deterioration. It is important to indicate that, based on the findings of Figure 37, the first half (upstream) of the deck presents lower slope than the second half of the deck, this could alter the performance as water sits longer on flatter areas causing faster deterioration. Figure 34, presents an RGB view of the deck's top surface.

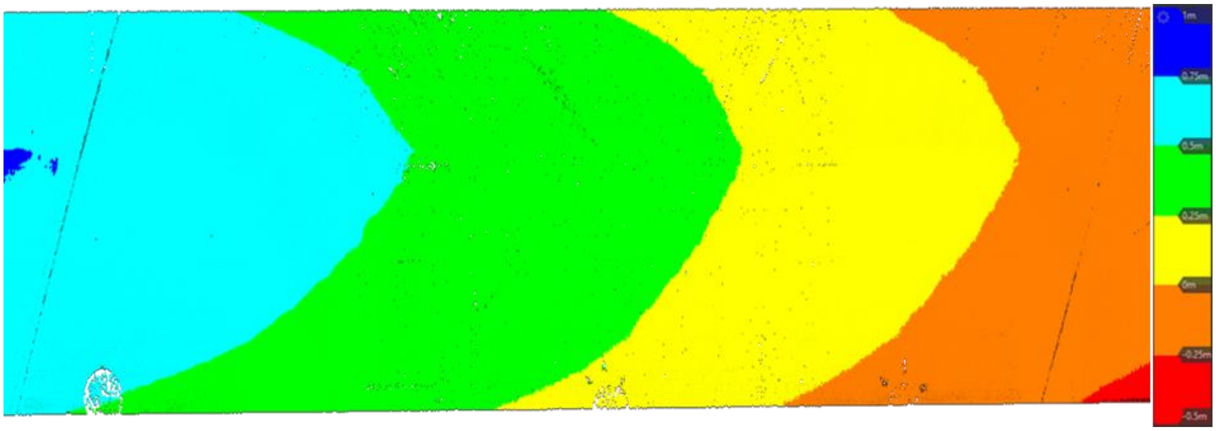


Figure 33. Structure 361632N - Elevation map.

Figure 34. Structure 361632N - RGB image of the deck's top surface.

The plan view presented on Figure 35 indicates the location of the longitudinal and transverse section within the deck, where Long A, Long B, Long C, and Long D are the cross section on the longitudinal direction, while Trans Top, Trans Mid, and Trans Bottom are the cross sections on the transverse direction. Figure 36 presents an approximate location of each of the aforementioned cross sections within structure 361632N.

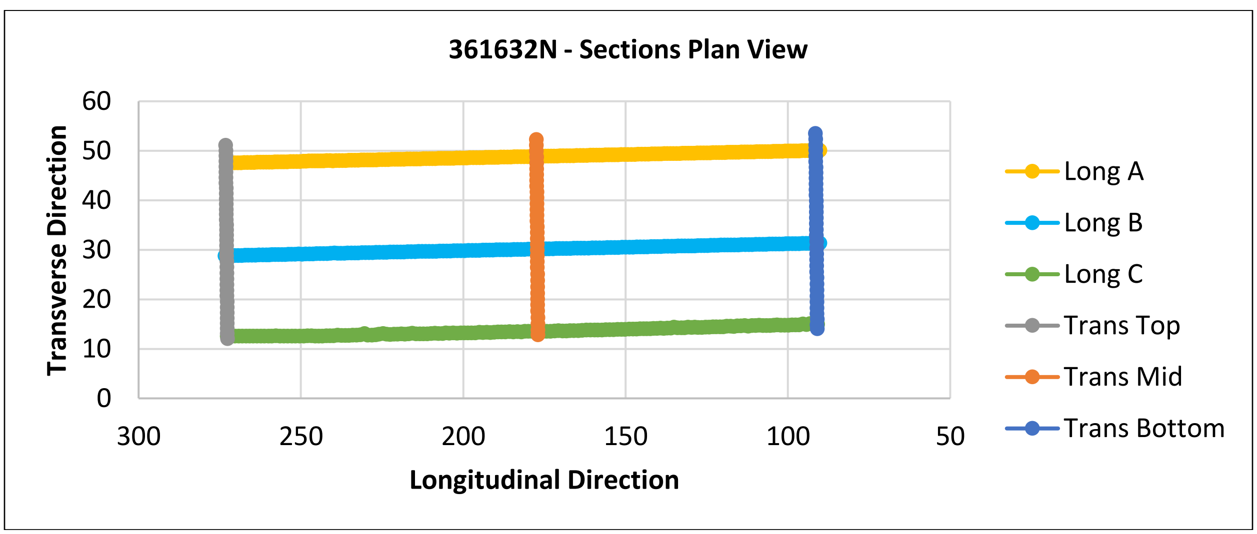


Figure 35. Structure 361632N - Sections Plan View.

Figure 36. Structure 361632N - Refence of cross section location.

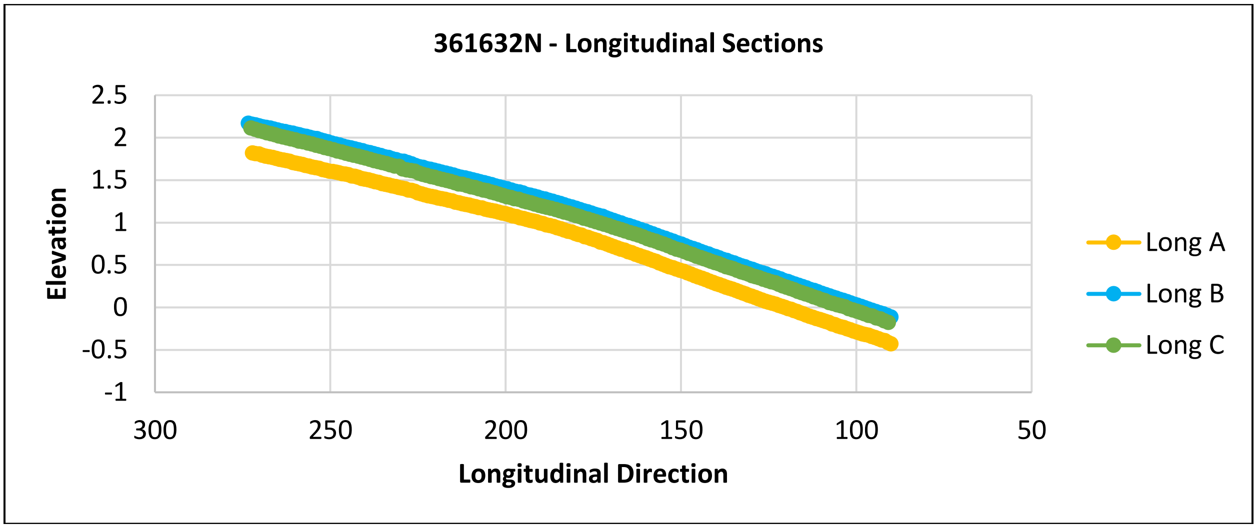


Figure 37. Structure 361632N - Longitudinal Sections.

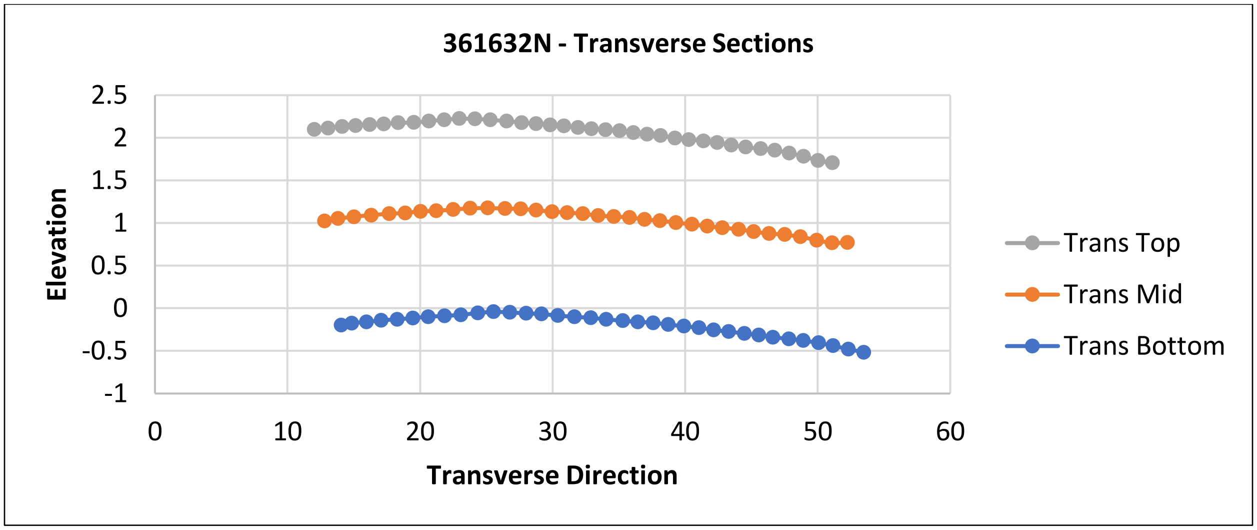


Figure 38. Structure 361632N - Transverse Sections.

Bridge 18G0701 - S Main ST(CR533) over Royce Brook

Structure 18G0701 is a newly constructed deck. It can be seen from Figure 39, Figure 43, and Figure 44 that the deck has proper slope for drainage on both the longitudinal and transverse directions. It is important to highlight that some low points were found along the deck as seen in Figure 43, this can be areas of concern in the long term. The plan view presented on Figure 41 indicates the location of the longitudinal and transverse section within the deck. Figure 40, presents an RGB view of the deck's top surface.

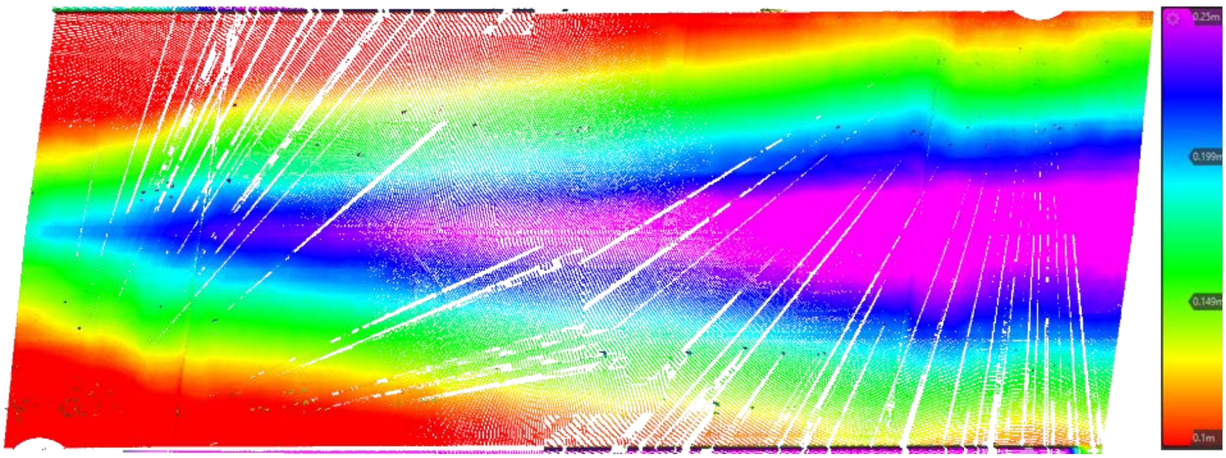


Figure 39. Structure 18G0701 - Elevation map.

Figure 40 Structure 18G0701 - RGB image of the deck's top surface.

The plan view presented on Figure 41, indicates the location of the longitudinal and transverse section within the deck, where Long A, Long B, Long C, and Long D are the cross section on the longitudinal direction, while Trans Top, Trans Mid, and Trans Bottom are the cross sections on the transverse direction. Figure 42 presents an approximate location of each of the aforementioned cross sections within structure 18G0701.

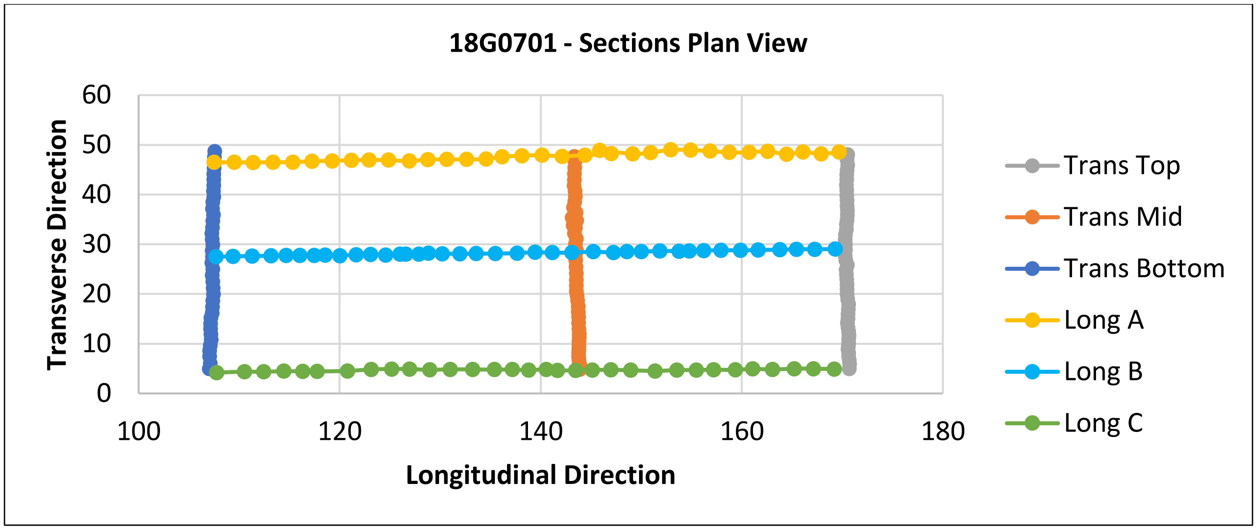


Figure 41. Structure 18G0701 - Sections Plan View.

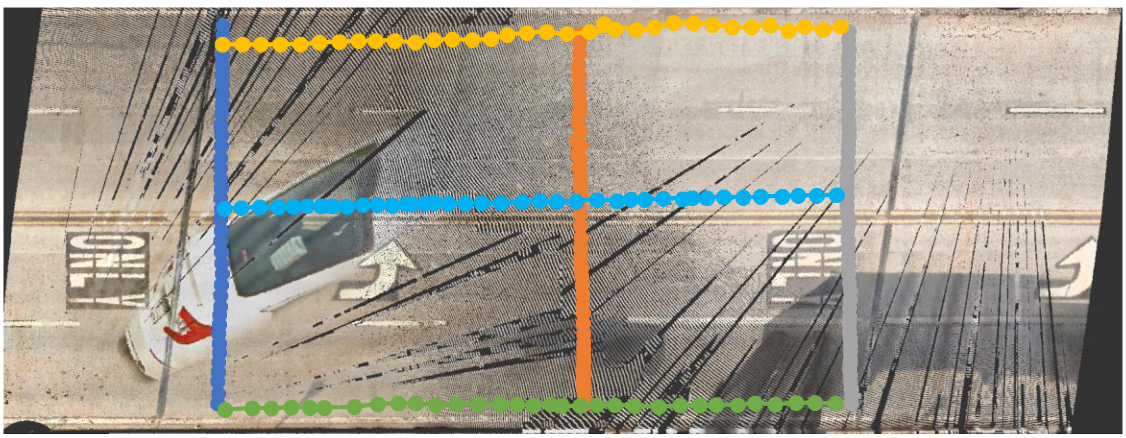


Figure 42. Structure 18G0701 - Refence of cross section location.

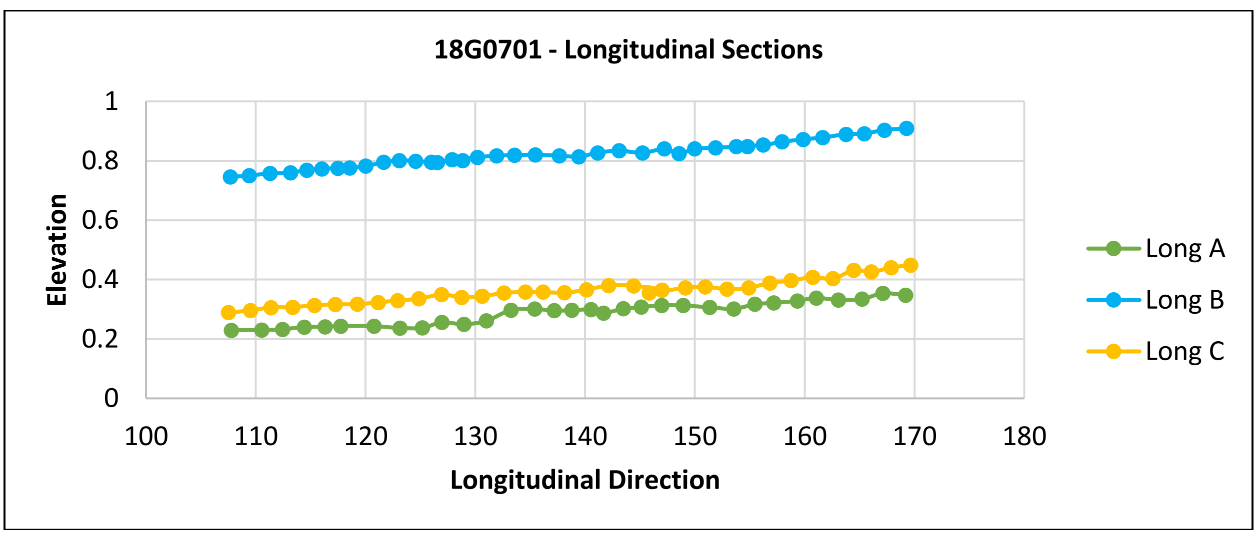


Figure 43. Structure 18G0701 - Longitudinal Sections.

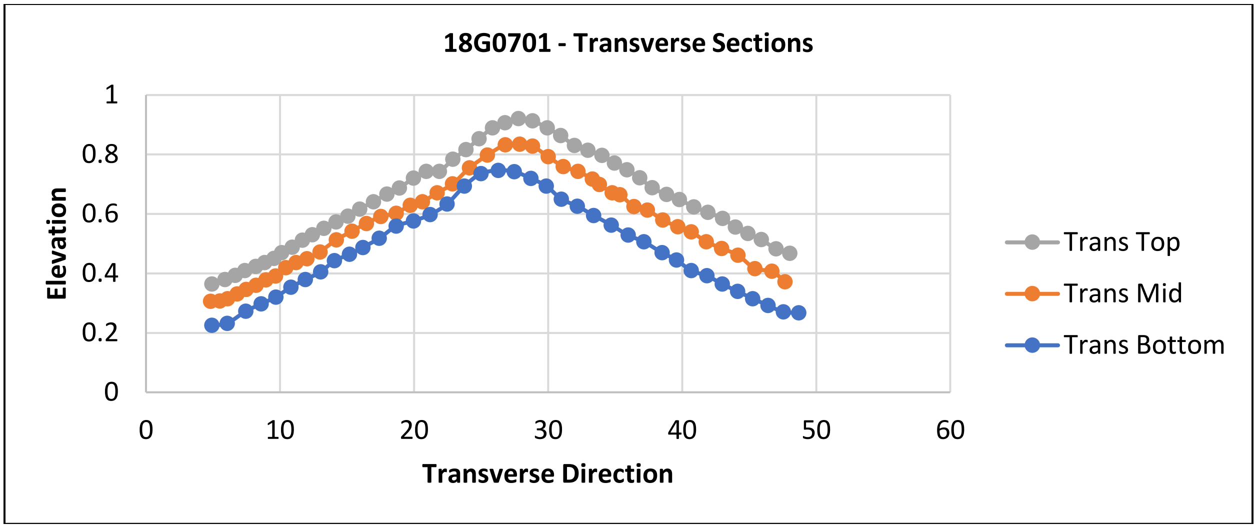


Figure 44. Structure 18G0701 - Transverse Sections.

Bridge 0821155 - Tomlin St (CR 607) over I-295

Structure 0821155 is a newly constructed structure. It can be seen from the left side of Figure 45 and Figure 49, the presence of a flatter region, which can be an area of concern if the long term. The transverse cross section slope of the deck is approximately 1.4%, slightly below the recommended 2%, this was estimated from the data found on Figure 50. Figure 46, presents an RGB view of the deck's top surface.

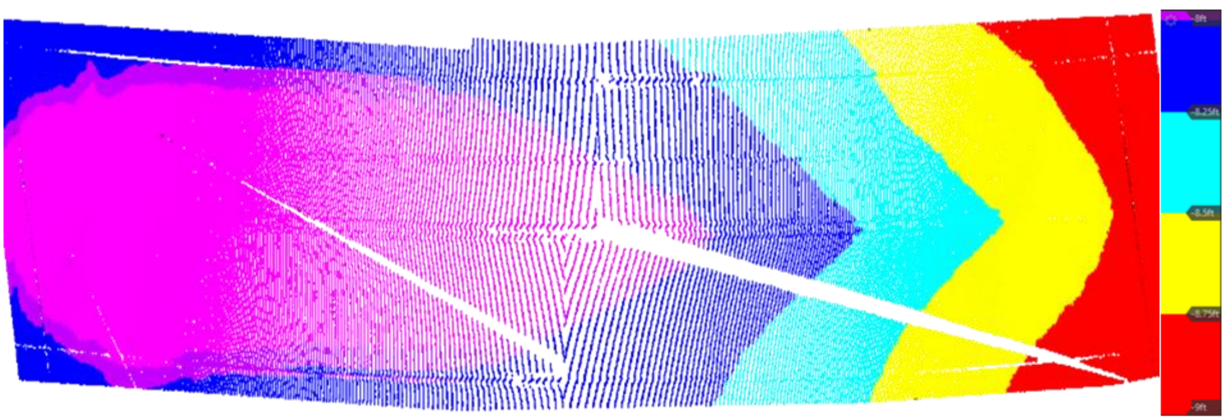


Figure 45. Structure 0821155 - Elevation map.

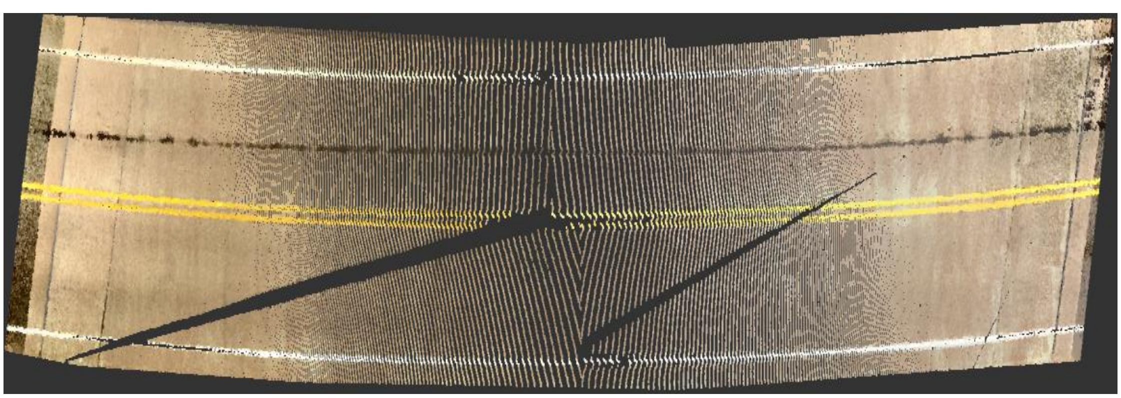


Figure 46. Structure 0821155 - RGB image of the deck's top surface.

The plan view presented on Figure 47, indicates the location of the longitudinal and transverse section within the deck, where Long A, Long B, Long C, and Long D are the cross section on the longitudinal direction, while Trans Top, Trans Mid, and Trans Bottom are the cross sections on the transverse direction. Figure 48 presents an approximate location of each of the aforementioned cross sections within structure 0821155.

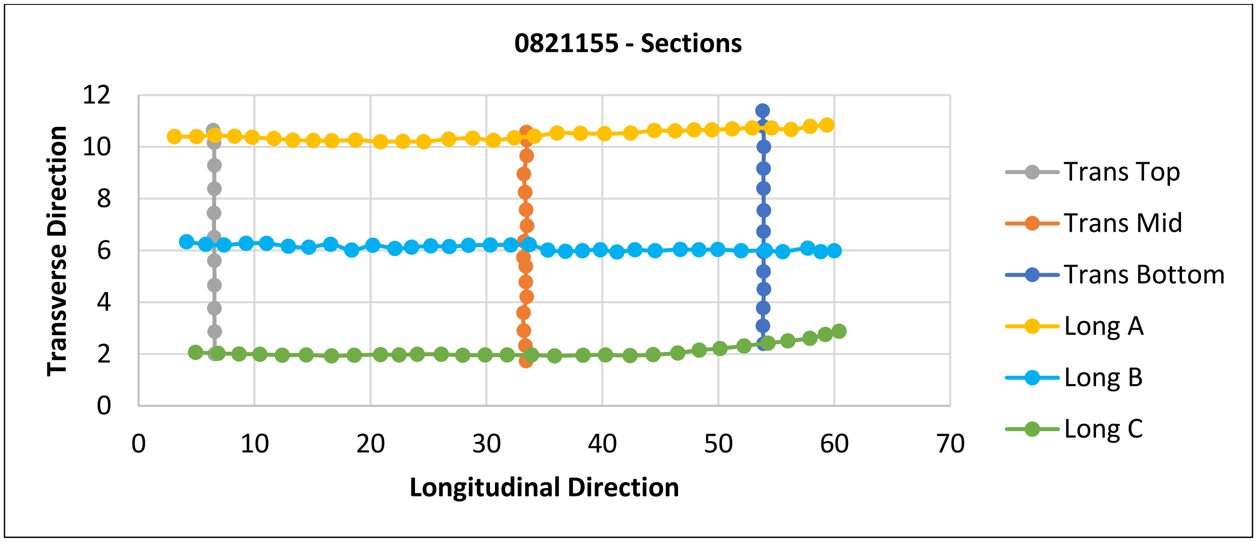


Figure 47. Structure 0821155 - Sections Plan View.

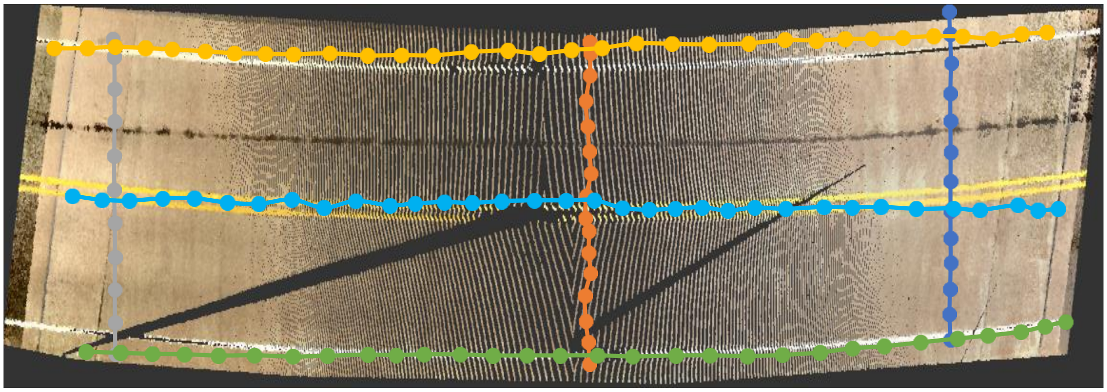


Figure 48 . Structure 0821155 - Refence of cross section location.

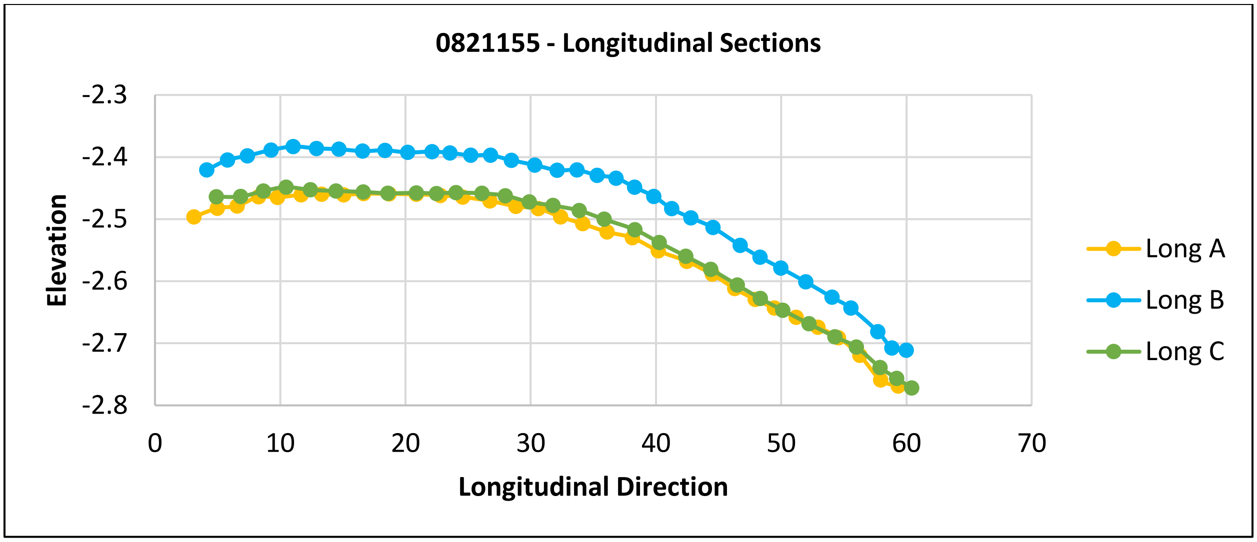


Figure 49. Structure 0821155 - Longitudinal Sections.

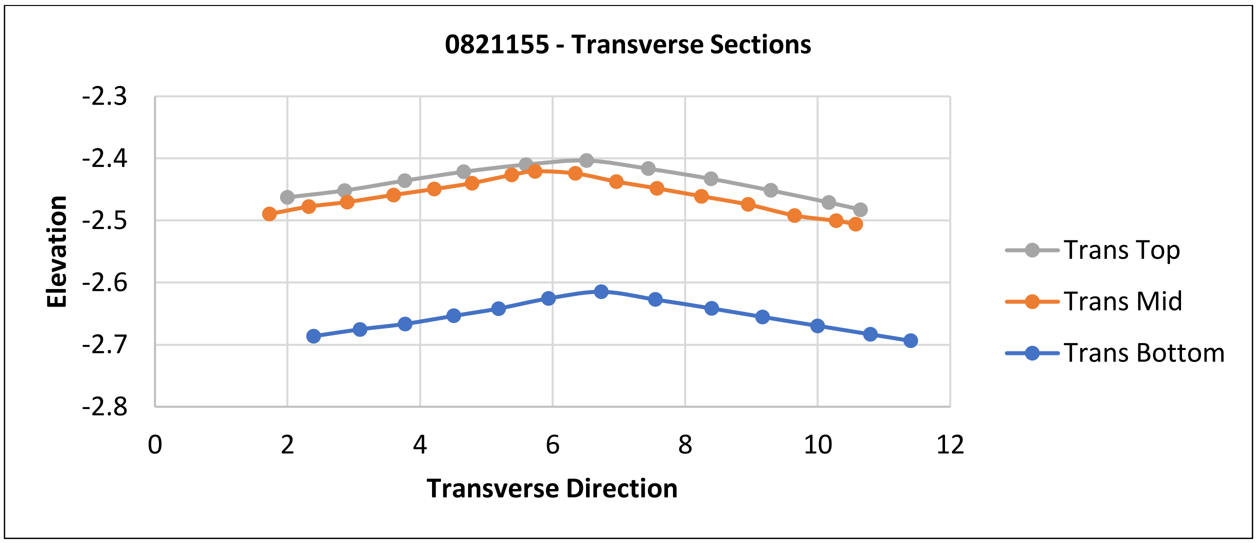


Figure 50. Structure 0821155 - Transverse Sections.

Bridge 1317154 - RT 138 EB over Garden State Pkwy NB

Structure 1317154 presents a uniform longitudinal slope of approximately 3% as seen and estimated from Figure 51 and Figure 55. The transverse slope estimated from Figure 56 is approximately 1.6%, slightly below the recommended 2%. There is not a clear area of concern where early deterioration would occur. It is important to highlight the low transverse slope found on this deck. The plan view presented on Figure 53, indicates the location of the longitudinal and transverse section within the deck, where Long A, Long B, Long C, and Long D are the cross section on the longitudinal direction, while Trans Top, Trans Mid, and Trans Bottom are the cross sections on the transverse direction. Figure 54 presents an approximate location of each of the aforementioned cross sections within structure 0821155.

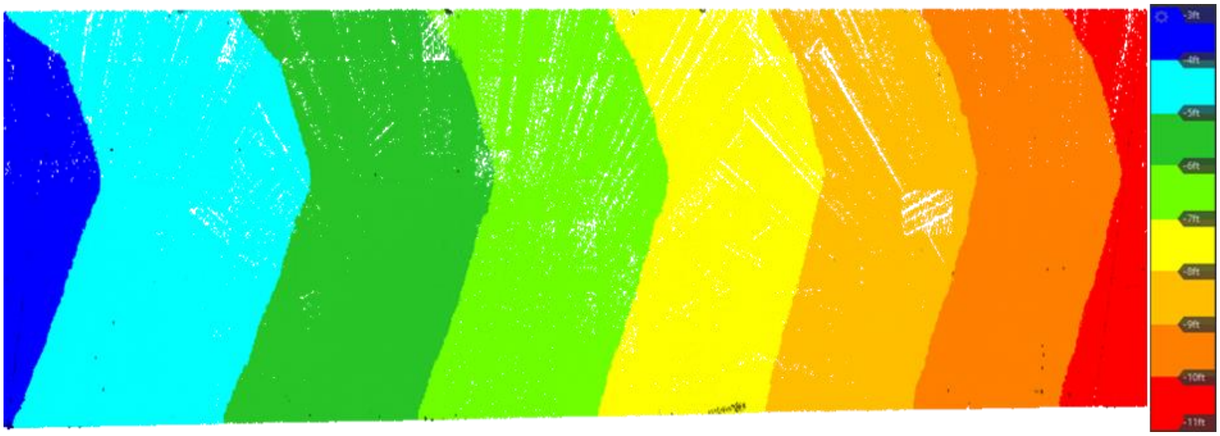


Figure 51. Structure 1317154 - Elevation map.

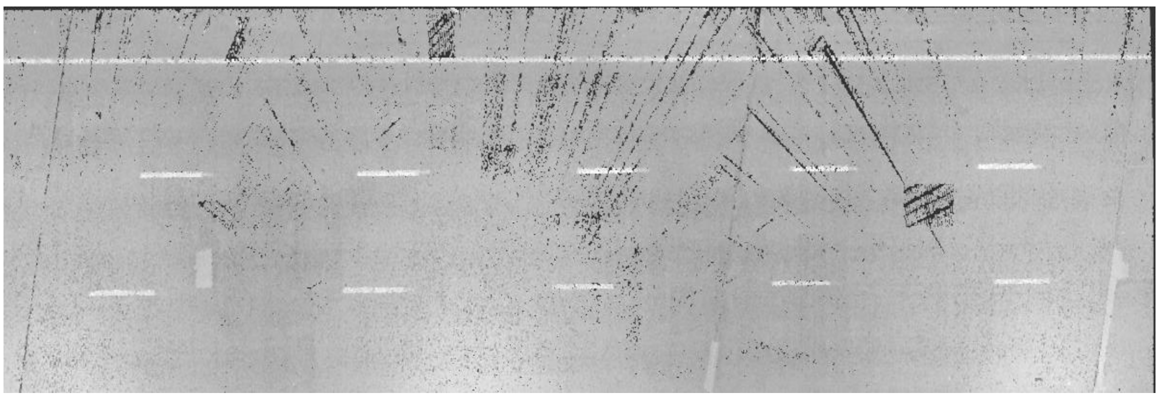


Figure 52. Structure 1317154 - RGB image of the deck's top surface.

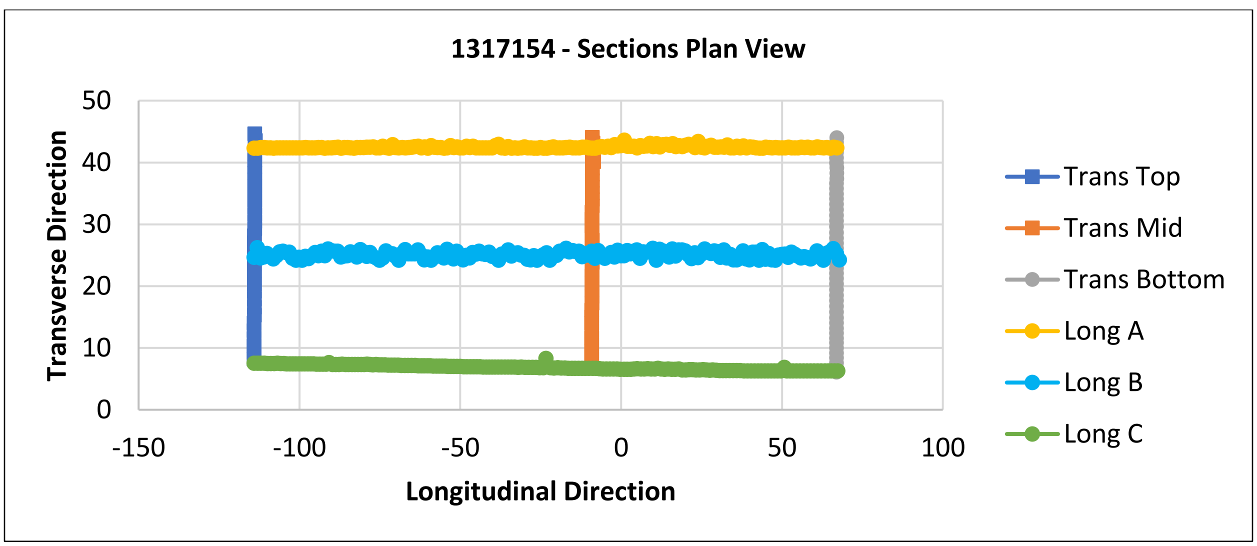


Figure 53. Structure 1317154 – Sections Plan View.

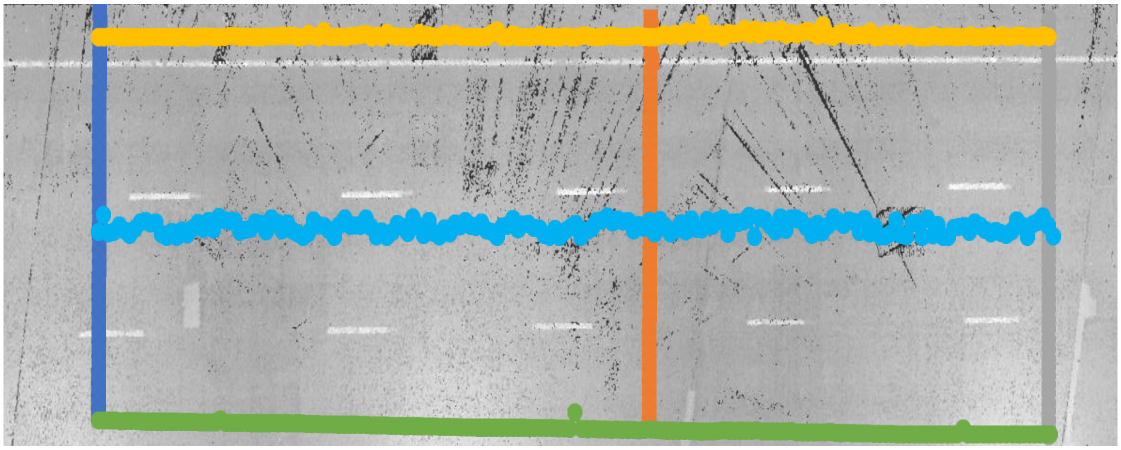


Figure 54. Structure 1317154 - Refence of cross section location.

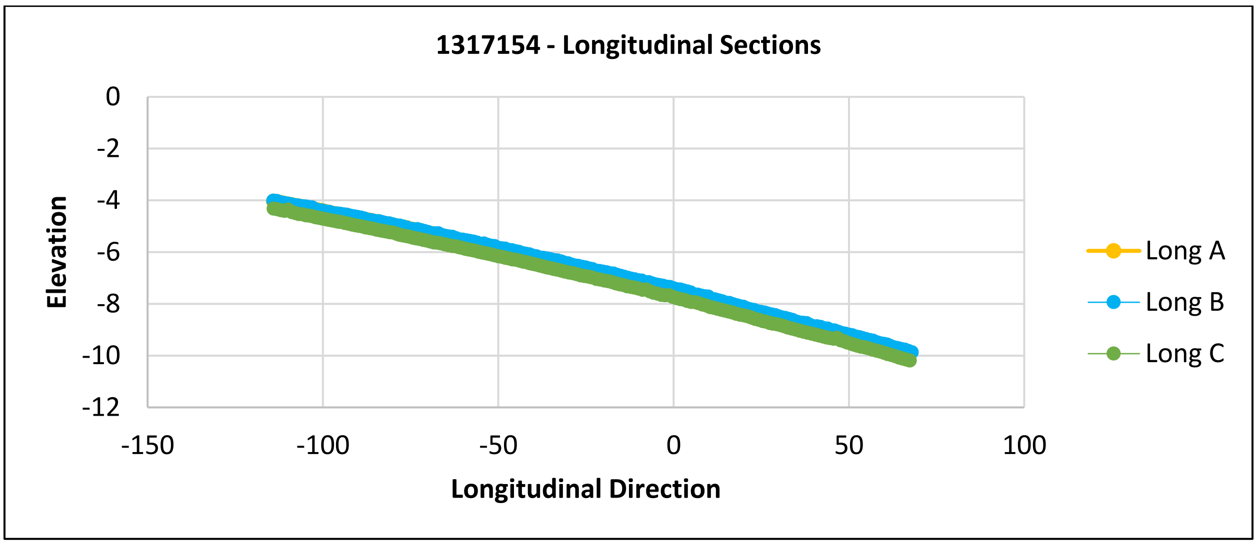


Figure 55. Structure 1317154 - Longitudinal Sections.

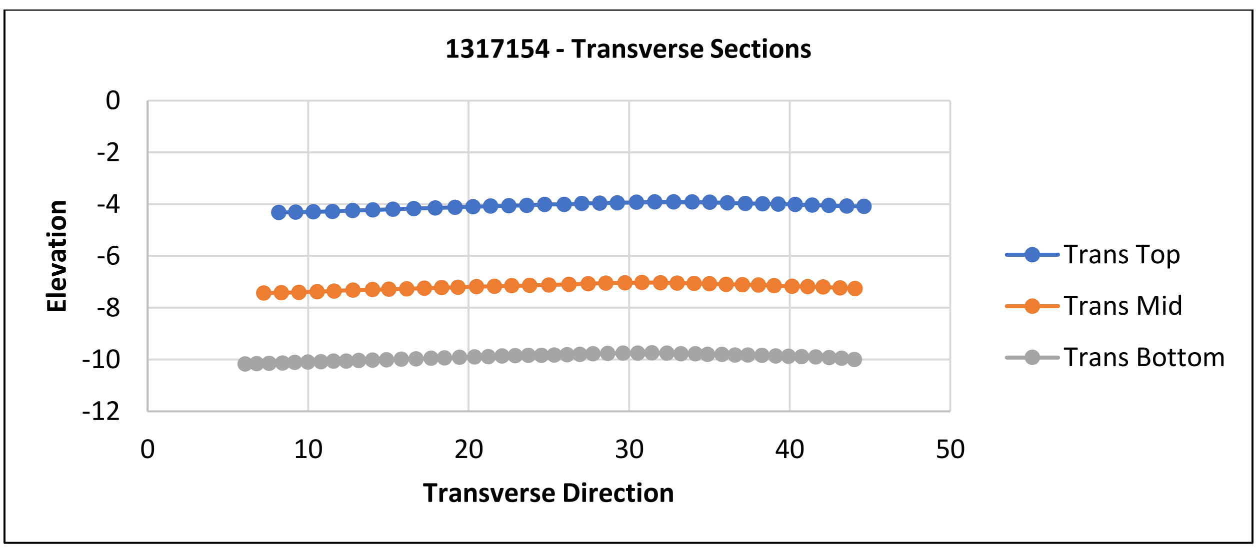


Figure 56. Structure 1317154 - Transverse Sections.

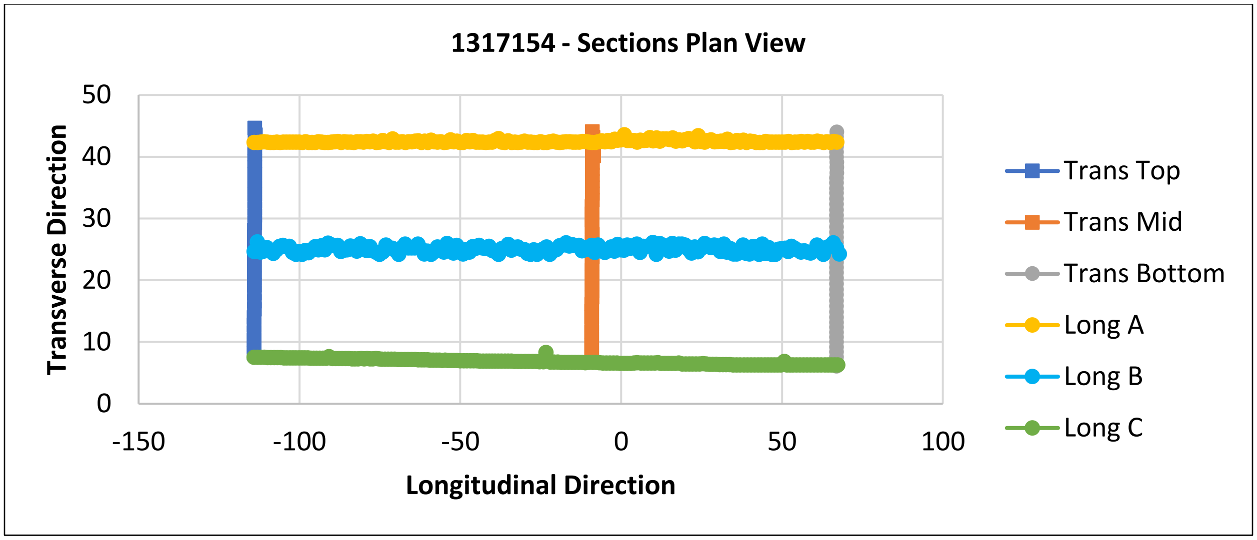


Figure 57. Structure 1317154 – Sections Plan View.

Bridge 1816154 & Structure 1816155 - I-78 over North Branch Raritan River

Structures 1816154 and 1816155 will be compared in this section, since these structures were included on this project as a case study presented by NJDOT. The twin bridges originally presented different levels of deck condition (3 for 1816155, and 6 for 1816154) which was a concern since the structures see the same level of traffic and have same dimensions of their structural components. Figure 58 and Figure 63 show the elevation maps of the top surface of the structures. Both structures present a longitudinal slope of approximately 2.3%, which can be estimated from Figure 61 and Figure 66. Structure 1816154 presents a transverse slope between 1 and 1.3% (see Figure 62), while structure 1816155 presents a uniform transverse slope of 1.3% (see Figure 65).

It is important to mention that during the data collection of Structure 1816155 a construction work was being performed on the premises of the bridge, which obstructed part of the deck and limited the access of the research team. For this, only half of the deck was available for data collection. From Figure 62 and Figure 67, the presence of mild rutting can be seen throughout all transverse directions, this can indicate the potential location of areas where water sits for longer periods of time, increasing the possibility of early deterioration. Based on the information gathered from the analyzed point cloud data, there is no clear evidence of the cause on the difference in condition stage between structures 1816154 and 1816155. The main evidences of deck damage found on the top surface of bridge decks were rutting and low points of vertical curvature. These aspects presented clear correlation with the deterioration stage of the deck.

After the performance of the data analysis of the bridges involved in this case study, a detailed deck survey was performed by NJDOT. The survey resulted on a deck condition rating of 3 for both structures. These results aligned with the information found on the point cloud data analysis, as there was no clear evidence that indicated mayor differences between the two decks.

Figure 58. Structure 1816154 - Elevation map.

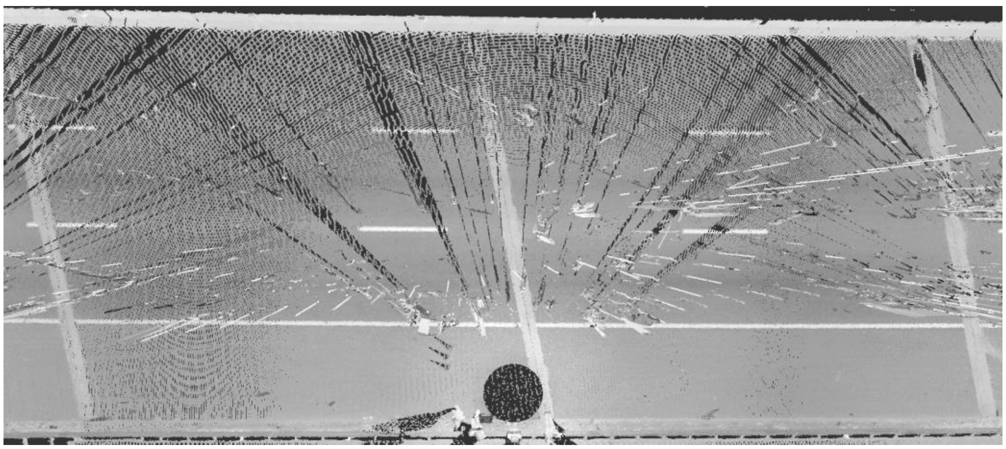


Figure 59. Structure 1816154 - RGB image of the deck's top surface.

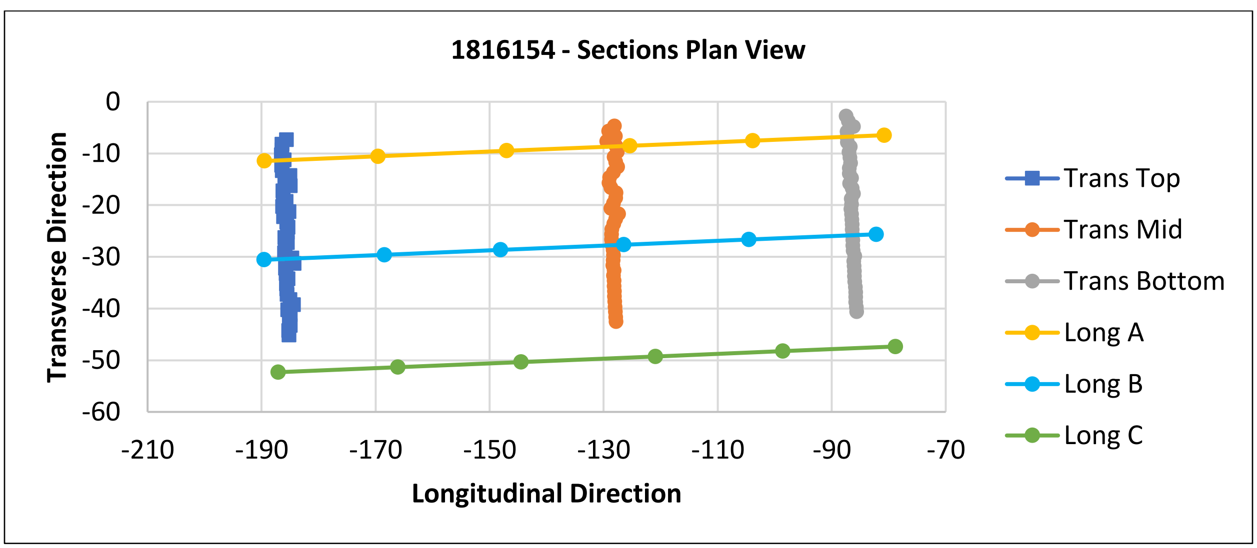


Figure 60. Structure 1816154 - Sections Plan View.

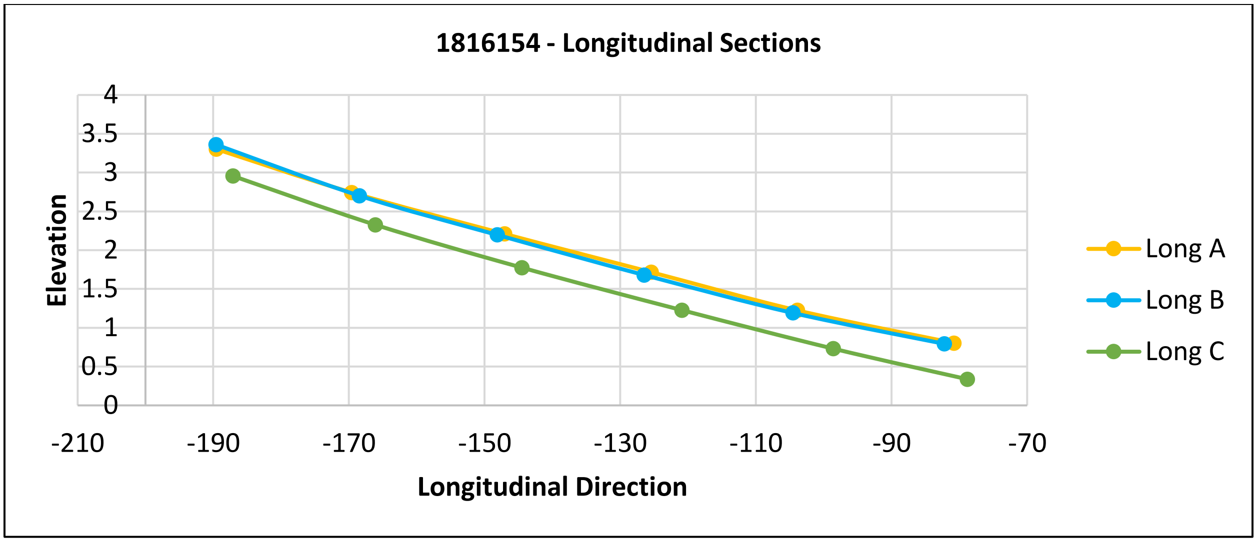


Figure 61. Structure 1816154 - Longitudinal Sections.

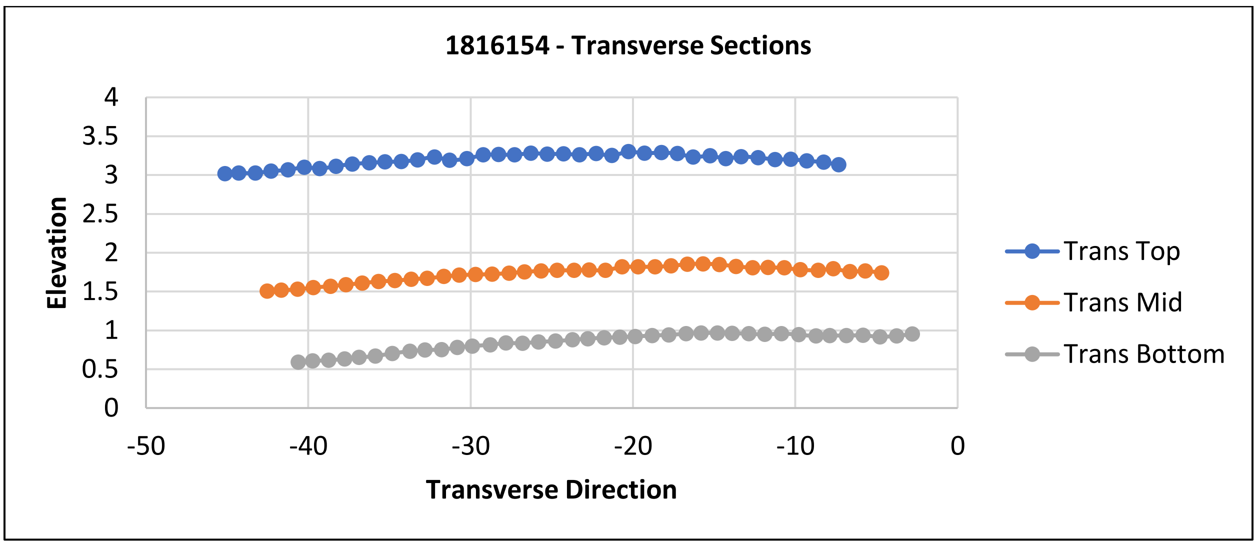


Figure 62. Structure 1816154 - Transverse Sections.

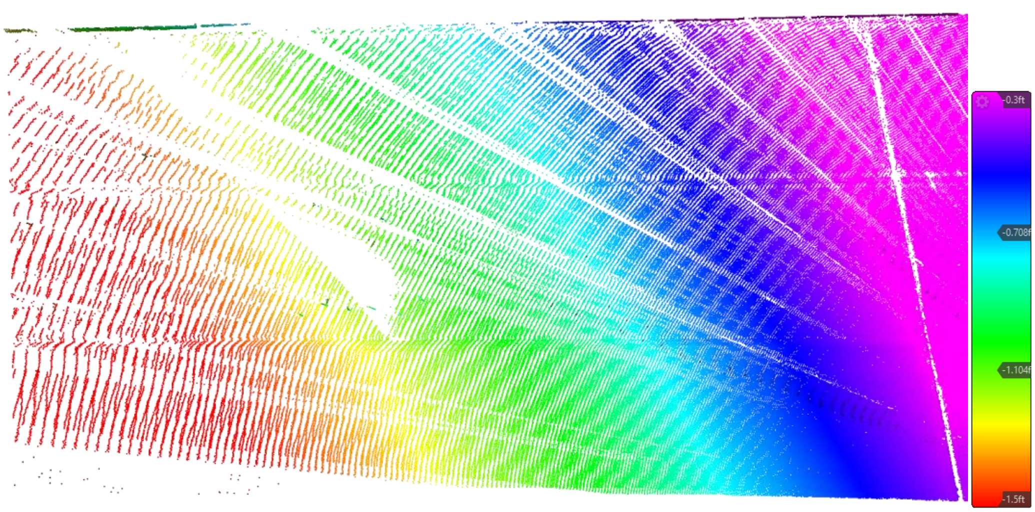


Figure 63. Structure 1816155 - Elevation map.

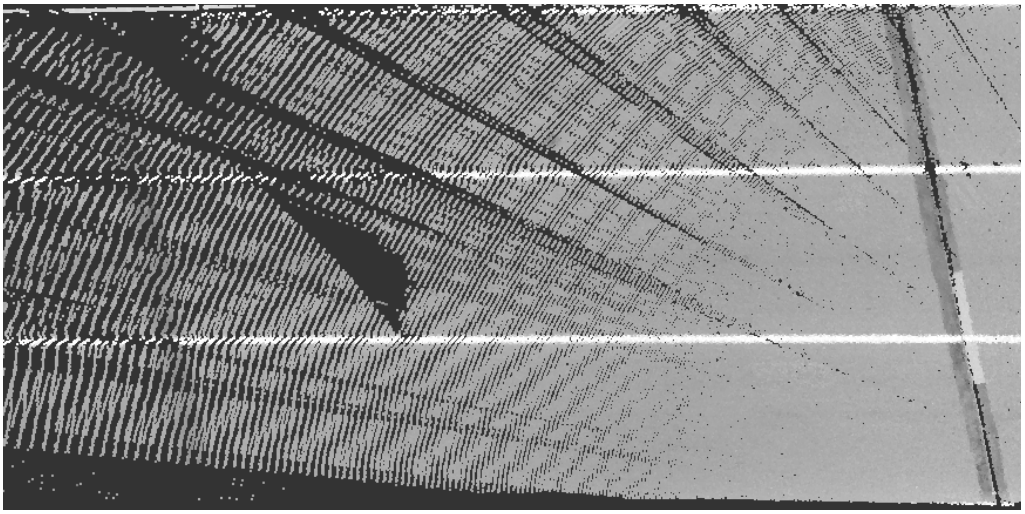


Figure 64. Structure 1816155 - RGB image of the deck's top surface.

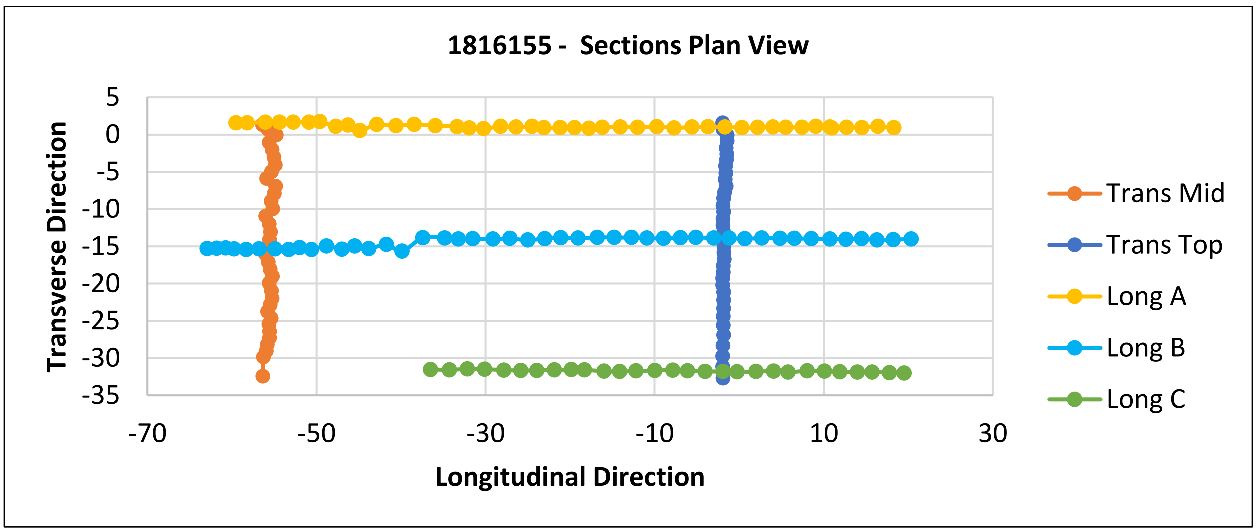


Figure 65. Structure 1816155 - Sections Plan View.

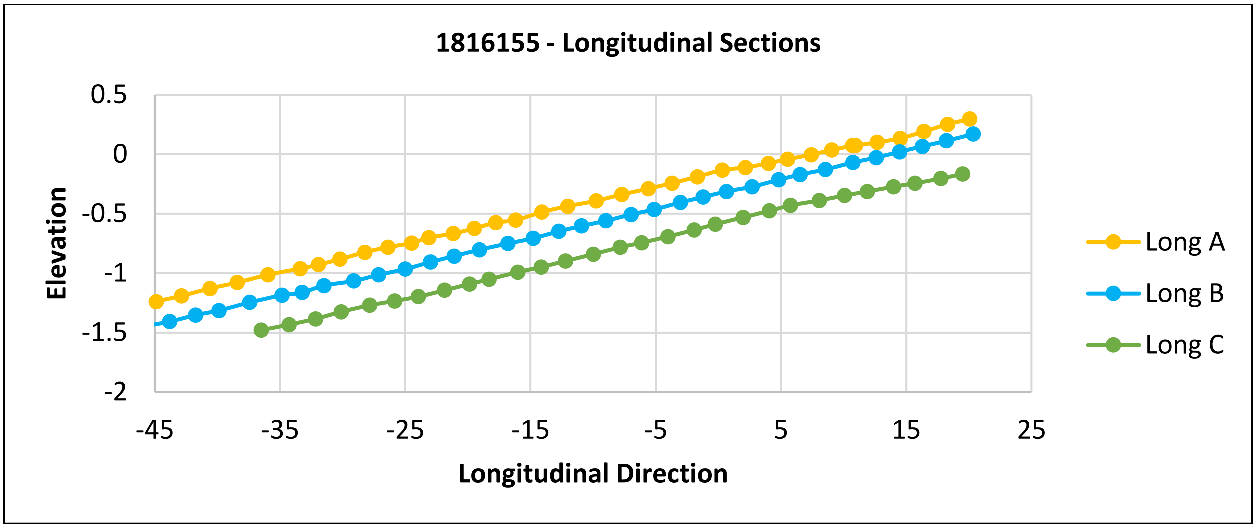


Figure 66. Structure 1816155 - Longitudinal Sections.

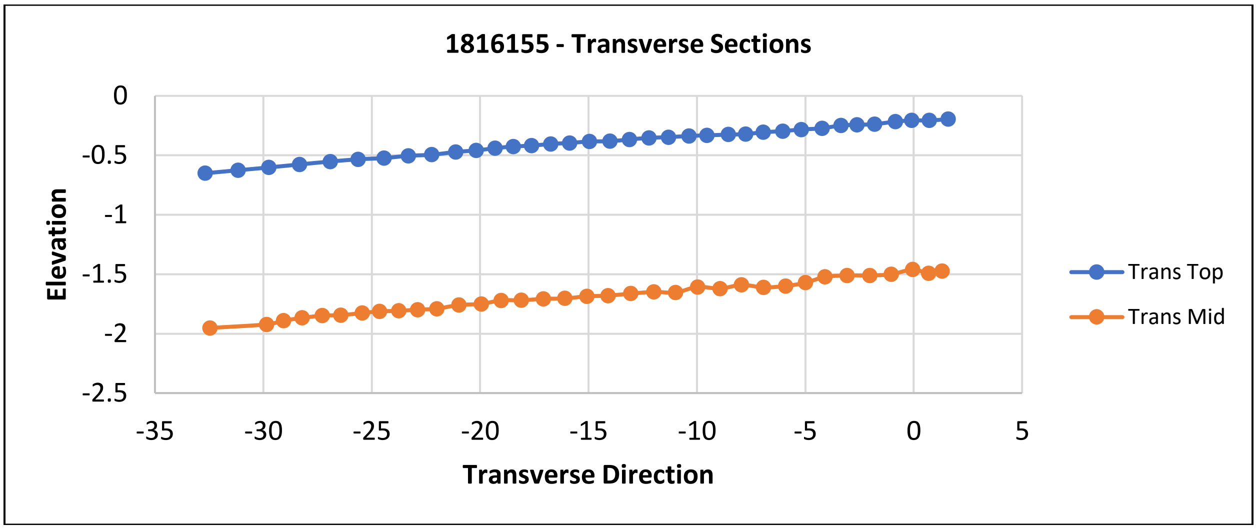


Figure 67. Structure 1816155 - Transverse Sections.

Conclusions

Point cloud data gathered via terrestrial laser scanners captures detailed characteristics of the geometry of bridge decks which allows to visualize the external deterioration of the member. This data does not reflect internal damage of the structure, nonetheless visibly captures evidence of deck deterioration as are spalling, potholes, rutting, and low points on vertical curvature.

Through the analysis of point cloud data, it is possible to correlate the geometry captured with overall condition stage of bridge decks. The data gathered and analyzed on this project shows promise in helping bridge owners to utilize point cloud data as a screening tool that can help prioritize the work required on their structures and improve asset management.

Recommendations

The use of point cloud data for estimating the overall condition stage of bridge decks is on an early developmental stage. The research team recommends a more extensive data collection of bridge decks geometry, to allow for a better interpretation of the trends found. The following diagram (Figure 68), represents the potential workflow that can be applied to effectively use point cloud data as a screening tool, to be implemented as a first step of routine inspections.

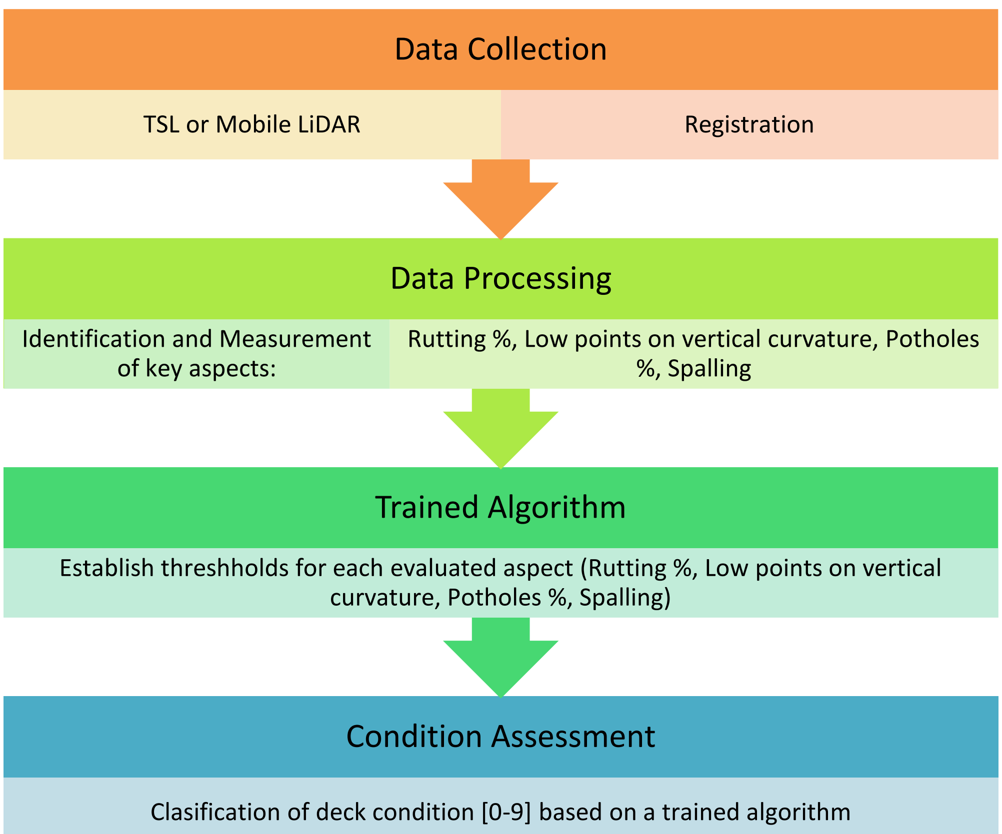


Figure 68. Bridge Deck Screening Protocol

Additionally, the research team recommends to rescan the bridges selected for this project in a 2 to 4-year period, to continue searching for deterioration patterns that are reflected in the geometry of the structure. This will be useful when training the algorithm that will be used to assess the deck.

Future Work

Following the finding of this research project and the recommendations of NJDOT officials, future projects in this research area will focus on measuring and analyzing the following aspects:

- Percentage of spall areas and mapping.
- Area of delamination (potentially combined with other technologies)
- Prediction of remaining service life.
- Estimation of volume of section loss.

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