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Construction Cycle 10 Support – Test Pavement Planning & Design

Final Design Report

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CONSTRUCTION CYCLE 10 DESIGN REPORT

A.1 SCOPE

This report documents technical and administrative decisions by engineers during the design of test items to achieve the objectives of the Construction Cycle 010 experiment. It is provided as an appendix of the CC10 test plan.

A.2 LOCATION OF EXPERIMENT

At the time of design, NAPTF contained three major experiment areas:

- CC9 from STA 0+00 to 3+00 with expected completion in July 2022,
- CC8 from STA 3+00 to 6+50 with expected completion in December 2022,
- Special projects and storage from STA 7+00 to 10+00. The special projects do not have an expected completion date at the time of writing.

FAA expects construction of CC10 in the first quarter of calendar year 2023, shortly after completion of CC8 post-traffic testing. CC10 will replace the CC8 test items. The area of CC8 from STA 3+00 to 6+00 has a subgrade CBR of 7%-8% and the area from STA 6+00 to 6+50 has a subgrade CBR of 3%-4%. The intended subgrade strength for the experiment was approximately CBR = 8%, so the trafficking area is limited to the 300 feet between STA 3+00 to 6+00. CC10 test items will be between STA 3+05 and 5+95 under the assumption that they all have the same subgrade strength and to leave a transition slab between the test items and the adjacent experiments. The demolition area will extend from STA 3+00 to STA 6+10 to provide space for equipment staging and site access ramps.

A.3 NUMBER OF TEST ITEMS

Engineers designed the experiment with three test items because at least three test items are required to confirm trends during trafficking and testing. A three-test-item configuration has room for fifteen slabs per test item, which provides an adequate amount of data to analyze the differences between cross sections. Additionally, due to the larger slab sizes and spatial limitations of 300 feet, four or more test items will not fit in the space available.

A.4 THICKNESS DESIGN

A.4.1 Expected Traffic

Design traffic was selected based on the goal of obtaining failure data at higher levels of traffic. A 2D gear configuration with a wheel load of 55,000 lbs/wheel and a tire pressure of 220psi was chosen for CC10 trafficking. These values are a reasonable representation of 2D aircraft in the commercial fleet and consistent with previous projects at NAPTF. CC8 used a wheel load of 55,000 lbs/wheel and a tire pressure of 220psi. The ARAS0004 Enhancements to In Pavement Light Fixtures project used a wheel load of 65,000 lbs/wheel and a tire pressure of 230psi. These values are slightly higher than the average wheel load (~52,000 lbs/wheel) and tire pressure (~210 psi) for all 2D aircraft in the FAA pavement design software FAARFIELD 2.0.

The CC8 trafficking values were chosen for design purposes. It is more demanding than the average aircraft, but not as demanding as the ARAS0004 traffic. Use of CC8 traffic levels should simplify comparison of CC10 with other CCs. A nominal pavement thickness of 15 inches should support over 100,000 passes of the design gear, but the design gear will not cause immediate failure of the thinner pavements. It also allows researchers to increase loads to complete the experiment in the allotted time if necessary.

A.4.2 P-501 Thickness

Pavement thickness was selected to comply with joint spacing requirements. Advisory Circular 150/5320-6G allows a minimum thickness of 13.5 inches and maximum thickness of 16 inches for pavements with 17.5-foot joint spacing. The difference in thickness between test items was set at one inch. A one-inch increment provides the maximum range of thicknesses to support Objective 3 of the test plan while allowing for the same joint spacing, dowel diameter, dowel length, and dowel spacing to be used in each test item. A difference in thickness of ½-inch would be difficult to construct, but a difference in thickness of more than one inch would result in either the thickest or thinnest slab violating FAA criteria. FAA recommends design thickness be rounded to the nearest ½-inch, so the options for P-501 thickness of each test item were 13.5 inches, 14.5 inches, and 15.5 inches; or 14 inches, 15 inches, and 16 inches. The thinner option of 13.5 inches, 14.5 inches, and 15.5 inches was selected to ensure the experiment could be completed within the expected 5-year execution window.

A.4.3 Pavement Cross Section

Advisory Circular 150/5320-6G requires a stabilized base in the pavement structure since the gross loads exceed 100,000 lbs [1]. Designers selected the P-403 asphalt base course as the stabilized base instead of P-306 lean concrete base course since asphalt base provides a larger difference in acoustic impedance between the base and the P-501 concrete surface. A greater difference makes the use of MIRA more effective. Maximizing the difference in acoustic impedance between surface and base layers should highlight any shadowing effect of subsurface damage in the P-501 concrete. P-403 asphalt placed directly on top of CBR = 7-8% subgrade would likely not meet compaction requirements. Designers considered P-209 base course for the construction platform, but rejected it over concerns the construction contractor could not achieve target density for it either due to the medium-soft subgrade. P-154 subbase course will be placed below the P-403 asphalt for constructability reasons. Advisory Circular 150/5320-6G indicates that subbase may be used in lieu of base course if it exhibits a CBR > 35% (note: CC9 P-154 exhibited a CBR ~ 60%).

A.4.4 Material Properties

A flexural strength of 700psi was selected for the P-501 based on experience with the local materials. Previous CCs required flexural strengths as low as 650psi, but supplier's off-the-shelf mixes routinely provided over 800psi. Creating a sufficiently weak mix design required violating several criteria in Advisory Circular 150/5370-10H [2]. Flexural strength in the 700psi range is much more achievable with local materials, and designers expect that the material delivered will have a flexural strength much closer to 725psi. The P-403 asphalt mix will be a ¾-inch NMAS with a PG 76-22 binder. The coarsest gradation was chosen from the P-403 specifications for stability and economy purposes in addition to being the closest to CC7 and CC9 gradations. The base binder grade for New Jersey based on climate is a PG 64-22, however, since the design aircraft loading is greater than 100,000 lbs, a 2-grade bump was required. As noted, P-154 used previously at NAPTF has a CBR of approximately 60%. The subgrade CBR is approximately 7% by design.

A.4.5 Constructability

The elevation of the top of the existing CC8 subgrade in the project location is approximately 55.35 to 55.50 feet with a finish grade elevation of 58.00 feet. The proposed finish grade was set at 58.00 feet to match surrounding test items. The total thickness above the subgrade for the proposed structure is 26.5 inches, which would yield a proposed top of subgrade of 55.79 feet. This would require almost four inches of subgrade fill. FAA possesses a limited quantity of subgrade material, and the process to place and accept additional subgrade is time consuming and adds considerable risk of delay to the construction project. For constructability purposes and conservation of P-152 subgrade required as fill, the P-154 subbase layer was increased to 9.5 inches (total structure = 30 inches), which would set the proposed top of subgrade at the existing 55.50 feet. FAARFIELD indicates the thicker subbase requires the same PCC thickness of 15.5 inches, so the design thickness of 15.5 inches is still valid.

CC10 is expected to require a minimal amount (200-300 cubic yards) of stockpiled P-152MR to use as fill material. Previous CCs has shown that the construction contractor will need to overcut the subgrade/subbase interface by several inches to reveal a clean, uncontaminated surface. As a result, it is anticipated that the construction contractor will cut to an elevation of 55.20-55.30 feet throughout the project, till the surface several inches, and incorporate new stockpiled P-152MR to reach an elevation of 55.50 feet.

For constructability purposes, the total thickness of the proposed structure will remain constant at 30 inches even though each test item has a different thickness of P-501. The top of subgrade will remain constant at 55.50 feet. The P-154 subbase thickness will inversely vary according to the slab thickness. Figure 1 shows a profile of the three proposed CC10 test items.

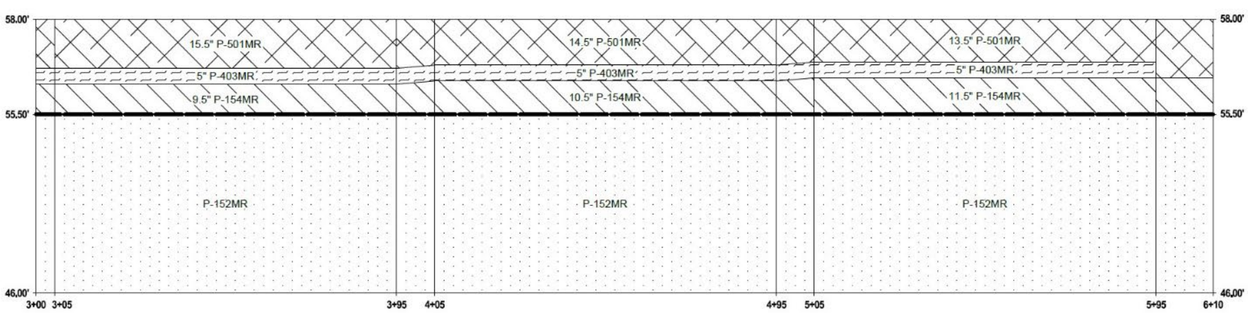


Figure 1. CC10 pavement thickness

A.5 JOINT SPACING

Advisory Circular 150/5320-6G states that for a rigid pavement with a stabilized base, the maximum distance between longitudinal joints for a P-501 slab with thickness between 13.5 inches and 16.0 inches is 17.5 feet. Additionally, the distance between transverse joints shall be less than or equal to 1.25 times the longitudinal joint spacing [1]. To support Objective 2, a slab size of 18.0 feet long by 17.5 feet wide will be used for CC10. This size slab is the maximum that will allow three test items of equal size, plus transition slabs, in the allotted area as shown in Figure 2. Dowels are 1-1/4 inches in diameter and 20 inches in length with 15 inches spacing, as per Advisory Circular 150/5320-6G for P-501 between 12.5 to 16 inches thick.

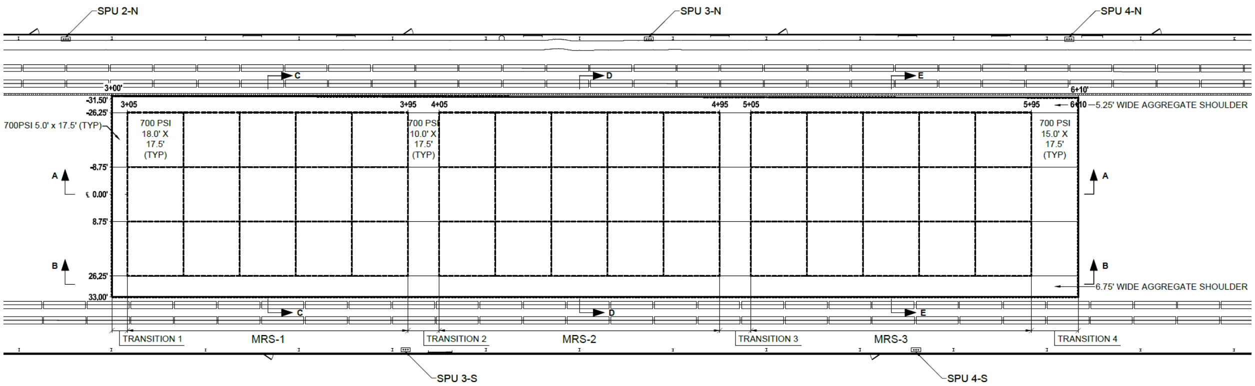


Figure 2. CC10 joint spacing plan

A.6 REINFORCEMENT OF TRANSITION SLABS

Advisory Circular 150/5320-6G states that concrete slabs exceeding a 1.25 length-to-width ratio (longest dimension of the slab divided by shortest dimension of the slab) should provide a minimum of 0.050 percent of the panel cross-sectional area in reinforcement in both directions. Transitions 1, 2, and 3 all exceed the 1.25 length-to-width ratio and require reinforcement to minimize the potential for cracking in these panels that may propagate to test item slabs. Using #3 rebar with a 3-inch clear spacing for longitudinal bars, 6-inch clear spacing for transverse bars, and spaced 12 inches on centers provides sufficient reinforcement for all three transitions, as shown in Table 1. Since all test items have a thickness over 9 inches, the reinforcement will be placed in the upper 1/3 of the panel.

Table 1. Required reinforcement for transitions

Transition	Direction of Traffic	Required Reinforcement (in^2)	Clear Spacing (in)	Bar Spacing (in)	Bar Size	Bar Area (in^2)	# of Bars	Total Reinforcement Area (in^2)
Transition 1	Longitudinal	1.628	3	12 O.C.	#3	0.11	18	1.980
	Transverse	0.465	6	12 O.C.	#3	0.11	5	0.550
Transition 2	Longitudinal	1.628	3	12 O.C.	#3	0.11	18	1.980
	Transverse	0.930	6	12 O.C.	#3	0.11	10	1.100
Transition 3	Longitudinal	1.523	3	12 O.C.	#3	0.11	18	1.980
	Transverse	0.870	6	12 O.C.	#3	0.11	10	1.100

A.7 EXPECTED TEST ITEM LIFE

After the test item pavements were designed, the expected life of each test item was verified as acceptable for purposes of the experiment using FAARFIELD. A typical wander sequence at NAPTF consists of 66 passes arranged in nine tracks. The NAPTV can complete approximately five wander patterns per day. There are 260 days in the year that can be utilized for trafficking, not accounting for holidays. The expected maximum utilization rate is 50% since the NAPTV is required for multiple projects at the NAPTF. A 75% efficiency rating was applied to account for routine NAPTV maintenance, material testing, and miscellaneous days off/activities that prevents trafficking. With these assumptions, the NAPTV will complete 32,175 annual passes on CC10 with the total number of passes over five years being 160,875. FAARFIELD 2.0 was used to verify the expected life of the thickest pavement was reasonably close to this value.

2D and a 3D UDA were created in FAARFIELD 2.0.2 with a dual tire spacing of 54 inches and tandem tire spacing of 57 inches to match the current configuration of the NAPTV. Figure 3 shows the 2D UDA created in FAARFIELD. Figure 4 shows the 3D UDA created in FAARFIELD. The 3D gear was included in the analysis in the event the FAA needs to increase the traffic levels for research or schedule purposes.

The structure of each test item was entered into FAARFIELD and a Life analysis performed to estimate the number of passes of design traffic each test item can support. Three design concrete flexural strengths were used in estimating the number of passes to failure: 650psi flexural strength (lower PWL of design strength), 700psi (target design strength) and 750psi flexural strength (upper PWL of design strength). These values bracket the actual pavement strength that can be expected for the selected design strength. A summary of the number of passes to failure for each test item and gear configuration is provided in Table 2. FAARFIELD section reports can be found in A.12.1.

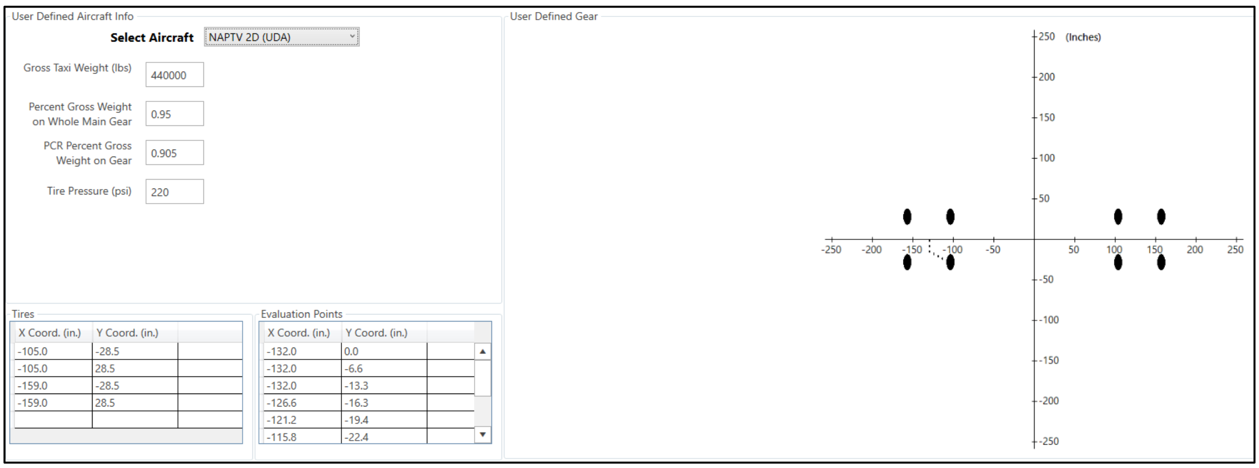


Figure 3. 2D User-defined aircraft inputs created in FAARFIELD 2.0.2

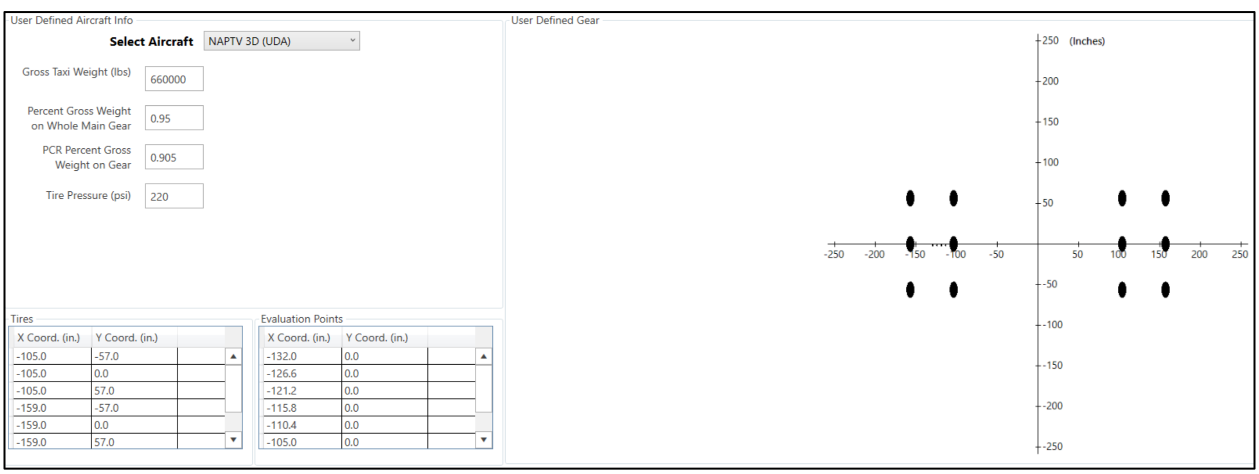


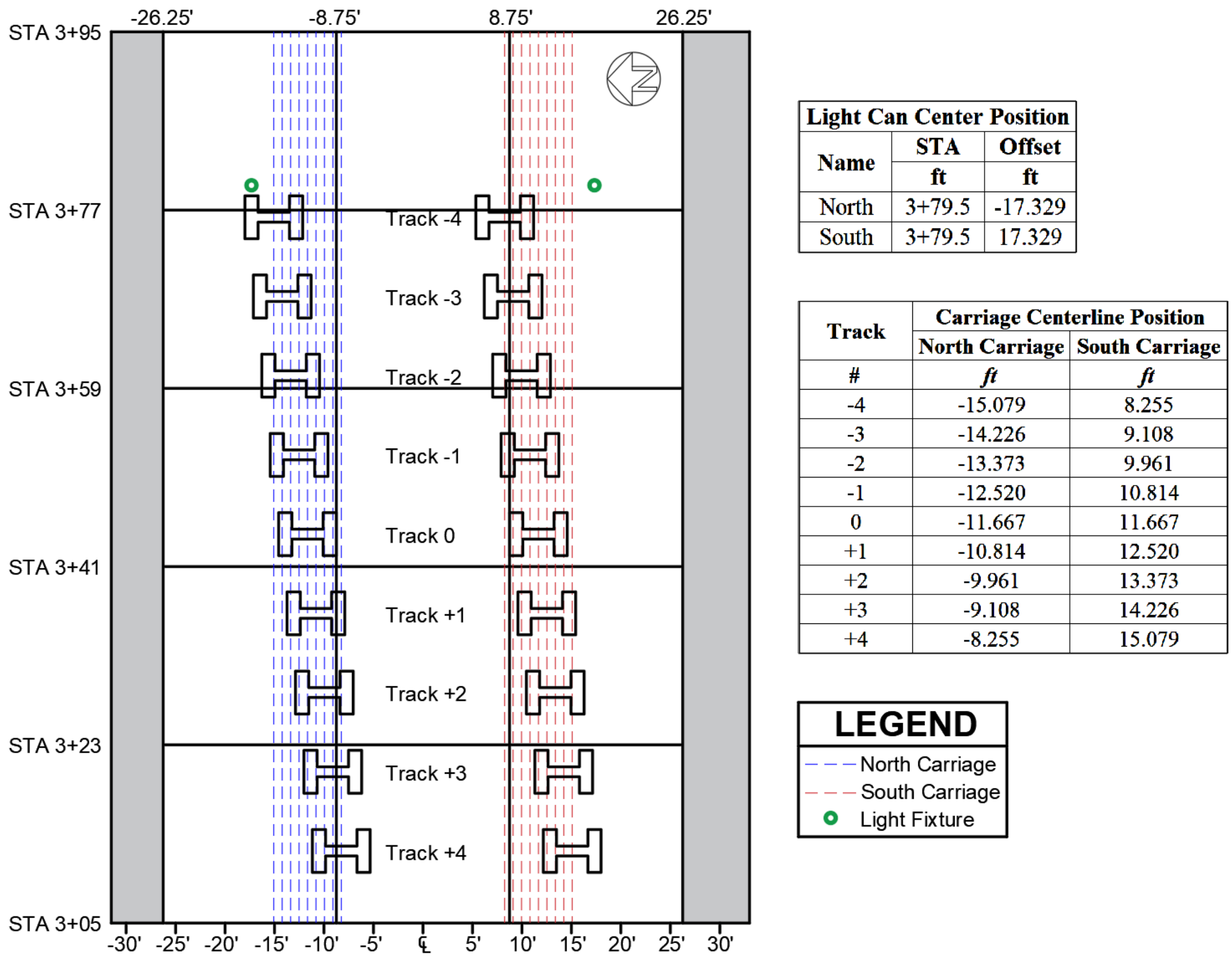
Figure 4. 3D User-defined aircraft inputs created in FAARFIELD 2.0.2

Table 2. CC10 expected passes to failure from FAARFIELD 2.0.2

Test Item	Gear	Wheel Load (pounds)	Expected Number of Passes		
			650psi Flex Concrete	700psi Flex Concrete	750psi Flex Concrete
MRS-1	2D	55,000	30,197	174,656	1,010,193
	3D	55,000	1,509	6,933	31,847
MRS-2	2D	55,000	5,379	27,196	137,493
	3D	55,000	418	1,734	7,203
MRS-3	2D	55,000	1,024	4,548	20,201
	3D	55,000	121	454	1,712

A.8 LIGHT FIXTURE LOCATIONS AND CONFIGURATION

FAA identified that two light fixtures should be incorporated into the CC10 design. Light fixtures were placed in test item slabs instead of transition area slabs so they were not placed in atypical slab sizes. It is common practice for the first and last slabs in a test item to be discounted during analysis in pavements projects, so designers placed the two light fixtures in the last slabs of MRS-1. The light fixture location within the slab, shown in Figure 5, was selected as being typical for a centerline light, and is neither over-conservative nor the best-case scenario. The fixtures are expected to be within the proposed traffic pattern (see Appendix B: Proposed CC10 Wander Pattern) and will not need a separate trafficking plan.



Light Can Center Position		
Name	STA	Offset
	ft	ft
North	3+79.5	-17.329
South	3+79.5	17.329

Track	Carriage Centerline Position	
	North Carriage	South Carriage
#	*ft*	*ft*
-4	-15.079	8.255
-3	-14.226	9.108
-2	-13.373	9.961
-1	-12.520	10.814
0	-11.667	11.667
+1	-10.814	12.520
+2	-9.961	13.373
+3	-9.108	14.226
+4	-8.255	15.079

Figure 5. Proposed in-pavement light fixture location

A.9 INSTRUMENTATION DESIGN

A.9.1 Pavement Instrumentation Design

A.9.1.1 Subgrade Moisture

One moisture sensor will be placed near the surface of the P-152 layer at the center of each test item. These sensors will be used to ensure that water is not permeating throughout the layers and compromising the strength of the subgrade.

A.9.1.2 Pavement Temperature

Two thermocouple trees (four depths per tree) will be placed in each test item. Thermocouples will be placed in the P-501 with depth spaced approximately 4 inches apart near the longitudinal edges of the north and south slabs. The concrete temperature profile is critical in evaluating strains/curling in the concrete.

A.9.1.3 Concrete Slab Bottom Vertical Stress

Ten pressure cells will be embedded into the surface of the P-403 asphalt layer for each test item. Pressure cells will be placed at the center and corners of slabs to monitor the stresses exerted at the bottom of the slab and monitor curling/warping. Per FEAFAA runs presented in A.12.2, the highest pressure at the bottom of the slab is 140 psi (965 kPa) for a 2D 60,000 lbs/wheel aircraft. Sensors will be sized accordingly.

A.9.1.4 Concrete Slab Center and Corner Vertical Deflection

Ten eddy current sensors will be installed in each test item at the surface of the P-403MR in locations that correspond to slab corners. These sensors will be used to monitor slab uplift to complement pressure cell curling/warping analysis. One additional eddy current sensor will be installed in each test item at the surface of the P-403MR in a location that is approximately center of slab. This sensor will be one foot away from a pressure cell and will be used to validate any instances where the pressure cell reads a null vertical stress.

A.9.1.5 Pavement Fatigue

76 strain gauges will be installed in each test item to monitor edge strains along longitudinal and transverse joints and bending strains at the corners of the slabs. Strain gauges in the longitudinal orientation will be placed along the longitudinal joint (9 feet from the nearest transverse joint) so it aligns with the inside wheel of Track 0. Strain gauges in the transverse orientation will be placed along the transverse joint of the outside slabs so it aligns with the outside wheel of Track 0. Strain gauges will be placed 3.5 feet from the corners of the outside slabs in a 45-degree orientation to capture bending stresses.

26 piezo-floating gate sensors will be installed in each test item to quantify any damage that is present in the pavement. Based on FEAFAA simulations, the maximum bottom stress along the transverse joint is at offsets ±12.8 feet and ±17.5 feet. Some strain gauges will be placed at these locations on the opposite side of the joint to compare strain responses to piezo-floating gate sensors. Sensors will be installed parallel to slab joints 1 inch from the bottom of the slab to capture the strain and damage at these locations. The maximum top and bottom stresses along the longitudinal joint are at 7.2 feet and 9.0 feet from the nearest transverse joint. The first indication of damage on the longitudinal joints are expected in these locations. Since strain gauges are already

placed mid-slab, piezo-floating gate sensors will be placed 7.2 feet from either transverse joints. The gauges will be installed parallel to slab joints 1 inch from the bottom of the slab.

FEAFAA simulations to determine expected strains for selecting gauge size are presented in A.12.2. The highest tensile strain 1 inch from the top or bottom of the slab is 100με (72kip wheel load on the 13.5-inch PCC section). Gauges will be sized accordingly.

A.9.1.6 Concrete Relative Humidity

Two relative humidity sensors will be placed in each test item. Their placement will mirror the placement of the thermocouples and will be used in monitoring warping of slabs.

A.9.1.7 Concrete Slab Joint Opening

Two eddy current sensors will be placed mid-slab on the longitudinal edges of each test item to monitor joint movement for incorporation into DGAC's rigid dynamic backcalculation model.

A.9.2 In-Pavement Light Fixture Instrumentation Design

Instrumentation for the in-pavement light fixtures was based on previous experiments at NAPTF, with two changes. First, the laser deflectometer did not provide useful data so this was removed from the design. Additionally, the previous light fixture experiment only included strain gauges at the bottom of the pavement since it was embedded in flexible pavement. Embedded strain gauges will be placed at the bottom and top of the concrete to match the embedded gauges in the surrounding rigid pavement to monitor top-down and bottom-up cracking. Two additional strain gauges (1 top, 1 bottom) located at the same distance from the transverse joint will be placed in the same slab for each light fixture to compare strains experiences in the penetration versus the pavement itself.

A.9.3 Data Acquisition System Design

The sensors supporting this experiment generate approximately 425 channels of data. A typical SPU supports 192 channels of data. Two SPUs are required to support the pavement test items, with a third to support the in-pavement light fixture instrumentation.

FAA wishes to upgrade SPU3 South to a National Instruments DAQ. It will be upgraded to include one NI cRIO 9035 chassis and 5 expansion chassis. Two enclosures will be designed with three chassis in each enclosure. Enclosure 1 will collect data for MRS-1. Enclosure 2 will collect data for MRS-2. Software has been written for previous construction cycles in LabVIEW, LabVIEW FPGA, and LabVIEW Real-Time to support these chassis. The existing software will be the starting point for developing the software to support CC10. The chassis will have bridge modules and analog input modules to support data from 152 strain gauges, 22 eddy current sensors, 20 pressure cells, and 52 piezo-floating gate sensors.

SPU4 South currently includes a VXI DAQ chassis with three modules capable of supporting 192 analog input channels total with the ability to use bridge completion boards to upgrade those channels to bridge input channels. This DAQ will be used for data from 76 strain gauges, 11 eddy current sensors, 10 pressure cells, and 26 piezo-floating gate sensors.

Existing Campbell CR1000 data loggers with multiplexor modules will be used to collect static data. Hardware and software for these data loggers already exist at NAPTF. They each have 16 analog inputs which can be connected to multiplexors. These will be used for the thermocouples and moisture sensors. A National Instruments cRIO DAQ chassis and one expansion chassis will be installed in the existing SPU3 North enclosure to support light fixture instrumentation data. Each light fixture requires 18 quarter bridge strain gauges inside the can and 10 pavement strain gauges. The DAQ chassis will be populated with quarter bridge and full bridge strain gauge modules.

A.9.4 Wireways and Cable Routing

All wires will be direct buried and routed to the nearest handhole. The wires will then be routed to the appropriate DAQ unit. Trunk lines will be used from the light fixtures to the DAQ.

A.10 ESTIMATED CONSTRUCTION SCHEDULE

CC10 is expected to require 198 days for construction. A summary schedule assuming a September 22, 2023 start date is provided in Figure 6. A detailed estimate is provided in Table 3. Only the effort required to remove the remaining P-154MR after CC8 post-traffic testing is included in this schedule.

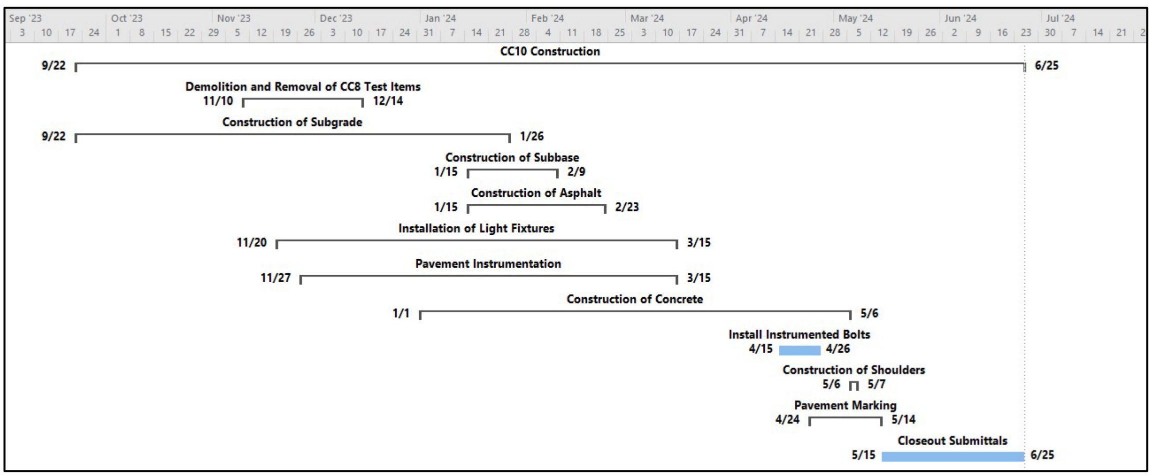


Figure 6. Estimated construction schedule summary

Table 3. Estimated construction schedule

Task Name	Duration	Start	Finish
CC10 Construction	198 days	Fri 9/22/23	Tue 6/25/24
Demolition and Removal of CC8 Test Items	25 days	Fri 11/10/23	Thu 12/14/23
Pre-Construction Submittals	20 days	Fri 11/10/23	Thu 12/7/23
P-101MR Demolition - STA 3+00 to 6+10	5 days	Fri 12/8/23	Thu 12/14/23
Construction of Subgrade	91 days	Fri 9/22/23	Fri 1/26/24
P-152MR Submittals	10 days	Fri 12/1/23	Thu 12/14/23
P-152MR Conditioning in 207 Yard	60 days	Fri 9/22/23	Thu 12/14/23
P-152MR Placement	30 days	Fri 12/15/23	Thu 1/25/24
Moisture Sensor Installation	1 day	Fri 1/26/24	Fri 1/26/24
Construction of Subbase	20 days	Mon 1/15/24	Fri 2/9/24
P-154MR Submittals	10 days	Mon 1/15/24	Fri 1/26/24
P-154MR Placement	10 days	Mon 1/29/24	Fri 2/9/24
Construction of Asphalt	30 days	Mon 1/15/24	Fri 2/23/24
P-403MR/P-603MR Submittals	20 days	Mon 1/15/24	Fri 2/9/24
P-403MR/P-603MR Placement	10 days	Mon 2/12/24	Fri 2/23/24
Installation of Light Fixtures	85 days	Mon 11/20/23	Fri 3/15/24
I-100MR/L-125MR/P-605/P-606/P-610MR Submittals	30 days	Mon 11/20/23	Fri 12/29/23
Instrumentation of Light Fixtures	40 days	Mon 1/1/24	Fri 2/23/24
I-100MR/L-125MR/P-610MR Installation	10 days	Mon 2/26/24	Fri 3/8/24
P-610 Curing	7 edays	Fri 3/8/24	Fri 3/15/24
Pavement Instrumentation	80 days	Mon 11/27/23	Fri 3/15/24
Pavement Instrumentation Submittals	40 days	Mon 11/27/23	Fri 1/19/24
Prepare DAQ and Instruments	30 days	Mon 1/22/24	Fri 3/1/24
Install Pavement Instrumentation	10 days	Mon 3/4/24	Fri 3/15/24
Construction of Concrete	90 days	Mon 1/1/24	Mon 5/6/24
P-501MR Submittals	55 days	Mon 1/1/24	Fri 3/15/24
P-501MR Placement	15 days	Mon 3/18/24	Fri 4/5/24
Curing	28 edays	Mon 4/8/24	Mon 5/6/24
Install Instrumented Bolts	10 days	Mon 4/15/24	Fri 4/26/24
Construction of Shoulders	2 days	Mon 5/6/24	Tue 5/7/24
Subbase Placement (ELEV 57.75')	1 day	Mon 5/6/24	Mon 5/6/24
Asphalt Placement (ELEV 58.00')	1 day	Tue 5/7/24	Tue 5/7/24
Pavement Marking	15 days	Wed 4/24/24	Tue 5/14/24
P-620MR Submittals	10 days	Wed 4/24/24	Tue 5/7/24
P-620MR Marking	5 days	Wed 5/8/24	Tue 5/14/24
Closeout Submittals	30 days	Wed 5/15/24	Tue 6/25/24

A.11 ESTIMATED PROJECT COST

CC10 construction costs were estimated using R.S. Means cost estimating software and are summarized in Table 4. The consultant cost is based on CC9 QA and inspection effort. Only the cost required to remove the P-154MR after CC8 post-traffic testing is included in this cost estimate.

Table 4. Summary of construction costs from RSMeans

Task	Bare Cost	Loaded Cost with Overhead and Profit
Task 1 – Demolition and Removal of CC8 Test Items	$32,048.50	$39,344.24
Task 2A – 207 Yard Clay Preparation	$114,374.90	$127,016.94
Task 2B – Construction of Subgrade	$50,601.91	$59,511.83
Task 3 – Construction of Subbase	$65,469.44	$79,854.77
Task 4 – Construction of Asphalt	$63,518.56	$74,790.11
Task 5 – Installation of Light Fixtures	$10,665.64	$12,844.82
Task 6 – Construction of Concrete	$118,963.57	$135,922.36
Task 7 – Pavement Marking	$5,807.91	$8,229.36
QA/Overhead/Management	N/A	$322,617.24
Total	**$461,450.43**	**$860,131.67**

A.12 DESIGN DATA

A.12.1 FAARFIELD Section Reports

All FAARFIELD section reports used to design the CC10 test items are provided on the following pages. These reports encompass the initial thickness determination as well as life calculations based on the designed cross sections.

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A.12.2 FEAFAA Results for Strain Gauge and Pressure Cell Design

Embedded strain gauges are placed 1 inch from the top and bottom of the slab to ensure that the gauges are adequately embedded in the material and will not be damaged from the tire. Pressure cells are embedded into the P-403 surface and will be flush with the interface of the P-403 and P-501 layer. FEAFAA 3.0.5 was used to determine the expected maximum tensile stresses at these locations in the slab for each test item. The load positions that yielded the highest stresses at the top and bottom of the concrete for 2D and 3D loading are given in Figure 7 below.

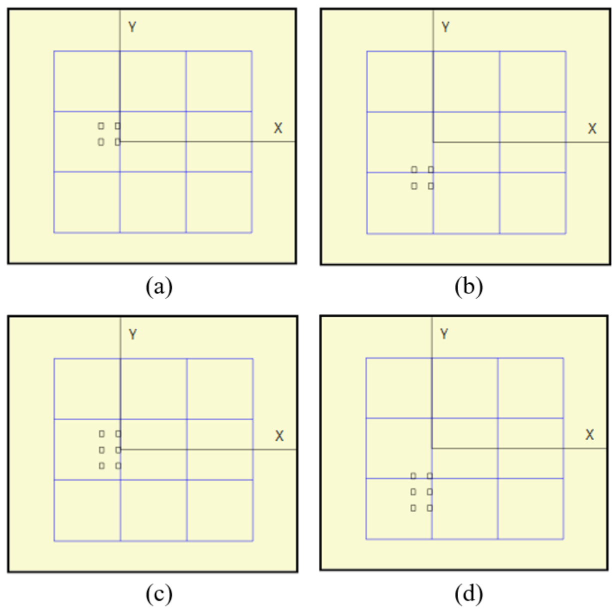

Figure 7. Load positions for maximum stresses for (a) 2D bottom of slab (b) 2D top of slab (c) 3D bottom of slab (d) 3D top of slab

FEAFAA does not directly output strains, so the following equations were used to convert the FEAFAA stresses to strains for strain gauge design.

$$Ep_{xx} = \frac{S_{xx} - 0.15 * \left(S_{yy} + S_{zz}\right)}{E_{pcc}} * 10^6$$

$$Ep_{yy} = \frac{S_{yy} - 0.15 * (S_{xx} + S_{zz})}{E_{pcc}} * 10^6$$

Where,

Ep_{xx}	=	Tensile strain in the x direction, με
Ep_{yy}	=	Tensile strain in the y direction, με
S_{xx}	=	Stress component in the x direction, psi
S_{yy}	=	Stress component in the y direction, psi
S_{zz}	=	Stress component in the z direction, psi
E_{pcc}	=	Elastic modulus of concrete, psi

The material properties that were used in the FEAFAA models are provided below in Table 5.

Table 5. Material properties used in FEAFAA 3.0.5

Layer	Modulus, psi
Concrete	5,500,000
Asphalt	711,000
Subbase	31,000
Subgrade	10,400

The subgrade and subbase modulus were taken as the minimum resilient modulus values from laboratory testing during CC8 [3]. The asphalt modulus was taken as the minimum elastic modulus from HWD testing during CC9 [4]. The concrete modulus was the anticipated value for a 700-750psi flexural strength mix, which falls between the elastic modulus obtained during CC8 HWD testing for 650psi and 900psi flexural strength mixes.

Four different loading cases were chosen when running FEAFAA to roughly simulate common aircraft: NAPTV 2D with 60,000 lbs/wheel (A380 wing gear), NAPTV 2D with 67,000 lbs/wheel (B787), NAPTV 2D with 72,000 lbs/wheel (A340-500 WV000 wing gear), and NAPTV 3D with 60,000 lbs/wheel (B777/A380 Belly). A 220psi tire pressure was selected to match anticipated trafficking of CC10. All loading cases are higher than the anticipated trafficking which would ensure the embedded strain gauges, piezo-floating gauges, and pressure cells could withstand the stresses and strains incurred by increasing the traffic loading and/or gear configuration. The stresses and strains for each case and test item are provided in Table 6.

Table 6. FEAFAA results at the interface and 1 inch from top and bottom of slab

Case	Location	X	Y	Z	Sxx	Syy	Szz	(Ep)yy	(Ep)xx
		in	in	in	psi	psi	psi	με	με
13.5" PCC 2D 60kip	Interface	-63.0	-7.2	0.0			-139.9		
	1" Bottom	-7.0	0.0	1.0	124.1	482.2	-58.4	85.9	
	1" Top	49.0	-115.2	12.5	178.8	-17.8	22.9		32.4
		-7.0	-28.8	12.5	-20.0	152.8	8.6	28.1	
14.5" PCC 2D 60kip	Interface	-63.0	-7.2	0.0			-137.8		
	1" Bottom	-7.0	0.0	1.0	108.5	455.9	-60.3	81.6	
	1" Top	49.0	-115.2	13.5	174.7	-16.7	21.9		31.6
		-7.0	-28.8	13.5	-19.3	149.2	7.5	27.4	
15.5" PCC 2D 60kip	Interface	-63.0	-7.2	0.0			-135.8		
	1" Bottom	-7.0	0.0	1.0	94.5	430.6	-62.0	77.4	
	1" Top	49.0	-115.2	14.5	165.8	-14.6	18.5		30.0
		-7.0	-28.8	14.5	-17.5	143.6	5.4	26.4	
13.5" PCC 67kip	Interface	-63.0	-7.2	0.0			-151.9		
	1" Bottom	-7.0	57.6	1.0	142.8	535.3	-40.4	94.5	
	1" Top	49.0	-115.2	12.5	198.4	-19.0	23.5		35.9
		-7.0	-28.8	12.5	-25.0	163.5	10.1	30.1	
14.5" PCC 2D 67kip	Interface	-63.0	-7.2	0.0			-149.4		
	1" Bottom	-7.0	57.6	1.0	124.7	505.6	-43.1	89.7	
	1" Top	49.0	-115.2	13.5	185.3	-18.1	25.4		33.5
		-7.0	0.0	13.5	-14.0	147.8	-0.5	27.3	

Table 6. FEAFAA results at the interface and 1 inch from top and bottom of slab (concluded)

Case	Location	X	Y	Z	Sxx	Syy	Szz	(Ep)yy	(Ep)xx
		in	in	in	psi	psi	psi	με	με
15.5" PCC 2D 67kip	Interface	-63.0	-7.2	0.0			-146.7		
	1" Bottom	-7.0	0.0	1.0	112.6	479.5	-45.1	85.3	
	1" Top	49.0	-115.2	14.5	176.9	-15.7	21.6		32.0
		-7.0	0.0	14.5	-12.9	141.1	5.2	25.9	
13.5" PCC 2D 72kip	Interface	-63.0	-7.2	0.0			-156.0		
	1" Bottom	-7.0	57.6	1.0	147.3	569.0	-35.9	100.4	
	1" Top	49.0	-115.2	12.5	219.6	-22.2	30.2		39.7
		-7.0	-28.8	12.5	-26.6	181.8	11.8	33.5	
14.5" PCC 2D 72kip	Interface	-63.0	-7.2	0.0			-154.3		
	1" Bottom	-7.0	57.6	1.0	132.3	538.6	-28.2	95.1	
	1" Top	49.0	-115.2	13.5	202.9	-18.9	24.8		36.7
		-7.0	-28.8	13.5	-22.4	173.0	8.7	31.8	
15.5" PCC 2D 72kip	Interface	-63.0	-7.2	0.0			-153.1		
	1" Bottom	-7.0	57.6	1.0	118.1	507.9	-26.6	89.9	
	1" Top	49.0	-115.2	14.5	194.8	-16.7	21.4		35.3
		-7.0	-28.8	14.5	-21.0	167.9	6.7	30.9	
13.5" PCC 3D 60kip	Interface	-63.0	-7.2	0.0			-136.3		
	1" Bottom	-7.0	0.0	1.0	144.1	468.0	-43.9	82.4	
	1" Top	56.0	-158.4	12.5	197.0	-65.4	13.8		37.2
		-7.0	-28.8	12.5	-23.0	181.0	11.0	33.2	
14.5" PCC 3D 60kip	Interface	-63.0	-7.2	0.0			-135.1		
	1" Bottom	-7.0	0.0	1.0	129.3	448.9	-41.1	79.2	
	1" Top	56.0	-158.4	13.5	186.1	-66.1	18.8		35.1
		-7.0	-28.8	13.5	-23.3	174.1	11.6	32.0	
15.5" PCC 3D 60kip	Interface	-63.0	-7.2	0.0			-134.0		
	1" Bottom	-7.0	0.0	1.0	114.1	426.5	-48.2	75.7	
	1" Top	56.0	-115.2	14.5	184.3	-14.4	19.1		33.4
		-7.0	-28.8	14.5	-19.7	168.3	8.6	30.9	

FEAFAA simulations were also performed to determine the specific locations along the longitudinal and transverse joints that would experience the maximum stress and damage. The expected trafficking conditions (2D, 220psi tire pressure, 55,000 lbs/wheel) were used in the simulations. Figure 8 through Figure 10 show the S_{xx} at the top of the slab on the transverse joint for 13.5-inch, 14.5-inch, and 15.5-inch concrete slabs. Figure 11 through Figure 13 show the S_{xx} at the bottom of the slab on the transverse joint for 13.5-inch, 14.5-inch, and 15.5-inch concrete slabs. Figure 14 through Figure 16 show the S_{yy} at the top of the slab along the longitudinal joint for 13.5-inch, 14.5-inch, and 15.5-inch concrete slabs. Figure 17 through Figure 19 shows the cumulative damage factor (CDF) for each slab thickness.

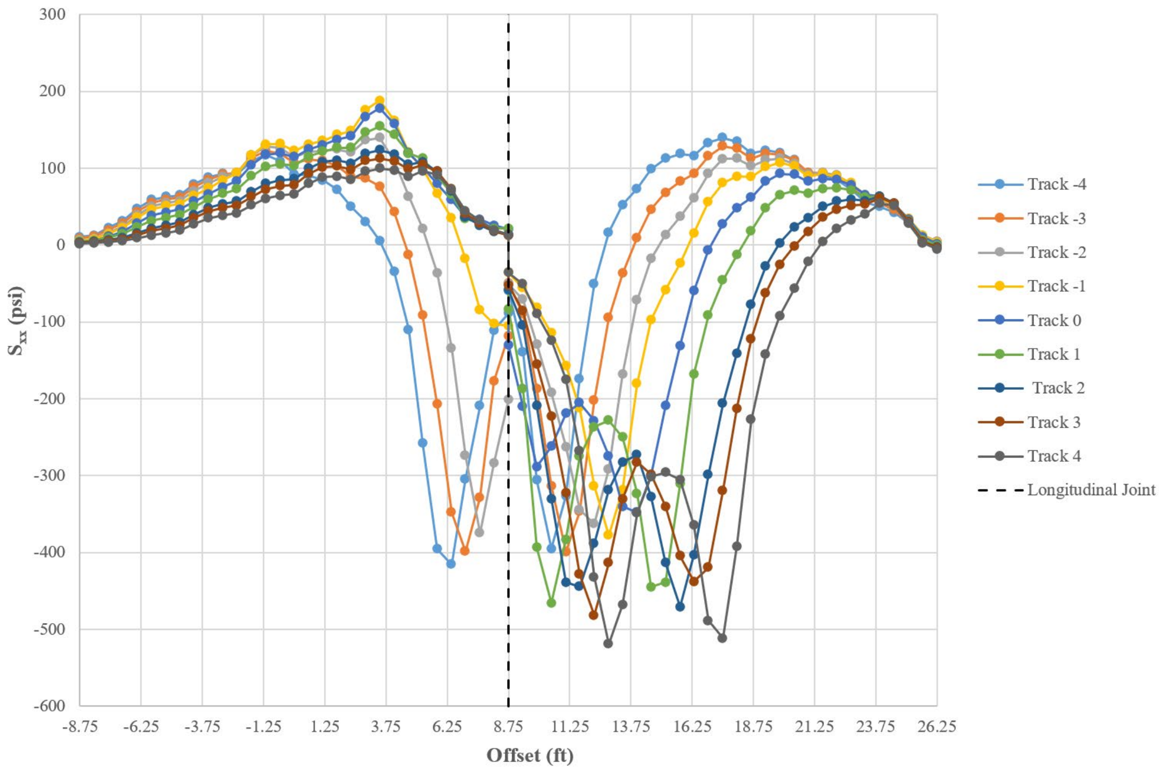

Figure 8. Top Sxx (psi) along transverse edge for 13.5-inch slab

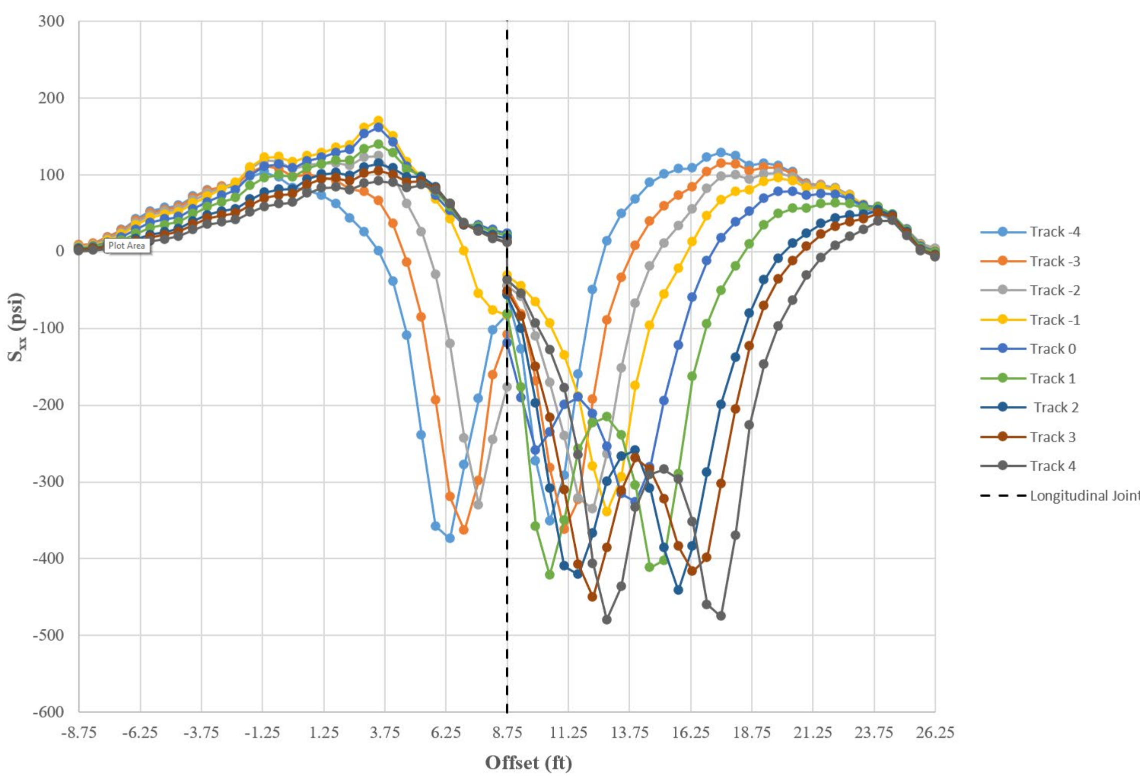

Figure 9. Top Sxx (psi) along transverse edge for 14.5-inch slab

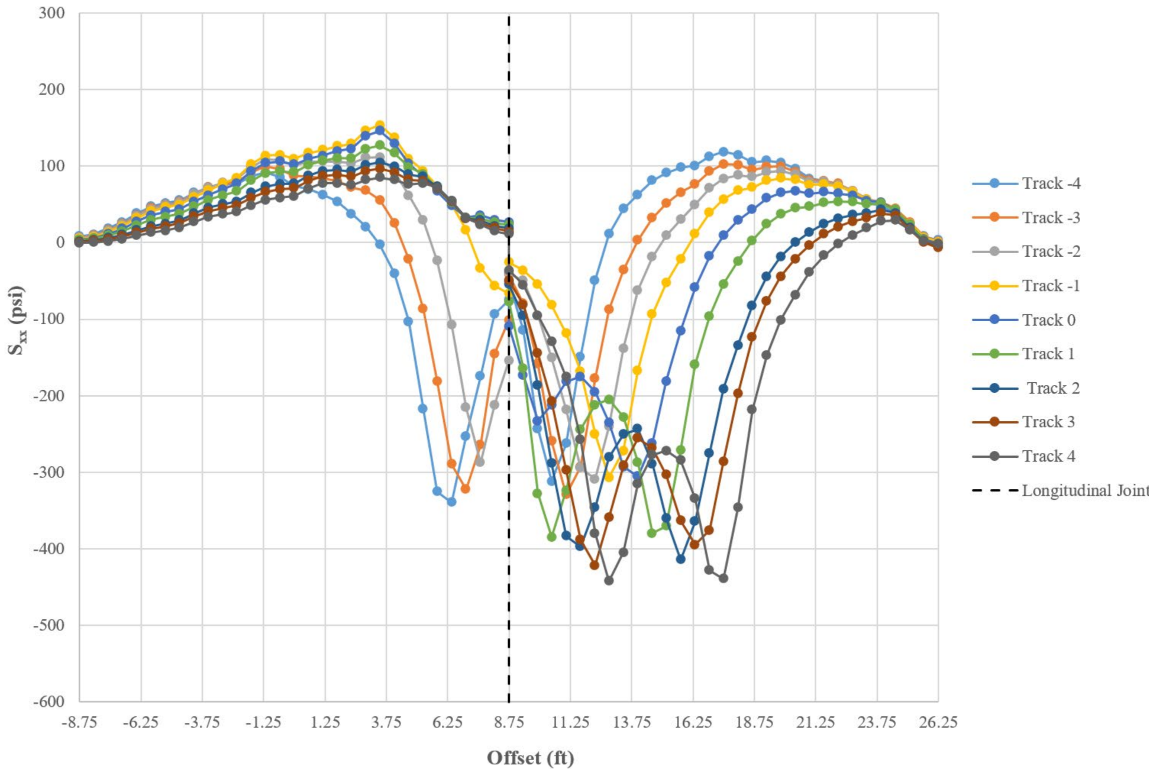

Figure 10. Top Sxx (psi) along transverse edge for 15.5-inch slab

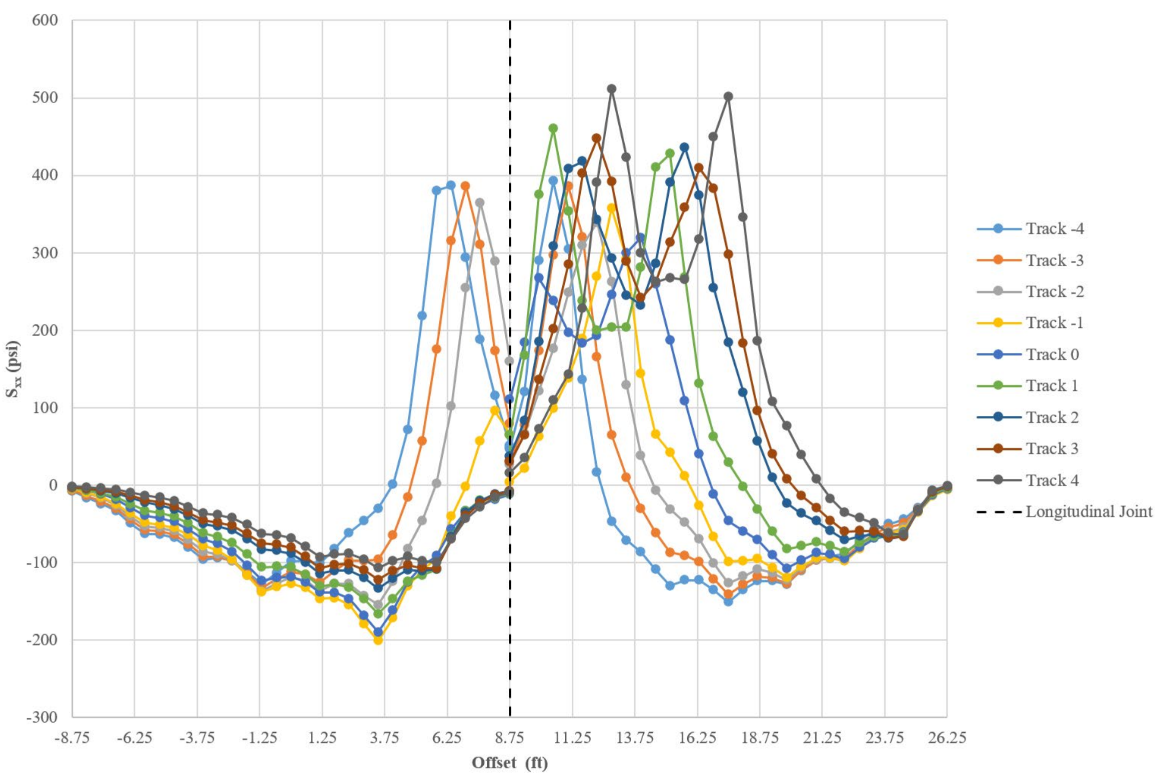

Figure 11. Bottom Sxx (psi) along transverse edge for 13.5-inch slab

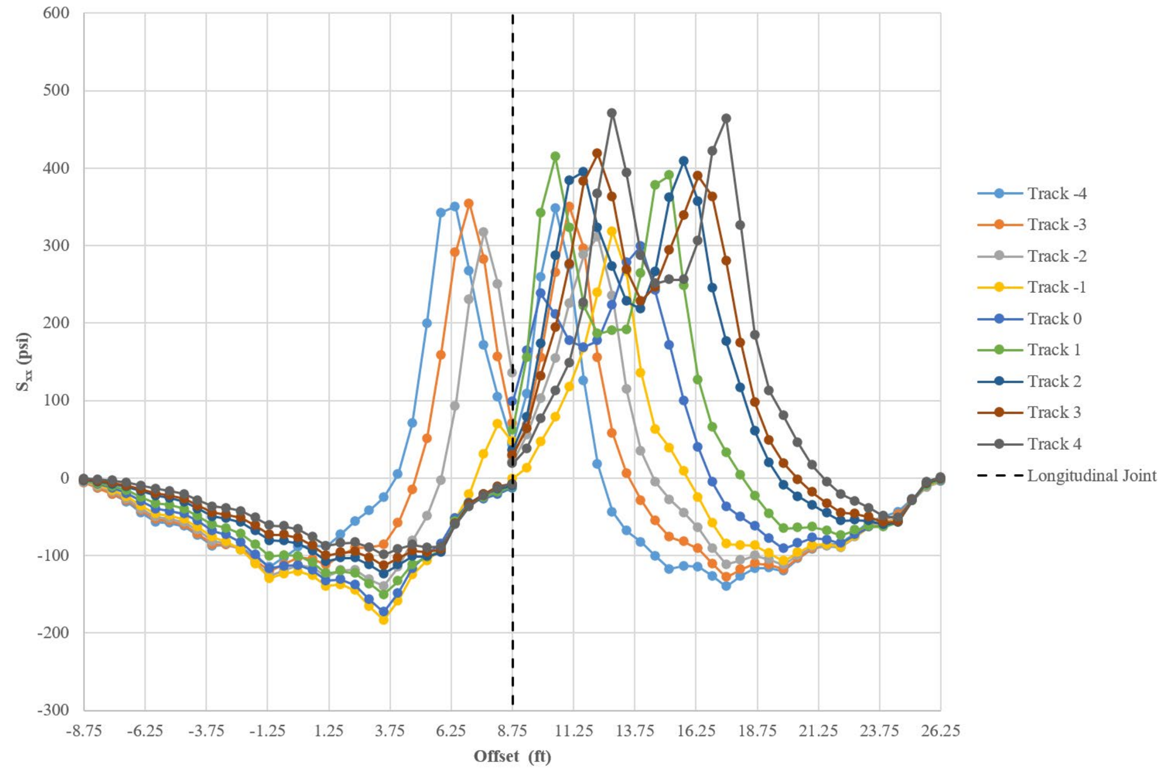

Figure 12. Bottom Sxx (psi) along transverse edge for 14.5-inch slab

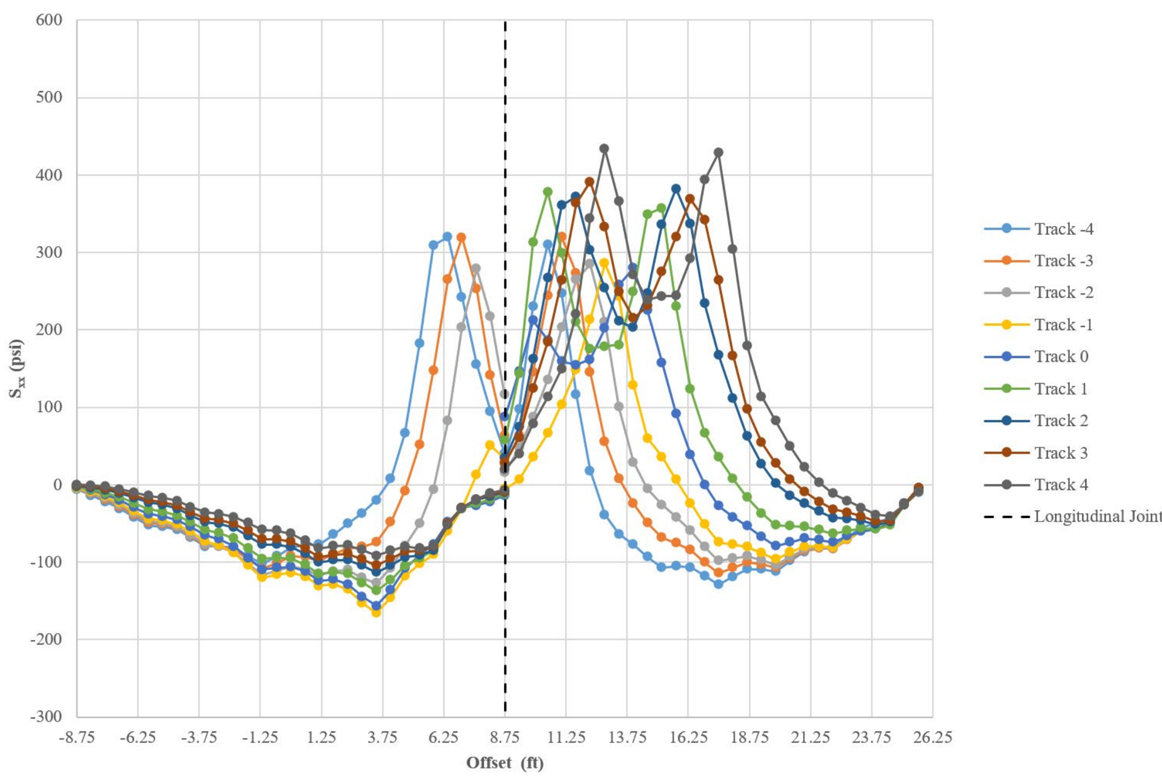

Figure 13. Bottom Sxx (psi) along transverse edge for 15.5-inch slab

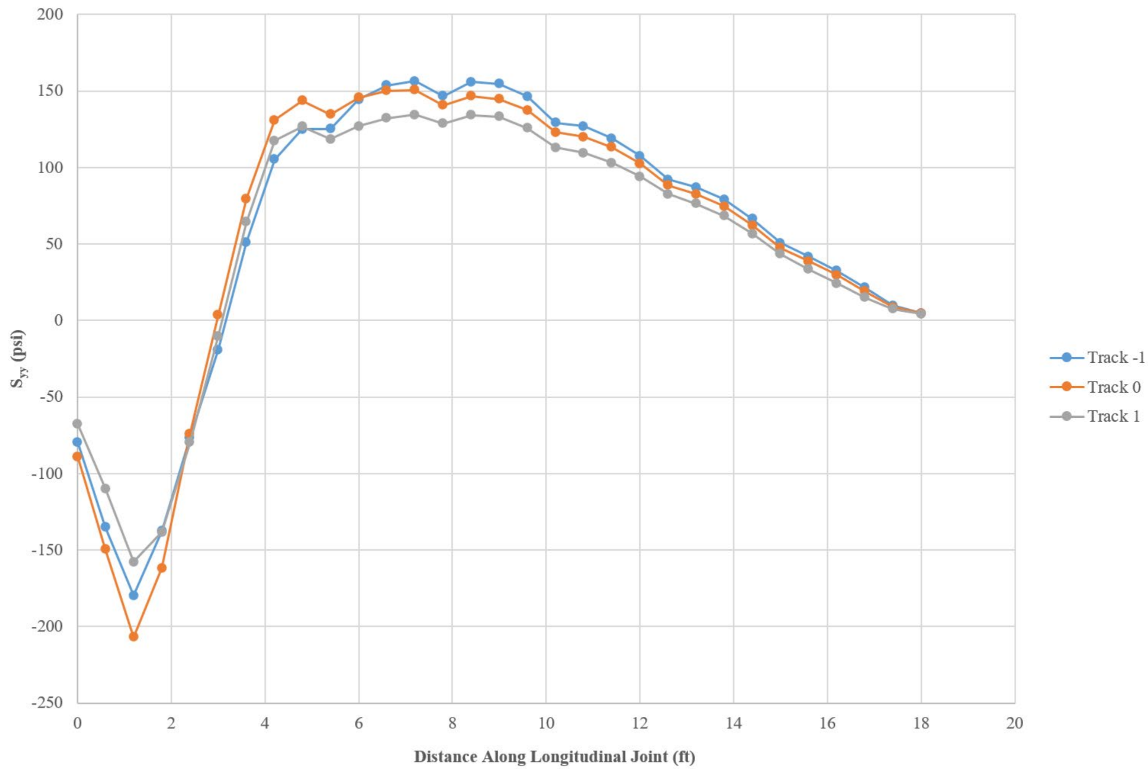

Figure 14. Top Syy (psi) along longitudinal edge for 13.5-inch slab

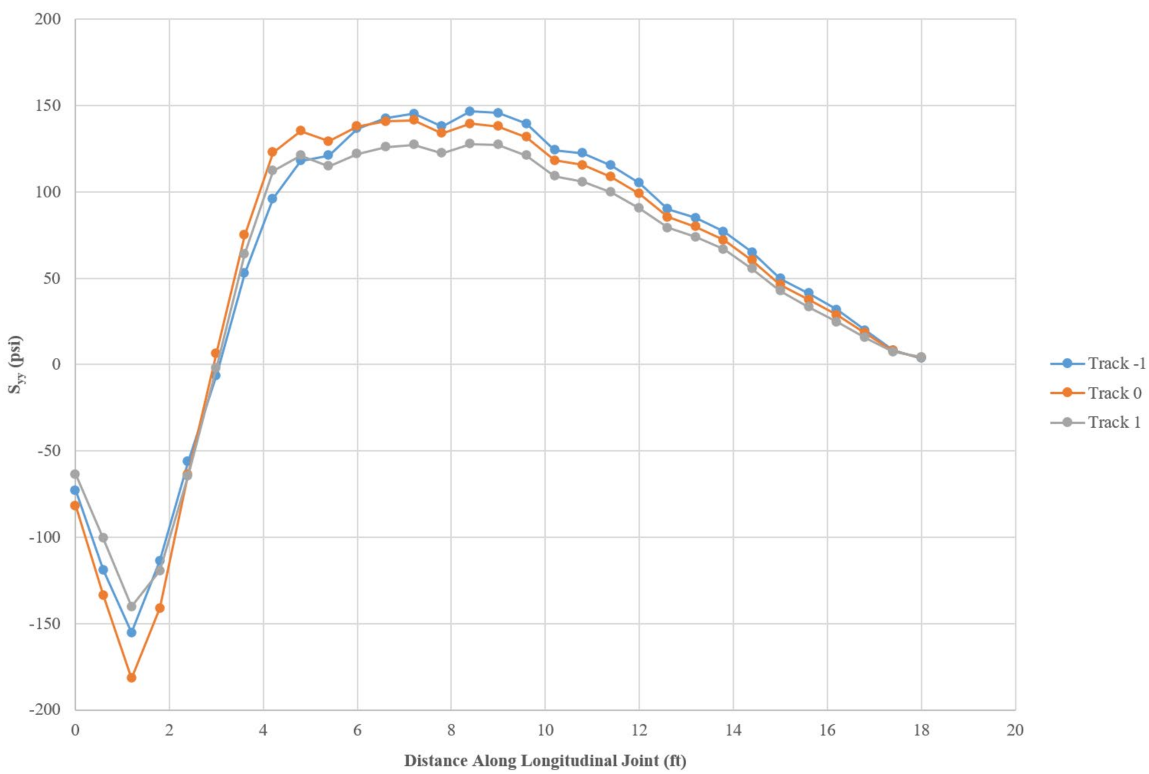

Figure 15. Top Syy (psi) along longitudinal edge for 14.5-inch slab

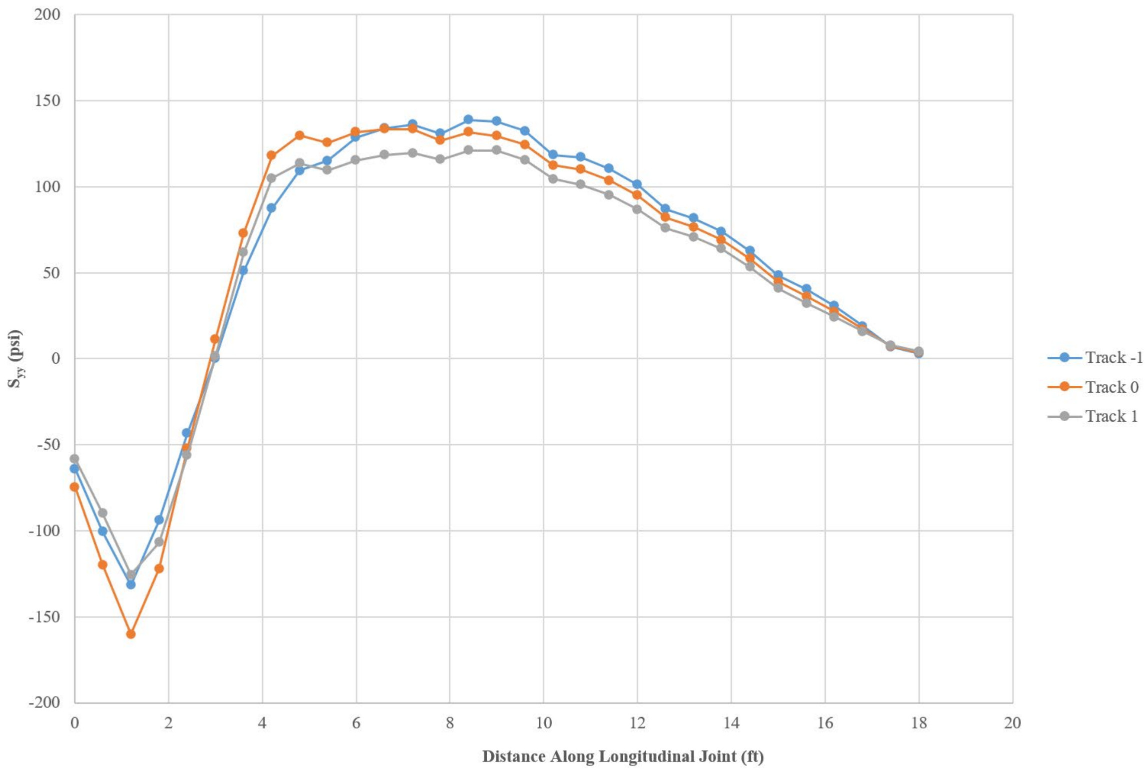

Figure 16. Top Syy (psi) along longitudinal edge for 15.5-inch slab

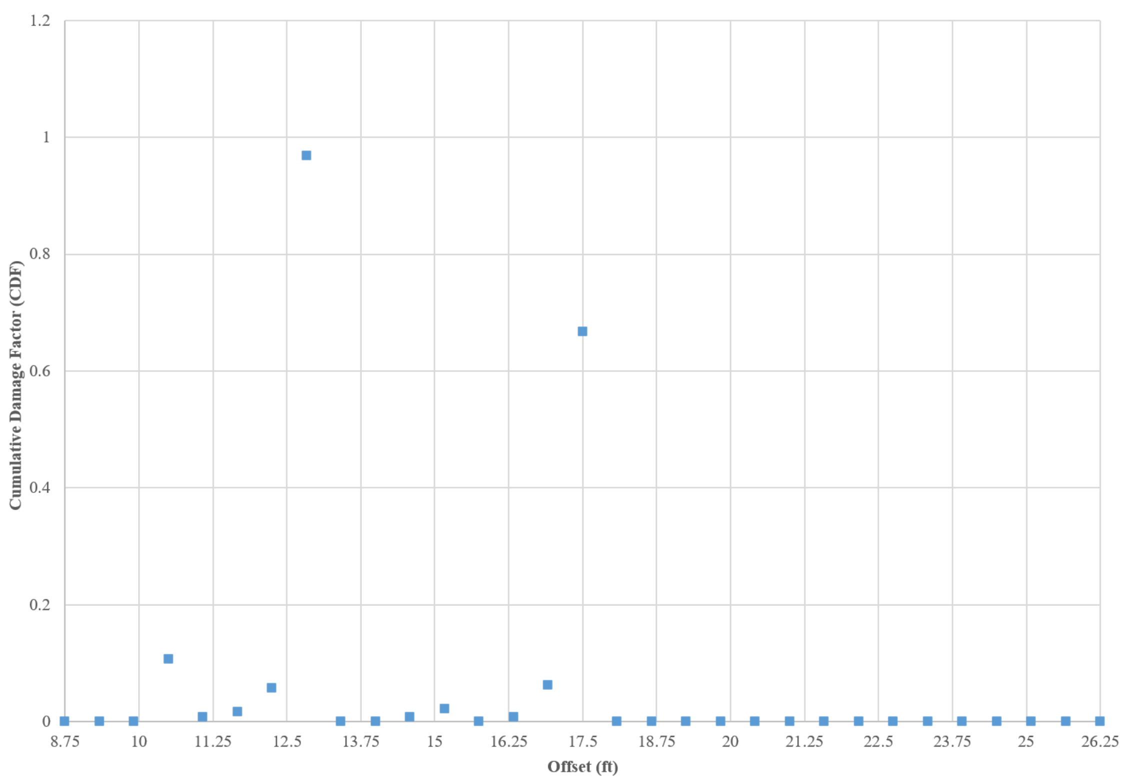

Figure 17. CDF for 13.5-inch slab

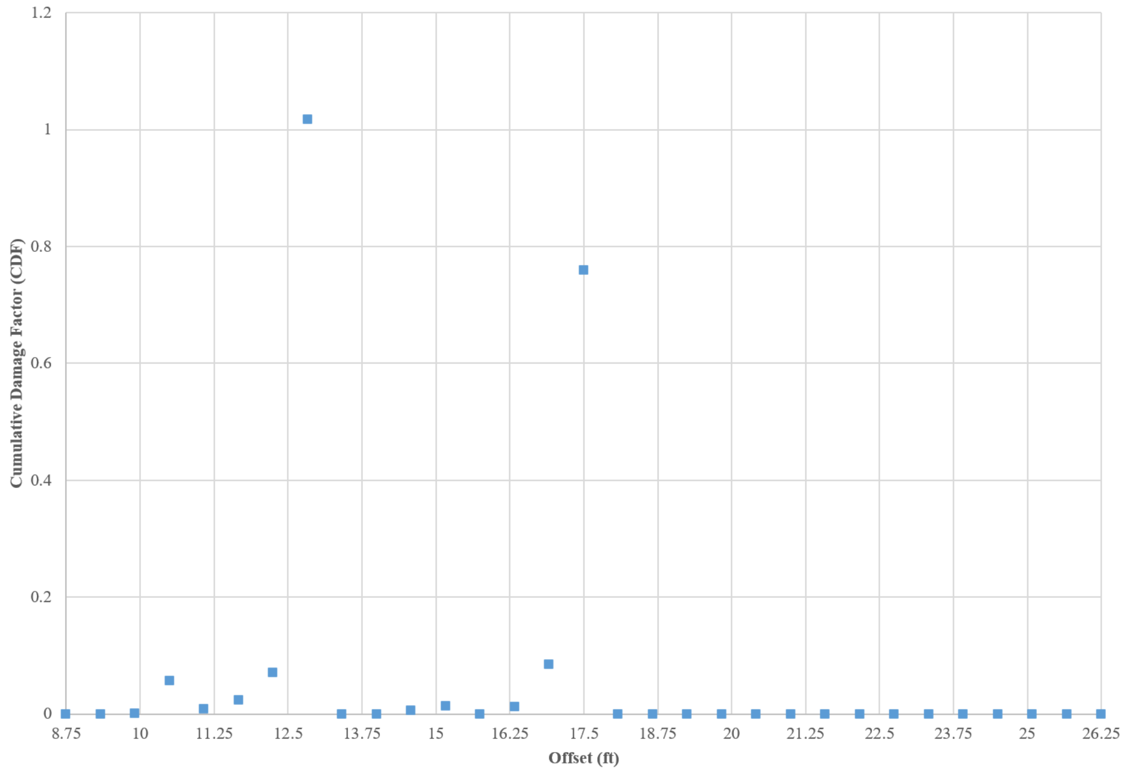

Figure 18. CDF for 14.5-inch slab

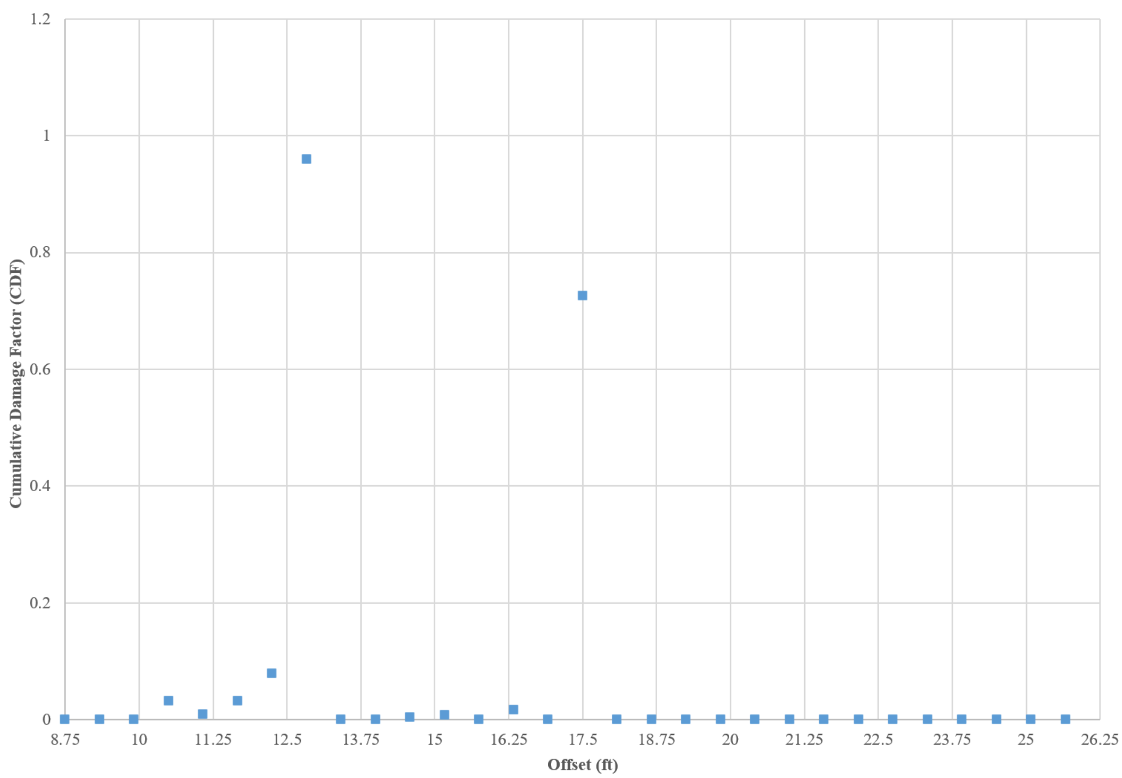

Figure 19. CDF for 15.5-inch slab

Based on the above figures, the maximum bottom stress along the transverse joint is at offsets ±12.8 feet and ±17.5 feet with damage first expected to occur at ±12.8 feet followed by ±17.5 feet. The maximum top stress along the transverse joint is at offset ±3.5 feet. The first damage is expected at this offset as well. The maximum top and bottom stresses along the longitudinal joint are at 7.2 feet and 9.0 feet from the nearest transverse joint. This is only applicable for the outer slabs. Damage along the longitudinal joints is expected in these locations.

APPENDIX B
PROPOSED CC10 WANDER PATTERN

Pass Sequence No.	Direction	Track No.	Carriage Centerline Location, ft.	
			North	South
1	West - East	-4	-15.079	8.255
2	East - West	-4	-15.079	8.255
3	West - East	-2	-13.373	9.961
4	East - West	-2	-13.373	9.961
5	West - East	0	-11.667	11.667
6	East - West	0	-11.667	11.667
7	West - East	2	-9.961	13.373
8	East - West	2	-9.961	13.373
9	West - East	4	-8.255	15.079
10	East - West	4	-8.255	15.079
11	West - East	3	-9.108	14.226
12	East - West	3	-9.108	14.226
13	West - East	1	-10.814	12.520
14	East - West	1	-10.814	12.520
15	West - East	-1	-12.520	10.814
16	East - West	-1	-12.520	10.814
17	West - East	-3	-14.226	9.108
18	East - West	-3	-14.226	9.108
19	West - East	-4	-15.079	8.255
20	East - West	-4	-15.079	8.255
21	West - East	-2	-13.373	9.961
22	East - West	-2	-13.373	9.961
23	West - East	0	-11.667	11.667
24	East - West	0	-11.667	11.667
25	West - East	2	-9.961	13.373
26	East - West	2	-9.961	13.373
27	West - East	4	-8.255	15.079
28	East - West	4	-8.255	15.079
29	West - East	3	-9.108	14.226
30	East - West	3	-9.108	14.226
31	West - East	1	-10.814	12.520
32	East - West	1	-10.814	12.520
33	West - East	-1	-12.520	10.814
34	East - West	-1	-12.520	10.814
35	West - East	-3	-14.226	9.108
36	East - West	-3	-14.226	9.108
37	West - East	3	-9.108	14.226
38	East - West	3	-9.108	14.226
39	West - East	1	-10.814	12.520
40	East - West	1	-10.814	12.520
41	West - East	-1	-12.520	10.814
42	East - West	-1	-12.520	10.814
43	West - East	-3	-14.226	9.108

Pass Sequence No.	Direction	Track No.	Carriage Centerline Location, ft.	
			North	South
44	East - West	-3	-14.226	9.108
45	West - East	-2	-13.373	9.961
46	East - West	-2	-13.373	9.961
47	West - East	0	-11.667	11.667
48	East - West	0	-11.667	11.667
49	West - East	2	-9.961	13.373
50	East - West	2	-9.961	13.373
51	West - East	-2	-13.373	9.961
52	East - West	-2	-13.373	9.961
53	West - East	0	-11.667	11.667
54	East - West	0	-11.667	11.667
55	West - East	2	-9.961	13.373
56	East - West	2	-9.961	13.373
57	West - East	1	-10.814	12.520
58	East - West	1	-10.814	12.520
59	West - East	-1	-12.520	10.814
60	East - West	-1	-12.520	10.814
61	West - East	1	-10.814	12.520
62	East - West	1	-10.814	12.520
63	West - East	-1	-12.520	10.814
64	East - West	-1	-12.520	10.814
65	West - East	0	-11.667	11.667
66	East - West	0	-11.667	11.667