Final Report on the Non-Destructive Inspection of the Tooth Rock & Vista Ridge Tunnels

Oregon Department of Transportation Contract B35752

R06G Tunnel Liner Investigation Project

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Prepared for:

Albert Nako, P.E.
Seismic Bridge Standards Engineer

ODOT, Tech Services, Bridge Engineering
4040 Fairview Industrial Drive SE, MS-4
Salem, OR 97302
Phone: (503) 986-3333
Albert.NAKO@odot.state.or.us

Prepared by:

Penetradar Technical Services Group

Penetradar Corporation
2509 Niagara Falls Boulevard
Niagara Falls, NY 14304
Phone: (716) 731-4369
info@penetradar.com

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1.0 Executive Summary

Evaluation of tunnel condition presents a challenging problem. Roadway and rail tunnels, by their very design are subject to a constant presence of moisture, even in relatively dry climates. This leads to a number of problems such as corrosion of embedded reinforcement, voids between the liner and base material, and water flow through and behind the liner, which sometimes appears in locations remote to the water source. Tunnels that are faced with tile or other surface materials can mask deeper flaws in the concrete liner and the source of the underlying problem. Manually intensive methods exist, however, because tunnels tend to be in high use and generally experience high traffic density, closures are undesirable, costly and in many cases impractical. Some tunnels have been in service for decades and because evaluating deterioration in these structures can be difficult, very little is sometimes known about their true condition. Inadequate methods of assessment and limited accessibility for inspection can lead to potential safety concerns and liability issues with motoring traffic. In recognition of these problems, nondestructive methods of evaluation have been proposed as a potential solution. This report describes the non-destructive methods and results obtained from our evaluation of the Tooth Rock Tunnel in Cascade Locks, Oregon & the Vista Ridge Tunnels in Portland, Oregon.

A nondestructive inspection of the Tooth Rock and Vista Ridge Tunnels were conducted on June 12-17, 2018 with the objective of determining the condition of the tunnel liner utilizing Ground Penetrating Radar (GPR) and Infrared Thermography (IRT) techniques in combination with High Resolution Video Imaging (HRI). Each method was used where applicable. GPR was utilized to identify areas of delaminated and deteriorated concrete, voids behind the liner and areas of high moisture concentration within the liner and behind the liner. The IRT technique was used to locate areas of potential water flow and wet liner surfaces, debonded tiles, and delaminated concrete, where possible. High resolution images of the tunnel liner were also produced for comparison with the subsurface information generated by GPR and IRT.

This work was conducted for the Oregon Department of Transportation as part of SHRP2 Implementation Assistance Program for Project R06G, Nondestructive Testing for Tunnel Linings.

The location and description of the three tunnels investigated are shown in Figure (1).

Figure 1. *Location of the Tooth Rock and Vista Ridge Tunnels*

Summary of Tunnel Investigation

The tunnel investigation was performed using ground penetrating radar and infrared thermography in combination with high resolution imaging of the liner surface. GPR testing was conducted using a non-contacting radar system, manufactured by Penetradar Corporation, along with a specialized electromechanical boom to position the antenna in close proximity to the surface. The inspection was performed in a series of longitudinal scans at a speed of up to 15 MPH, along the length of the tunnel wall at all clock positions around the inside circumference. The results of the GPR survey were presented in the form of an "unfolded" 2D plot, graphically depicting defects that were detected. The Infrared Thermography and High Resolution Imaging techniques were also performed in continuous scans and analyzed to produce plan-view images of the liner showing thermal anomalies and areas of potential deterioration along with high resolution images of the surface. The use of these NDT technologies provides a more comprehensive picture of the current condition of the tunnel liners.

The GPR inspection of the Tooth Rock and Vista Ridge tunnels determined concrete condition based upon measurement of radar signal properties. Measurement of radar signal attenuation levels and dielectric constants can be used as a general indicator of concrete condition and moisture content, respectively. Greater attenuation levels suggest a greater likelihood of deterioration, whereas higher dielectric measurements are indicative of higher moisture content and concrete in unsound condition.

Based on attenuation threshold levels prescribed in ASTM D6087 (and SHRP C-101), a threshold of -6 dB or greater, relative to maximum were used as an indicator of unsound concrete. The attenuation levels were quantified and further subdivided into what were classified as Low Attenuation (-6db to -7db), Medium to High Attenuation (-7db or more). Higher measured dielectric constant indicates the presence of moisture in concrete or the location of water filled voids. Moisture content in the concrete liner was estimated using a first order linear interpolation method based on measured dielectric constant.

Infrared Thermography detects delamination and areas of moisture based on unequal heating or cooling of the defect relative to the surrounding areas. Delaminations or debonded areas may appear as “hot” spots or “cool” spots in the thermal image depending on whether the material is undergoing a heating or cooling cycle. Areas of moisture may appear as cooler areas due to evaporation, in certain instances when ambient temperature is greater, however, the opposite may be true in other cases. IRT technology has been effective in detecting surface moisture and water flow through tunnel walls.

Along with the GPR and IRT methods, a high resolution image of the tunnel liner was produced using a 4K resolution camera. The HRI technique provides a visual record and detailed documentation of the liner surface in a plan-view format, allowing comparison with the NDT results and an archival record of visual condition.

The results from the NDT inspections are summarized below. An in-depth analysis and explanation of each analysis method and their significance are detailed later in this report.

The Tooth Rock Tunnel, Hwy 02 EB, MP 45.21 (Structure #04555)

The Tooth Rock Tunnel is an 811.7 foot, horseshoe-shaped structure, originally constructed in 1936, and lined with concrete. The nondestructive testing of the Tooth Rock Tunnel was conducted on June 14-15, 2018 between the hours of 6:00PM – 7:00AM. Single lane closures were used for the right and left lanes, providing access to half of the tunnel in each closure. With a linear liner width of 65 feet, the tunnel has approximately 52,760 square feet of surface area.

Figure 2. *View of the Tooth Rock Tunnel's West Portal at the time of the NDT inspection.*

Summary of Results for the Tooth Rock Tunnel

The GPR inspection of the Tooth Rock Tunnel detected varying levels of signal attenuation. Higher levels of attenuation typically correspond to greater incidence of delamination or deterioration in the concrete liner. This was found in 6.3% or 3317 square feet of the concrete liner, with 4.5% of the attenuation detections being classified as "medium or high" suggesting higher probabilities of deterioration/delamination in the liner at these locations. Detailed plan-view mappings showing probable areas of deterioration are provided later in this report.

The measurement of the dielectric constant at the surface of the liner was used as an indication of moisture content in the concrete material. Moisture content percentages by volume are divided into three levels which are classified as low (less than 2%), moderate (2% -10%) and high amounts of moisture (10% or greater). For the Tooth Rock Tunnel, 50.7% (26,778 ft^2) of the concrete liner was found to have low moisture content, 48.5% (25,578 ft^2) with moderate moisture content and 0.8% (404 ft^2) of the concrete to have a high moisture content.

To detect air-filled voids behind the liner, the GPR waveforms were analyzed at the interface between the liner and base material. In this tunnel, a distinct signal was observed from the back of the liner which was measured. Areas of air-filled voids were determined to exist based on the identification of specific radar waveform features which are characteristic of this type of defect. The quantity of air-filled voids found in the Tooth Rock Tunnel was found to be 1.9% or 1015 square feet.

Percentages and spatial area of defects, in square feet, are summarized in Table 1 below.

TABLE 1.

SUMMARY OF GPR TUNNEL INSPECTION – TOOTH ROCK

Attenuation/Deterioration	***GPR***	
	Percentage	***Area (SQFT)***
Total	6.3	3317
Low Attenuation/Deterioration (-6 dB to -7 dB)	*1.8*	*938*
Medium or High Attenuation/Deterioration (-7 dB or more)	*4.5*	*2379*
Dielectric Constant (Moisture Content - %)	***Percentage***	***Area (SQFT)***
Total	Average Dielectric Constant 8.2 Average Moisture Content 2.6%	
<8.0 (2%)	50.7	26778
8.0-14.0 (2% - 10%)	48.5	25578
>14.0 (10%+)	0.8	404
Air-Filled Voids	***Percentage***	***Area (SQFT)***
Total	1.9	1015

Vista Ridge Eastbound Tunnel, Hwy 47. MP 73.53 (Structure #09103)

The 1,019 feet long Eastbound Vista Ridge Tunnel is a horseshoe-shaped structure consisting of steel sets and tile finished concrete liner. The nondestructive testing of the Vista Ridge Eastbound Tunnel was conducted in the evening of June 15, 2018 from 9:00 pm through 9:00 am on June 16, 2018. Due to the limited work time available to complete the inspection, single lane closures of the left and right lanes were used. The tunnel wall surface area inspected was approximated 51,969 square feet.

A reinforced concrete slab suspended from the arch of the tunnel separated the tunnel into two portions. The lower section carried traffic on Highway 47, while the upper area served as a ventilation adit. The eastbound tunnel adit NDT inspection was performed on June 12, 2018 between the hours of 8:00AM – 4:00PM. Both the arch and floor of the adit were inspected with GPR only.

Figure 3. *View of the Vista Ridge Eastbound Tunnel at the time of inspection.*

Summary of Results for the Vista Ridge Eastbound Tunnel

Our inspection for liner deterioration based on measurement of GPR attenuation found similar quantities in the right and left walls of roughly 5 to 6 percent. These are the quantities that exceeded the -6 dB threshold, which is the threshold for possible concrete deterioration. However, while overall quantities were similar, the right lane wall of the Vista Ridge Eastbound Tunnel was found to contain greater levels of attenuation than the left lane wall suggesting it to be in a worse physical condition. The percent and total area (in square feet) exceeding each threshold are shown in Table 2.

The measurement of the dielectric constant at the surface of the liner was used as an indication of moisture content in the concrete material. Our measurements found the left lane wall to have an average calculated dielectric constant of 10.6, which is roughly estimated to be a 5.8% moisture content by volume, while the right lane wall was found to have a significantly greater average dielectric constant of 15.0, corresponding to an estimate of approximately 11.7% moisture by volume in the concrete. Table 2 below provides a breakdown of dielectric constants and estimated moisture content in the concrete.

Areas of air-filled voids were determined to exist based on the identification of specific radar waveform features which are characteristic of this type of defect. The quantity of air-filled voids found in the Vista Ridge Eastbound Tunnel was 9.2% or 845 square feet on the right lane side and 5.4% or 497 square feet on the left lane side, resulting in 7.3% or 1,346 square feet overall.

TABLE 2.
SUMMARY OF GPR TUNNEL INSPECTION – VISTA RIDGE EASTBOUND

Attenuation	***GPR***	
	Percentage	***Area (SQFT)***
Right Lane Wall – Total	6.1	1677
Low Attenuation/Deterioration (-6 dB to -7 dB)	*2.5*	*676*
Medium or High Attenuation/Deterioration (-7 dB or more)	*3.6*	*1001*
Left Lane Wall – Total	5.4	1321
Low Attenuation/Deterioration (-6 dB to -7 dB)	*2.6*	*647*
Medium or High Attenuation/Deterioration (-7 dB or more)	*2.8*	*674*
Total	5.7	2998
Low Attenuation/Deterioration (-6 dB to -7 dB)	*2.5*	*1323*
Medium or High Attenuation/Deterioration (-7 dB or more)	*3.2*	*1675*
Dielectric Constant (Moisture Content - %)	***Percentage***	***Area (SQFT)***
Right Lane Wall	Average Dielectric Constant 15.0 Average Moisture Content 11.7%	

Dielectric Constant (Moisture Content - %)	***Percentage***	***Area (SQFT)***
<8.0 (2%)	0.2	48
8.0-14.0 (2% - 10%)	35.4	9735
>14.0 (10%+)	64.4	17731
Left Lane Wall	Average Dielectric Constant Average Moisture Content	10.6 5.8%
<8.0 (2%)	21.9	5349
8.0-14.0 (2% - 10%)	64.9	15884
>14.0 (10%+)	13.2	3223
Total	Average Dielectric Constant Average Moisture Content	12.8 8.7%
<8.0 (2%)	10.4	5397
8.0-14.0 (2% - 10%)	49.3	25619
>14.0 (10%+)	40.3	20954
Air-Filled Voids	***Percentage*** *(of area scanned for voids)*	***Area (SQFT)*** *(of area scanned for voids)*
Right Lane Wall	9.2	845
Left Lane Wall	5.4	497
Total	7.3	1346

Vista Ridge Westbound Tunnel, Hwy 47. MP 73.56 (Structure #09103B)

The 1,061 feet long Westbound Vista Ridge Tunnel is a horseshoe-shaped structure consisting of steel sets and tile finished concrete liner. The nondestructive testing of the Vista Ridge Eastbound Tunnel was performed on June 15-16, 2018 between the hours of 9:00PM – 9:00AM. Single lane closures of the left and right lanes were used. The tunnel wall surface area inspected was approximated 50,928 square feet.

With construction similar to the eastbound tunnel, the westbound Vista Ridge tunnel was constructed with a reinforced concrete slab suspended from the arch of the tunnel. The slab separated the tunnel into two portions. The lower section carried Highway 47 traffic, whereas the upper area serves as a ventilation adit. The westbound tunnel adit NDT inspection was performed on June 13, 2018 between the hours of 8:00AM – 4:00PM. Both the arch and floor of the adit were inspected using GPR only.

Figure 4. *View of the Vista Ridge Westbound Tunnel Liner at the time of the inspection.*

Summary of Results for the Vista Ridge Westbound Tunnel

Our inspection for GPR attenuation found also found similar quantities in the right and lane walls of the westbound tunnel of roughly 11 to 12 percent that exceed the -6 dB threshold with both exhibiting similar amount of what would be defined as severe attenuation and potential deterioration. The percent and total area (in square feet) exceeding each threshold are shown in Table 2.

The measurement of the dielectric constant at the surface of the liner was used as an indication of moisture content in the concrete material. Our measurements found the left lane wall to have an average calculated dielectric constant of 10.6, which is estimated to be approximately 5.8% moisture content by volume, while the right lane wall was found to have a greater average dielectric constant of 15.0, corresponding to an estimate of approximately 11.7% moisture by volume in the concrete. Table 2 shows a breakdown of dielectric constants and estimated moisture content in the concrete.

The quantity of air-filled voids found in the Vista Ridge Westbound Tunnel was 3.2% or 305 square feet on the right lane side and 2.3% or 219 square feet on the left lane side, corresponding to 2.7% or 524 square feet overall.

TABLE 3.
SUMMARY OF GPR TUNNEL INSPECTION – VISTA RIDGE WESTBOUND

Attenuation	***GPR***	
	Percentage	***Area (SQFT)***
Right Lane Wall – Total	11.6	2943
Low Attenuation/Deterioration (-6 dB to -7 dB)	*4.6*	*1162*
Medium or High Attenuation/Deterioration (-7 dB or more)	*7.0*	*1781*
Left Lane Wall – Total	10.5	2665
Low Attenuation/Deterioration (-6 dB to -7 dB)	*3.8*	*958*
Medium or High Attenuation/Deterioration (-7 dB or more)	*6.7*	*1707*
Total	11.0	5608
Low Attenuation/Deterioration (-6 dB to -7 dB)	*4.2*	*2120*
Medium or High Attenuation/Deterioration (-7 dB or more)	*6.8*	*3488*
Dielectric Constant (Moisture Content - %)	***Percentage***	***Area (SQFT)***
Right Lane Wall	Average Dielectric Constant 15.1 Average Moisture Content 11.9%	
<8.0 (2%)	5.3	1348
8.0-14.0 (2% - 10%)	27.7	7050
>14.0 (10%+)	67.0	17066
Left Lane Wall	Average Dielectric Constant 13.4 Average Moisture Content 9.6%	
<8.0 (2%)	7.5	1901
8.0-14.0 (2% - 10%)	55.1	14039
>14.0 (10%+)	37.4	9524
Total	Average Dielectric Constant 14.3 Average Moisture Content 10.8%	
<8.0 (2%)	6.4	3249
8.0-14.0 (2% - 10%)	41.4	21089
>14.0 (10%+)	52.2	26590

Air-Filled Voids	***Percentage*** *(of area scanned for voids)*	***Area (SQFT)*** *(of area scanned for voids)*
Right Lane Wall	3.2	305
Left Lane Wall	2.3	219
Total	2.7	524

Comparison of Vista Ridge Eastbound and Westbound Tunnels

A comparison of concrete condition based on the measured attenuation distribution for the eastbound and westbound Vista Ridge Tunnels, found higher levels of signal attenuation in the westbound tunnel. With roughly twice the average level of signal attenuation, this comparison would suggest the westbound tunnel liner to be in generally worse physical condition than the eastbound tunnel.

Generally, concrete in poor condition tends to hold more moisture than concrete in sound condition. A comparison of moisture content between the eastbound and westbound Vista Ridge tunnels found higher moisture content (based upon higher dielectric measurements) in the westbound tunnel. A moisture content of 10% or greater was more likely to occur in the westbound tunnel, and with an average dielectric constant of 14.3, the westbound tunnel was estimated to have an average moisture content of 10.8%. The eastbound tunnel, with an average dielectric of 12.8 was determined to have a moisture content of approximately 8.7%. While there was only a difference of roughly 2% on average, the spread of values was significantly greater in the westbound than the eastbound tunnel. This lack of uniformity in the westbound tunnel and greater uniformity in moisture levels in the eastbound tunnel liner supports the suggestion that the eastbound tunnel is in better physical condition than the westbound tunnel.

Vista Ridge Tunnel Adits

The floor and arch areas were scanned with a handheld GPR antenna. A measurement of attenuation and moisture, similar to that performed for the liner walls, was also conducted for the adit floor and arch section. Table 4 below shows the results of this analysis. The westbound adit (floor and arch) was found to have significantly higher attenuation levels as compared to the eastbound adit.

For the adit areas, moisture content was measured in a different way due to the type of GPR antenna used. While overall moisture measurements were similar for both adits, there were differences in the location where these levels occurred. In the eastbound adit, moisture levels in the floor were more than double that of the arch, whereas, in the westbound adit, higher moisture levels were found in the arch with lesser amounts in the floor.

TABLE 4.
SUMMARY OF GPR TUNNEL INSPECTION

VISTA RIDGE EASTBOUND ADIT

Attenuation	***GPR Percentage***
Floor – Total	3.9
Low Attenuation (-6 dB to -7 dB)	*2.4*
Medium or High Attenuation (-7 dB or more)	*1.5*
Arch – Total	7.7
Low Attenuation (-6 dB to -7 dB)	*0.5*
Medium or High Attenuation (-7 dB or more)	*7.2*
Total	5.8
Low Attenuation (-6 dB to -7 dB)	*1.5*
Medium or High Attenuation (-7 dB or more)	*4.3*

VISTA RIDGE WESTBOUND ADIT

Attenuation	***GPR Percentage***
Floor – Total	7.9
Low Attenuation (-6 dB to -7 dB)	*4.7*
Medium or High Attenuation (-7 dB or more)	*3.2*
Arch – Total	10.3
Low Attenuation (-6 dB to -7 dB)	*1.4*
Medium or High Attenuation (-7 dB or more)	*8.9*
Total	9.1
Low Attenuation (-6 dB to -7 dB)	*3.0*
Medium or High Attenuation (-7 dB or more)	*6.1*

Higher Moisture Content	***GPR Percentage***
Floor – Total	16.3
greater than 2% more	*15.7*
greater than 4% more	*0.6*
Arch – Total	8.3
greater than 2% more	*7.4*
greater than 4% more	*0.9*
Total	12.3
greater than 2% more	*11.5*
greater than 4% more	*0.8*

Higher Moisture Content	***GPR Percentage***
Floor – Total	9.2
greater than 2% more	*8.8*
greater than 4% more	*0.4*
Arch – Total	14.2
greater than 2% more	*11.5*
greater than 4% more	*2.7*
Total	11.7
greater than 2% more	*10.1*
greater than 4% more	*1.6*

Vista Ridge Tunnel Comparison

There was found a level of correspondence between the condition assessment of the tunnel liner and adit for both the east and westbound tunnels. While both tunnels were found to be in reasonably good condition based on GPR measurements it was also determined that the eastbound tunnel was in better condition than the westbound tunnel.

Plan-View Maps

The results of the survey that are summarized in the tables above are also provided in detailed plan-view, colorized topographical mappings for each method or measurements type, along with infrared thermographic temperature maps and high resolution images of the tunnel liner walls/ceilings. An example of each type of mapping is shown in Figure 5. These mappings for each detection type and inspection are shown on the same plan-view maps as separate layers where each can be individually turned on and off by clicking the corresponding check boxes (for comparison purposes).

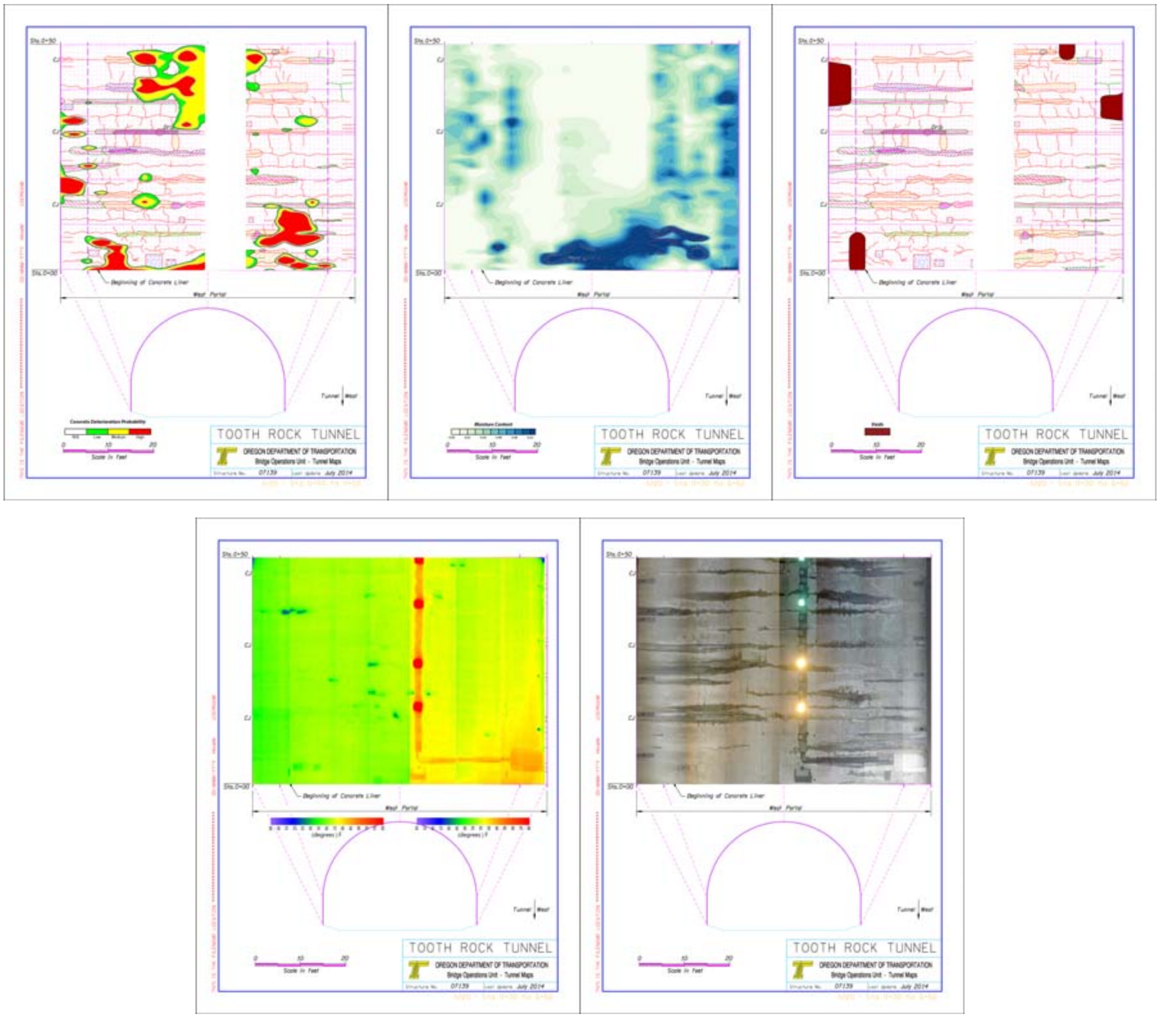


Figure 5. *Unfolded Plan-view maps show GPR Attenuation (top left); Moisture Content (top middle); Air-Filled Voids (Top Right); Infrared Thermography Temperature Measurements (Bottom Left); and High Resolution Imaging (Bottom Left). These maps are shown in 50-foot sections near the West Portal of the Tooth Rock Tunnel.*

2.0 Equipment Used

Our multi-sensor tunnel inspection system consisted of a combination of non-destructive technologies that included Ground Penetrating Radar, Infrared Thermography and High Resolution Video imaging. All equipment was installed onto a roadway vehicle, which included a specialized GPR and antenna positioning device that was developed for the tunnel inspection based on non-contacting GPR technology. For the adit areas, a man-portable GPR system was used. The IRT and HRI systems, originally developed for roadway use were utilized for evaluation of the tunnel liners.

2.1 Ground Penetrating Radar

High resolution, ground penetrating radar operates in a manner that is analogous to acoustic sounding, only at much higher frequencies. A short pulse, high resolution, ground penetrating radar emits precisely timed, very short radio frequency (RF) pulses of low power, repeated at a very high rate. The transmitted pulse is radiated outward by the radar antenna into the ground. Wherever there exists a change or discontinuity in the propagation medium, such as two differing material layers, a portion of the RF energy is reflected. The energy remaining is then coupled through the boundary. The amplitude of the reflected signal and its complement passing through a boundary depend on the difference between the electrical impedance (relative dielectric constants) of the materials at the boundary. RF reflections or radar target echoes are then observed by the antenna, coupled into the receiver and processed for display, recording and detection.

2.1.1 GPR System Configuration

A GPR system developed by Penetradar for tunnel inspection was utilized for this inspection. The radar consisted of an IRIS™ control unit and 1ns (1GHz) horn antenna, manufactured by Penetradar Corporation. The IRIS is a multi-channel GPR that can operate with both contacting and non-contacting antennas. For the tunnel application, a non-contacting antenna is preferred, since this permits an antenna standoff of approximately one foot and a fully mobile and relatively high speed inspection. The non-contacting horn antenna nominally produces a 1.0 ns monocycle signal (1GHz center frequency) operating with a 5MHz PRF and a 100Hz scan rate. This radar also employs a special “Autolock” range tracker which compensates for antenna distance to the surface.

2.1.2 GPR Antenna Positioning System

To precisely position the antenna and also accommodate obstructions that may be encountered during data collection, a specialized antenna positioning system was used. This system was developed specifically for Penetradar’s air-coupled GPR antennas and allows both angular movement and radial movement of the GPR horn antenna to obtain the desired standoff distance. With interior features in the tunnel such as piping, electrical power cables and hangers, it was necessary for the antenna positioning system to retract the antenna and then reposition it during travel to avoid potential obstacles. The basis for this system is a motorized trolley constructed around a high strength fiberglass rail. This rail and trolley were designed to support the radar antenna and move it radially to/from the inside tunnel wall surface. To facilitate use on the test vehicle the trolley/rail assembly was then mounted on a rotating support that permitted angular movement. With a reach of over 20 feet this system provided antenna access to all inside circumferential areas within the tunnel. The antenna positioning system is shown in Figure (6).

Figure 6. *Antenna Positioning System developed for the tunnel inspection shown installed on a rotating support that permits angular and radial movement of the antenna, and enabling access to all parts of the tunnel surface.*

2.1.3 Handheld GPR Antenna (used for Adit areas)

For the portions above the ceiling of the Vista Ridge Tunnels, a man-portable GPR system configured with one contacting antenna was used to scan the floor of the adit and tunnel arch. The man-portable system incorporated a GPR control unit and 1GHz contacting antenna combination, along with integrated distance measurement instrument (DMI) for distance logging of data. In operation, the man-portable system collects GPR data as the contacting antenna is pushed along the surface of the material under inspection. The IRIS-MP, man-portable GPR system is shown in Figure 7.

Figure 7. *Penetradar's 1 GHz hand-held antenna (with cart shown above) was utilized for the GPR inspection of the Vista Ridge Adit areas (both floor and arch). The IRIS-MP (man-portable) radar system incorporates a GPR control unit and contacting antenna. The antenna can be attached to the cart for man-portable operation on the floor or attached to a telescopic pole for contact with the arch above.*

2.2 Infrared Thermography

Infrared Thermography detects delamination and areas of moisture based on unequal heating or cooling of the defect relative to the surrounding areas. Delaminations or debonded areas may appear as "hot" spots or "cool" spots depending on whether the material is undergoing a heating or cooling cycle. This is the underlying property that defines the use of this technology for detection of delamination in structures such as bridge decks. In tunnels, however, without an external heating source, a condition close to temperature equilibrium may exist where the temperature gradients may be much lower. Areas of moisture may appear as cooler areas due to evaporation, in certain instances when ambient temperature is greater, however, the opposite may be true in other cases. Nevertheless, IRT technology has been effective in detecting surface moisture and water flow through tunnel walls.

2.2.1 IRT System Configuration

The IRT system used for the inspection was based on leading edge thermographic technology and consisted of a high resolution, high precision thermal camera. For the tunnel inspection, the IRT camera was mounted onto a vehicle, collecting a continuous image roughly 12 feet in width while the vehicle traveled along the length of the tunnel. The camera has a resolution of 800 x 600 pixels and the ability to measure temperature with a resolution greater than 0.1 degree centigrade. The IRT image is digitally recorded at 30FPS (frames per second) for subsequent analysis along with distance (DMI) information generated by the survey vehicle to ensure proper location referencing. The IRT survey collects continuous and quantitative thermal data as the survey vehicle travels, which after appropriate processing, is converted to a plan-view format. This is done by specialized image processing software, developed by Penetradar, which is similar to that used in thermal line scan imaging. The end result are thermal images that are precisely scaled representations of the object or structure under test, preserving their proper size, shape and location. After this preprocessing is completed, delamination at the top reinforcing steel level and/or overlay debonding are then identified in accordance with ASTM D4788-03. This state-of-the-art technique is superior to conventional methods which rely on direct analysis of forward-view thermal images.

2.3 High Resolution Video Imaging

Along with the GPR and IRT methods, a high resolution image of the tunnel wall was generated. A high resolution video imaging system was used to produce a visual record. Recording video along with distance information is a relatively straight forward procedure, however, it is useful to present the video image in a plan-view, on the same scale and in a manner similar to NDT data to permit comparison. To produce this type of format it was necessary to utilize a special image processing technique, similar to that used in IRT image processing, which converted a forward-view image to a plan-view. The images provided in this report were produced by extracting portions of each recorded video frame, based on distance traveled, and assembling an accurately scaled "plan-view" image of the wall. While equivalent to a line-scan recording, this method produced a correctly scaled image, presented on the same scale as the GPR and IRT. The visual image is useful for viewing surface features of the tunnel alongside all of the other detections. Figure (8) shows an example of the plan-view image after imaging processing.

Figure 8. *An example of an unfolded, high resolution video image of the Tooth Rock tunnel liner after image processing. The unfolded format provides an overview of the liner condition and permits a direct comparison with NDT results.*

2.4 Distance Measurement System

A high-resolution distance measurement instrument (DMI) was utilized on the test vehicle, which provided distance information to the IRIS GPR, IRT and HRI equipment. The DMI has an accuracy of +/- 100 mm per km (+/- 6.5 inch per mile) and a resolution of 5 mm (0.2 inch).

3.0 Data Collection

3.1 GPR Survey - Tunnels

Prior to the commencement of the inspection, the client, the Oregon Department of Transportation, and the contractor, Penetradar, developed a survey plan to ensure efficient use of limited work hours, establish the optimal method of data collection, and determine the means for referencing and correlating the NDT data. The inspection was performed from June 12, 2018 through June 17, 2018 during hours that minimized interference with traffic. Because of the limited time available for the inspection, it was determined that the most efficient strategy would be to collect NDT data in a series of continuous longitudinal scans along the length of the tunnels using lane closures. For GPR tests, seventeen and twelve longitudinal antenna scans were made at fixed "clock positions", spaced three feet apart (when possible) around the inside circumference of the Tooth Rock and Vista Ridge (Eastbound & Westbound) Tunnels, respectively. The number of scans collected were based upon the tunnel size, the accessibility to the liner surface, and the presence of appurtenances such as lighting fixtures and obstructions. For the Vista Ridge Tunnel ceiling slab and top portion of the tunnel liner, a series of longitudinal GPR scans were also collected in the adit areas. Figure (9) shows the relative position of the GPR antenna scans that were made along the inside of the tunnel surface. The IRT and HRI data were also collected concurrently in a series of longitudinal scans along the length of the tunnel. The number of scans needed for complete coverage of the inside surface was determined on-site, to ensure contiguous coverage.

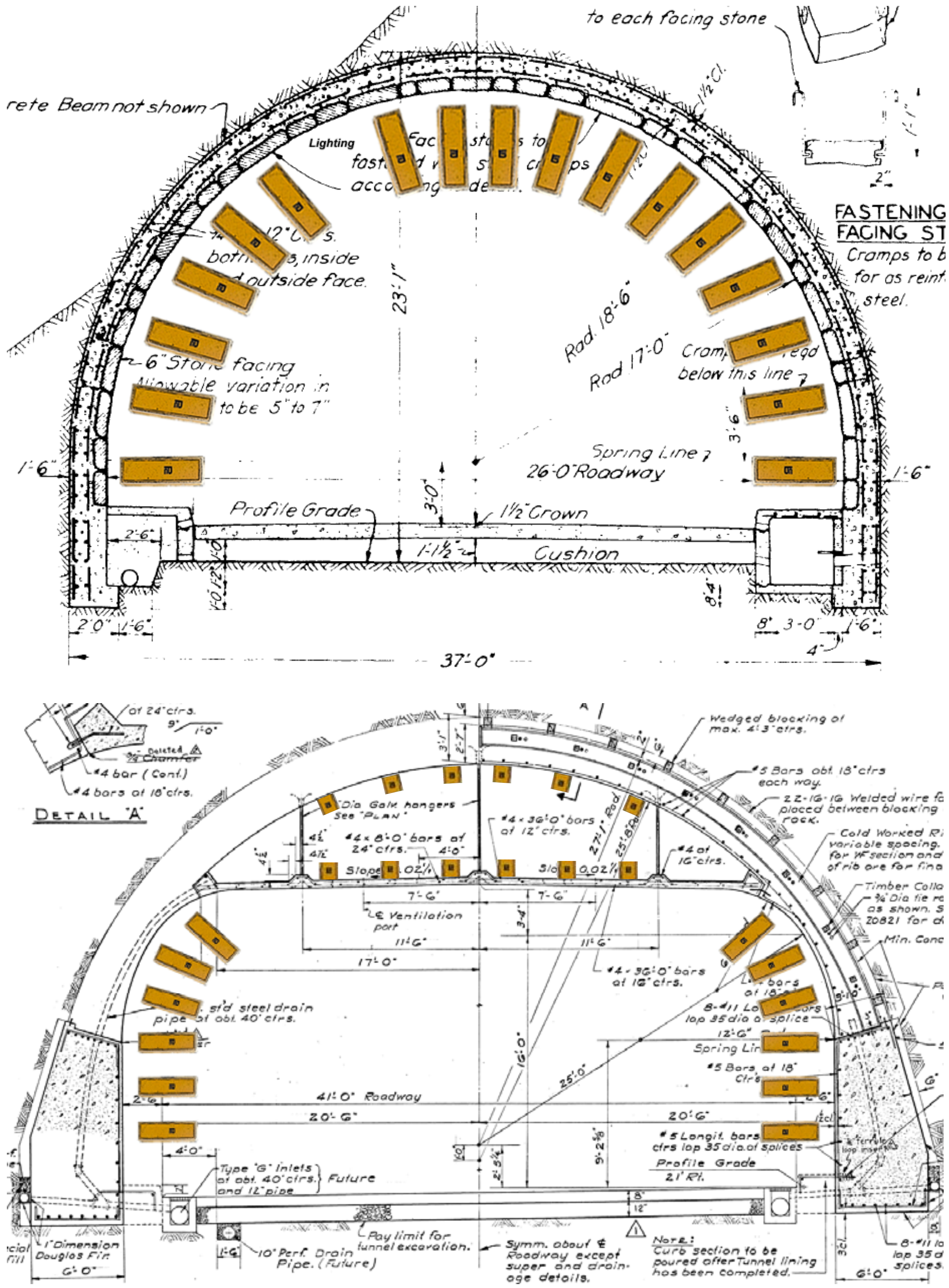


Figure 9. *Location of Antenna Scans in Tooth Rock (Top) and Vista Ridge Tunnels (Bottom). Locations of the handheld antenna scans are also shown in the adit areas of the Vista Ridge Tunnels.*

GPR data was collected with a two-person crew, consisting of a vehicle operator who also managed the collection of data, and an equipment operator to monitor and control the height of the antenna with the antenna positioning device. The antenna passes were made in a continuous manner, however when obstructions were encountered the antenna was retracted to clear the obstruction and then restored to the nominal inspection standoff distance. The tunnel inspection GPR system in operation is shown in Figure (10).

Figure 10. *GPR test vehicle shown with fully extended antenna boom on antenna positioning system, scanning the ceiling of the tunnel at a height of 21 feet. The rail structure with the motorized trolley allows for rapid adjustments of the radar antenna height during testing when encountering obstructions inside of the tunnel.*

Additional GPR scans were made with our 500MHz low frequency antenna in the lower portions of the Vista Ridge Tunnels, as shown in Figure (11). This antenna was used in the void analysis of the thick tunnel liner.

Figure 11. *Penetradar's 60AGC 500 MHz air-coupled antenna shown installed on the antenna positioning system. With greater penetration depths, this low frequency antenna was used for the detection of voids behind section of thick tunnel liner (Vista Ridge Tunnels).*

3.1.1 GPR Survey – Adits

The GPR data for the Vista Ridge Adits (Floor and Arch) was collected with a contacting style, man-portable GPR and a two-person crew. The man-portable system was used in a manner similar to the vehicle based GPR, making a series of parallel scan passes on either the floor of the adit or the upper portions of the liner. For the upper portions of the liner the antenna was detached and hand-carried or attached to a telescoping pole. Six antenna passes were made on the floor of each adit and six antenna passes were made on the arch (ceiling).

3.2 IRT / High Resolution Video Imaging Survey

For the tunnel inspection the IRT equipment was installed onto a test vehicle in a side-looking configuration. Data were collected in a series of longitudinal scans along the length of the tunnel and in a manner similar to the GPR data collection, IRT "scans" were made at several clock positions to cover the walls and ceiling of the tunnels. The IRT equipment as utilized for the inspection is shown in Figure 12.

A high resolution video camera was also used to document surface features within the tunnel. High resolution imaging was performed concurrently with the infrared thermography, using the same Distance Measurement Instrument (DMI) for location referencing. Collecting the two NDT data sets at the same time allowed for synchronization of locations and proper registration of data. The video imaging equipment was co-located on the same support hardware as the IRT equipment.

Figure 12. *Infrared thermography and high resolution imaging equipment used for tunnel inspection*

4.0 Results of Survey

Analysis of GPR Data - To identify defects in the tunnel liner, our analysis centered on the measurement of radar signal attenuation levels and dielectric constants as a general indicator of concrete condition and moisture content, respectively. Greater attenuation levels suggest a greater likelihood of deterioration, whereas higher dielectric measurements are indicative of higher moisture content and concrete in unsound condition.

Attenuation Measurement – Our analysis utilized the GPR methods based on ASTM D6087-03 and SHRP C101 which measured signal attenuation to predict the condition of the concrete. According to ASTM D6087, signal attenuation can be used as a general indicator of deterioration and delamination in concrete bridge decks. Although tunnel liners are not exposed to the same environmental conditions as bridge decks and the construction method is different, there are enough similarities in materials comprising these structures to warrant the use of this technique.

Based on attenuation threshold levels prescribed in ASTM D6087 (and SHRP C-101), a threshold of -6 dB or more, relative to maximum was used as an indicator of unsound concrete. Attenuation levels can be quantified and further subdivided into what is classified as Low Attenuation (-6db to -7db) and Medium to High Attenuation (-7db or more), and the level of attenuation can be used to provide an indication of the likelihood of deteriorated concrete.

Dielectric Measurement - Concrete in unsound condition can be hygroscopic, and hold significant amounts of moisture. In tunnels, high levels of moisture within a concrete liner can be an indication of deteriorated concrete, poor concrete consolidation during construction (honeycombing), moisture accumulation in base layers or some other type of incipient problem. GPR, with its ability to measure the electrical properties of materials, can be used to both identify areas of saturated concrete and quantify the moisture level based on measurement of the dielectric constant of the material.

It is well known that the dielectric constant of concrete is a function of many different variables, including the moisture content; and there is a direct relationship between moisture content and dielectric constant in concrete. We are able to estimate the moisture content in concrete based on a linear interpolation of dielectric constant using two extremes. Dry concrete with a relative dielectric constant of 6.25 represents an approximate low value whereas pure water, with a dielectric of 81 represents the maximum. Every other moisture condition will lie between these values. Once the dielectric constants from the GPR waveforms are determined, it is then possible to directly convert those measurements into moisture content percentages.

Analysis of IRT Data – The analysis of infrared thermographic data involves the mapping of temperature information in an image format. Since IRT data is produced in a video raster format, lines of temperature data can be digitally extracted from each image frame and reassembled to produce a distance-scaled, thermal mapping of the tunnel liner. This preprocessing method ensures proper scaling and normalizes thermal intensity in the final output. Detection of liner defects and water flow is based on identification of relative differences in temperature in the thermal mapping.

The results of the nondestructive evaluation of the Tooth Rock and Vista Ridge Tunnels are provided as a series of plan-view mappings, which are included as an appendix. The plan-view mappings show 50 foot sections of the tunnel in an "unfolded" format, depicting the location and spatial extent of defects and detections. A detailed discussion of the results is provided in the following sections.

4.1 Tooth Rock Tunnel – Ground Penetrating Radar

The ground penetrating radar inspection of the Tooth Rock Tunnel focused on the detection of deterioration/delamination (by measurement of signal attenuation), moisture content in the concrete liner (by measurement of relative dielectric constant) and air-filled voids at the back of the liner.

The GPR waveforms were analyzed using one or more techniques previously described to identify and quantify each type of defect.

4.1.1 Deteriorated Concrete - (GPR Attenuation)

For the Tooth Rock Tunnel, 6.3% of the area was found to have attenuation levels in excess of -6 dB (i.e. less than or equal to 25% of the power level of the maximum measurement), and 4.5% of the tunnel liner exhibited attenuation levels we classified as "medium or high", with attenuation levels of greater than -7db. This corresponds to 3,317 ft^2 and 2,379 ft^2 of tunnel area, respectively at these attenuation levels. Figure (13) shows the distribution of the GPR signal attenuation for the Tooth Rock Tunnel. (The colors of the graph for the attenuated areas match the corresponding attenuation maps shown later in this report.)

GPR Attenuation Distribution of Tooth Rock Tunnel

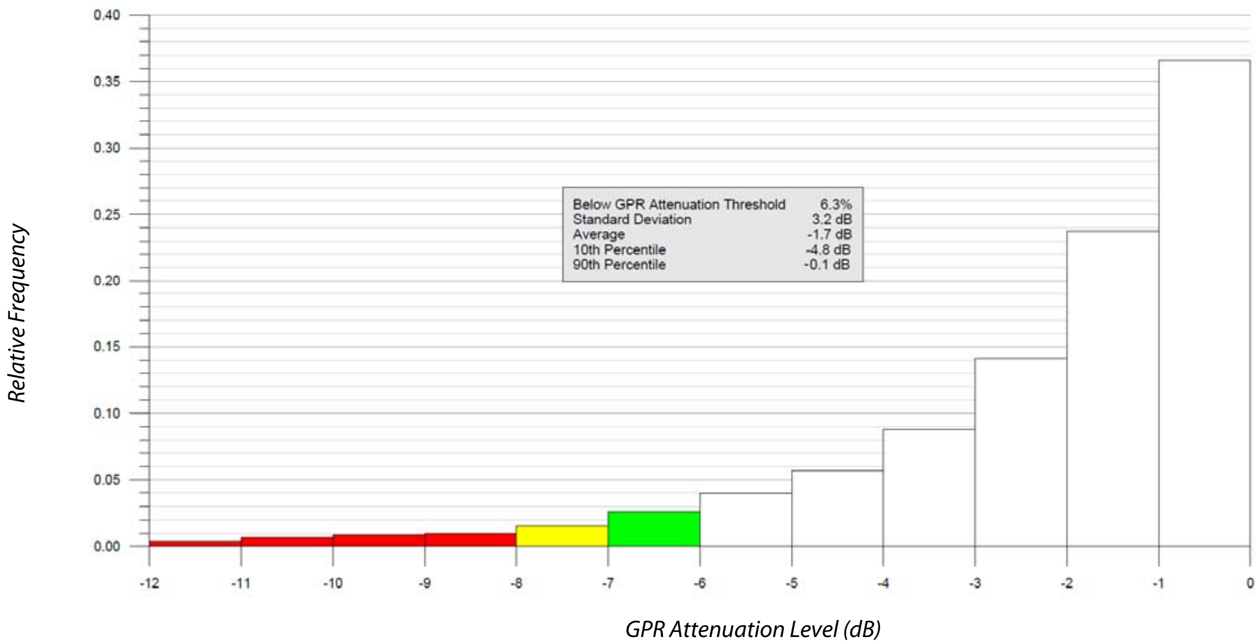


Figure 13. *The histogram shows the distribution of attenuation in the GPR signal. The attenuation level is the ratio of the measured GPR signal versus the maximum signal amplitude from the GPR scan. The relative frequency shows the percentage of attenuation values of all measured values on a 1 dB interval.*

4.1.2 Moisture Content – (Relative Dielectric Constant)

The average dielectric constant of the west wall was determined to be 8.2. This value corresponds to 2.6% moisture by volume. Figure (14) shows the distribution plot of calculated moisture content of the concrete of the Tooth Rock Tunnel. (The colors of the graph for the moisture connect values match the corresponding moisture maps shown later in this report.) Just as in the GPR attenuation distribution charts, the moisture content values are shown in relation to frequency of occurrence. There are three percentages given for ranges of dielectric constants for concrete that relate to low (less than 2%), moderate (2%-10%) and high (10% or greater) amounts of moisture content in the concrete. For the Tooth Rock Tunnel, 50.7% (26,778 ft^2) of the concrete liner was found to have low moisture content, 48.5% (25,578 ft^2) with moderate moisture content and 0.8% (404 ft^2) of the concrete to have a high moisture content.

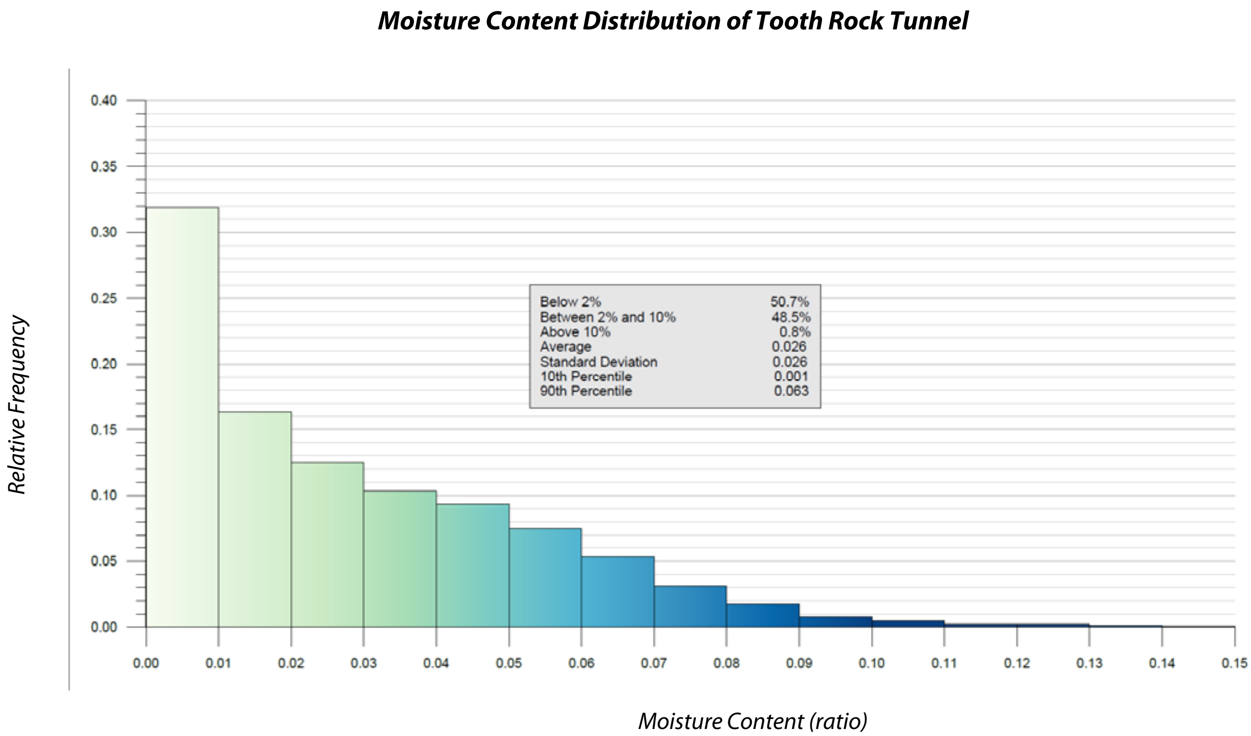


Figure 14. *Histogram showing the distribution of calculated moisture content based on relative dielectric content of concrete in the Tooth Rock Tunnel. The dielectric constant is calculated based on measurement of the surface reflection coefficient of the liner, which is related to moisture content in the liner. The relative frequency shows the percentage of moisture content ratio values falling within a specific range. Higher calculated moisture content generally derives from higher dielectric constants.*

4.1.3 Air-Filled Voids

To detect air-filled voids behind the liner, the GPR waveforms were analyzed at the interface between the liner and base material. In this tunnel, a distinct signal was observed from the back of the liner which was measured. Areas of air-filled voids were determined to exist based on detection of those reflective signals that exceeded a running mean value, over a prescribed distance. Air-filled voids were found in 1.9% or 1015 square feet of the Tooth Rock liner.

4.2 Tooth Rock Tunnel – Infrared Thermography

Thermal maps produced for the Tooth Rock Tunnel are provided in this report which provide detailed thermal imaging of the tunnel liner.

Since the IRT inspection of the left lane side of the liner and the right lane side of the liner were performed at different times due to traffic control limitations, temperature measurement distributions were generated separately from each side of the liner. Because of the different inspection times, the ambient temperature inside the tunnel changed, resulting in a different range of temperatures measured for each side of the liner. These measured temperature distributions are shown in Figures (15) and (16), which show temperature plotted with a 0.1 °F increment. The atmospheric conditions at the time of each inspection are provided with each distribution graph.

The mean temperature was 62.2 °F for the right lane wall with 80% of the values ranging between 61.4 – 62.7 and the mean temperature was 57.7 °F for the left lane wall with 80% of the values ranging between 56.4 – 58.2.

The temperature distribution plots of both sides roughly follow a normal (Gaussian) distribution with some key differences. The right lane wall temperatures were tightly distributed with a majority of the values falling within a smaller range of the temperature values than a normal distribution. This implies that that there was little temperature variation in the right wall. The left lane wall temperatures followed a normal distribution with the main difference being a skewing toward the high temperature end.

Although temperature measurements were tightly distributed, the infrared inspection identified warmer areas, possibly the result of debonded or delaminated concrete, and cooler areas throughout the tunnel which were caused by water flow. A large area of these cooler sections can be found from Sta 1+50 to Sta 2+00.

Infrared Temperature Distribution of Tooth Rock Tunnel (Right Lane Wall)

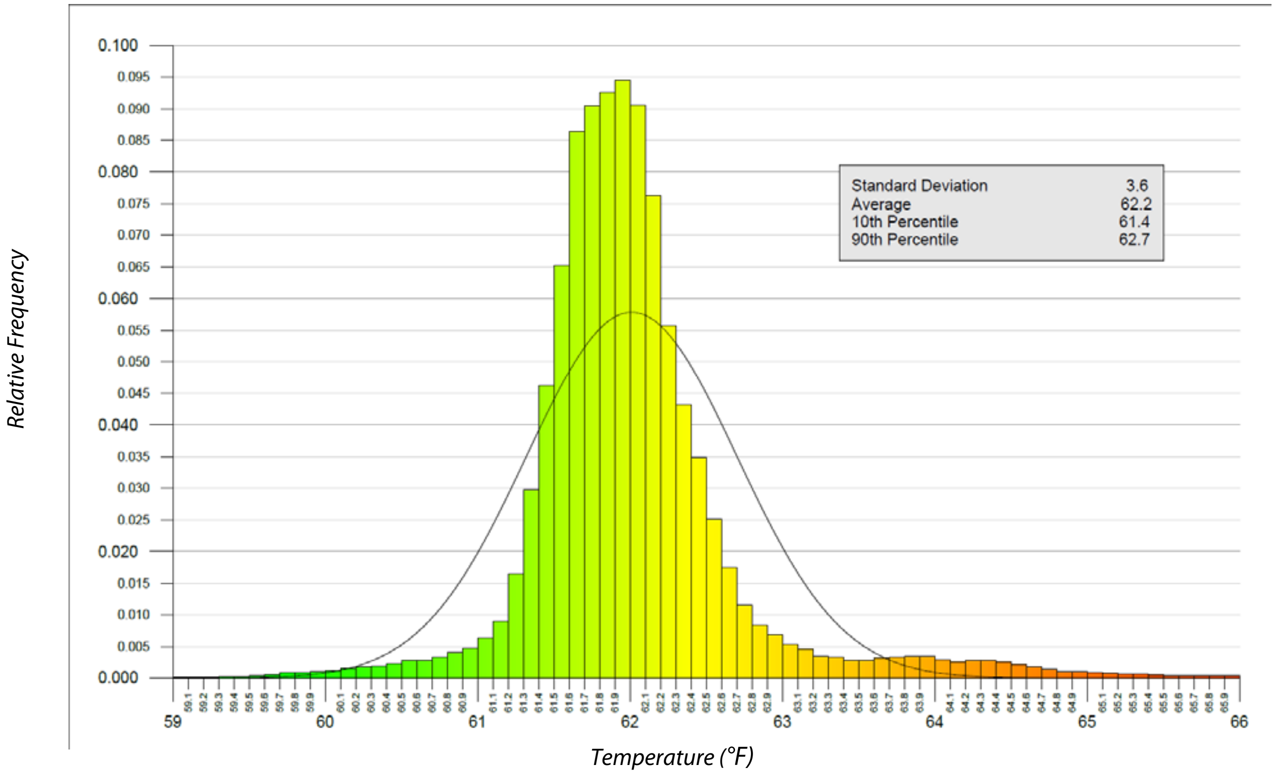


Figure 15. *The histogram showing the distribution of temperature values recorded during the Infrared Thermography scan of the Tooth Rock Tunnel – Right Lane Wall.*

Time of Inspection: *06/14/2018 – 7:00 PM*
Atmospheric Conditions: *Temperature: 65 ·F – Humidity: 54% – Winds: 6 MPH*

Infrared Temperature Distribution of Tooth Rock Tunnel (Left Lane Wall)

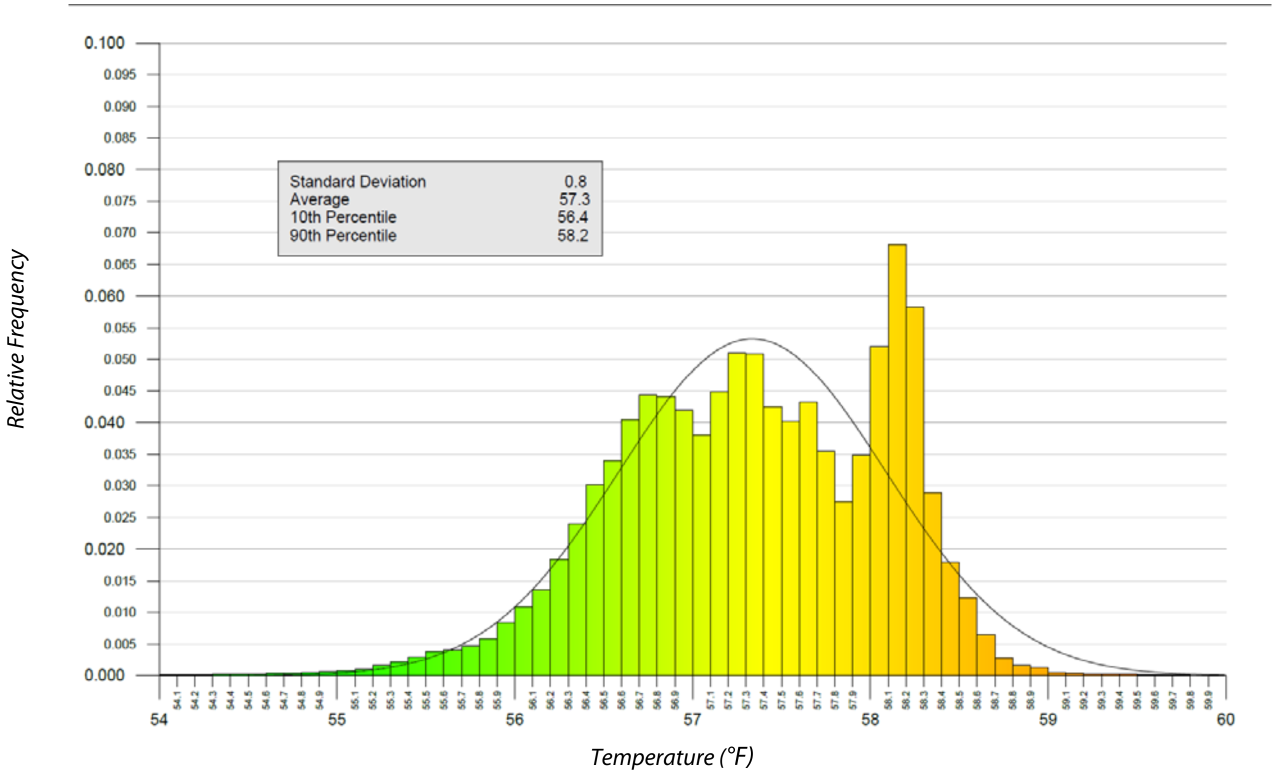


Figure 16. *The histogram showing the distribution of temperature values recorded during the Infrared Thermography scan of the Tooth Rock Tunnel – Left Lane Wall.*

Time of Inspection: 06/15/2018 – 6:00 AM
Atmospheric Conditions: Temperature: 56 ·F – Humidity: 77% – Winds: 5 MPH

4.3 Vista Ridge Tunnels – Ground Penetrating Radar

The ground penetrating radar inspection of the Vista Ridge Tunnels focused on the detection of deterioration/delamination (by measurement of signal attenuation), moisture content in the concrete liner (by measurement of relative dielectric constant) and air-filled voids at the back of the liner.

In addition to the foregoing, the use of GPR to detect debonded tile facing was investigated. Manual soundings of the Vista Ridge liner revealed extensive debonding of tiles, primarily around construction joints. However, while GPR has been shown to be effective in detecting debonding in other applications, including detecting debonded shotcrete overlays and near range laminar fractures, in this instance it did not prove effective. We believe that the reason for this is twofold. First, it is likely that the "debonded" tiles were not entirely separated from the concrete liner and did not provide a definitive interface for the GPR to identify. If they were separated, the gap may have been too small to be detected using this technology. The second, and perhaps more significant is that the individual tile, with dimensions of approximately 16 square inches, is small in proportion to the air-coupled GPR antenna footprint, which at a one-foot standoff distance is over 200 square inches. A single tile occupies less than 10% of the spatial resolution of the antenna and when debonded would represent a challenge to detect, especially in the case of a low reflectivity target such as a very thin air-gap. Better results may be obtained in the future using a small footprint, contacting antenna with ultra-high range resolution (i.e. center frequency in the range of 2.0GHz -2.5GHz).

4.3.1 GPR Attenuation

For the Vista Ridge tunnel liner evaluation, signal attenuation was continuously measured and thresholds ranging from -6 dB to -8 dB (of the maximum measured signal strength) were applied to the measurements to identify areas of probable defects.

Vista Ridge Eastbound Tunnel – Right Lane Wall, 6.1% of the area was found to have attenuation levels in excess of -6 dB (less than or equal to 25% of the power level of the maximum measurement), and 3.6% of the tunnel liner exhibited attenuation levels classified as “medium or high”, with attenuation levels of greater than -7db. This corresponds to 1,677 ft^2 and 1,001 ft^2 of tunnel area, respectively at these attenuation levels.

Vista Ridge Eastbound Tunnel – Left Lane Wall, 5.4% of the area was found to have attenuation levels in excess of -6 dB (i.e. less than or equal to 25% of the power level of the maximum measurement). 2.8% of the tunnel liner exhibited attenuation levels we classified as “medium or high”, with attenuation levels of greater than -7db. This corresponds to 1,321 ft^2 and 674 ft^2 of tunnel area, respectively at these attenuation levels.

This amounts to combined values of 5.7% and 3.2% above the -6 dB and -7 dB thresholds for the Vista Ridge Eastbound Tunnel walls, corresponding to 2,998 ft^2 and 1,675 ft^2 of tunnel area, respectively at these attenuation levels.

Vista Ridge Westbound Tunnel – Right Lane Wall, 11.6% of the area was found to have attenuation levels in excess of -6 dB (less than or equal to 25% of the power level of the maximum measurement), and 7.0% of the tunnel liner exhibited attenuation levels classified as “medium or high”, with attenuation levels of greater than -7db. This corresponds to 2,943 ft^2 and 1,781 ft^2 of tunnel area, respectively at these attenuation levels.

Vista Ridge Westbound Tunnel – Left Lane Wall, 10.5% of the area was found to have attenuation levels in excess of -6 dB (less than or equal to 25% of the power level of the maximum measurement), and 6.7% of the tunnel liner exhibited attenuation levels classified as "medium or high", with attenuation levels of greater than -7db. This corresponds to 2,665 ft^2 and 1,707 ft^2 of tunnel area, respectively at these attenuation levels.

This amounts to combined values of 11.0% and 6.8% above the -6 dB and -7 dB thresholds for the Vista Ridge Westbound Tunnel walls and corresponds to 5,608 ft^2 and 3,488 ft^2 of tunnel area, respectively at these attenuation levels.

Figures (17), (18), (19), (20), (21) and (22) below shows the distribution of the GPR signal attenuation for the both walls of each Vista Ridge Tunnel and the combined for each direction. (The colors of the graphs for the attenuated areas match the corresponding attenuation maps shown later in this report.)

GPR Attenuation Distribution of Vista Ridge Eastbound (Right Lane)

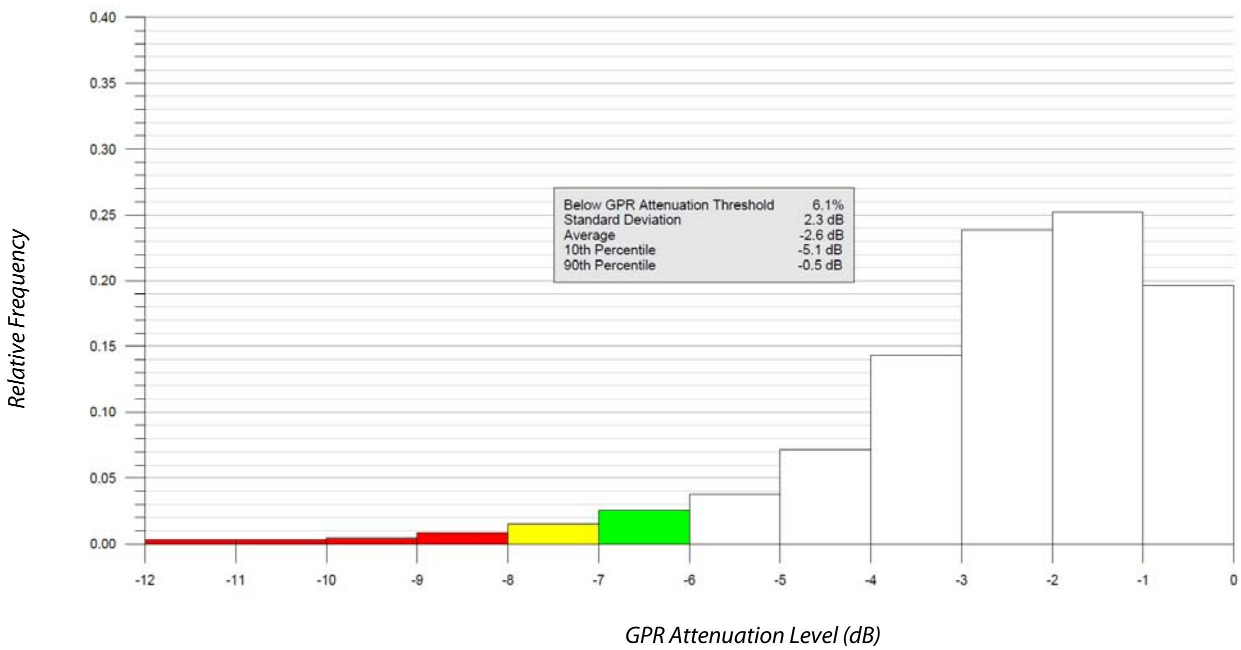


Figure 17. *The histogram shows the distribution of attenuation in the GPR signal. The attenuation level is the ratio of the measured GPR signal versus the maximum signal amplitude from the GPR scan. The relative frequency shows the percentage of attenuation values of all measured values on a 1 dB interval.*

GPR Attenuation Distribution of Vista Ridge Eastbound (Left Lane)

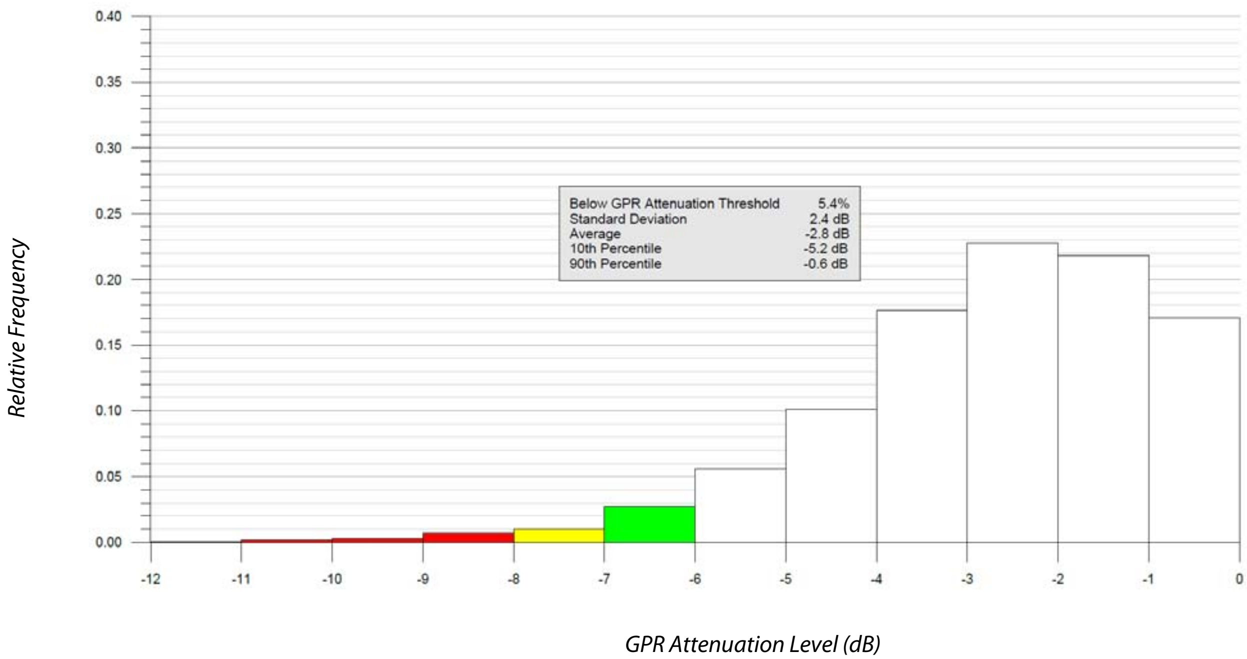


Figure 18. *The histogram shows the distribution of attenuation in the GPR signal. The attenuation level is the ratio of the measured GPR signal versus the maximum signal amplitude from the GPR scan. The relative frequency shows the percentage of attenuation values of all measured values on a 1 dB interval.*

GPR Attenuation Distribution of Vista Ridge Eastbound (Total)

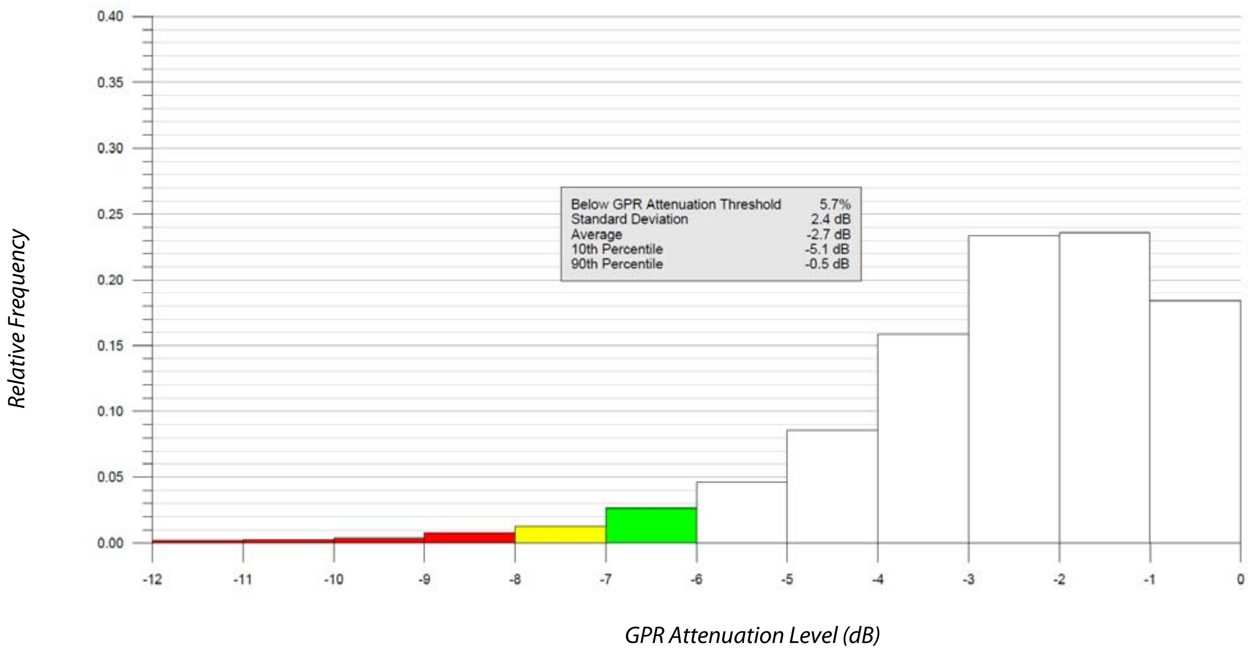


Figure 19. *The histogram shows the distribution of attenuation in the GPR signal. The attenuation level is the ratio of the measured GPR signal versus the maximum signal amplitude from the GPR scan. The relative frequency shows the percentage of attenuation values of all measured values on a 1 dB interval.*

GPR Attenuation Distribution of Vista Ridge Westbound (Right Lane)

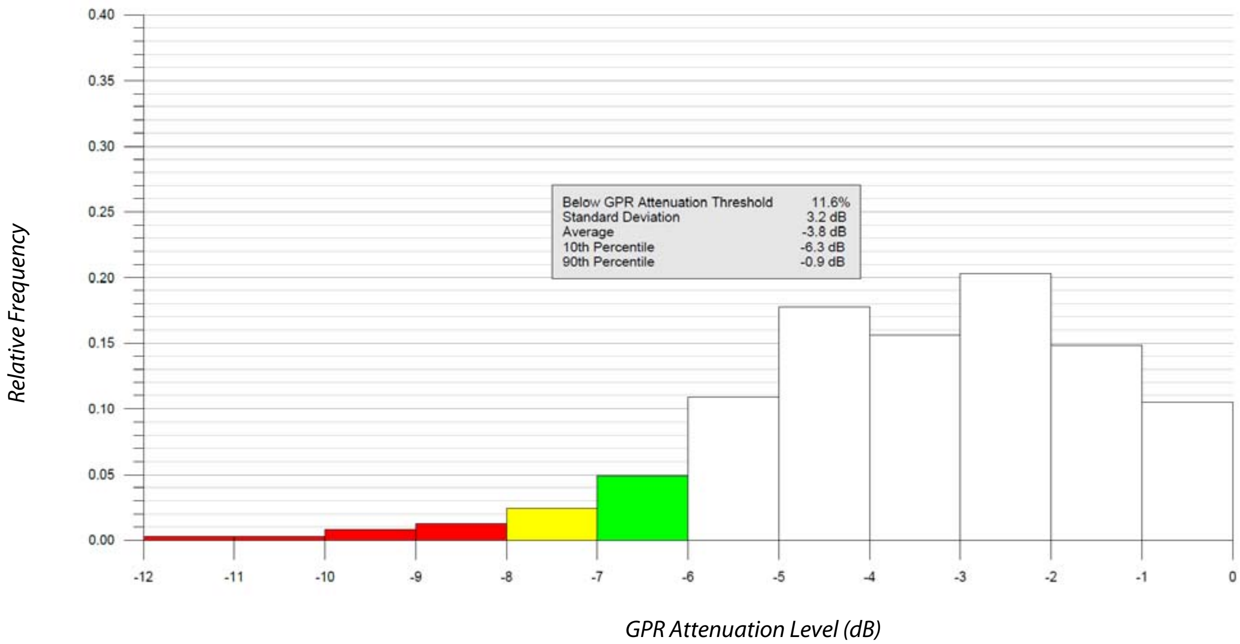


Figure 20. *The histogram shows the distribution of attenuation in the GPR signal. The attenuation level is the ratio of the measured GPR signal versus the maximum signal amplitude from the GPR scan. The relative frequency shows the percentage of attenuation values of all measured values on a 1 dB interval.*

GPR Attenuation Distribution of Vista Ridge Westbound (Left Lane)

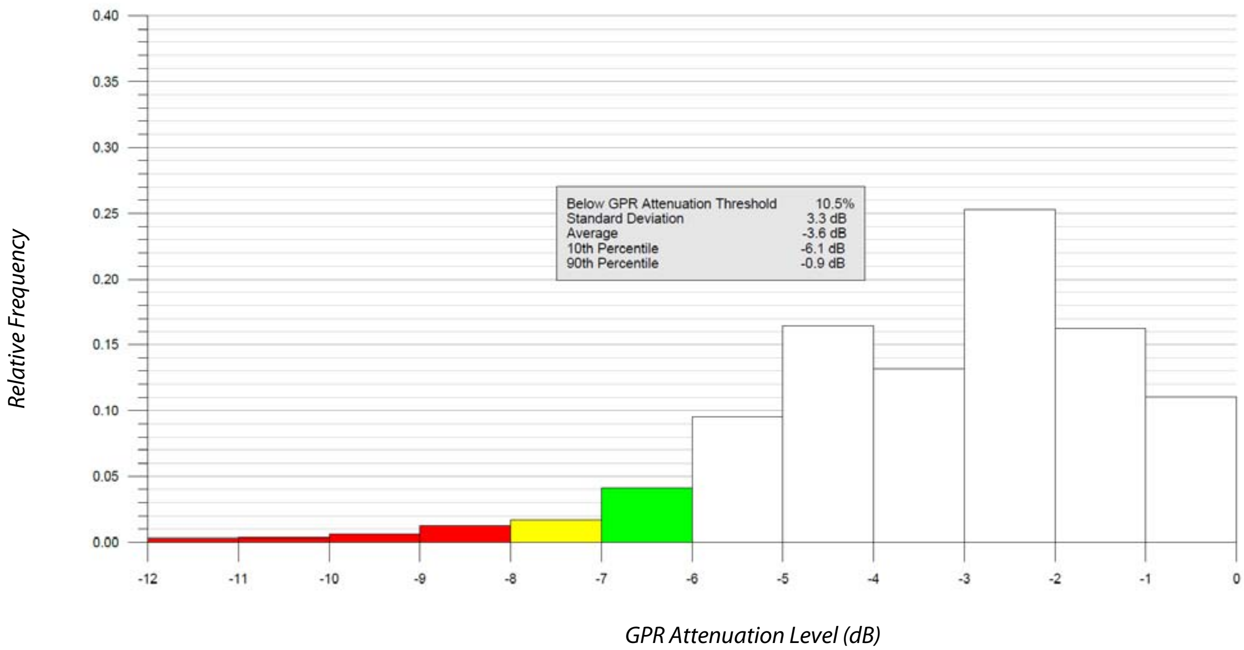


Figure 21. *The histogram shows the distribution of attenuation in the GPR signal. The attenuation level is the ratio of the measured GPR signal versus the maximum signal amplitude from the GPR scan. The relative frequency shows the percentage of attenuation values of all measured values on a 1 dB interval.*

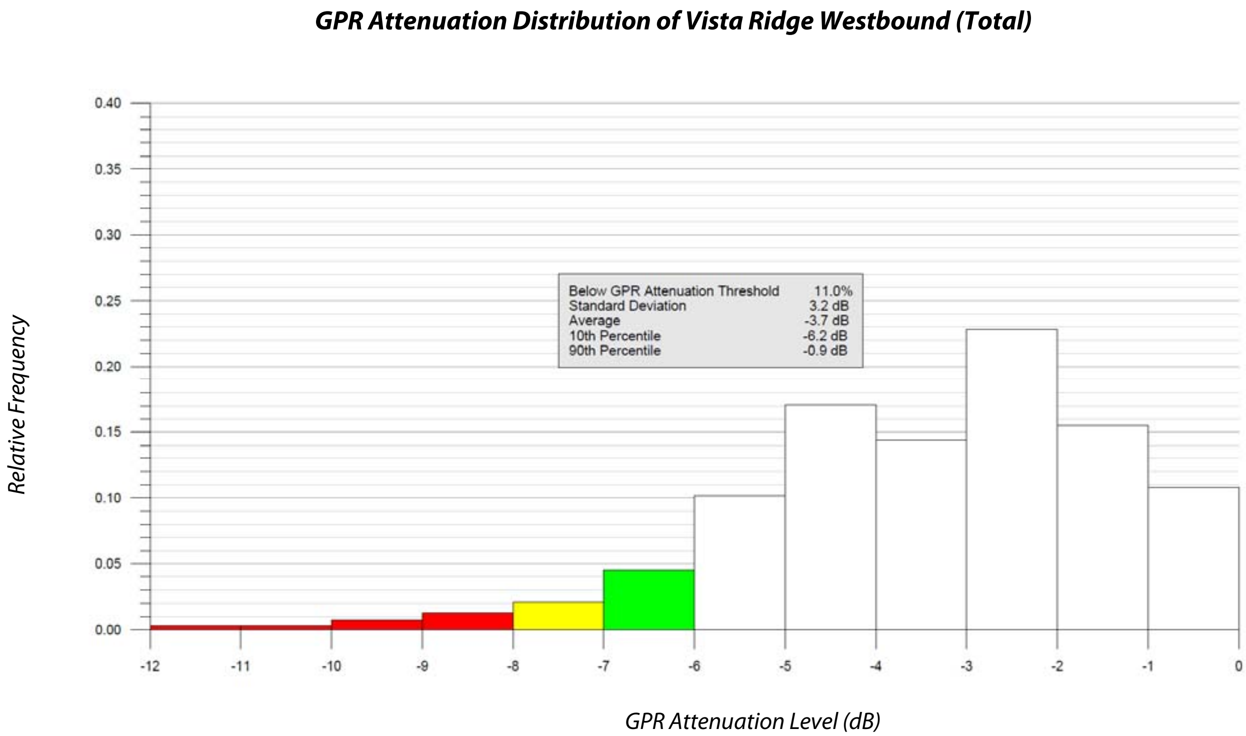


Figure 22. *The histogram shows the distribution of attenuation in the GPR signal. The attenuation level is the ratio of the measured GPR signal versus the maximum signal amplitude from the GPR scan. The relative frequency shows the percentage of attenuation values of all measured values on a 1 dB interval.*

4.3.1.1 GPR Attenuation Comparison between Vista Ridge Tunnels

In comparing the attenuation distribution for the eastbound and westbound Vista Ridge tunnels; it is evident that the Westbound tunnel exhibited higher amounts of attenuation for all values exceeding the GPR attenuation threshold of -6db. With roughly twice the attenuation found in the westbound than the eastbound tunnel, a comparison would suggest the westbound tunnel to be in generally worse physical condition than the eastbound tunnel. The comparison of the two sides is shown in Figure (23) below.

GPR Attenuation Distribution Comparison of Vista Ridge Tunnels

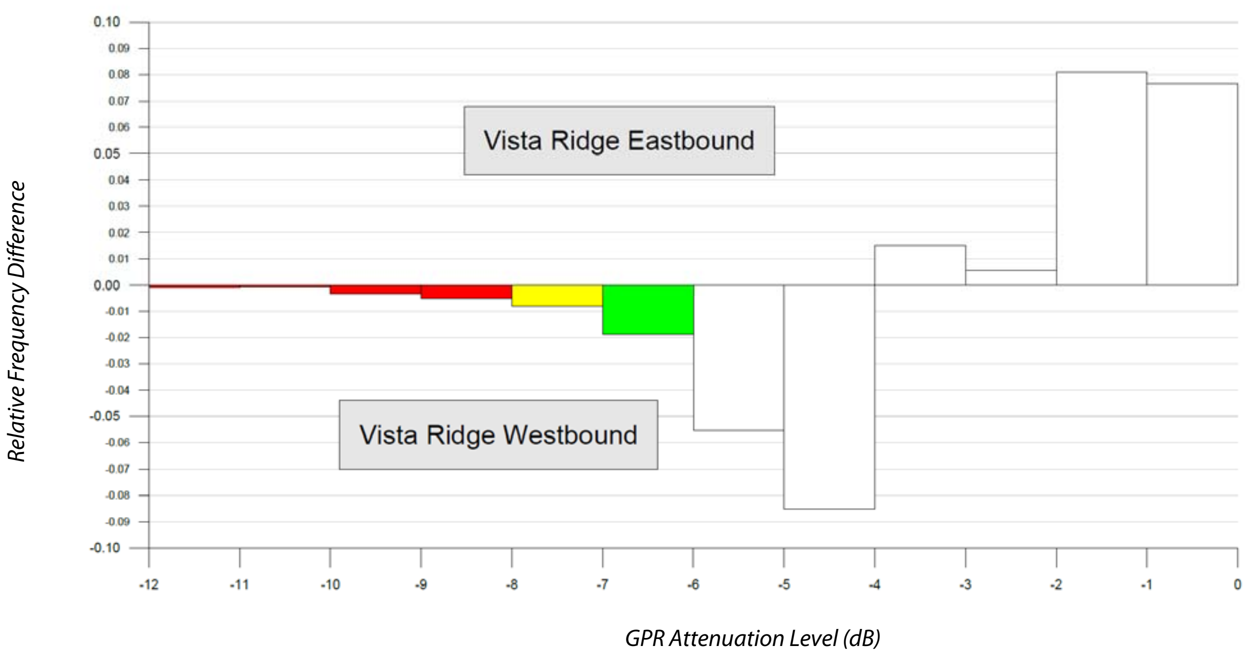


Figure 23. *The comparison shows the difference in the relative frequencies of each GPR attenuation level for the Vista Ridge Eastbound and Westbound Tunnels. This shows that high attenuation levels were found in a greater percentage of the westbound tunnel eastbound tunnel, suggesting that the westbound tunnel is in worse condition.*

4.3.2 Moisture Content – (Relative Dielectric Constant)

In tunnels, high levels of moisture within a concrete liner can be an indication of deteriorated concrete, poor concrete consolidation during construction (honeycombing), moisture accumulation in base layers or some other type of incipient problem. GPR, based on its ability to measure the electrical properties of materials, can be used to both identify areas of saturated concrete and quantify the moisture level based on measurement of the dielectric constant of the material.

Figure (24), (25), (26), (27), (28) and (29) show the distribution plots of calculated moisture content of the concrete of the Vista Ridge Tunnels. (The colors of the graph for the moisture connect values match the corresponding moisture maps shown later in this report.) Just as in the GPR attenuation distribution charts, the moisture content values are shown in relation to frequency of occurrence. There are three percentages given for ranges of dielectric constants for concrete that relate to low (less than 2%), moderate (2%-10%) and high (10% or greater) amounts of moisture content in the concrete.

Vista Ridge Eastbound Tunnel

After analyzing the GPR data and calculating the relative dielectric constant of the concrete we found the right lane wall to have an average of dielectric constant of 15.0, which corresponds to 11.7% moisture by volume. The left lane wall averaged 10.6 for dielectric constant and 5.8% moisture resulting in an overall average dielectric constant of 12.8 and 8.7% moisture by volume.

For the right lane wall, 0.2% (48 ft^2) of the concrete liner was found to have low moisture content, 35.4% (9,735 ft^2) with moderate moisture content and 64.4% (17,731 ft^2) of the concrete to have a high moisture content.

For the left lane wall, 21.9% (5,349 ft^2) of the concrete liner was found to have low moisture content, 64.9% (15,884 ft^2) with moderate moisture content and 13.2% (3,223 ft^2) of the concrete to have a high moisture content.

Overall, for the Eastbound Tunnel, 10.4% (5,397 ft^2) of the wall concrete was found to contain less than 2% moisture by volume, 49.3% (25,619 ft^2) between 2% and 10% moisture by volume and 40.3% (20,954 ft^2) above 10% moisture by volume.

Vista Ridge Westbound Tunnel

The average dielectric constant for the right lane wall was found to be 15.1. This value corresponds to 11.9% moisture by volume. The left lane wall averaged 13.4 for dielectric constant and 9.6% moisture resulting in an overall average dielectric constant of 14.3 and 10.8% moisture by volume for the Westbound tunnel.

For the right lane wall, 5.3% (1,348 ft^2) of the concrete liner was found to have low moisture content, 27.7% (7,050 ft^2) with moderate moisture content and 67.0% (17,066 ft^2) of the concrete to have a high moisture content.

For the left lane wall, 7.5% (1,901 ft^2) of the concrete liner was found to have low moisture content, 55.1% (14,039 ft^2) with moderate moisture content and 37.4% (9,524 ft^2) of the concrete to have a high moisture content.

This resulted in total values for the Westbound Tunnel of 6.4% (3,249 ft^2) below 2% moisture by volume, 41.4% (21,089 ft^2) between 2% and 10% moisture by volume and 52.2% (26,590 ft^2) above 10% moisture by volume.

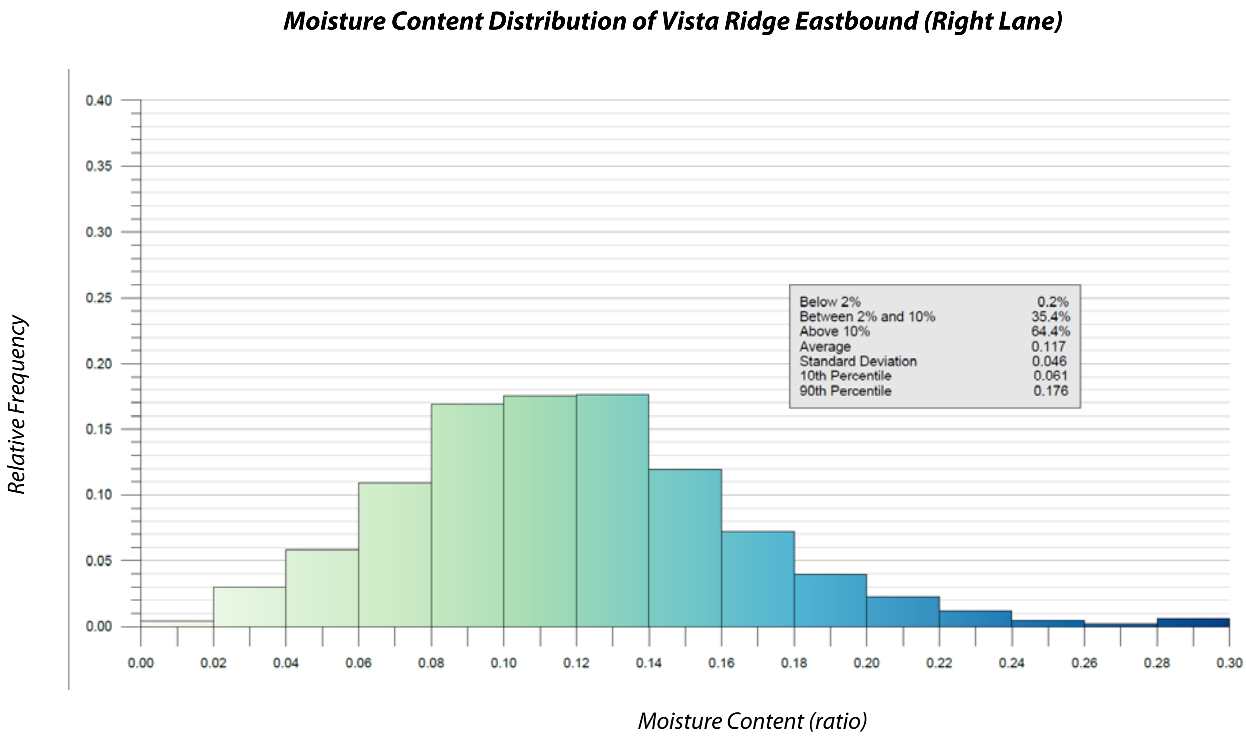


Figure 24. *Histogram showing the distribution of calculated moisture content based on relative dielectric content of concrete in the Vista Ridge Eastbound Tunnel – Right Lane.*

Moisture Content Distribution of Vista Ridge Eastbound (Left Lane)

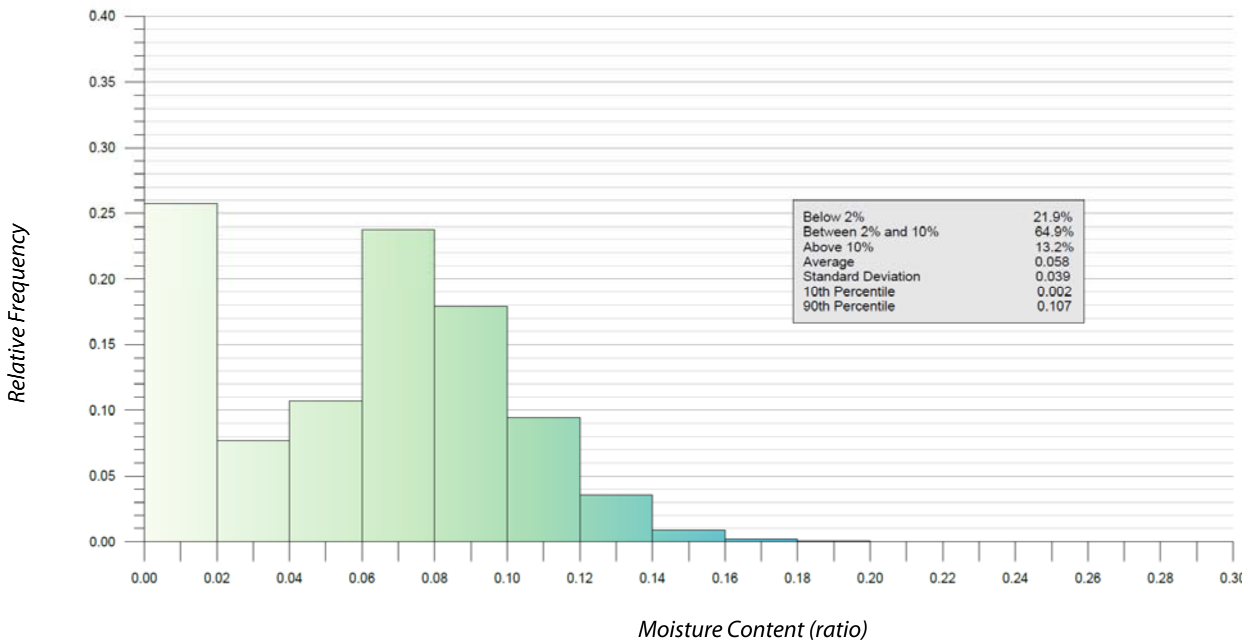


Figure 25. *Histogram showing the distribution of calculated moisture content based on relative dielectric content of concrete in the Vista Ridge Eastbound Tunnel – Left Lane.*

Moisture Content Distribution of Vista Ridge Eastbound (Total)

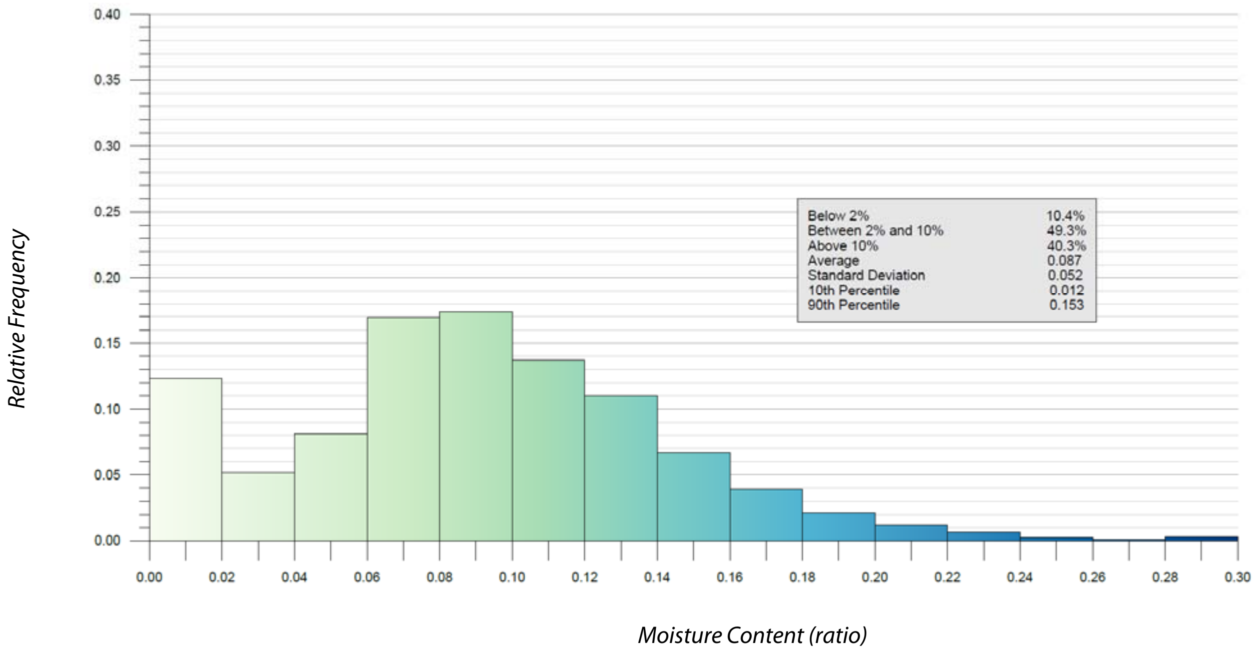


Figure 26. *Histogram showing the distribution of calculated moisture content based on relative dielectric content of concrete in the Vista Ridge Eastbound Tunnel – Both Walls.*

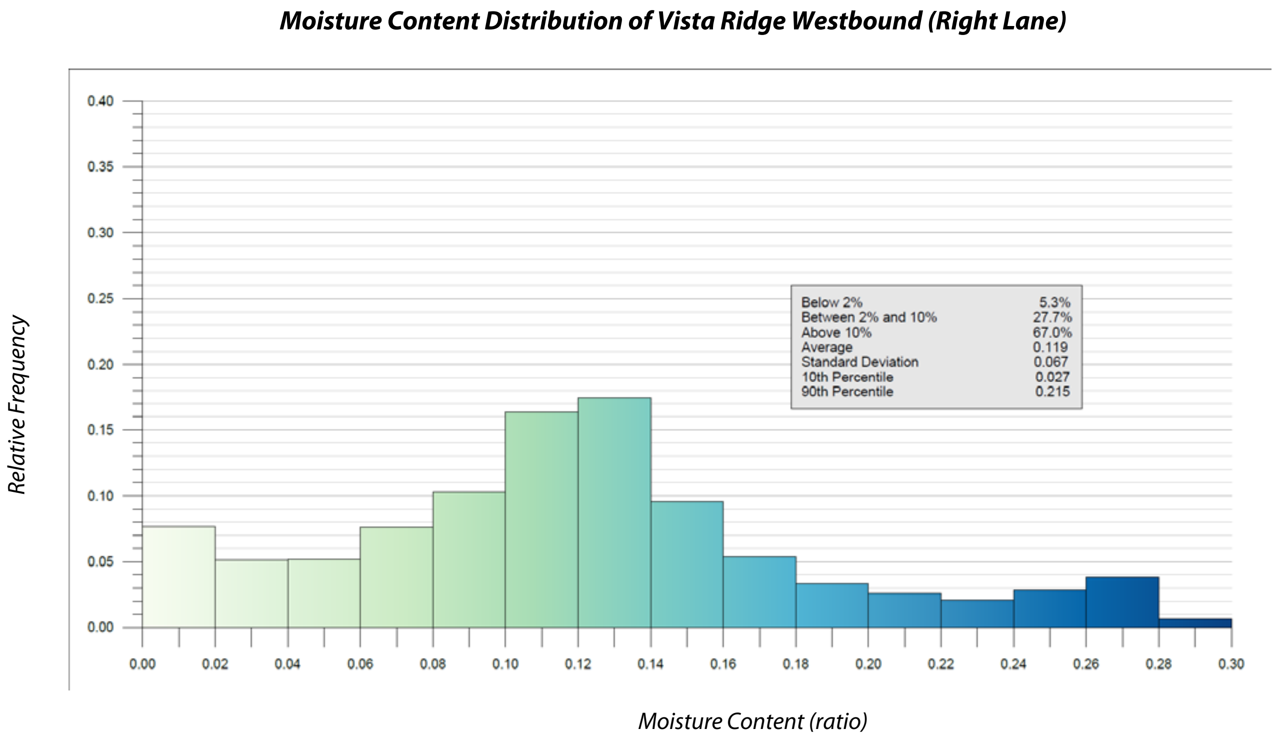


Figure 27. *Histogram showing the distribution of calculated moisture content based on relative dielectric content of concrete in the Vista Ridge Westbound Tunnel – Right Lane.*

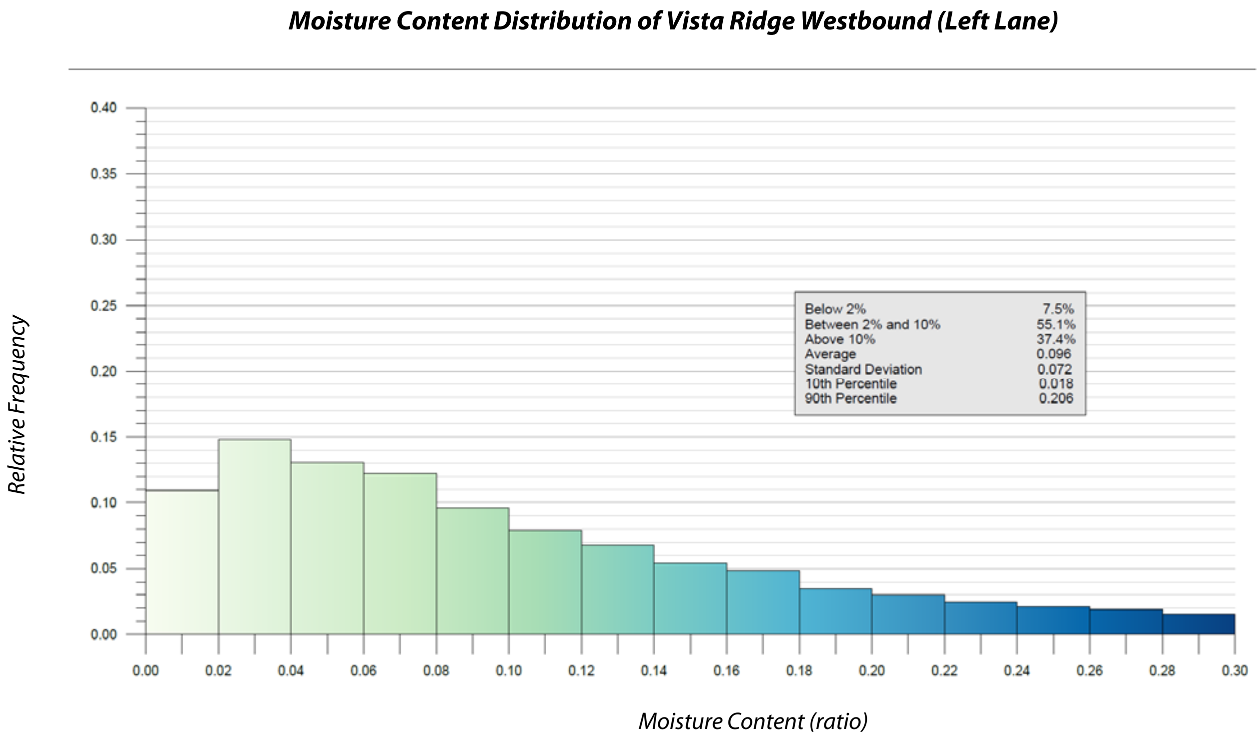


Figure 28. *Histogram showing the distribution of calculated moisture content based on relative dielectric content of concrete in the Vista Ridge Westbound Tunnel – Left Lane.*

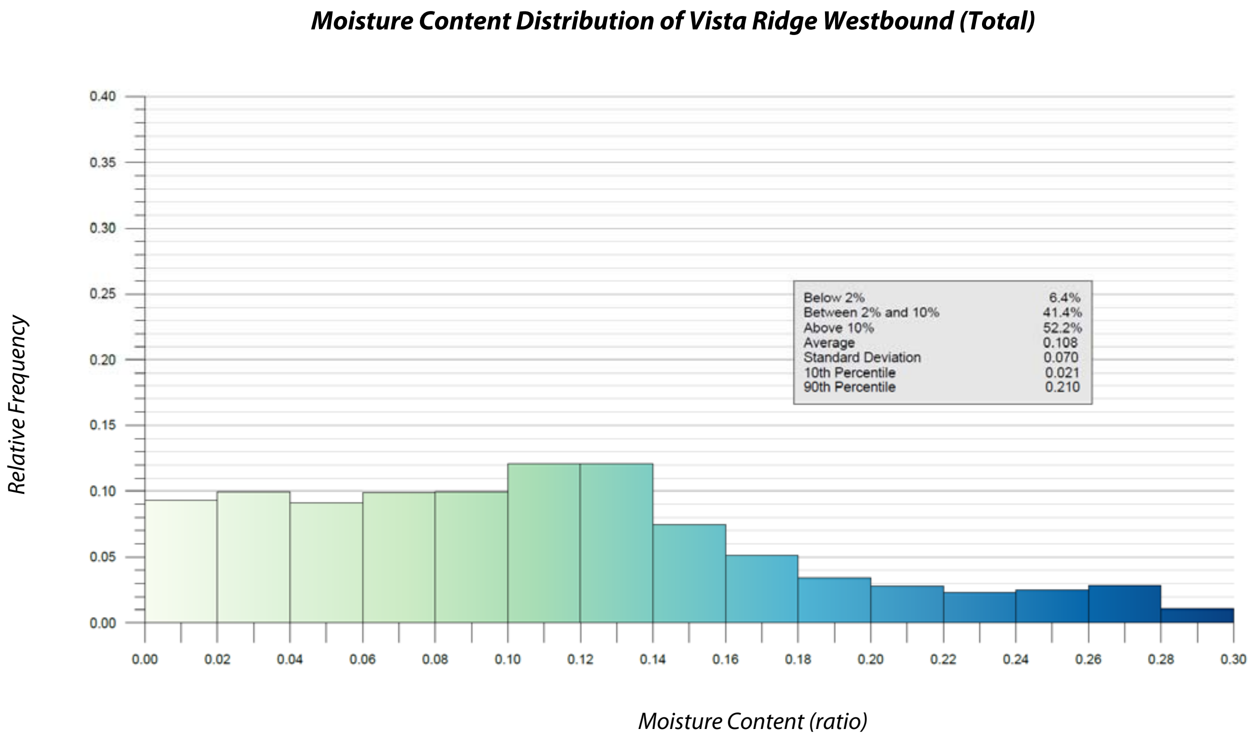


Figure 29. *Histogram showing the distribution of calculated moisture content based on relative dielectric content of concrete in the Vista Ridge Westbound Tunnel – Both Walls.*

4.3.2.1 Moisture Content Comparison between Vista Ridge Tunnels

With an average dielectric of 14.3, the westbound wall was estimated to have 10.8% moisture content, whereas the eastbound tunnel, with an average dielectric of 12.8 was determined to have a moisture content of approximately 8.7%. A comparison of moisture content between the eastbound and westbound Vista Ridge tunnels reveals generally higher moisture content values (dielectric measurements) in the westbound tunnel, which suggests that it is in worse physical condition. This is illustrated by Figures (26) & (29).

Although the westbound tunnel has roughly 2% more moisture on average than the eastbound tunnel, the histogram in Figure (30) shows a significant distribution difference between them. Higher moisture levels are more prevalent in the westbound tunnel while lower moisture levels are found in the eastbound tunnel. In addition, the eastbound tunnel moisture is more uniform and closely distributed about its mean value. The opposite is the case for the westbound tunnel, where moisture content widely varies.

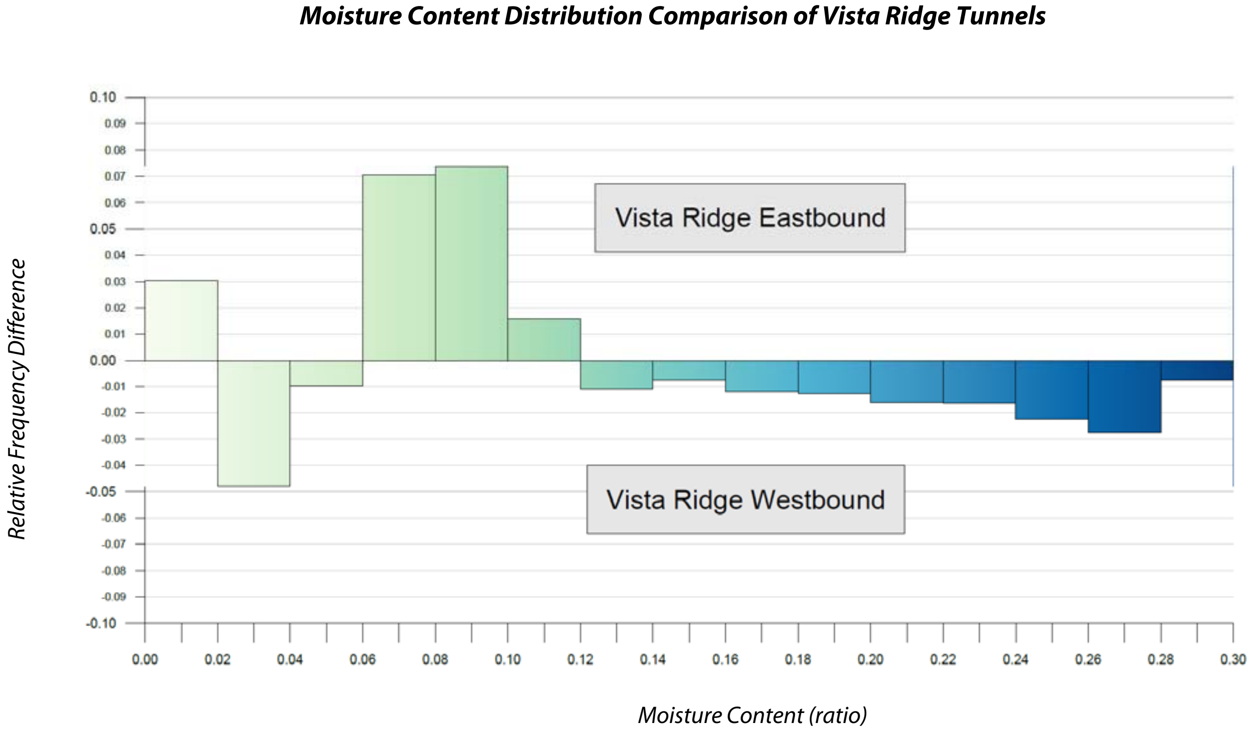


Figure 30. *The comparison shows the difference in the relative frequencies of the calculated moisture content values for the westbound and eastbound Vista Ridge Tunnels. A greater number of measurements below a moisture percentage of12 (measured dielectric constant of 15.2) were found in the eastbound tunnel while a greater number of moisture percentage above 12 were found in the westbound tunnel which implies a greater overall presence of moisture content in the westbound tunnel. This difference equates to the westbound tunnel containing 2% more moisture than the eastbound tunnel, overall.*

4.3.3 Air-Filled Voids

To detect air-filled voids behind the liner, the GPR waveform was analyzed at the interface between the liner and base material. In this tunnel, a distinct signal was observed from the back of the liner which was measured. Areas of air-filled voids were determined to exist based on detection of those reflective signals that exceeded a running mean value, over a prescribed distance.

The quantity of air-filled voids found in the Vista Ridge Eastbound Tunnel was 9.2% or 845 square feet on the right lane side and 5.4% or 497 square feet on the left lane side, resulting in 7.3% or 1,346 square feet overall.

The quantity of air-filled voids found in the Vista Ridge Westbound Tunnel was 3.2% or 305 square feet on the right lane side and 2.3% or 219 square feet on the left lane side, resulting in 2.7% or 524 square feet overall.

These percentages are based on the areas scanned with the 60AGC 500 MHz air-coupled antenna. The use of this antenna was necessary to achieve greater depth penetration to locate voids at the back side of the liner.

4.4 Vista Ridge Tunnels – Infrared Thermography

Thermal maps produced for both the Eastbound and Westbound Vista Ridge Tunnels are provided in this report which provide detailed thermal imaging of the tunnel liner.

Since the infrared inspection of the left lane wall and the right lane wall were performed at different times due to because of lane closure restrictions, temperature measurement distributions were generated separately for each wall. Because of the different inspection times, the ambient temperature inside the tunnel changed, resulting in a different range of temperatures measured for each side of the liner. These measured temperature distributions are shown in Figures (31), (32), (33), (34) which show temperature plotted with a 0.1 °F increment. The atmospheric conditions at the time of each inspection are provided with each distribution graph.

The mean temperature of the Eastbound Tunnel, right lane wall was 59.2 °F, with 80% of the values ranging between 57.8 – 60.3, and the mean temperature for the left lane wall was 64.5 °F, with 80% of the values ranging between 63.2 – 65.7.

The mean temperature of the Westbound Tunnel, right lane wall was 68.4 °F with 80% of the values ranging between 67.0 – 69.6 and the mean temperature value was 63.6 °F for the left lane wall with 80% of the values ranging between 61.9 – 64.8.

The infrared inspection of the Vista Ridge Tunnels did not yield as definitive a result as was found in the Tooth Rock Tunnel. We believe the main reason for this is due to the reflective properties of the tile face. In the presence of heavy traffic, the heat generated by passing vehicles may have been reflected from the tile face instead of being absorbed, causing thermal anomalies to be observed in the IRT records.

Infrared Temperature Distribution of Vista Ridge Eastbound (Right Lane Wall)

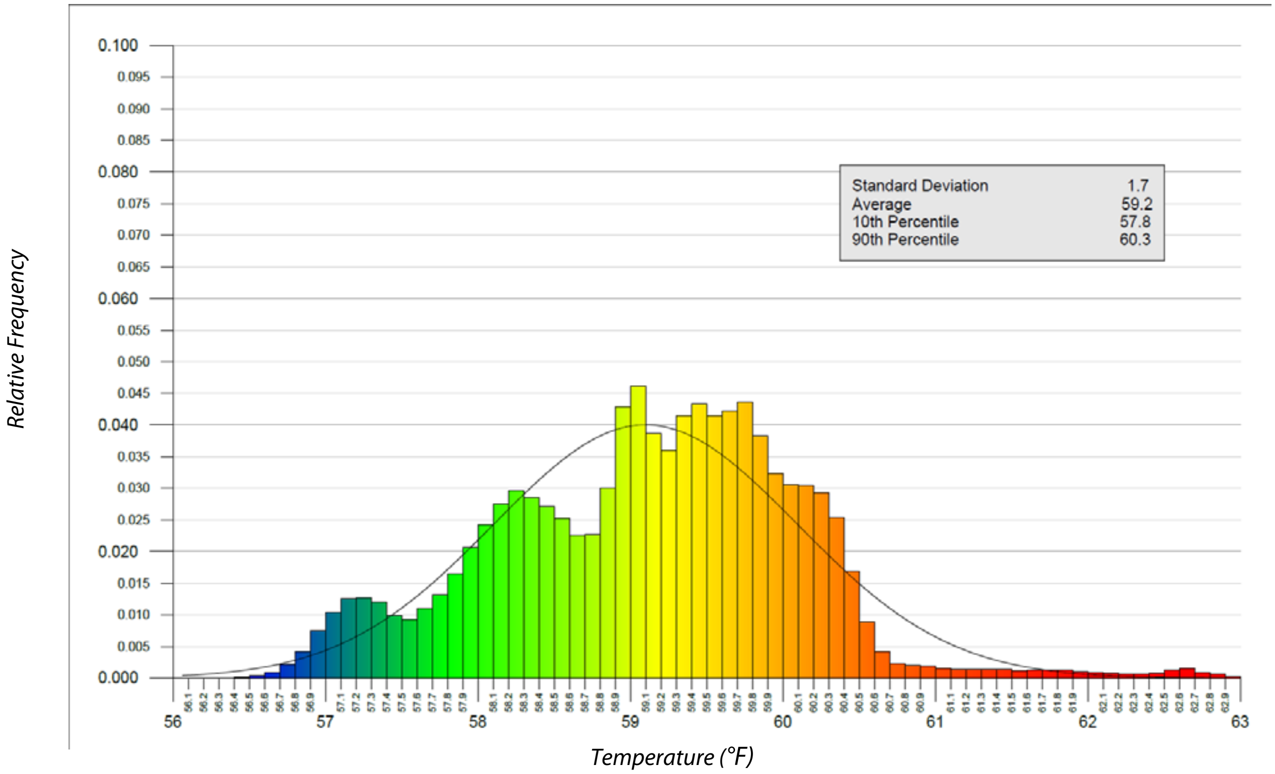


Figure 31. *The histogram showing the distribution of temperature values recorded during the Infrared Thermography scan of the Tooth Rock Tunnel – Right Lane Wall.*

Time of Inspection: 06/16/2018 – 8:00 AM
Atmospheric Conditions: Temperature: 59 ·F – Humidity: 69% – Winds: 6 MPH

Infrared Temperature Distribution of Vista Ridge Eastbound (Left Lane Wall)

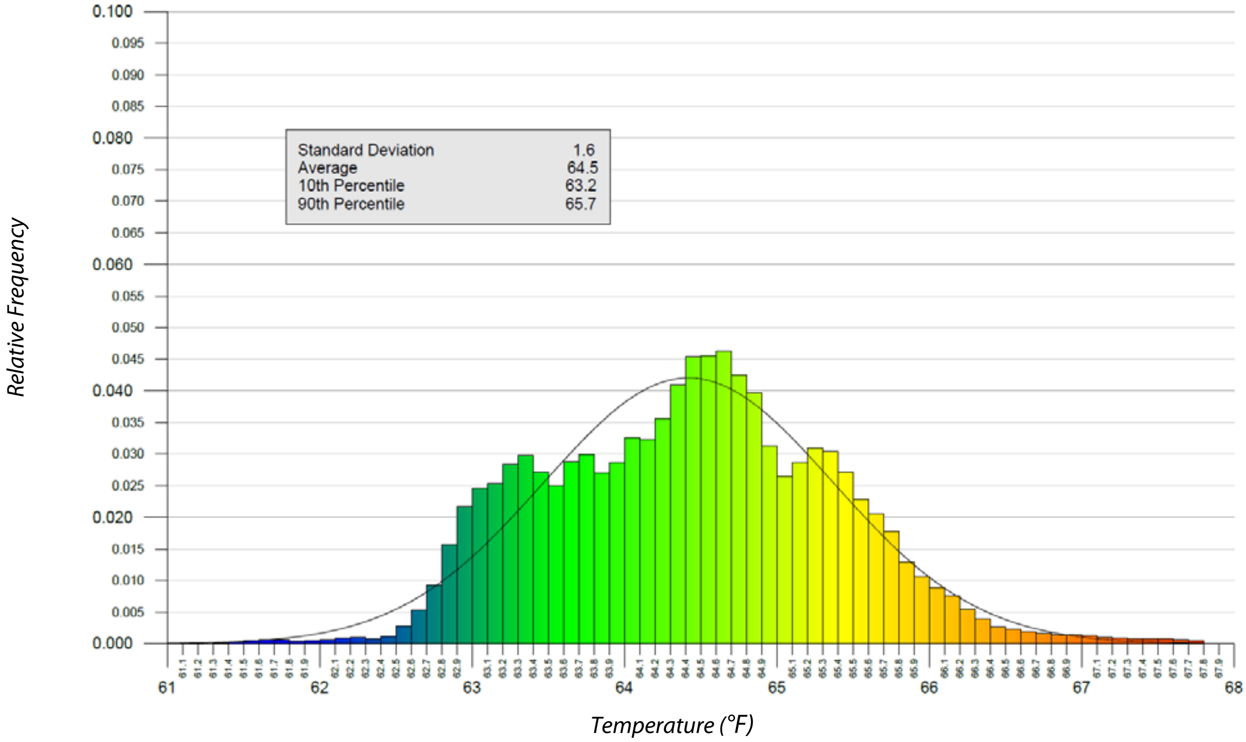


Figure 32. *The histogram showing the distribution of temperature values recorded during the Infrared Thermography scan of the Tooth Rock Tunnel – Left Lane Wall.*

Time of Inspection: 06/15/2018 – 9:30 PM
Atmospheric Conditions: Temperature: 63 ·F – Humidity: 60% – Winds: 9 MPH

Infrared Temperature Distribution of Vista Ridge Westbound (Right Lane Wall)

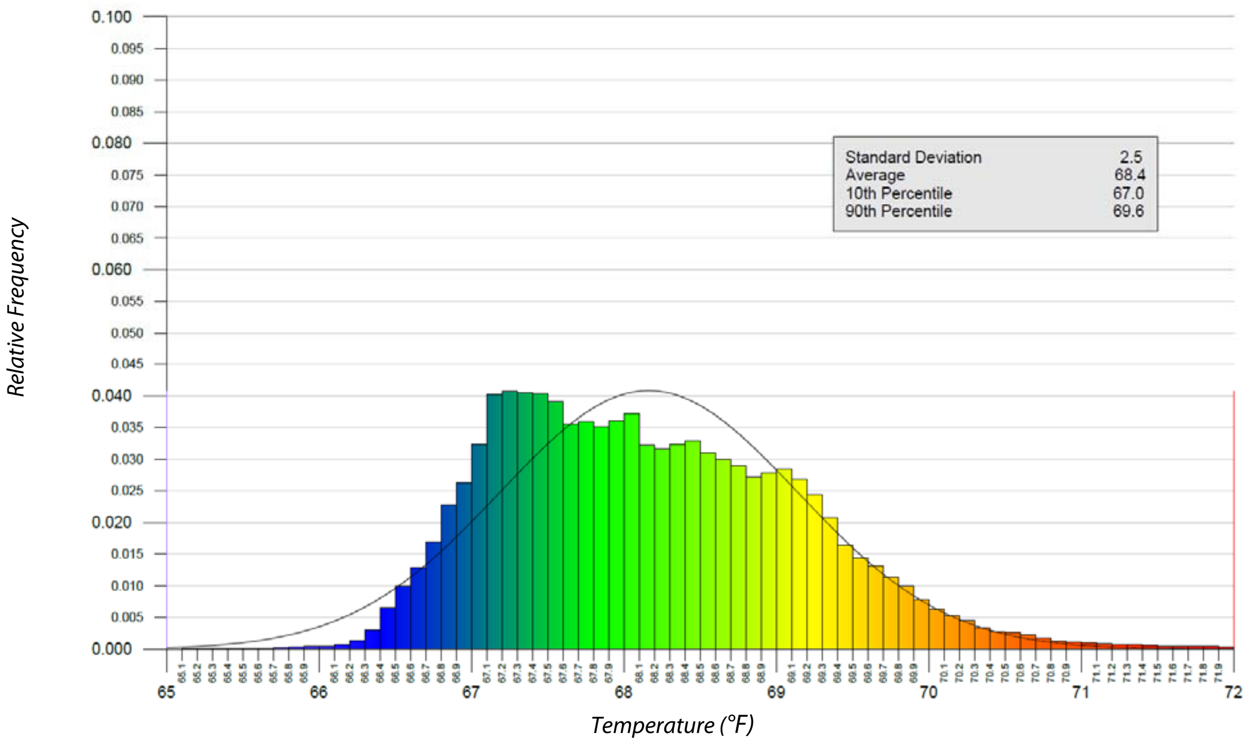


Figure 33. *The histogram showing the distribution of temperature values recorded during the Infrared Thermography scan of the Vista Ridge Westbound Tunnel – Right Lane Wall.*

Time of Inspection: 06/16/2018 – 9:15 PM
Atmospheric Conditions: Temperature: 66 ·F – Humidity: 78% – Winds: 6 MPH

Infrared Temperature Distribution of Vista Ridge Westbound (Left Lane Wall)

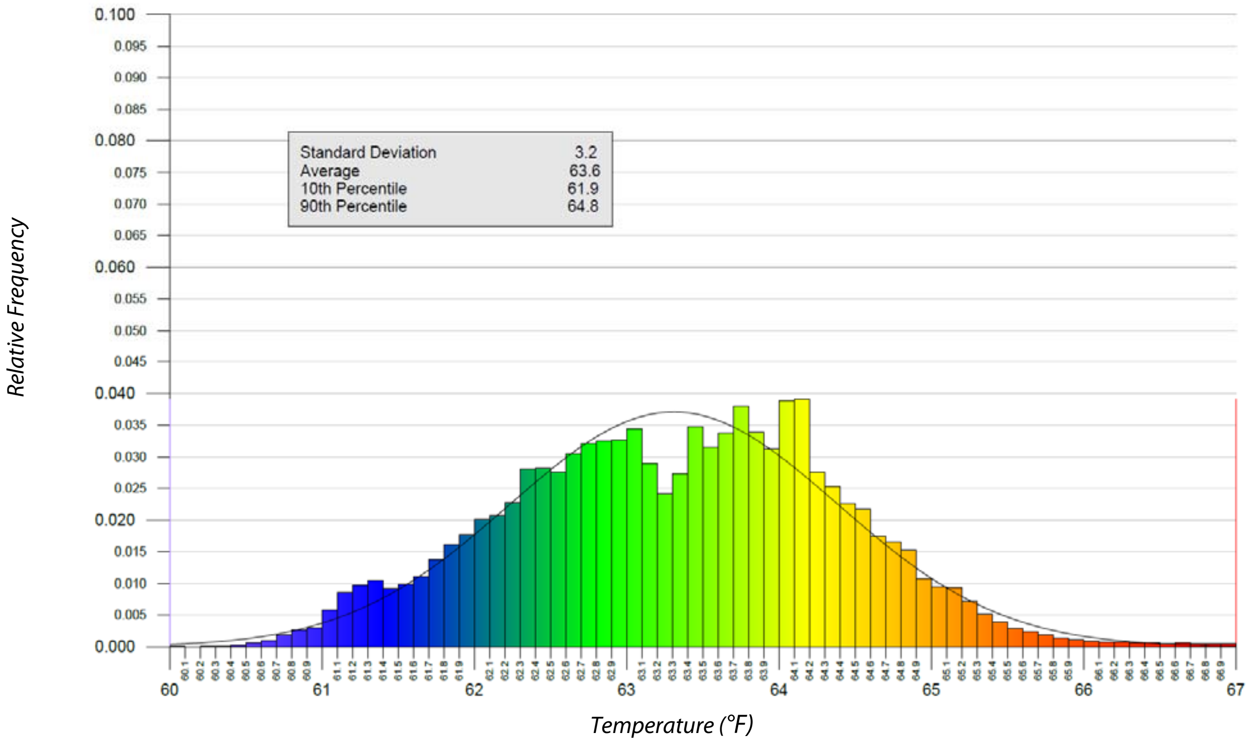


Figure 34. *The histogram showing the distribution of temperature values recorded during the Infrared Thermography scan of the Vista Ridge Westbound Tunnel – Left Lane Wall.*

Time of Inspection: *06/17/2018 – 7:30 AM*
Atmospheric Conditions: *Temperature: 61 ·F – Humidity: 90% – Winds: 3 MPH*

4.5 Vista Ridge Tunnels – Adits

A contacting type GPR was used in the inspection of the adit areas of the Vista Ridge Tunnels. Measurement of signal attenuation and dielectric constant were used, similar to the method described for the liners.

Dielectric constant was determined based on propagation delay measurements, since contacting antennas cannot measure surface reflectivity as is possible with air-coupled antennas.

Due to the nature of the adit inspection (only twelve passes were collected) and the narrow beam characteristics of contacting antennas, we are not determining the area of GPR attenuation or moisture content. The mappings for the adits may show some correlation between scans, but this is mainly due to the interpolation of the CADD software and does not affect the actual percentages of the defects detected.

4.5.1 GPR Attenuation

Vista Ridge Eastbound Adit

For the adit floor, 3.9% of the GPR scans were found to have attenuation levels in excess of -6 dB (i.e. less than or equal to 25% of the power level of the maximum measurement), and 1.5% of the tunnel liner exhibited attenuation levels classified as "medium or high", with attenuation levels of greater than -7db.

For the adit arch, 7.7% of the GPR scans were found to have attenuation levels in excess of -6 dB (i.e. less than or equal to 25% of the power level of the maximum measurement), and 7.2% of the tunnel liner exhibited attenuation levels classified as "medium or high", with attenuation levels of greater than -7db.

This amounts to combined values of 5.8% and 4.3% above the -6 dB and -7 dB thresholds, respectively, for the Vista Ridge Eastbound Adit.

Vista Ridge Westbound Adit

For the adit floor, 7.9% of the GPR scans were found to have attenuation levels in excess of -6 dB (i.e. less than or equal to 25% of the power level of the maximum measurement), and 3.2% of the tunnel liner exhibited attenuation levels classified as “medium or high”, with attenuation levels of greater than -7db.

For the adit arch, 10.3% of the GPR scans were found to have attenuation levels in excess of -6 dB (i.e. less than or equal to 25% of the power level of the maximum measurement), and 8.9% of the tunnel liner exhibited attenuation levels classified as “medium or high”, with attenuation levels of greater than -7db.

This amounts to combined values of 9.1% and 6.1% above the -6 dB and -7 dB thresholds, respectively, for the Vista Ridge Westbound Adit.

Comparison

A comparison revealed higher GPR attenuation (and greater levels of concrete deterioration) in the westbound tunnel adit (5.8% for the eastbound adit and 9.1% for the westbound adit). This is consistent with the findings for the tunnel liner walls and suggests that the westbound adit is in worse physical condition.

4.5.2 Moisture Content

Since the adit areas used a ground-coupled GPR antenna, surface reflection values could not be used to determine moisture content values in the concrete. To estimate the amount of moisture in the adit areas, a measurement of propagation delay difference in the radar signal was performed. Greater propagation delay occurs in the presence of moisture. Although more quantitative moisture estimates could not be made, differences or changes in propagation delay could be measured on a relative basis and reported for comparison purposes. This method is useful in identifying concentrated areas of excess moisture in the concrete.

Vista Ridge Eastbound Adit

For the adit floor, 16.3% of the GPR scans were found to have a time delay 2% greater than the normal time delay for the concrete slab, and 0.6% of the concrete slab floor exhibited time delays 4% greater than the normal time delay values.

For the adit arch, 8.3% of the GPR scans were found to have a time delay 2% greater than the normal time delay for the concrete liner, and 0.9% of the concrete arch exhibited a time delay 4% greater than the normal time delay values.

This corresponds to a combined value of 12.3% of the adit with time delay 2% greater than the norm and 0.8% of the adit with time delay 4% greater than the norm for the Vista Ridge Eastbound Adit.

Vista Ridge Westbound Adit

For the adit floor, 9.2% of the GPR scans were found to have a time delay 2% greater than the normal time delay for the concrete slab, and 0.4% of the concrete slab floor exhibited time delays 4% greater than the normal time delay values.

For the adit arch, 14.2% of the GPR scans were found to have a time delay 2% greater than the normal time delay for the concrete liner, and 2.7% of the concrete arch exhibited a time delay 4% greater than the normal time delay values.

This corresponds to a combined value of 11.7% of the adit with time delay 2% greater than the norm and 1.6% of the adit with time delay 4% greater than the norm for the Vista Ridge Westbound Adit.

Comparison

Comparing the values for the propagation delay (relative moisture content) in the adits, the eastbound and westbound adits were found to have similar amounts, overall. The eastbound adit appeared to have higher moisture in the floor whereas the westbound appeared to have higher moisture in the arch.

5.0 Conclusions and Recommendations

The goals of this project were to introduce NDT methods for tunnel evaluation as a continuation of the SHRP R06G research project. The focus of the work performed was to demonstrate that a combination of non-destructive technologies: Ground Penetrating Radar (GPR), Infrared Thermography (IRT) along with High Resolution Imaging (HRI) can be used to provide quantitative information on the condition of tunnel liners and use of these non-destructive methods can be an effective strategy for both routine monitoring of tunnel liner condition and for evaluation of tunnels in advance of rehabilitation.

This application has identified a specific set of requirements that differentiate it from others. For tunnel liner evaluation, specialized GPR equipment is required, which utilizes non-contacting antenna technology, and customized antenna positioning equipment is necessary to facilitate inspection of all parts of the tunnel liner. IRT testing requires a high resolution thermal camera and special software to convert the raw images to plan view format. High resolution imaging is also useful in tunnel evaluation for comparison with results from the NDT methods. Those images should be presented in a format similar to the NDT methods. For confined areas such as ventilation adits, lightweight, portable GPR equipment can provide useful information on the condition of concrete components and identify areas of potential water flow.

The methods outlined in this report define procedures for collection and analysis of data. GPR data collection involves making a series of longitudinal scans along the length of the tunnel, in all clock positions, and with reference to distance. The IRT and HRI techniques also require the recording of a series of scans along the length of the tunnel, with the number of scans being sufficient to cover all parts of the tunnel liner.

The inspection of the Tooth Rock and Vista Ridge Tunnels has provided better and more quantitative information on the condition of the tunnel liners. Non-destructive GPR technology provides information on the internal condition of the concrete liner, as well as possible areas of water saturated concrete, based on measurement of signal attenuation and dielectric constant of the concrete. This information is not easily obtained by other means or without extensive destructive testing. The thermographic method, is useful in identifying locations of water flow through the liner and high resolution imaging provides a labor-saving, visual record of the liner surface that can be used to document repair locations and for future comparison.

While no one technology can provide all of the information needed to ascertain the condition of tunnels, it is our belief that a combination of methods provides the best approach. The technologies that were employed as part of this project have been in existence for some time and in use in other applications, and while NDT as applied to tunnels is still a relatively new application, additional work should focus on understanding strengths and limitations of the methods as well as development of standards. The full potential and ultimate success of these methods will only be realized through continued development and use.

McMILLEN JACOBS ASSOCIATES

Technical Memorandum

To:	Anthony Alongi, Penetradar	Project:	R06G Tunnel Lining Investigation Project
From:	Bryan Duevel, PE, GE Jamie Schick, CEG	cc:	File
Date:	October 15, 2018	Job No:	5859.0
Subject:	Vista Ridge Tunnel Visual Inspection Summary		

Revision Log

Revision No.	Date	Revision Description
0	6/26/18	Draft Submittal
1	10/15/18	Final Submittal

1.0 Introduction

This memorandum summarizes the results of our visual inspection of the Vista Ridge Tunnel (Highway 47, Structure Numbers 09103 and 09103B), located in Portland, Oregon. This work was completed in general accordance with our subcontract with Penetradar, dated June 16, 2018. Penetradar is the prime consultant for ODOT Contract No. B35752, R06G Tunnel Liner Investigation Project.

The general scope of work for the project is to perform non-destructive testing (NDT) of the tunnel liners for the Vista Ridge Tunnel, and the Tooth Rock Tunnel (Highway 2, Structure Number 04555) using Ground-Penetrating Radar, high resolution photography and Infrared Themography Analysis. The objective of the NDT is to identify and map any defects behind or within the tunnel linings. Included in the scope of work is visual inspection of the Vista Ridge Tunnels to assess the general condition of the structural lining, and perform detailed inspections of twenty 3-foot by 3-foot areas for quality control of the NDT results. Further, the visual inspections were used to focus the data reduction efforts to specific areas or to types of defects.

Tooth Rock Tunnel was not visually inspected as part of this contract but a detailed inspection was completed by McMillen Jacobs Associates in 2014. Tunnel maps from that inspection will be used to interpret the NDT data.

2.0 Tunnel Description

The Vista Ridge Tunnel is located on Oregon Highway 47 (US Highway 26) at approximate milepost 73.53 immediately west of downtown Portland, Oregon. There are two individual tunnels, conveying eastbound (EB) and westbound (WB) traffic. Each tunnel is between 1,000 and 1,100 feet long. The tunnels are horseshoe-shaped and have interior dimensions of approximately 45 feet wide (between sidewalls) and 28 feet tall in the crown. A reinforced concrete slab is suspended from the crown which separates the tunnel into two openings; the travel lanes and the ventilation adits. The slab provides a typical vertical clearance of 19.5 feet above the roadway. The maximum clearance in the adit is approximately 7 feet at centerline. A 40-foot rock pillar separates the two tunnels. The tunnels generally have the same support systems and dimensions. Tunnel data is summarized in Table 1. A typical tunnel section is shown in Figure 1.

Table 1. Vista Ridge Tunnel Data

Data	EB Tunnel	WB Tunnel
Structure Number	09103	09103B
Milepost	73.53	73.56
Length (ft)	1,018	1,061
Sidewall-Sidewall Width (ft)	45	45
Maximum Height (ft)	28	28
Average Daily Traffic (ADT)	13,400	11,800

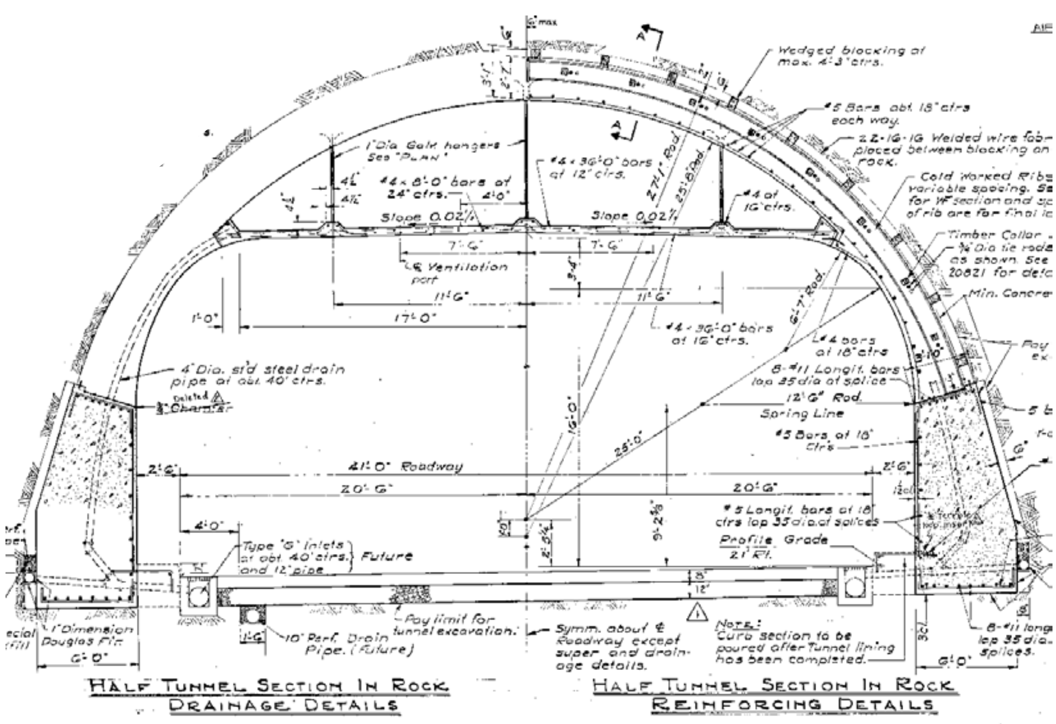


Figure 1. Typical Section for Vista Ridge Tunnels (ODOT, 1968)

Record drawings for the tunnels (ODOT, 1968) were reviewed prior to the inspection. The Vista Ridge Tunnel was constructed in the mid- to late-1960s primarily through basalt. Near the portals, the basalt transitions to overburden soils. Typical tunnel support in rock consists of steel sets (ranging from W14x48 to W14x103) at 2- to 4-foot centers. Steel sets are blocked to the excavation line. The steel sets are encased in a reinforced, cast-in-place (CIP) concrete lining with a typical thickness of about 3 feet in the crown and quarterarch. Below the quarterarch, the sidewall thickness increases to a maximum of 6 feet at the footing (shown in Figure 1). Near the portals (within soil), the tunnel barrel is solely reinforced CIP concrete, and has thicknesses ranging from about 3 feet in the crown to 4-feet-6-inches in the sidewall. Although construction methods are not discussed in the record drawings, it is presumed that the rock portion of the tunnel was constructed using drill-and-blast methods, while the soil portions of the tunnels were constructed using cut-and-cover methods.

The ceiling slab separating the roadway from the ventilation adit consists of a 6-inch-thick, reinforced CIP concrete slab. The slab is tied into the tunnel lining concrete at the perimeter and supported by 1-inch diameter steel rod hangers embedded in the crown concrete. The hangers are placed in rows of 3 across the tunnel width, spaced on 2-foot centers (see Figure 1). All exposed lining surfaces (sidewalls and crown slab) within the roadway opening are covered in ceramic tile affixed with approximately 2 inches of cement grout.

There are no mechanical ventilation systems; ventilation is provided through natural movement through the ventilation adit and roadway opening.

3.0 Tunnel Inspection Methodology

3.1 Document Review

Prior to performing the tunnel condition assessment, McMillen Jacobs reviewed ODOT’s available design drawings and inspection maps. Specifically, the following documents were reviewed:

- Vista Ridge Tunnel Design Drawings, dated 1968;
- Vista Ridge Tunnel Inspection Maps (developed by ODOT), dated November 2010 and April 2014.

3.2 Inspection Overview

The Vista Ridge Tunnel visual inspections were performed between June 12 and June 16, 2018. The tunnel adits were inspected on June 12 and 13. The core inspection team consisted of two tunnel engineers. The roadway openings for the two tunnels were inspected on June 15 and 16, 2018. The roadway openings inspection was led by a senior engineering geologist and assisted by ODOT personnel. Certified (National Tunnel Inspection Standards) NTIS tunnel inspectors led all inspections. The visual inspections were performed in conjunction with the NDT testing of the tunnel linings.

In general, the visual inspections met the standards of a “routine” inspection of the tunnel lining elements (per NTIS), consistent with the scope of work. Visual inspections of the electrical, mechanical, and civil elements were not performed.

3.3 Tunnel Stationing

During the initial tunnel walkthrough, tunnel inspection stationing was established using previous tunnel inspection markings. Stationing was confirmed to be consistent with previous inspections using the existing tunnel condition maps. Station 0+00 for both tunnels is located on the west side of the tunnel barrel, at the ventilation inlet/outlet. Field stationing was completed in the tunnels using a measuring wheel. No detailed surveying was performed as a part of this project.

3.4 Tunnel Wall Location

The positions of observed features along the tunnel wall were identified using clock positions (looking to the east). Using this reference system, the tunnel crown corresponds to 12:00. The adit slab connection points with the tunnel crown corresponds to the approximate 10:00 (north) and 2:00 (south) positions, respectively. The base of the tunnel sidewalls correspond to the 8:00 (north) and 4:00 (south) positions, respectively. The clock positions are referred to in defect descriptions but are not included on the tunnel maps.

3.5 Inspection Procedures

The objective of the inspection was to assess and document the current condition of the Vista Ridge Tunnel lining using primarily visual methods. The inspection of the tunnel lining included:

- Review of historical tunnel maps for accuracy, documentation of any new defects/cracks/spalls in the tunnel lining and its overall condition.
- Documentation and measurement of seeps.
- Photo documentation of typical defects
- Sounding concrete with a hammer to detect drummy or delaminated areas.

Inspections were performed from the adit slab or ground level. Tunnel observations are presented in Section 4.

3.6 Tunnel Mapping

Tunnel features and defects were mapped during the inspection in general accordance with the 2015 FHWA Specifications for the National Tunnel Inventory (SNTI) and the Tunnel Operations, Maintenance, Inspection, and Evaluation (TOMIE) Manual (2015). The existing tunnel maps were updated where applicable. Areas of active seepage during the inspection were also noted. The updated maps are included in Appendix A.

3.7 Defect Classification

Defects are defined as any deterioration of tunnel system elements from their initial condition and can be as minor as a hairline crack or as significant as an open hole in the concrete lining. Defects were classified according to the Condition State (CS) definitions presented in the FHWA SNTI (2015). Generalized descriptions of these classifications are presented in Table 2. ***Note that in general, defects that have a depth of less than or equal to ¼ of the lining thickness and no offset are not typically considered structurally significant.***

Table 2. Defect Descriptions

Defect Type	Condition State 1	Condition State 2	Condition State 3	Condition State 4
Delamination/ Spall/Patched Area	None	Delaminated, Spall ≤1 in. deep or ≤ 6 in. diameter. Patched area that is sound.	Spall > 1 in. deep or > 6 in. diameter. Patched area that is unsound or showing distress.	Defects impact strength and serviceability of the element or tunnel.
Exposed Rebar	None	Present without measurable section loss.	Present with measurable section loss.	
Efflorescence/ Rust Staining	None	Surface white without build-up or leaching without rust staining.	Heavy build-up with rust staining.	
Cracking	Width < 0.012 in. or spacing > 5.0 ft	Width 0.012-0.1 in. below spring line or spacing of 1.0 – 5.0 ft	Width >0.1 in below spring line or >0.012 in. above spring line or spacing of < 1 ft.	
Leakage (Seepage)	Dry Surface	Saturated surface indicating seepage may be present or evidence of past seepage.	Fully saturated with surface seepage.	Seepage could range from dripping to flowing.

3.8 Tunnel Element Condition Descriptions

Tunnel lining elements were assigned Condition State (CS) ratings considering their overall condition taking into account structure integrity, defects, and discontinuities. The rating system follows the FHWA SNTI (2015) and ranges from 1 to 4. The qualitative descriptions of the condition states are as follows:

- CS 1 – Good Condition
- CS 2 – Fair Condition
- CS 3 – Poor Condition
- CS 4 – Severe Condition – Potentially reduced strength or serviceability

3.9 Tunnel Photography

The conditions observed at the time of the inspection were documented with photographs. Select photographs showing typical tunnel conditions are presented in Section 4 of this memorandum.

4.0 Tunnel Condition Observations

4.1 General

This visual assessment of the tunnel lining condition has been developed based on our review of design drawings and visual observations and surface measurements of the tunnel. The results of our observations are described in the following sections, organized by the section of tunnel inspected. Appendix A includes updated tunnel inspection maps.

4.2 EB Adit

The entire EB Adit is lined with CIP concrete. Overall the concrete liner was observed to be in good condition (CS1). The concrete was sound based on regular concrete sounding with a hammer. Figure 3 shows the typical conditions of the EB Adit.

Figure 3. Typical adit conditions. Photo taken in EB Adit at approximate Station 3+00, looking west.

Minor lining cracking was observed throughout the EB Adit. Cracking is typically transverse (parallel to roadway), and most prominent between the 10:00 to 11:00 and 1:00 to 2:00 clock positions. Cracks typically had apertures between 0.01 and 0.05 inches and had minor efflorescence staining and buildup. Typical cracks are discontinuous and have lengths of less than 8 feet. These cracks are typically categorized as CS3 due to the presence of efflorescence and their position in the tunnel. Very few longitudinal, diagonal, or pattern cracks were observed. Cracking was more prevalent between Stations 1+00 and 1+50. This location is coincident with the transition between rock and soil cover conditions at the west end of the tunnel. No cracks showing signs of offset, load concentration, or other unusual characteristics were observed.

Construction joints are present in the tunnel lining at 20-foot intervals. The construction joints typically show efflorescence, water staining and minor spalling (less than 1-inch deep/wide). Efflorescence buildup is regularly heavy and shows rust staining. These joints are categorized as CS3. Typical construction joint conditions are shown in Figure 4.

No new defects of significance (since the last inspection) were observed during the inspection. One small area (approximately 2 wide by 2 feet long) of drummy concrete was observed near the tunnel centerline at Station 1+10.

The concrete lining was generally dry. Thirteen actively dripping areas were observed, each located along construction joints. In each area, seepage was measured at less than 5 drips per minute.

Figure 4. Typical construction joint. Photo taken in EB Adit at approximate Station 1+70, looking south.

Overall, the tunnel lining conditions observed were consistent with those described during previous inspections. There were no observations of lining degradation since previous inspections. The only prominent defect which may be considered for closer evaluation with the NDT data is the drummy concrete near Station 1+10.

4.3 WB Adit

The entire WB Adit is lined with CIP concrete. Overall the concrete liner was observed to be in good condition (CS1). The concrete was sound based on regular concrete sounding with a hammer.

Minor lining cracking was observed throughout the WB Adit, though less so than the EB Adit. Cracking is typically transverse (parallel to roadway), and most prominent between the 10:00 to 11:00 and 1:00 to 2:00, and at the 12:00 clock positions. Cracks typically had apertures between 0.01 and 0.05 inches and had minor efflorescence staining and buildup. Typical cracks are discontinuous and have lengths of less than 8 feet. These cracks are typically categorized as CS3 due to the presence of efflorescence and their position in the tunnel. Very few longitudinal, diagonal, or pattern cracks were observed. Cracking was more prevalent between Stations 1+00 and 1+50. No cracks showing signs of offset, load concentration, or other unusual characteristics were observed.

Construction joints are present in the tunnel lining at 20-foot intervals. The construction joints typically show efflorescence, water staining and minor spalling (less than 1-inch deep/wide). There was generally less efflorescence, staining, and evidence of past water flow than in the EB Adit. These joints are categorized as CS3. Typical construction joint conditions are shown in Figure 4.

No new defects of significance (since the last inspection) were observed during the inspection.

The concrete lining was generally dry. One actively dripping area was observed, located along a crack. Seepage was measured at less than 5 drips per minute.

Overall, the tunnel lining conditions observed were consistent with those described during previous inspections. There were no observations of lining degradation since previous inspections. The were no prominent defects visually identified that may warrant closer evaluation with NDT data.

4.4 EB Roadway

The EB roadway opening of the tunnel is lined with four-inch square tile along the entire length. The tile lining limited visual observations of the concrete liner to areas where cracks had transmitted through the tile and spalls had removed tile as well as concrete. Longitudinal (circumferential) cracks were typically irregularly spaced and less than 10 feet in length. Transverse cracks were more common and typically occurred at approximately 2 to 3 o'clock and 9 to 10 o'clock. These cracks varied from approximately 5 to 20 feet in length. The aperture of cracks was generally 0.01 to 0.05 though the majority could not be measured directly from the ground. These cracks are typically categorized as CS3 due their position in the tunnel. No cracks showing signs of offset, load concentration, or other unusual characteristics were observed. Construction joints are present at approximately 20-foot spacing.

Numerous spalls were historically mapped in this tunnel, primarily above springline (about 7 ft above roadway). The majority of these appeared to be relatively small (less than 6-12 inches in diameter). In some cases, minor spalls (less than 3 inches) and short cracks were concentrated in small (less than 100 square feet) areas (Figure 5). Several transverse spalls were along cracks near the 2 to 3 o'clock and 9 to 10 o'clock position. These are near the transition to the adit slab. Due to access these were not quantified but they appeared to be primarily CS2 and CS3 defects.

Figure 5. Concentrated area of small spalls and cracks. Photo taken in EB Tunnel at approximate Station 9+50, looking southeast.

The tunnel lining was generally dry. Minor seepage staining was present on both transverse and longitudinal cracks (Figure 6). One moist area was observed near Station 4+06 at the foot of the north tunnel wall. Active seepage was not measurable. Minor efflorescence was observed in several locations however this is likely removed with the regular wall washing completed by ODOT maintenance forces.

Figure 6. Water staining along transverse and longitudinal construction joints. Photo taken in EB Tunnel at approximate Station 9+75, looking southeast.

The primary defect observed is the debonding of the surface tile. Detailed inspection of the lower seven feet of tile identified numerous locations where tile was identified as drummy by sounding. While previously unreported it is unclear when this condition developed. Areas of debonding are generally limited in extent and primarily along construction joints and in areas where water flow is evident. Along construction joints only one to two tile widths were impacted. The extent of debonded tile in the lower 7 feet of each tunnel wall is recorded on the tunnel maps in Appendix A. NDT evaluation should be focused on shallow defects to capture areas of debonding tile, particularly around construction joints.

4.5 WB Roadway

The WB roadway opening of the tunnel is also lined with four-inch square tile along the entire length. In general, more new fractures were mapped in this tunnel relative to the east-bound tunnel. However the timing of crack development is difficult to determine, and the identification of cracks may have been due to closer inspection. Longitudinal (circumferential) cracks were typically widely spaced and less than 10 feet in length. Transverse cracks were also more common and typically occurred at approximately 2 to 3 o'clock and 9 to 10 o'clock. These cracks varied from approximately 5 to 20 feet in length. The aperture of cracks was generally 0.01 to 0.05 though the majority could not be measured directly from the ground.. No other cracks showing signs of offset, load concentration, or other unusual characteristics were observed. Construction joints are present at approximately 20-foot spacing.

Historically mapped spalls in the west-bound tunnel were relatively limited and primarily above springline. The majority of these appeared to be relatively small (less than 6 to 12 inches). Relative to the east-bound tunnel the number of spalls was significantly less. Due to access these were not quantified but they appeared to be primarily CS2 and CS3 defects.

The tunnel lining was generally dry. Seepage staining was limited and significantly less than what was observed in the east-bound tunnel. Observed staining occurred on both transverse and longitudinal cracks. Two moist areas were observed near Stations 2+90 and 3+18, both at the foot of the right (south) tunnel wall (Figure 7). Active seepage was not measurable. Efflorescence was not observed in this tunnel however this is likely removed with the regular wall washing completed by ODOT maintenance forces.

Figure 7. Wet area and staining at the base of the tunnel wall. Yellow grease pencil identified debonded tile. Photo taken in WB Tunnel at approximate Station 2+90, looking south.

The primary defect observed is the debonding of the surface tile, similar to the east-bound tunnel. Detailed inspection of the lower seven feet of tile identified numerous locations where tile was sounded drummy. While previously unreported it is unclear when this condition developed. Debonded tile was present along most construction joints in this tunnel. Other areas were generally limited in extent and primarily in areas where water flow is evident. Along construction joints only one to two tile widths were impacted. The extent of debonded tile in the lower 7 feet of each tunnel wall is recorded on the tunnel maps in Appendix A. NDT evaluation should be focused on shallow defects to capture areas of debonding tile, particularly around construction joints.

4.6 Detailed Inspections

The original scope of work called for detailed window mapping during the inspection. With the assistance of ODOT inspectors a detailed inspection was completed along both sides of each tunnel up to seven feet above ground. This included systematic sounding of the tile and recording of all defects. Mapped defects were primarily limited to debonded tiles as discussed above. Some additional cracking was also mapped as part of this inspection. Minor additional defects also included collision damage (scrapes and gouges) from past impacts.

5.0 Summary and Recommendations

5.1 Liner Observation Summary

Overall, the tunnel is considered to be in good condition per the SNTI classification system. Observed defects, evidence of seepage, and the overall tunnel liner condition were consistent with those noted during previous inspections. No portion of the lining was considered to be in critical condition.

The most predominant lining defects were cracking, efflorescence, seepage, and drummy tiles. No cracks showed signs of offset, load concentration, or other unusual characteristics. All the observed defects are typical for the type of lining and drainage systems within the tunnel. ***None of the defects are indicative of poor lining performance nor are they considered structurally significant. Further, no defects are in critical condition or in need of immediate repair.***

However, the drummy tile may continue to degrade over time, eventually leading to complete debonding and falling of tiles onto the roadway surface. While this is not structurally significant to the tunnel lining, it does pose a significant hazard to the traveling public.

5.2 Recommendations for NDT Evaluation

In general, no prominent defects were visually observed in the tunnel adits aside from typical degradation along construction joints. Therefore, there are no predominant areas of focus for the interpretation of NDT data.

In the roadway openings, drummy tiles were identified throughout both tunnels. These drummy areas typically extended 1 to 2 tiles around each side of construction joints. Drummy tiles were also observed in areas where water stains were noted. We recommend that NDT data interpretation be focused on the tile depth, especially around construction joints and overhead. The condition of the lining behind the tiles is expected to be similar to that observed in the adit and have relatively few defects.

5.3 Repair/Monitoring Recommendations

The TOMIE defines three levels of repair recommendations: critical finding, priority repair, and routine repair. There were no conditions observed during the current inspection that are considered a critical finding or necessitate a priority repair. Nor were there any routine repair items (which are typically undertaken as part of scheduled or routine tunnel maintenance programs) identified during the inspection. There are maintenance and inspection recommendations that fall under the routine repair category. Our recommendations are as follows:

<u>Routine Maintenance:</u>

- <u>*Drainage Cleaning*</u>*:* We understand that the tunnel drainage system is periodically cleaned. This cleaning includes removal of debris from catch basins and gutters and flushing of sidewall drains. We recommend that this be continued on an annual or biannual basis.

<u>Future Inspections:</u>

- <u>*Tile Sidewall Condition Monitoring*</u>*:* Numerous areas of drummy tile were observed within the roadway openings. While none of these areas were in need of immediate repair, tile condition should be monitored during all future inspections, as tile condition is expected to degrade over time.

- <u>*Crown Sidewall Condition Monitoring:*</u> The crown tile was inspected only using visual methods during the current inspection. It is expected that its condition is similar to that of the sidewalls (that is, areas of locally drummy tile should be expected). The crown tile should be inspected with hand tools for soundness during the next detailed inspection (when lane closures will be required). If the condition of sidewall tiles deteriorates to the point of localized (complete) debonding prior to the next detailed inspection, the crown inspection should be accelerated to confirm loose tiles are not present above the travel lanes.

6.0 References

Federal Highway Administration, 2015, *Tunnel Operations, Maintenance, Inspection, and Evaluation (TOMIE) Manual*, FHWA-IF-15-005.

Federal Highway Administration, 2015, *Specifications for the National Tunnel Inventory*, FHWA-IF-15-006.

Oregon Department of Transportation, 1968. Vista Ridge Tunnel (Bridge No. 09103 and 09103B) Construction Drawings.

Oregon Department of Transportation, 2010. Vista Ridge Tunnel Inspection Maps.

Oregon Department of Transportation, 2014. Vista Ridge Tunnel Inspection Maps.

ATTACHMENTS

Appendix A: Tunnel Inspection Maps

Appendix A

Tunnel Inspection Maps

TUNNEL MAP LEGEND

RED DENOTES NEW OBSERVATION - JUNE 2018

BLUE DENOTES ACTIVE WATER OBSERVATION - JUNE 2018

Scaling — *Scaling is light - loss of surface mortar without exposure of coarse aggregate unless otherwise indicated*

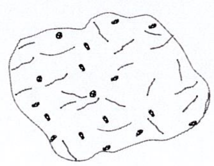
Moist to Wet Seepage Area/Stain

Dry Seepage Stains

Tile or Concrete Spall

DRUMMY CONCRETE

Areas of Short Cracks and Small Spalls



Metal Plate or Box

Seep

Scrape or Gouge

Coreholes Patched Unless Noted Otherwise

Drain Inlets

Type 2 - Roadway 15 x 32 in.

Tile and Concrete

Crack Fine

All cracks are fine (Cf, △ 1mm) unless otherwise indicated as Cm - medium, 1-2 mm or Cw - wide, >2mm

Tile and Concrete

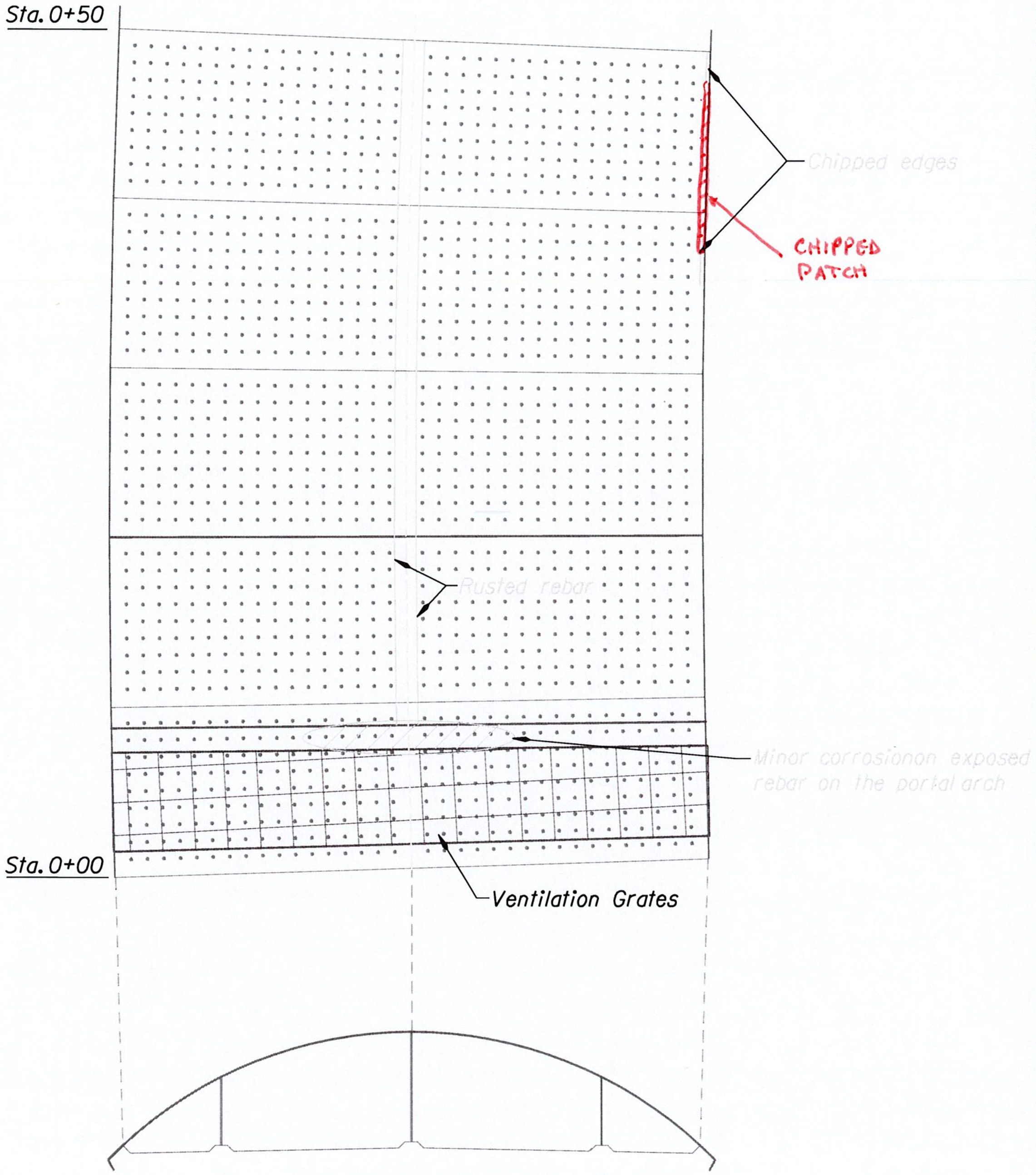
Construction Joint

VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION

Bridge Operations Unit - Tunnel Maps

Structure No. 09103 Last Update Oct. 2014



VENTILATION ADIT ARCH

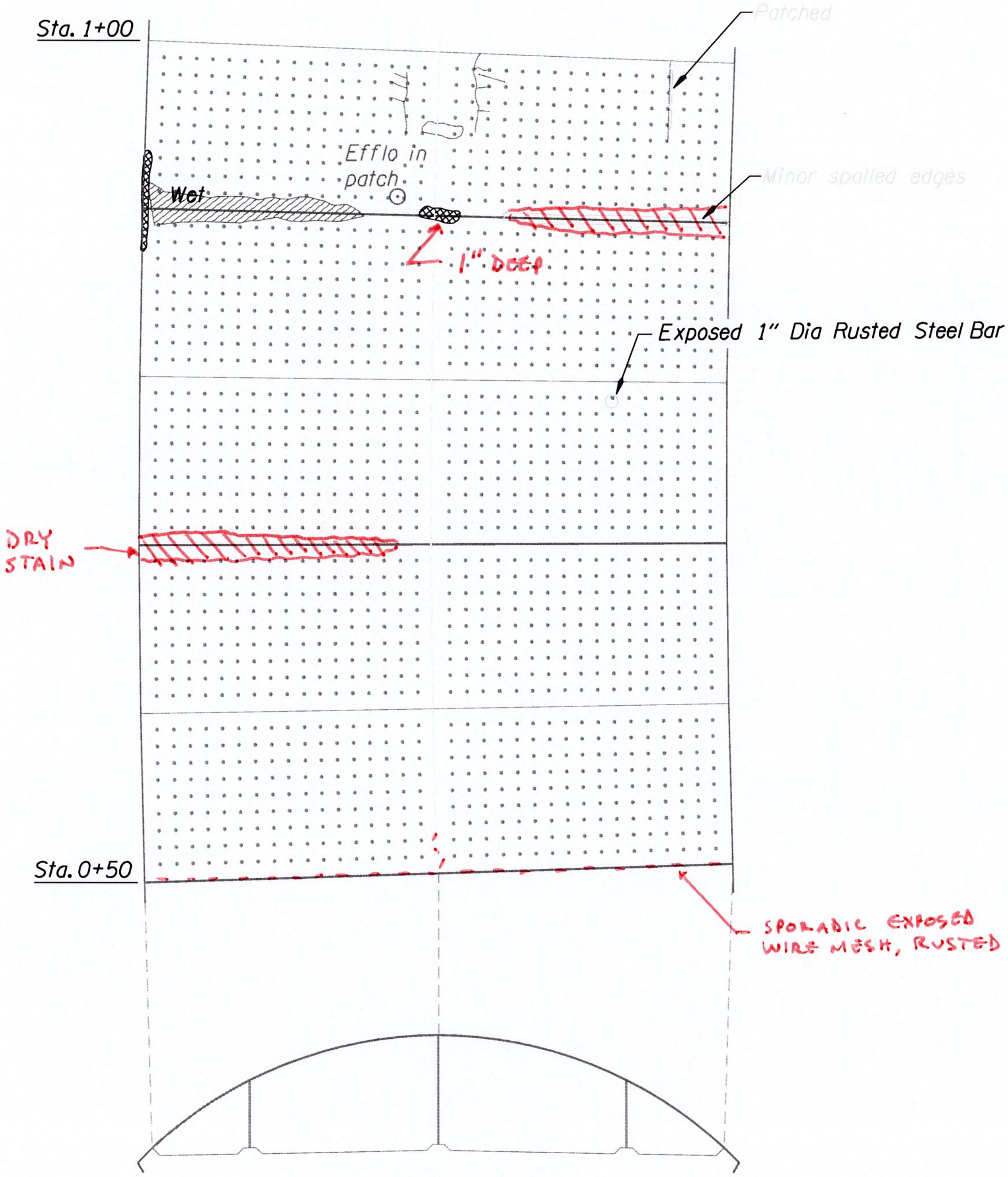
0 10 20
Scale in feet

VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103 Last Update Oct. 2014

Arch - Sta 0+00 to 0+50



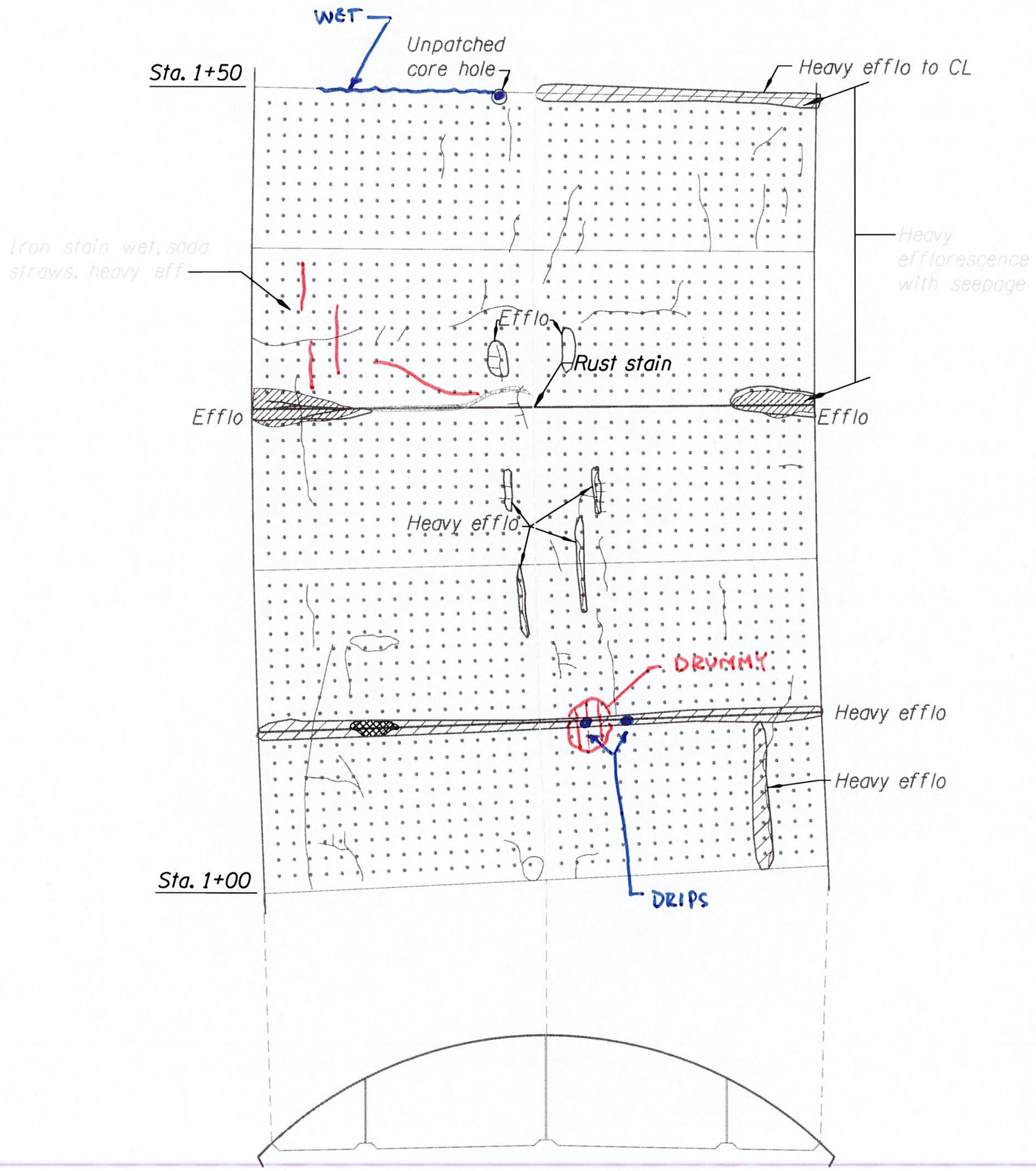
VENTILATION ADIT ARCH

0 10 20
Scale in feet

VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103 Last Update Oct. 2014



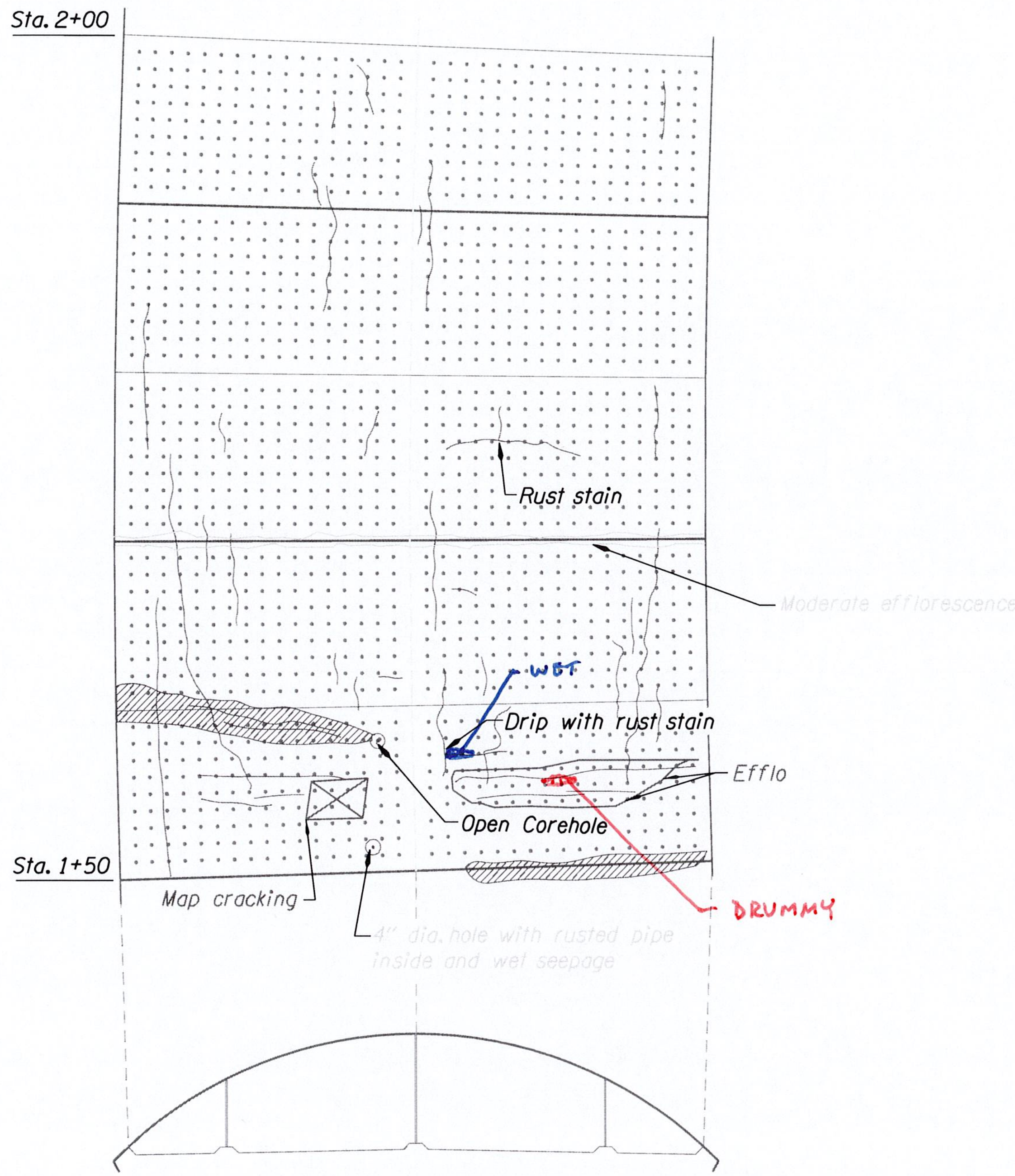
VENTILATION ADIT ARCH

0 10 20
Scale in feet

VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103 Last Update Oct. 2014



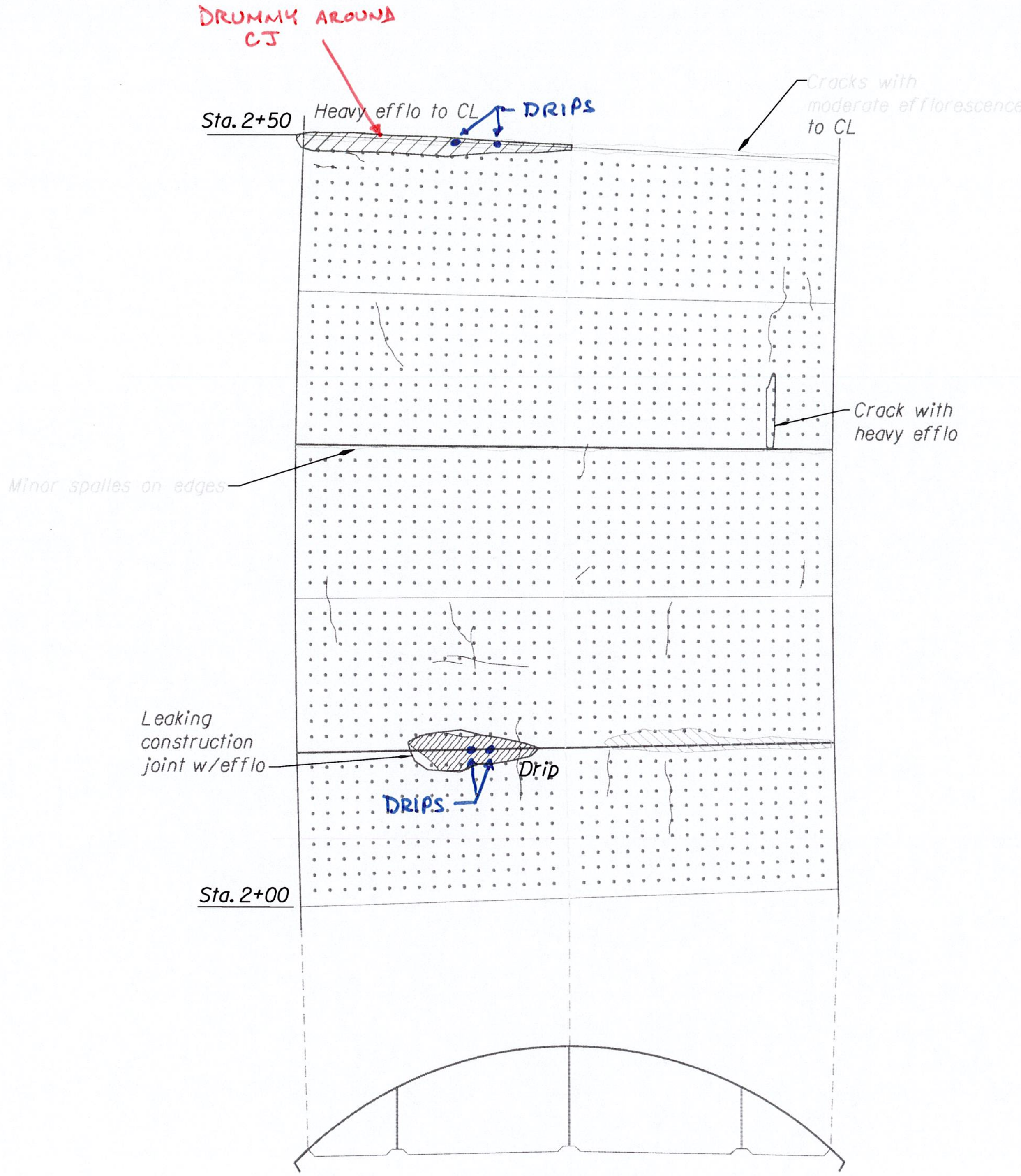
VENTILATION ADIT ARCH

0 10 20
Scale in feet

VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103 Last Update Oct. 2014



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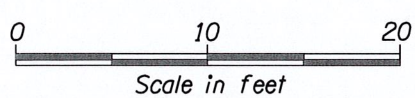

VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION

Bridge Operations Unit - Tunnel Maps

Structure No. 09103 Last Update Oct. 2014

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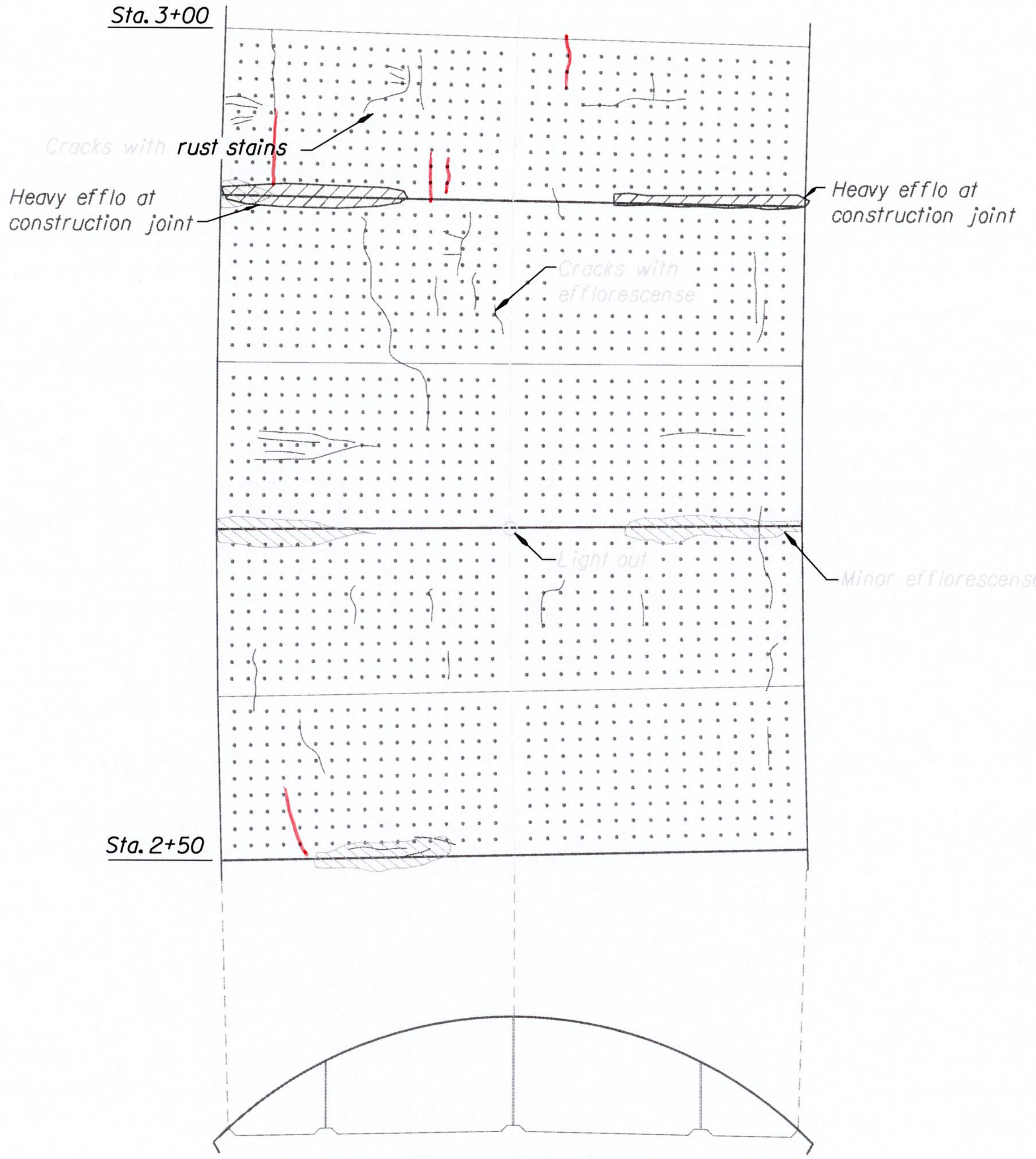

VENTILATION ADIT ARCH

0 10 20
Scale in feet

VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103 Last Update Oct. 2014

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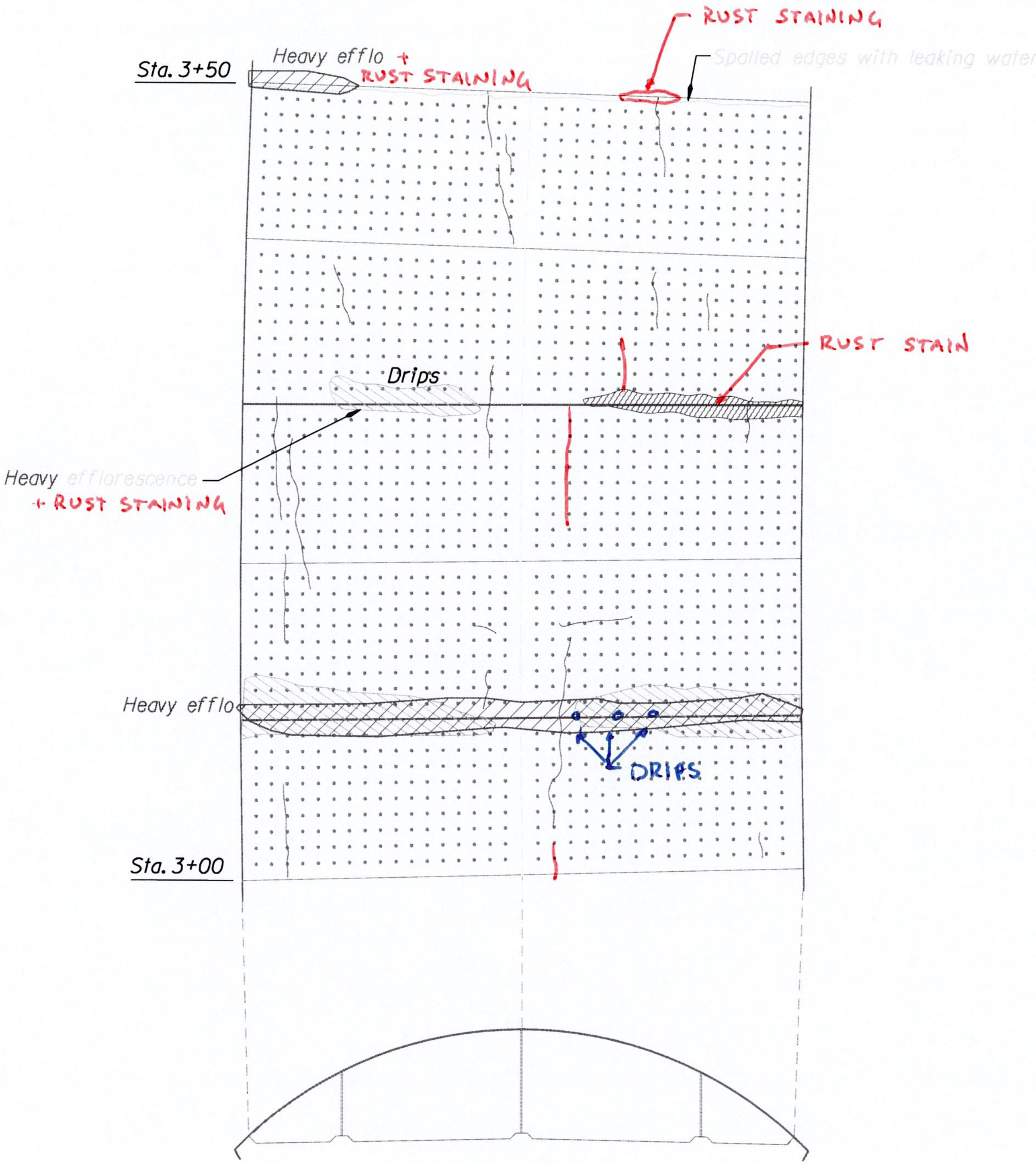

VENTILATION ADIT ARCH

0 10 20
Scale in feet

VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103 Last Update Oct. 2014

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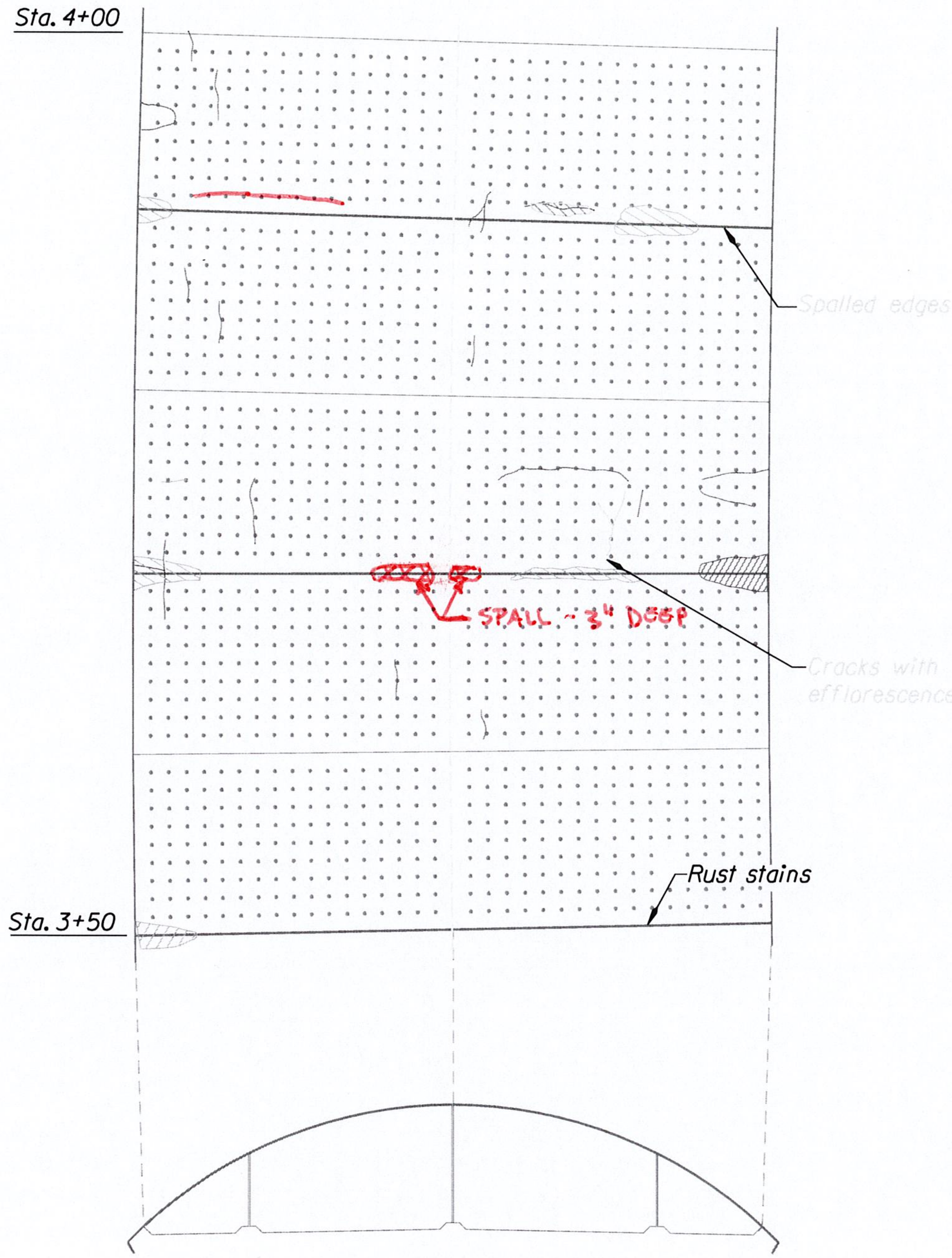

VENTILATION ADIT ARCH

0 10 20
Scale in feet

VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103 Last Update Oct. 2014

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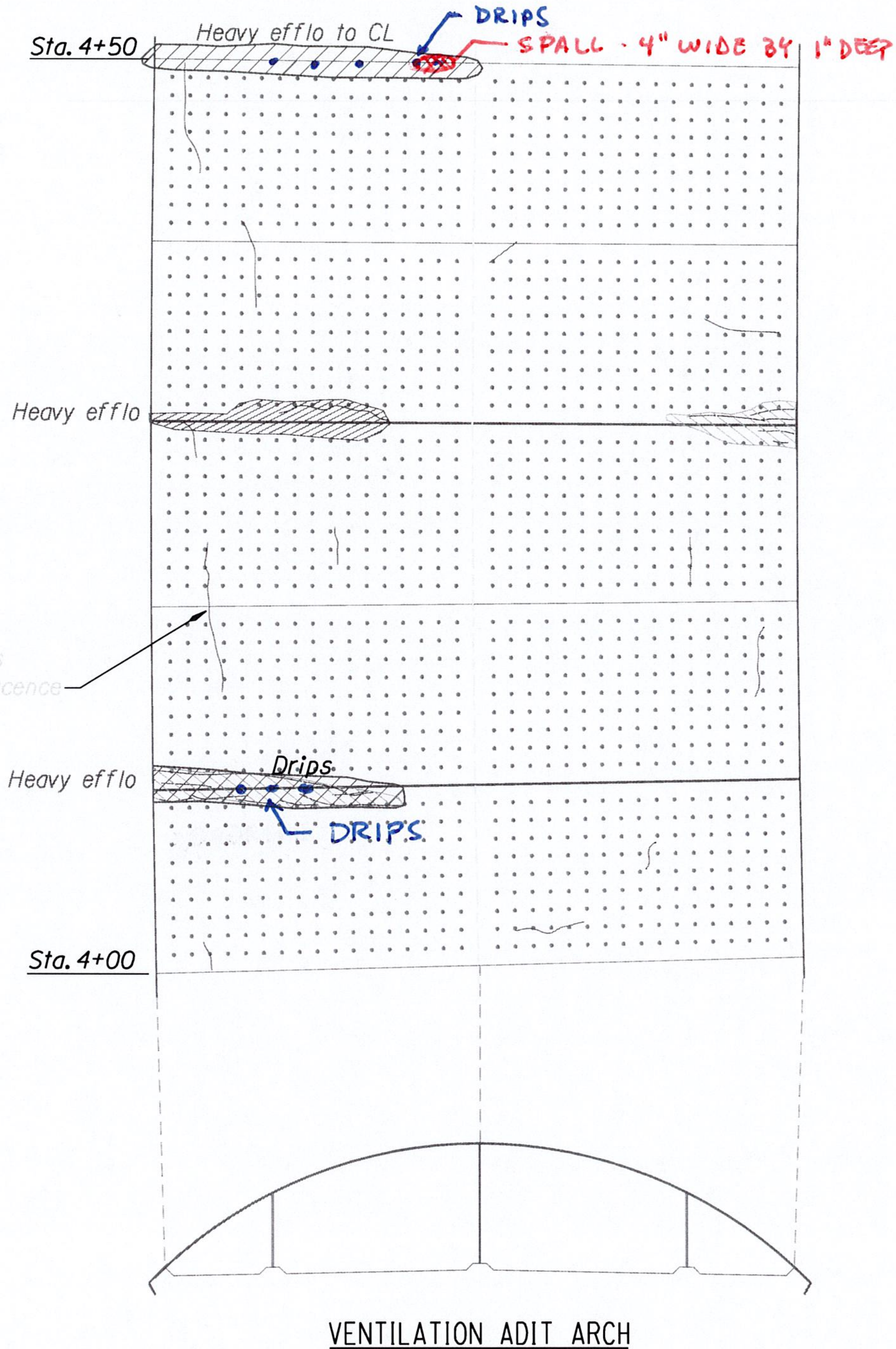

VENTILATION ADIT ARCH

0 10 20
Scale in feet

VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103 Last Update Oct. 2014

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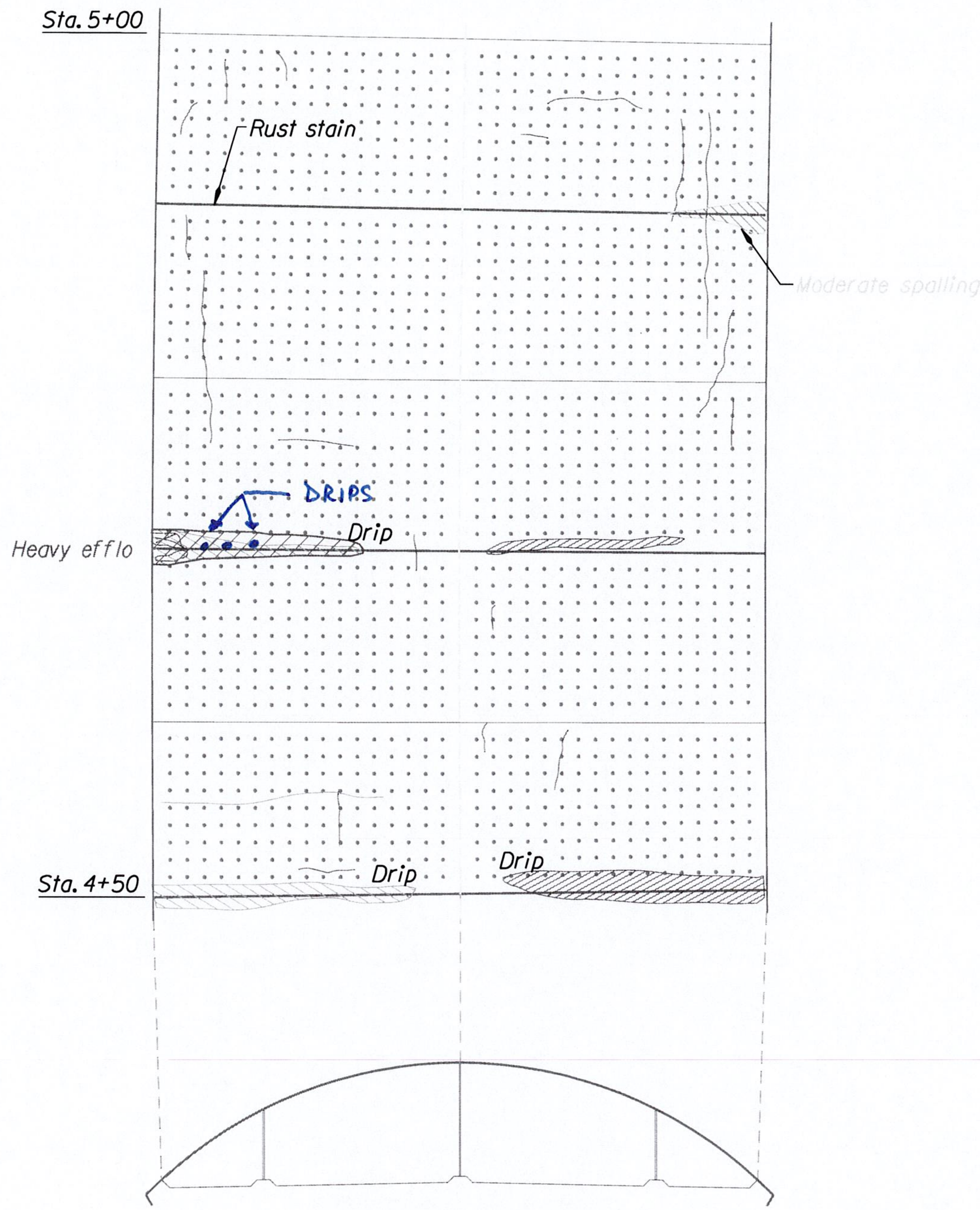

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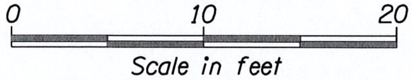
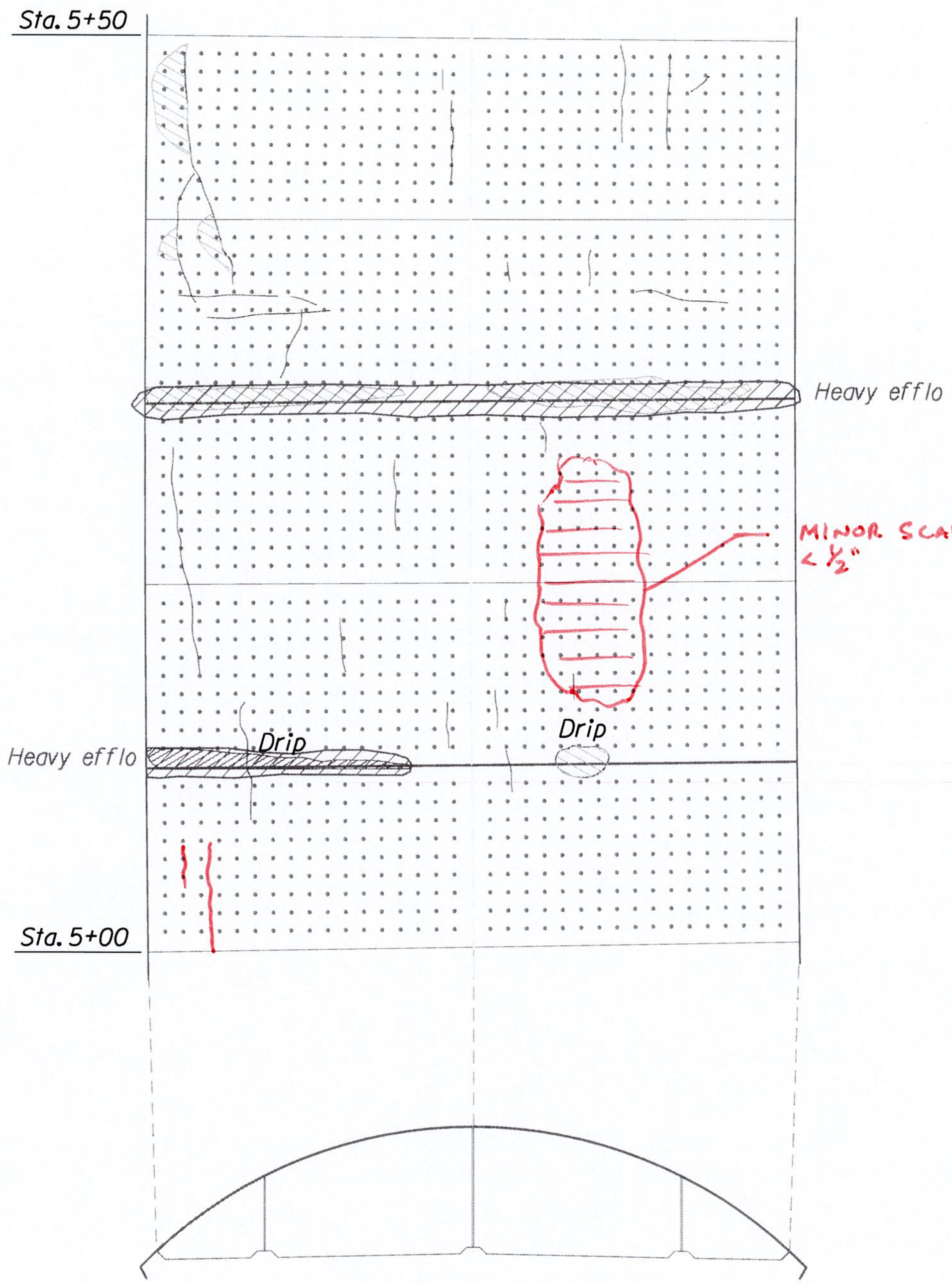


VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103 Last Update Oct. 2014



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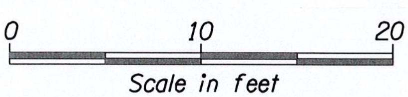

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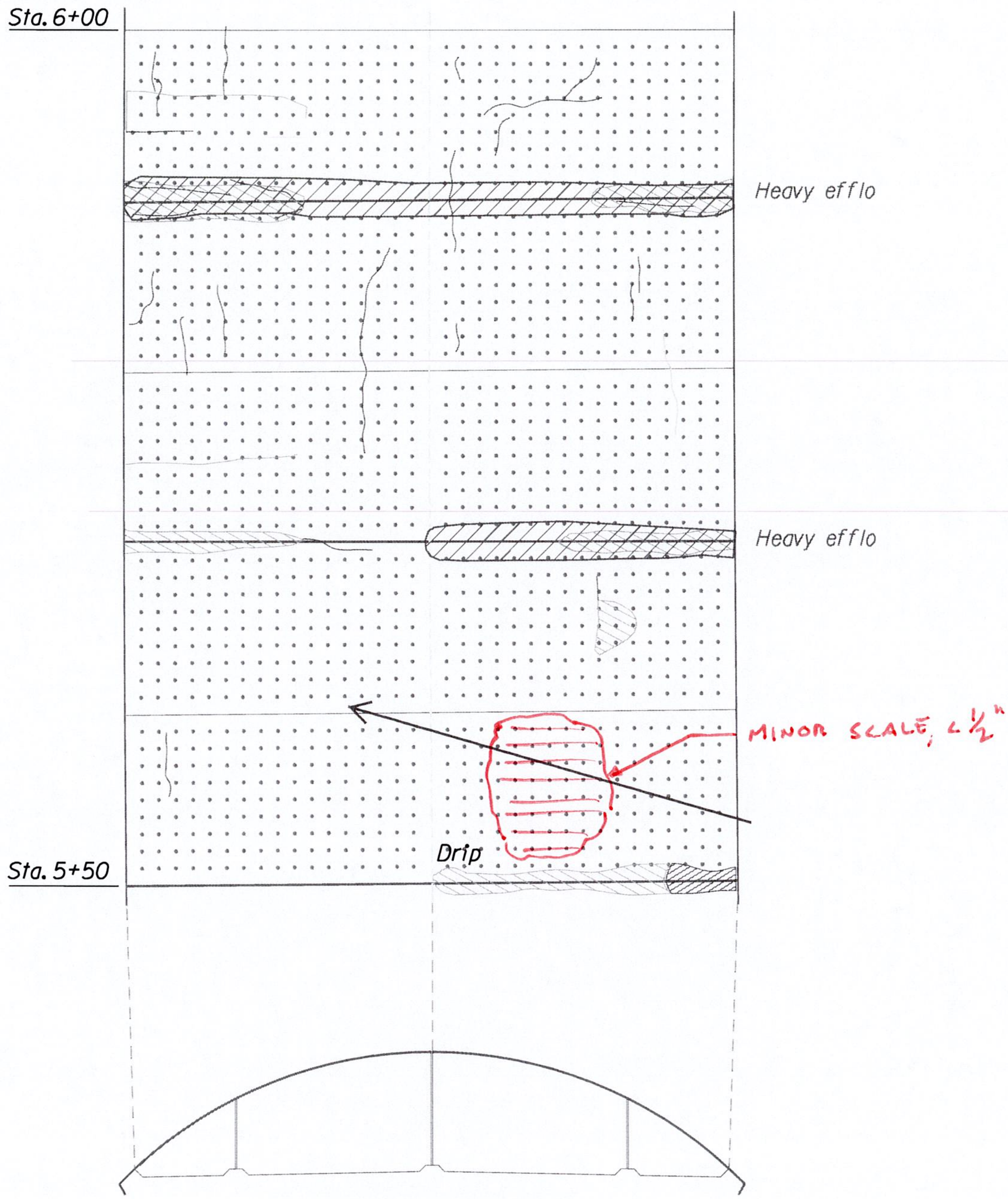
OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103 Last Update Oct. 2014



VENTILATION ADIT ARCH

0 10 20
Scale in feet

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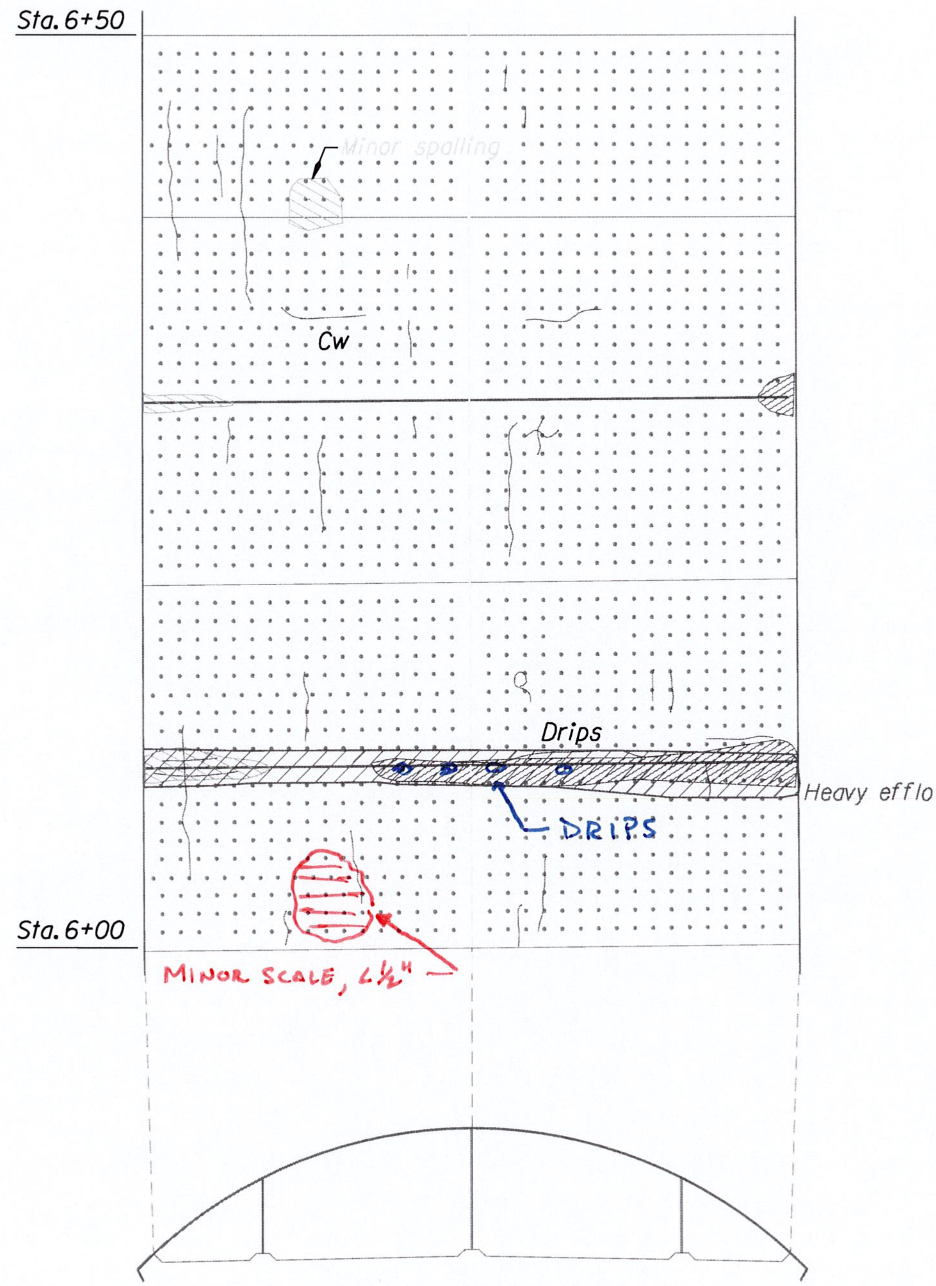
OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103 Last Update Oct. 2014



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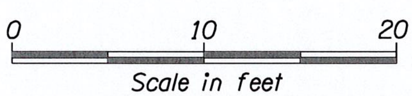
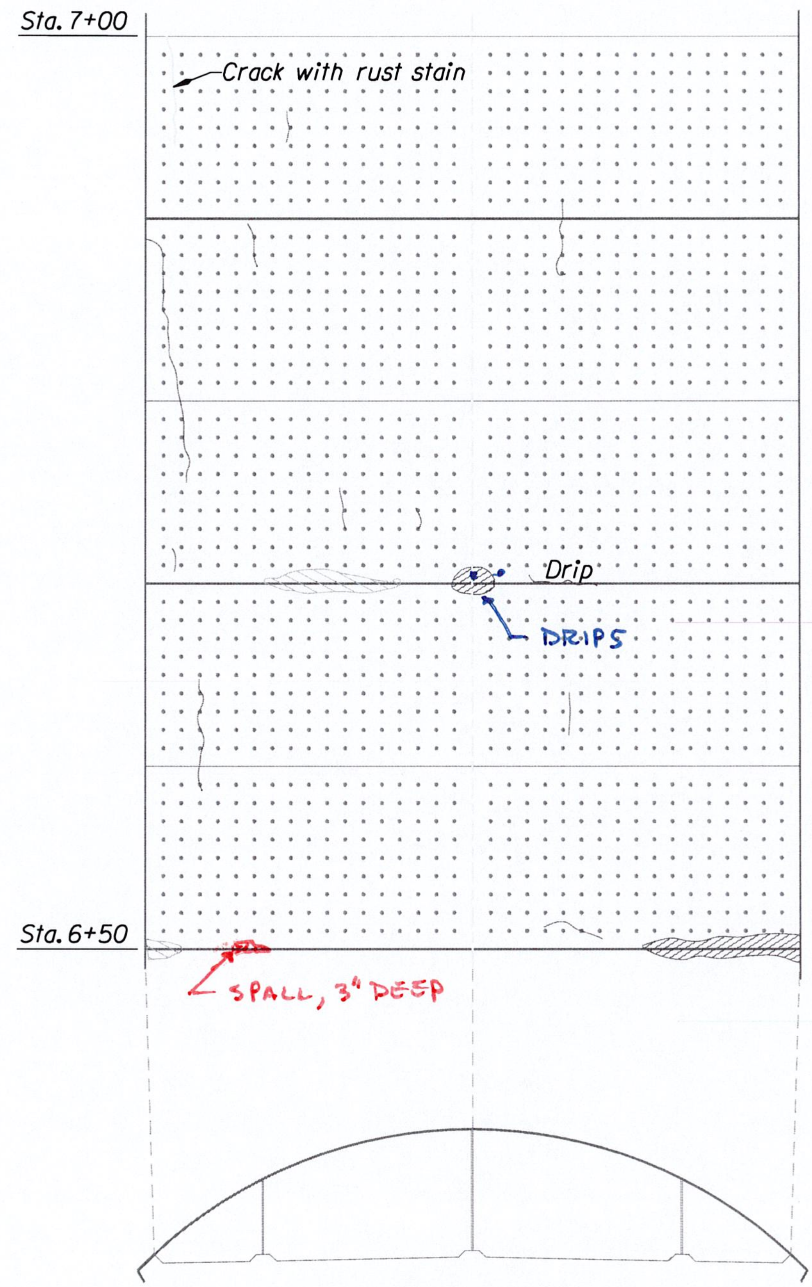


VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION

Bridge Operations Unit - Tunnel Maps

Structure No. 09103 Last Update Oct. 2014



VENTILATION ADIT ARCH

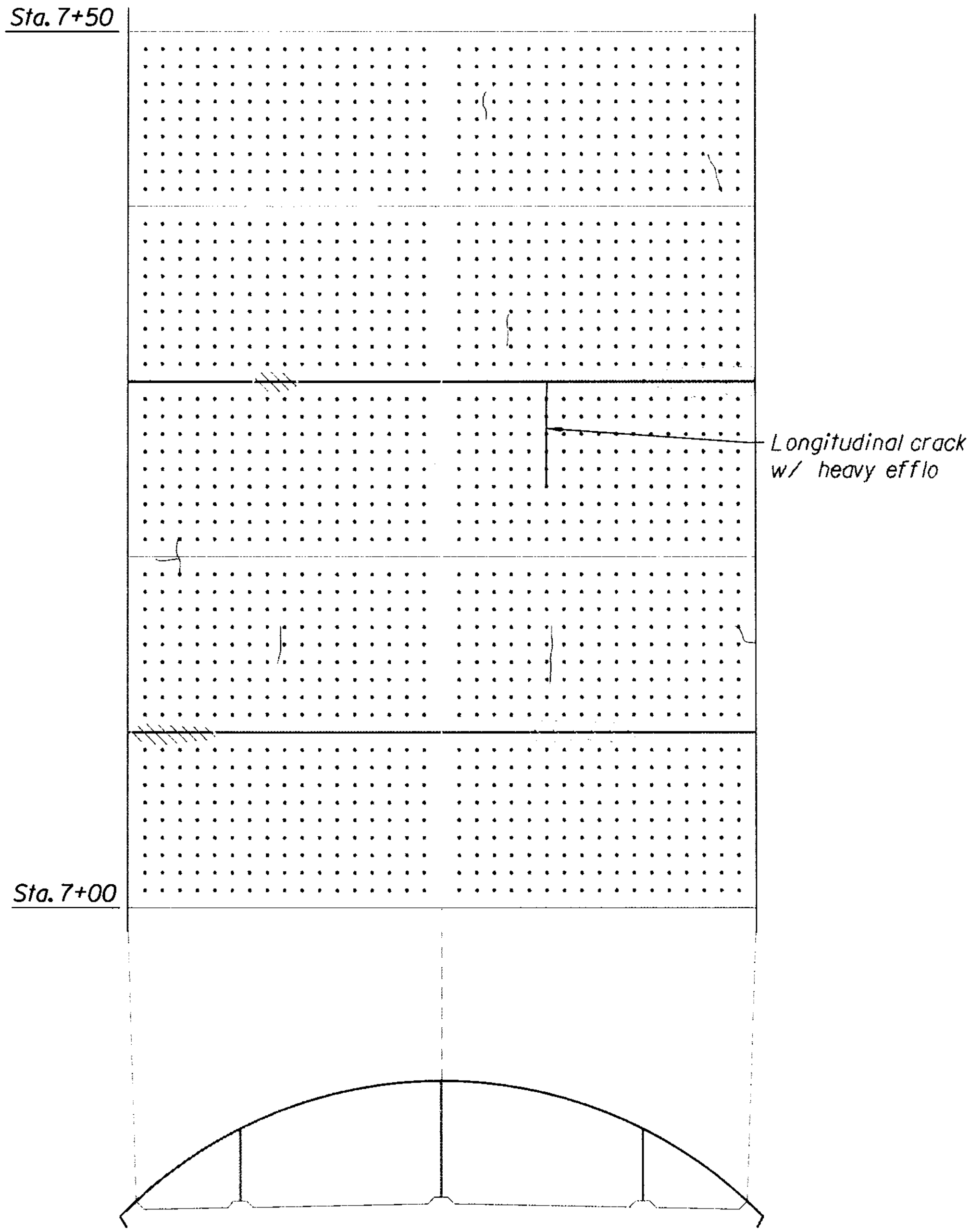
0 10 20
Scale in feet

VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103 Last Update Oct. 2014

Arch - Sta 6+50 to 7+00



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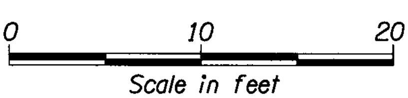
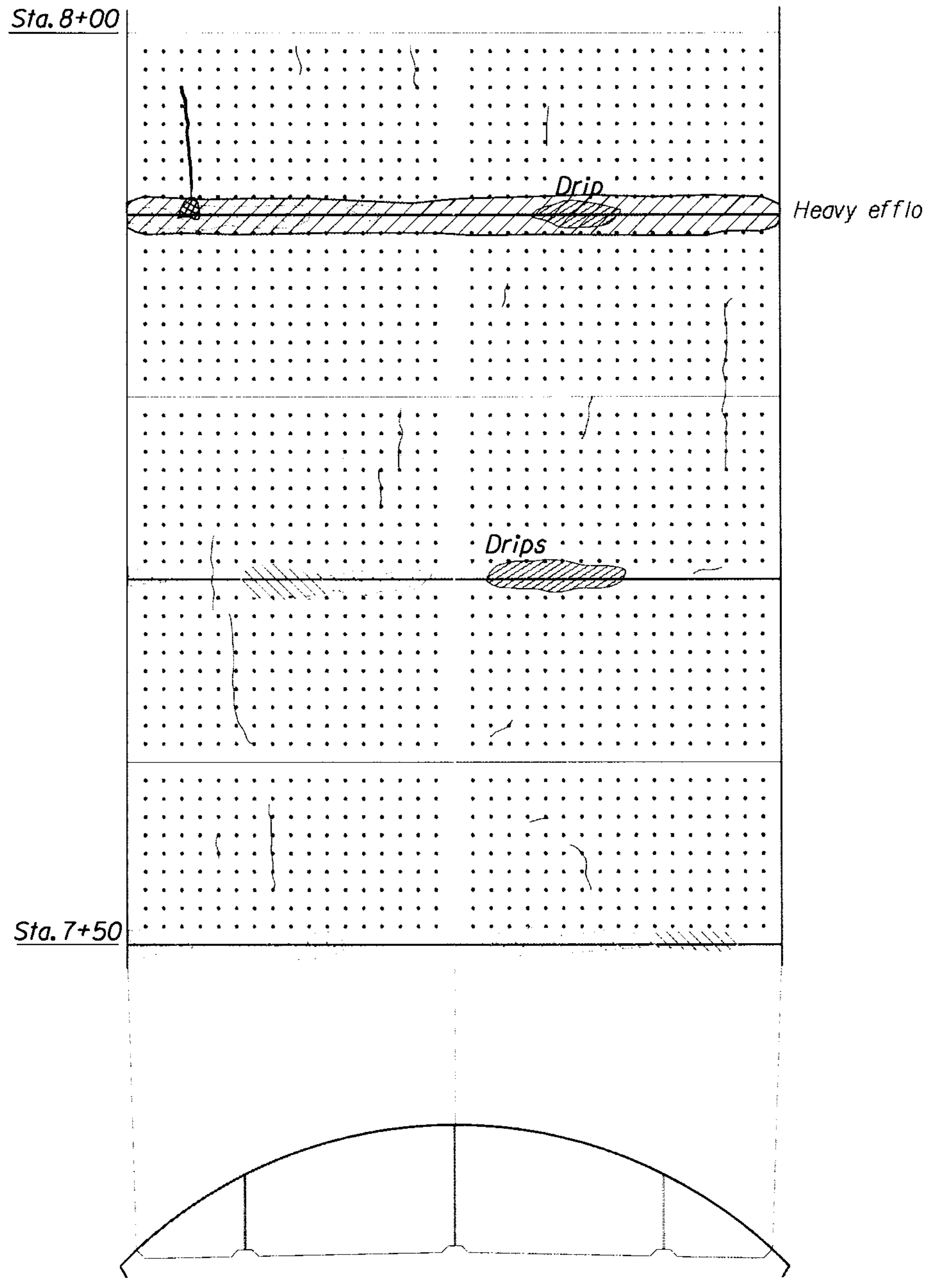


VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103 Last Update Oct. 2014



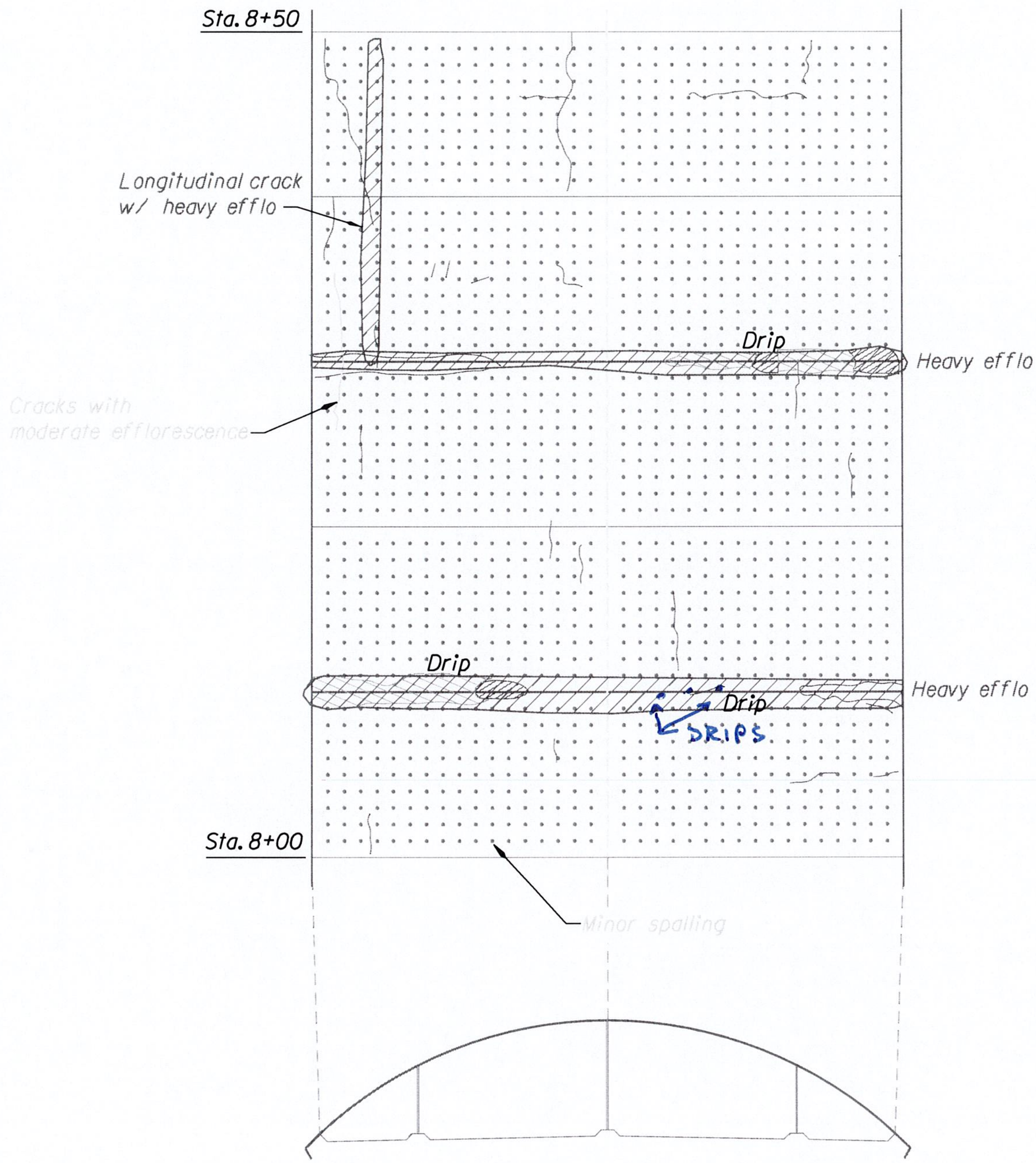
VENTILATION ADIT ARCH

0 10 20
Scale in feet

VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103 Last Update Oct. 2014



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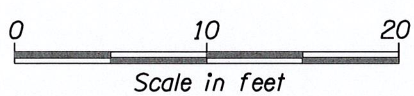

VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103 Last Update Oct. 2014

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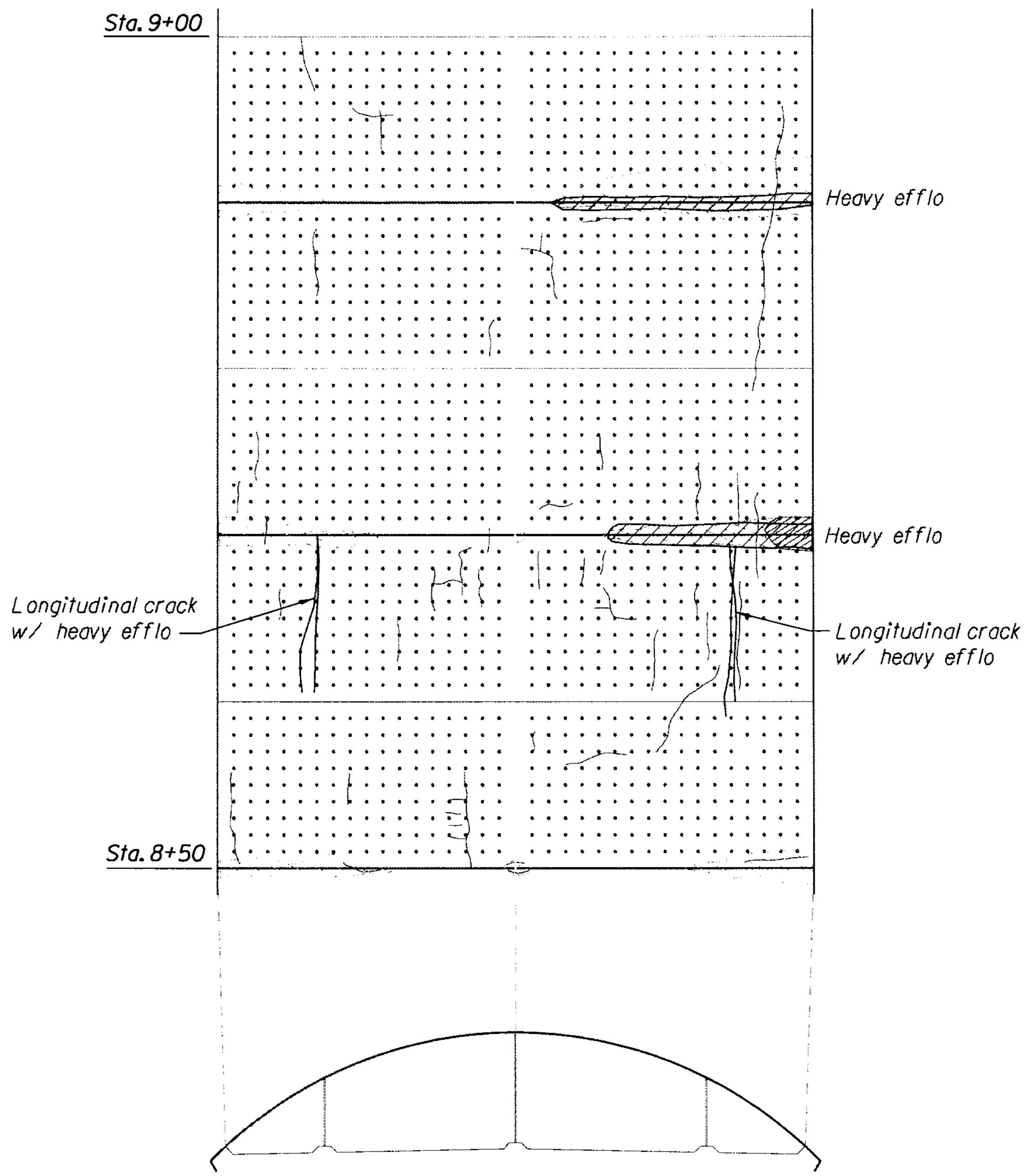


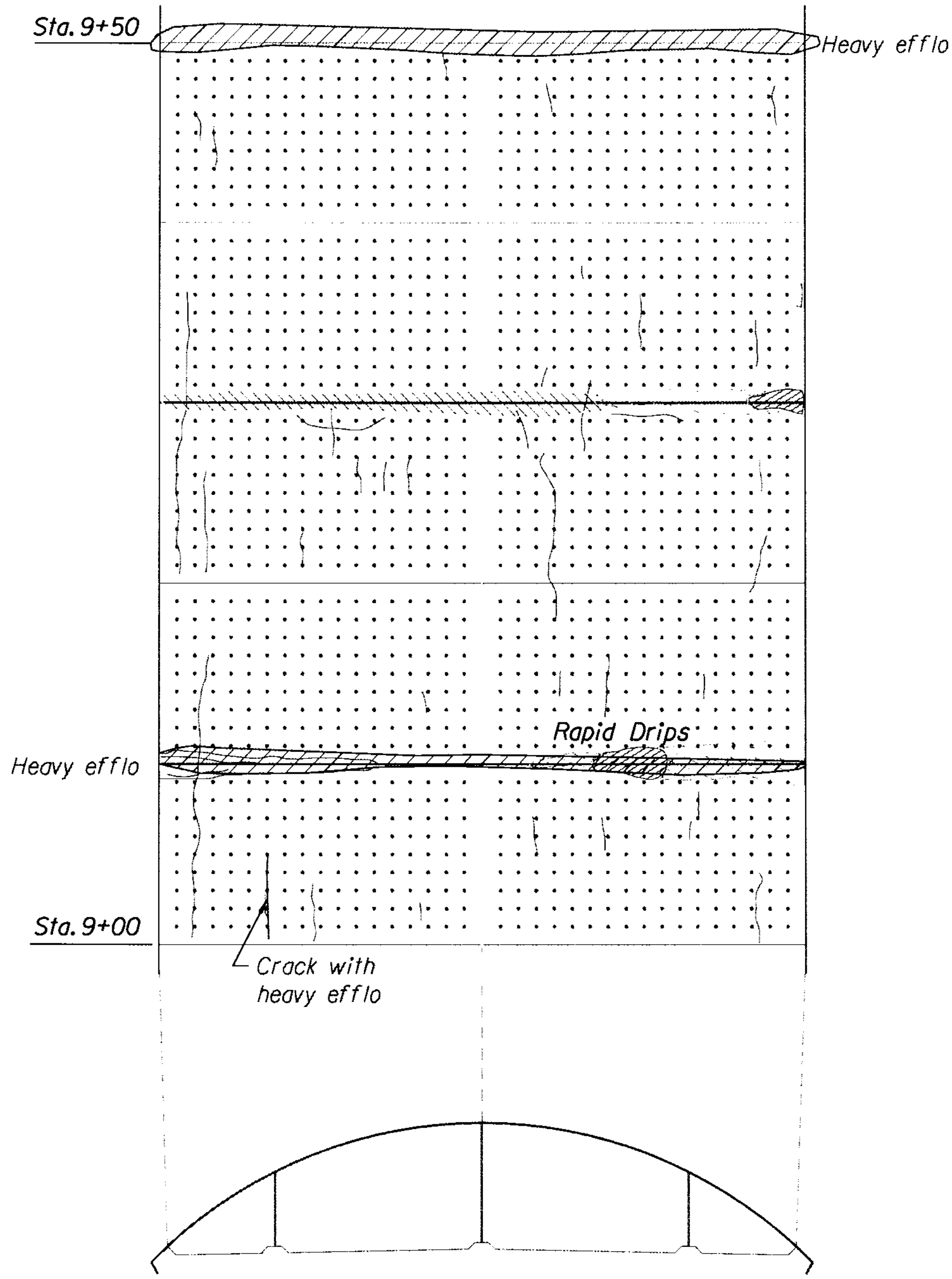
VENTILATION ADIT ARCH

0 10 20
Scale in feet

VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103 Last Update Oct. 2014



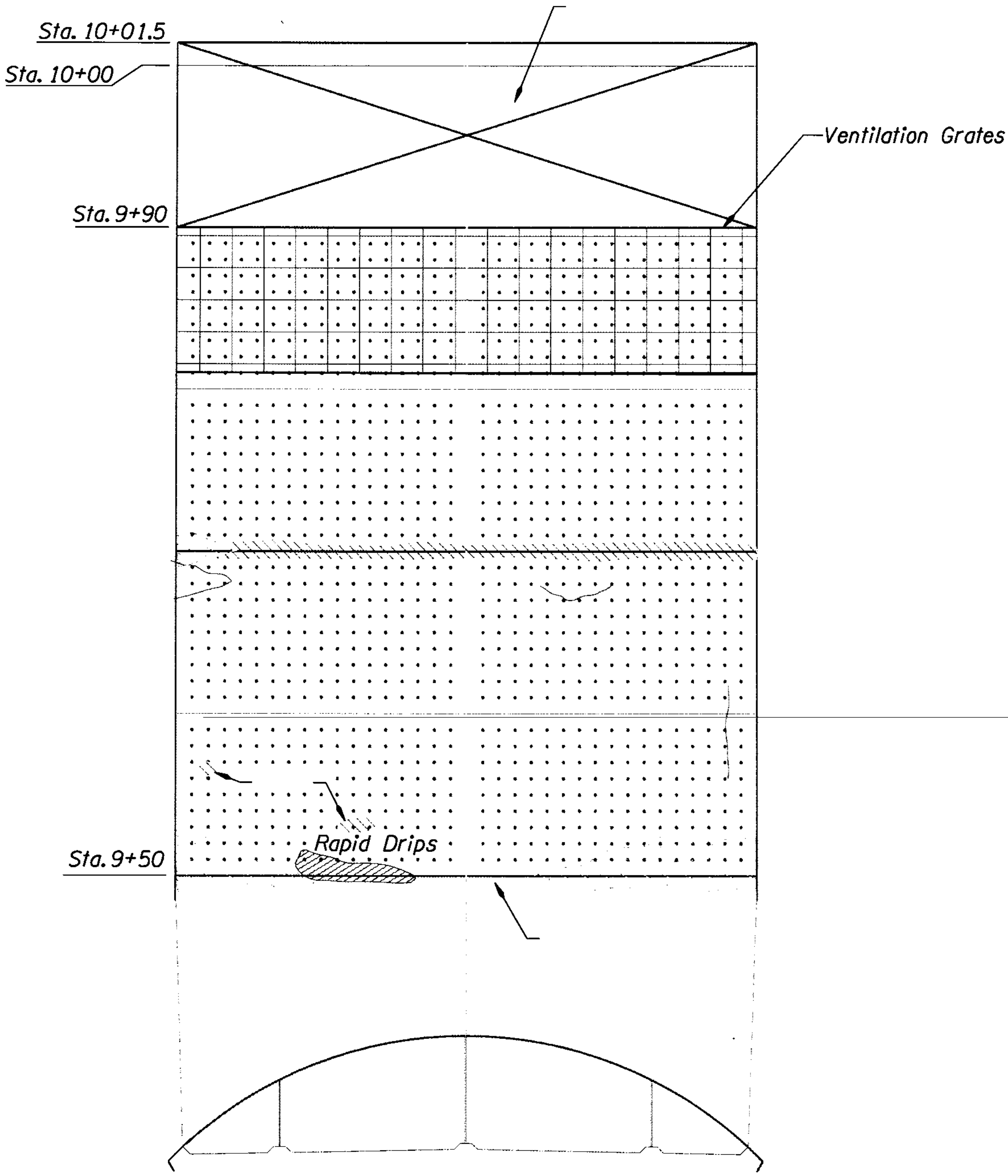
VENTILATION ADIT ARCH

0 10 20
Scale in feet

VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103 Last Update Oct. 2014



VENTILATION ADIT ARCH

0 10 20
Scale in feet

VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103 Last Update Oct. 2014

TUNNEL MAP LEGEND

RED DENOTES NEW OBSERVATIONS - JUNE 2018
BLUE DENOTES ACTIVE WATER OBSERVATIONS - JUNE 2018

Scaling — *Scaling is light - loss of surface mortar without exposure of coarse aggregate unless otherwise indicated*

Moist to Wet Seepage Area/Stain

Dry Seepage Stains

Tile or Concrete Spall

Areas of Short Cracks and Small Spalls

Metal Plate or Box

Seep

Scrape or Gouge

Coreholes Patched Unless Noted Otherwise

Drain Inlets

Type 2 - Roadway 15 x 32 in.

Tile and Concrete

Crack Fine

All cracks are fine (Cf, △1mm) unless otherwise indicated as Cm - medium, 1-2 mm or Cw - wide, >2mm

Tile and Concrete

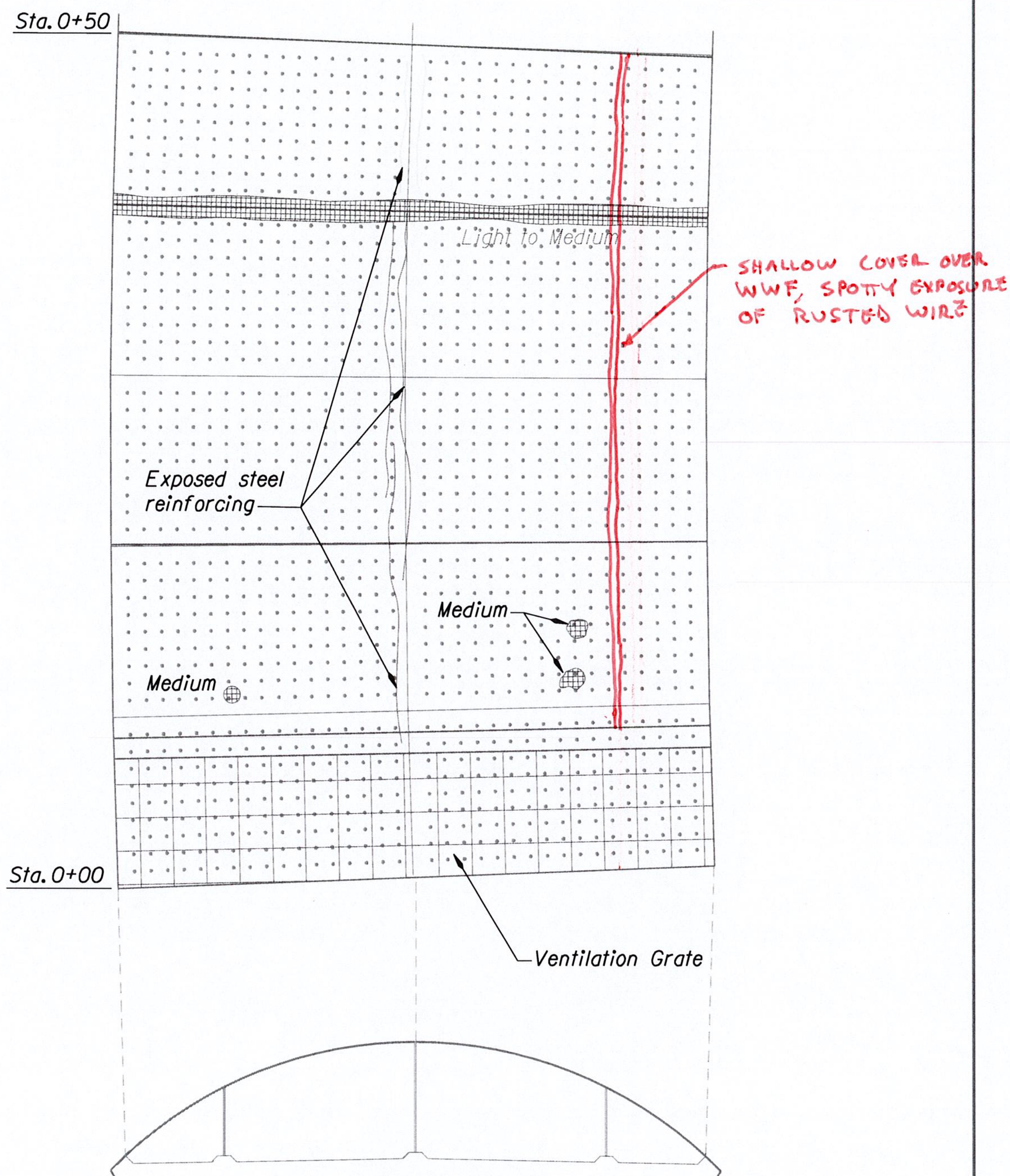
Construction Joint

VISTA RIDGE TUNNEL (WB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No.	09103B	Last Update	Oct. 2014

Arch - Legend



VENTILATION ADIT ARCH

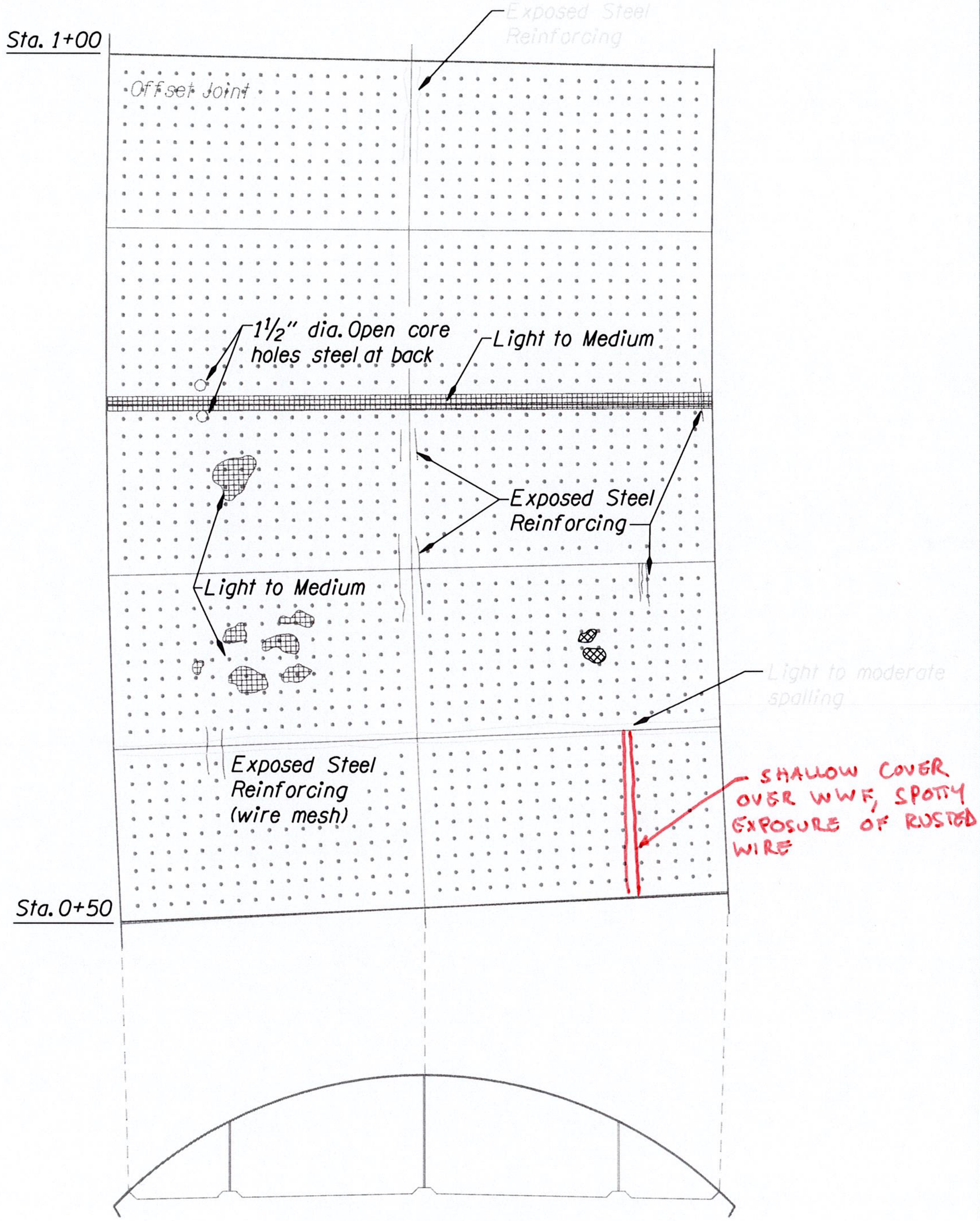
0 10 20
Scale in feet

VISTA RIDGE TUNNEL (WB)

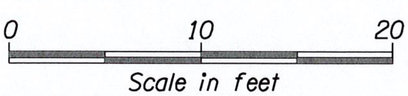
OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No.	09103B	Last Update	Oct. 2014

Arch - Sta 0+00 to 0+50



VENTILATION ADIT ARCH

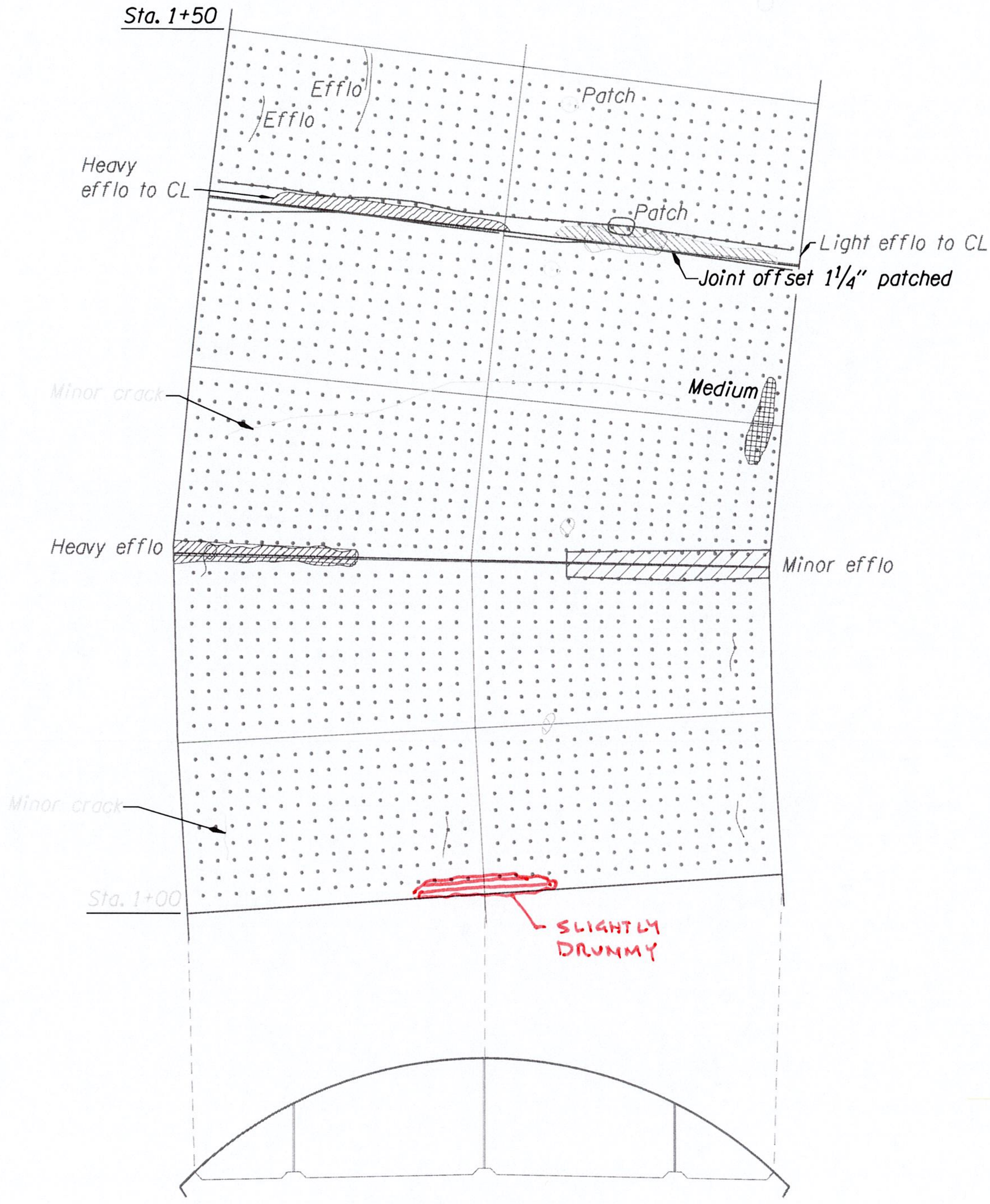


VISTA RIDGE TUNNEL (WB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No.	09103B	Last Update	Oct. 2014

Arch - Sta 0+50 to 1+00



VENTILATION ADIT ARCH

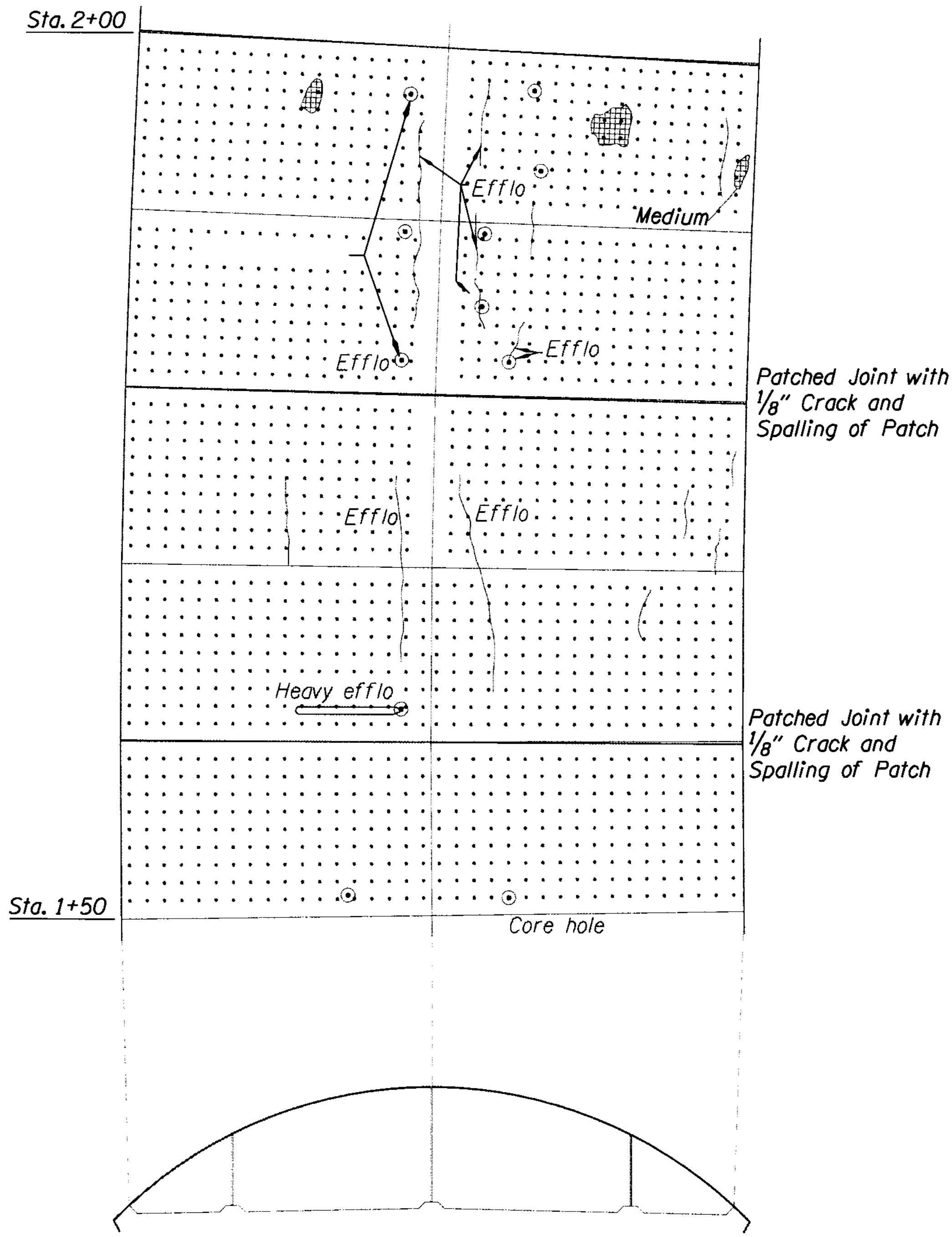
0 10 20
Scale in feet

VISTA RIDGE TUNNEL (WB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

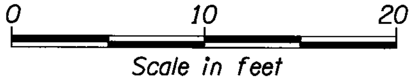
Structure No.	09103B	Last Update	Oct. 2014

Arch - Sta 1+00 to 1+50



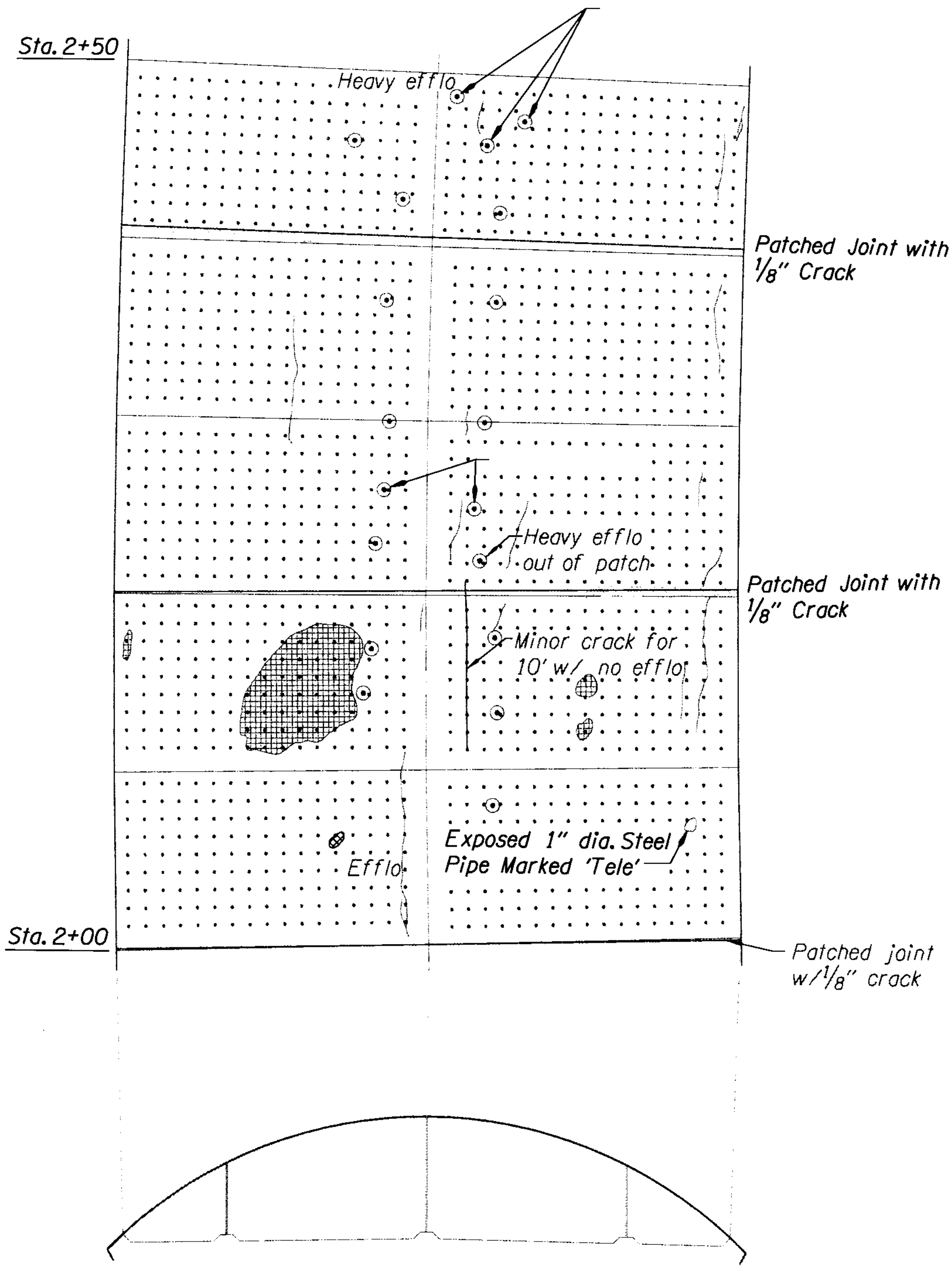
VENTILATION ADIT ARCH

VISTA RIDGE TUNNEL (WB)



09103B

Oct. 2014



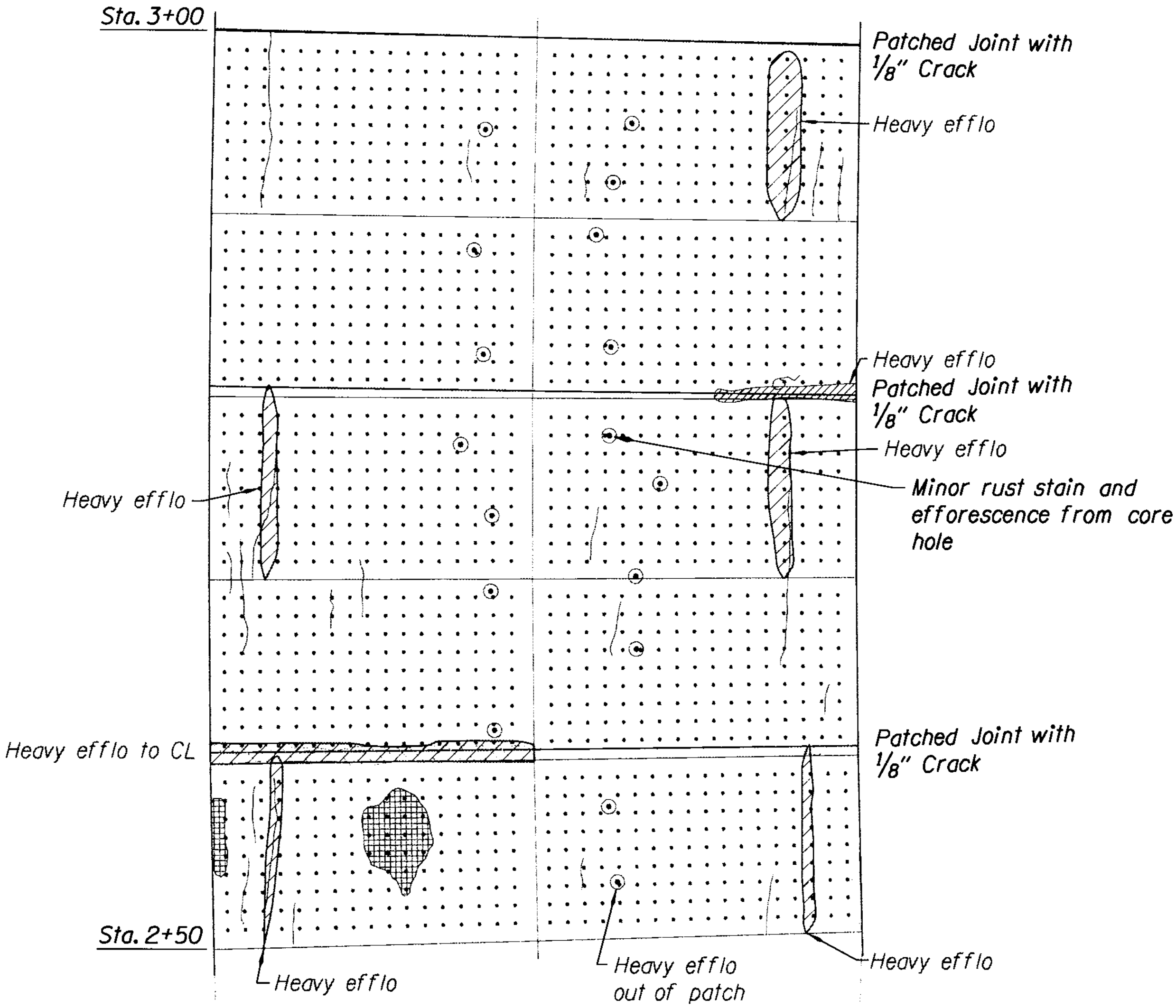
VENTILATION ADIT ARCH

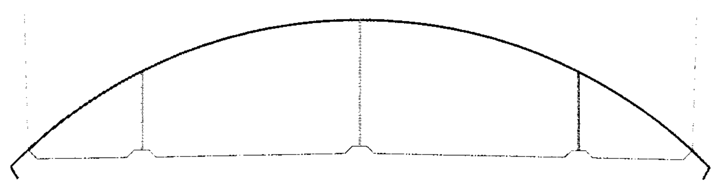
VISTA RIDGE TUNNEL (WB)

0 10 20
Scale in feet

09103B

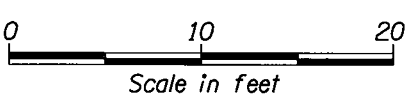
Oct. 2014





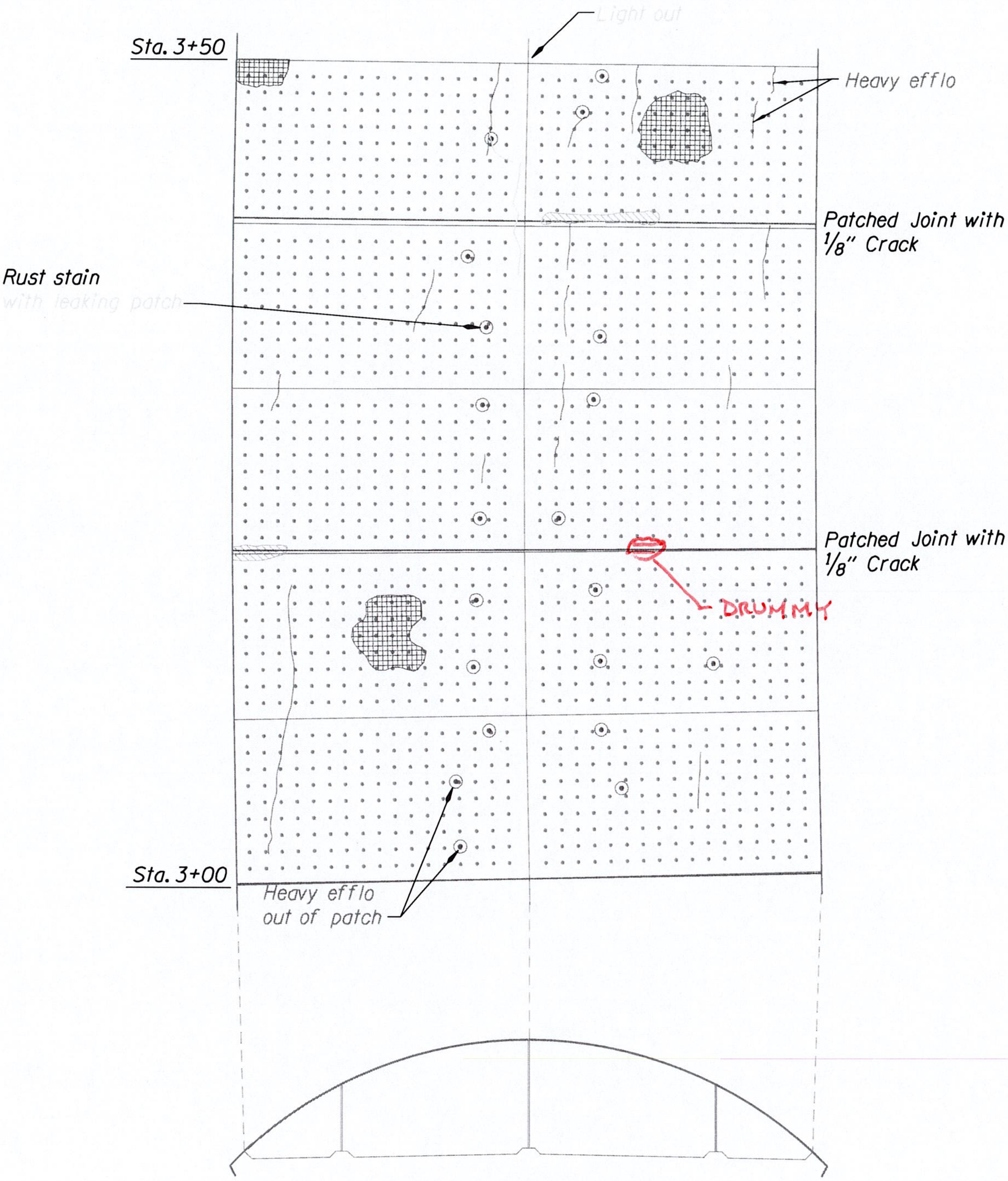
VENTILATION ADIT ARCH

VISTA RIDGE TUNNEL (WB)

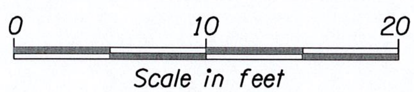


09103B

Oct. 2014



VENTILATION ADIT ARCH

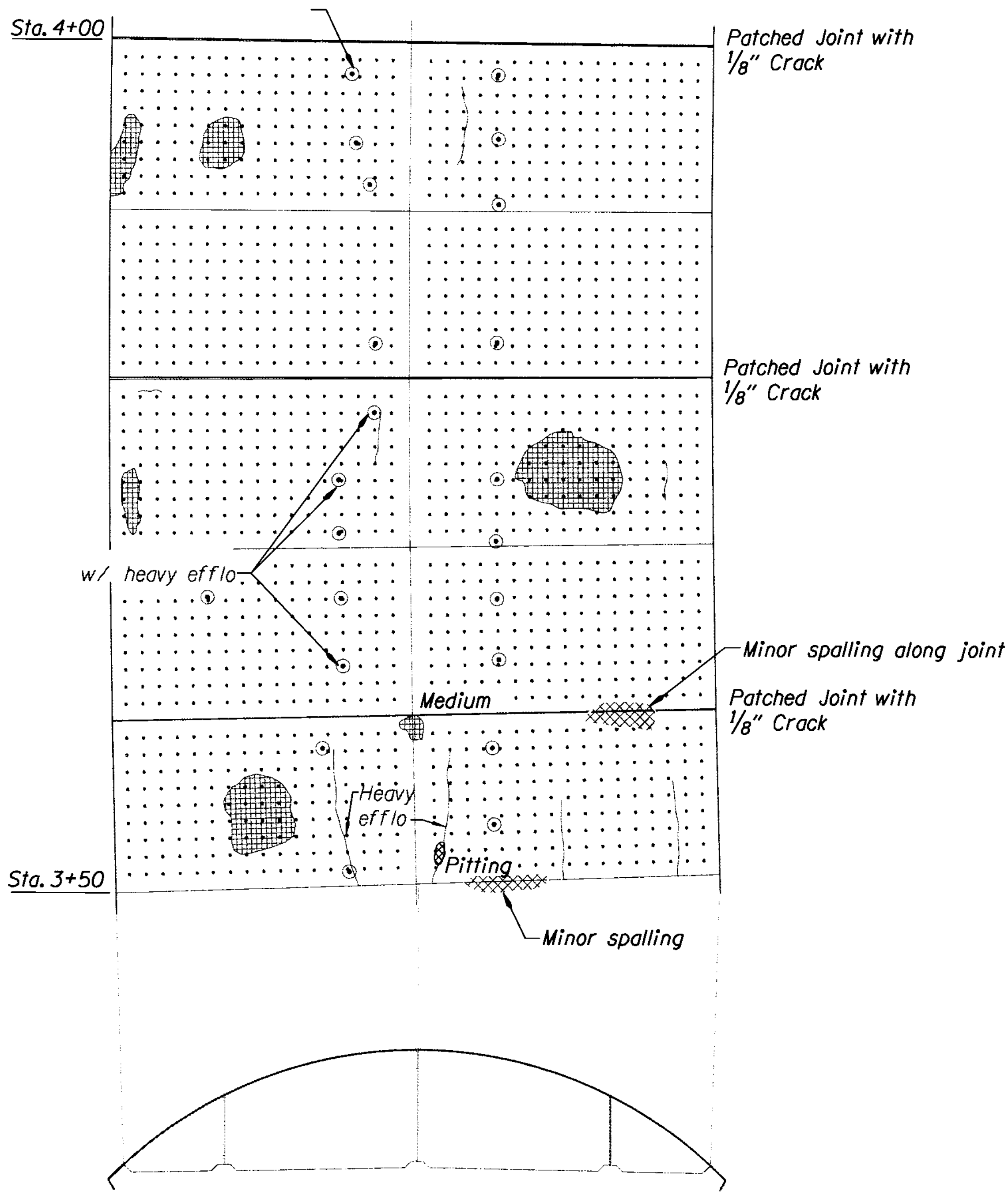


VISTA RIDGE TUNNEL (WB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No.	09103B	Last Update:	Oct. 2014

Arch - Sta 3+00 to 3+50

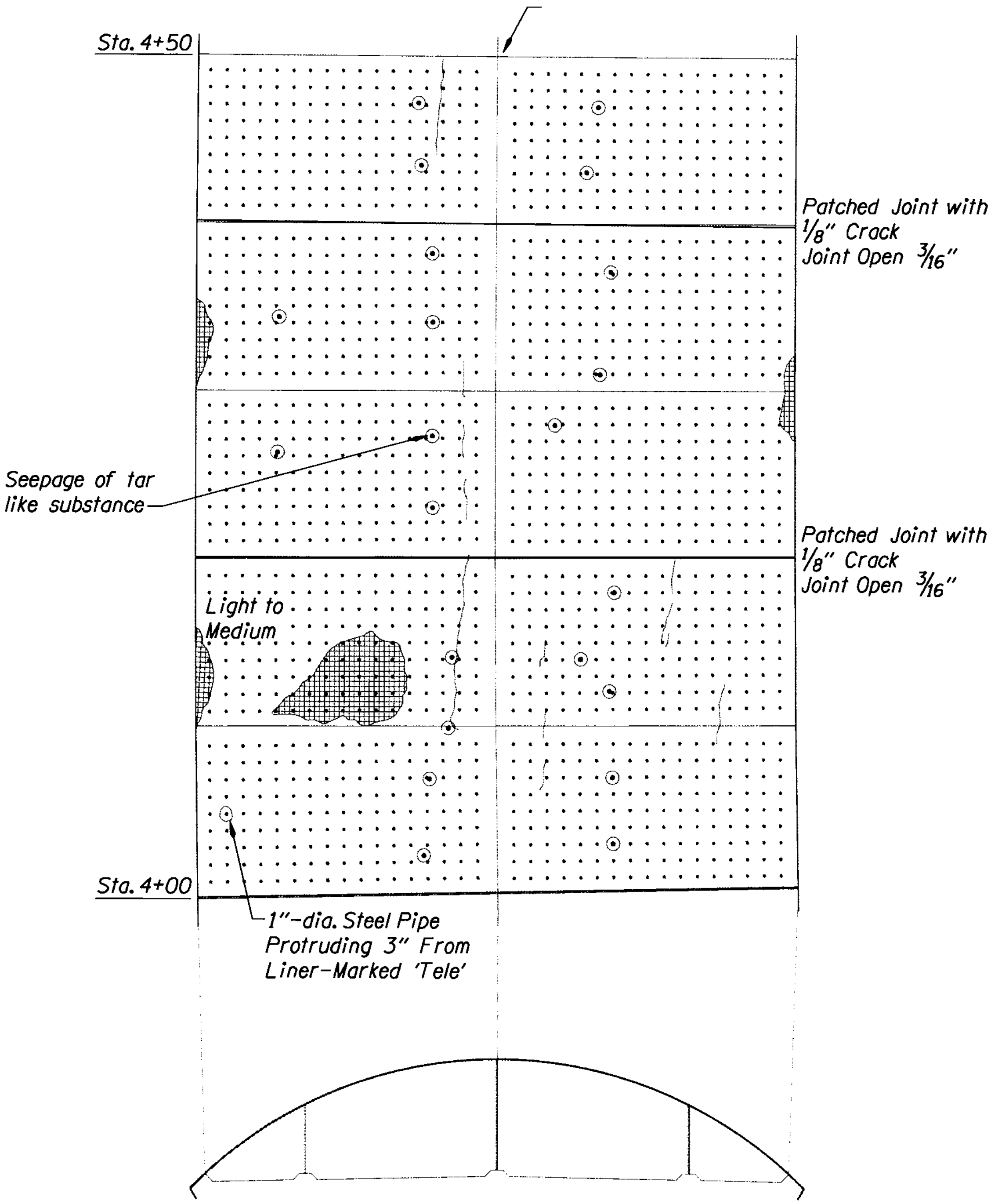


VENTILATION ADIT ARCH

VISTA RIDGE TUNNEL (WB)

0 10 20
Scale in feet

09103B Oct. 2014



VENTILATION ADIT ARCH

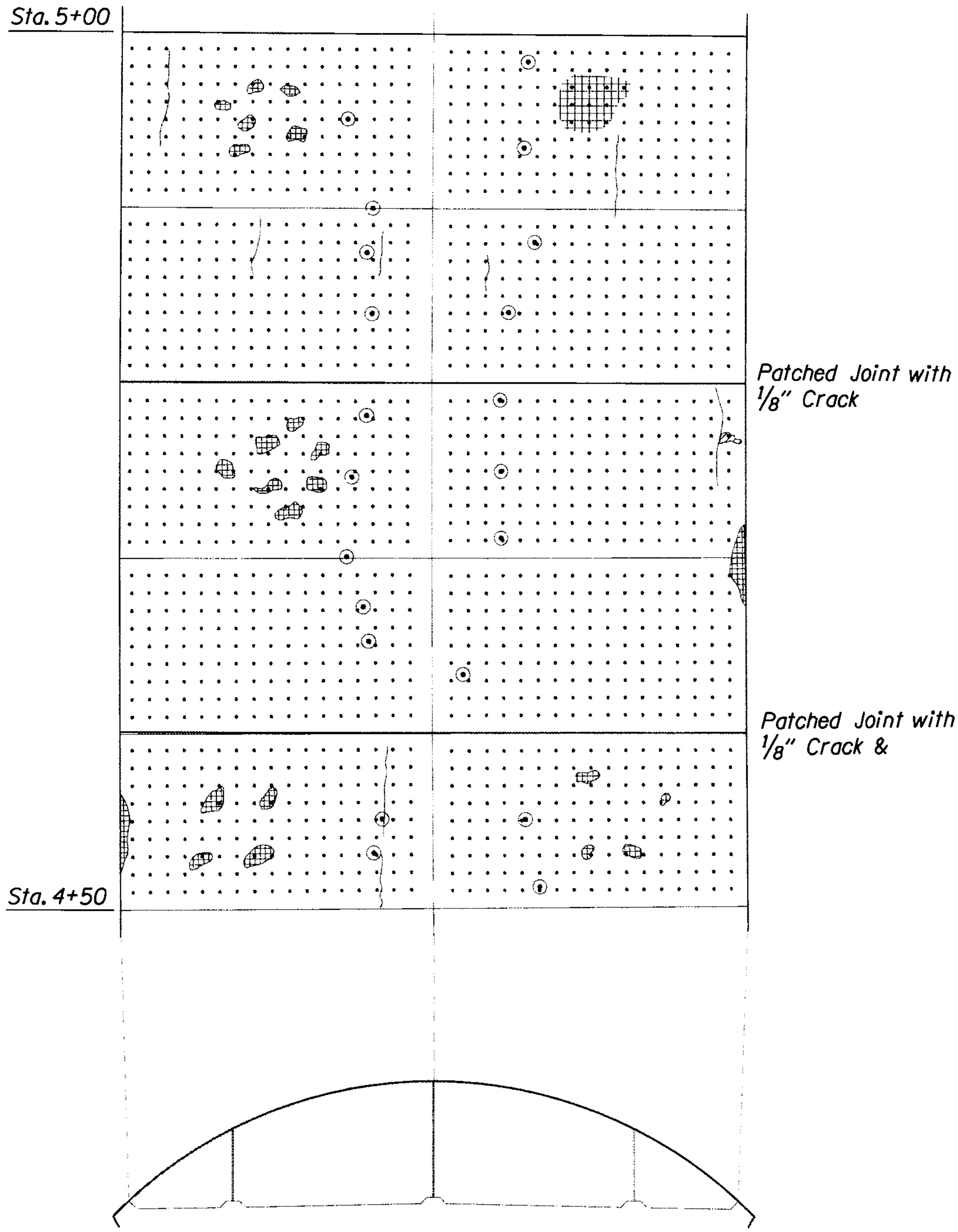
VISTA RIDGE TUNNEL (WB)

0 10 20

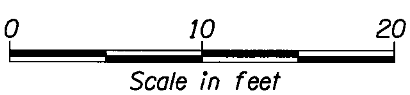
Scale in feet

09103B

Oct. 2014



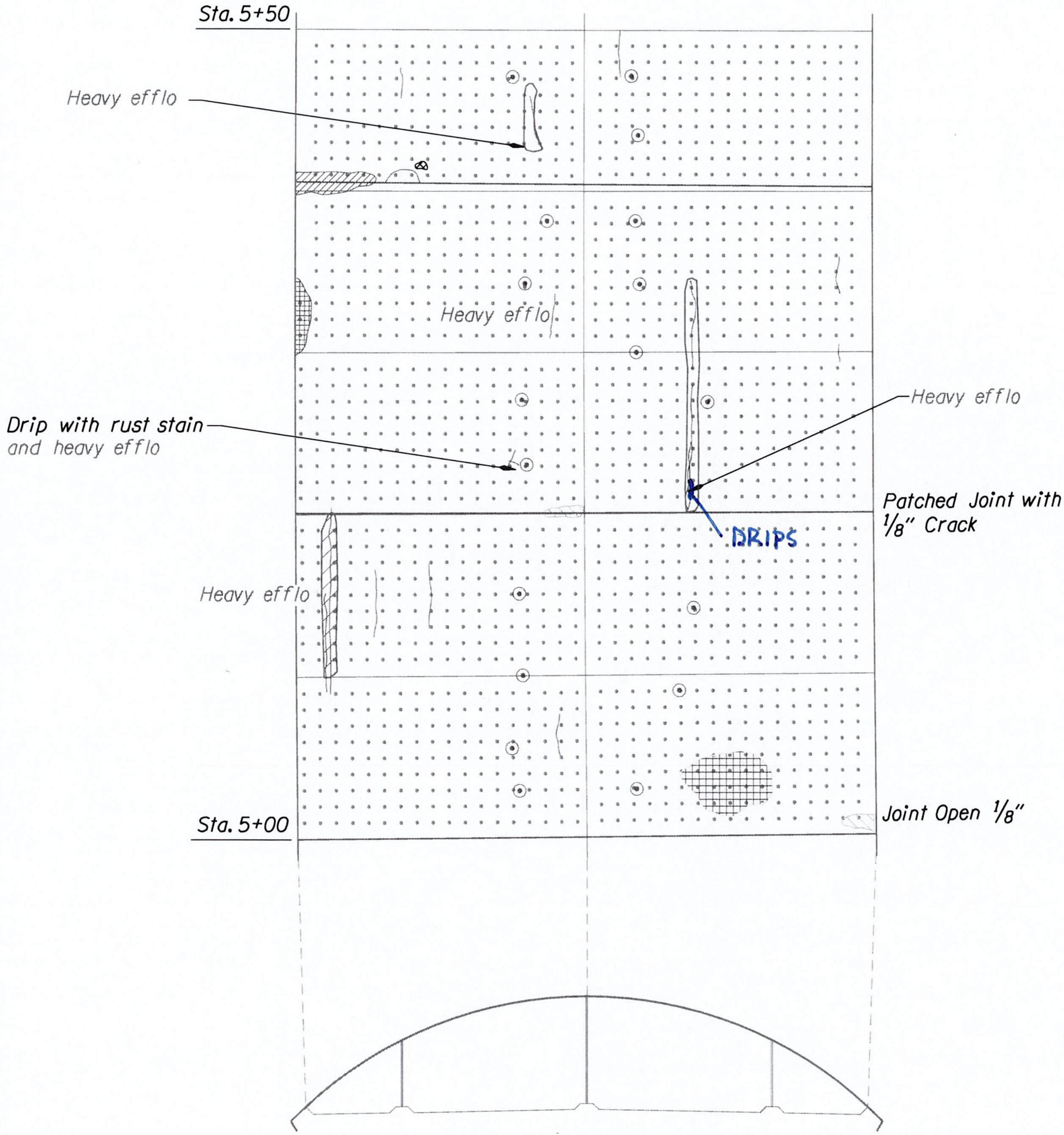
VENTILATION ADIT ARCH



VISTA RIDGE TUNNEL (WB)

09103B

Oct. 2014



VENTILATION ADIT ARCH

0 10 20

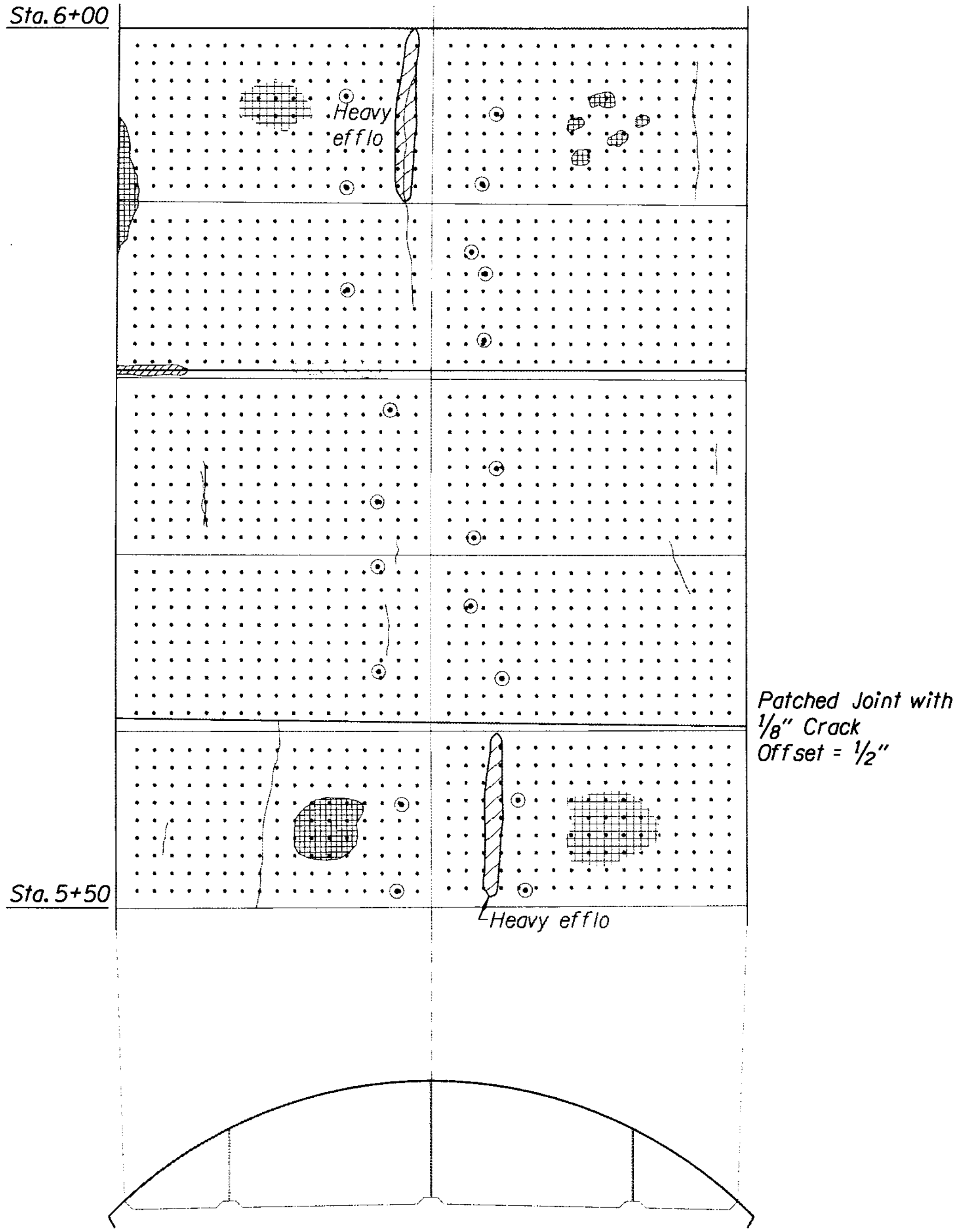
Scale in feet

VISTA RIDGE TUNNEL (WB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No.	09103B	Last Update	Oct. 2014

Arch - Sta 5+00 to 5+50



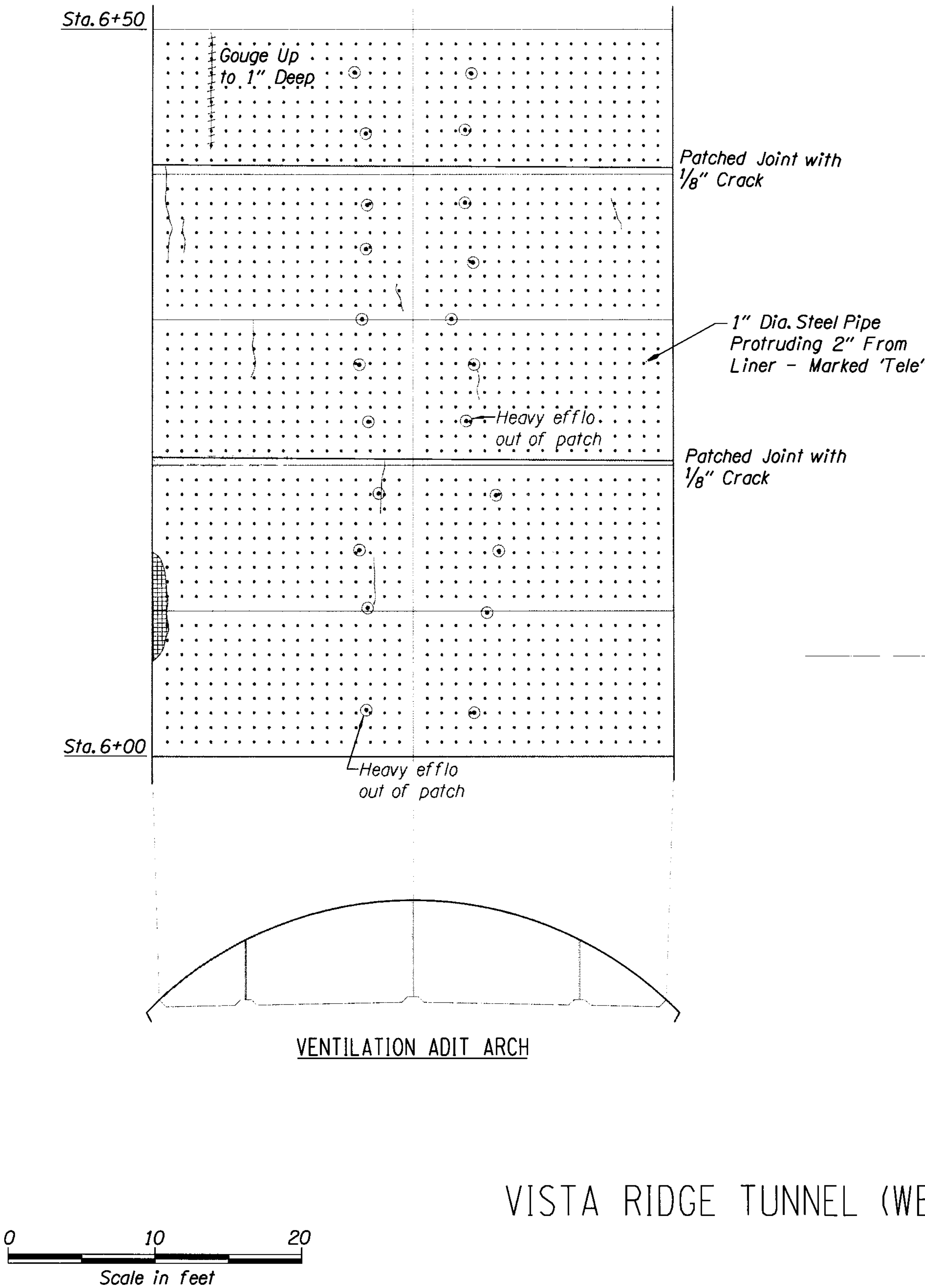
VENTILATION ADIT ARCH

VISTA RIDGE TUNNEL (WB)

0 10 20
Scale in feet

09103B

Oct. 2014



VISTA RIDGE TUNNEL (WB)

09103B Oct. 2014

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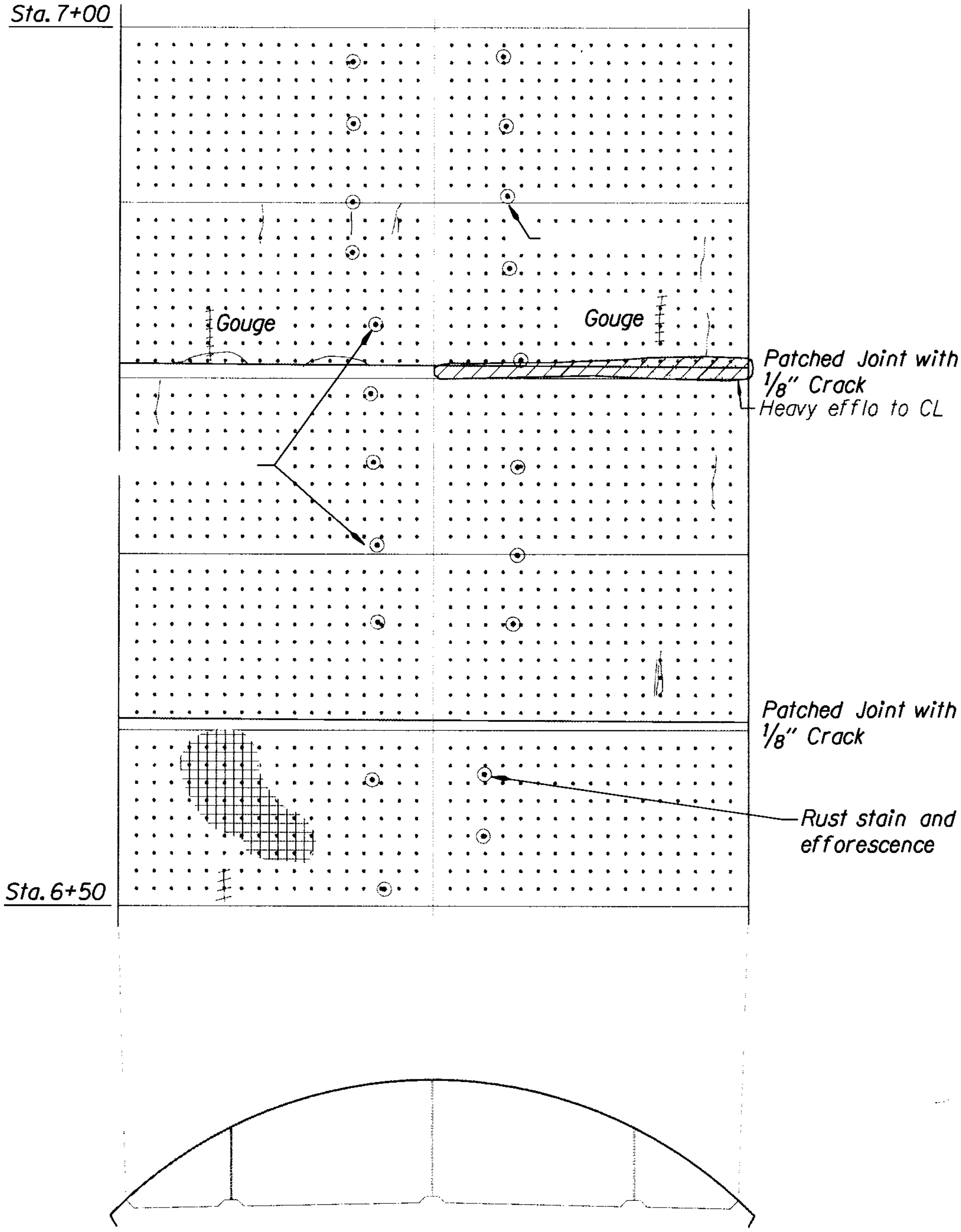
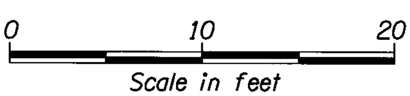
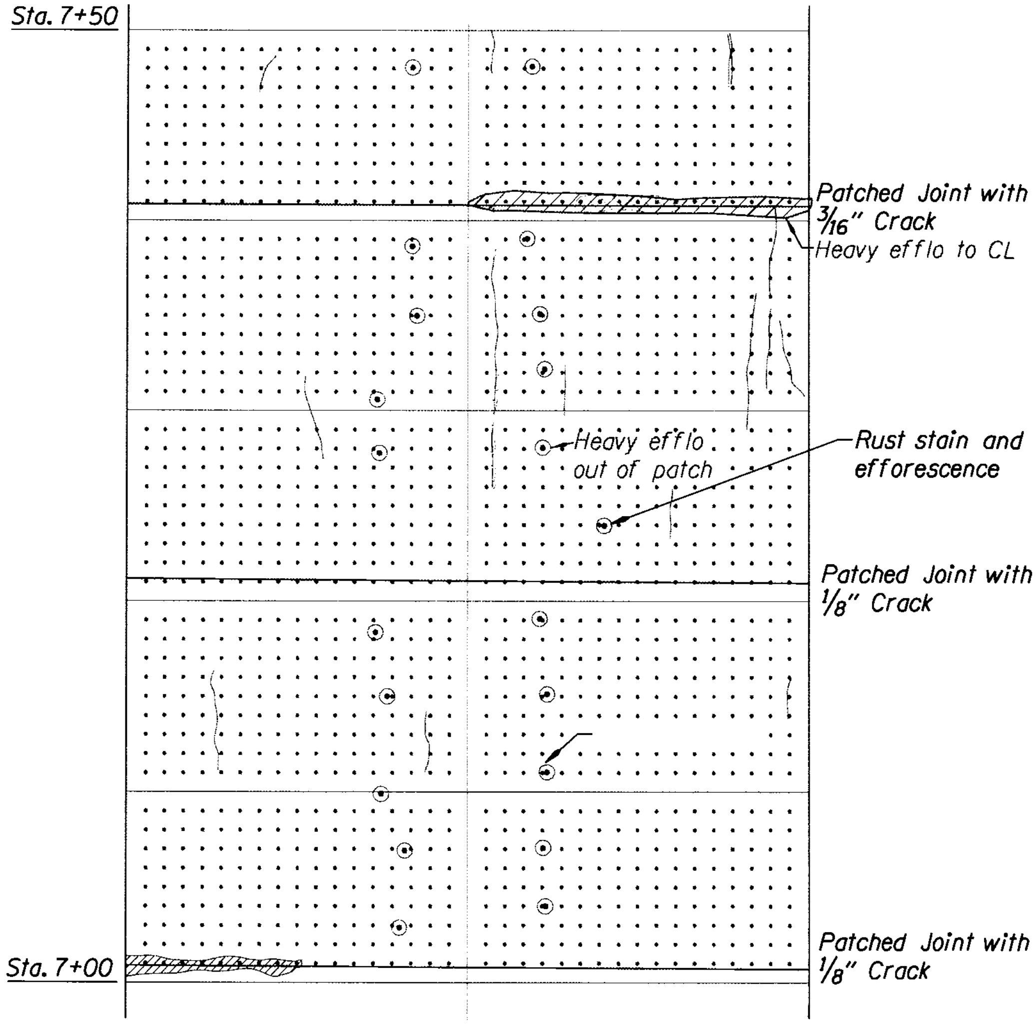


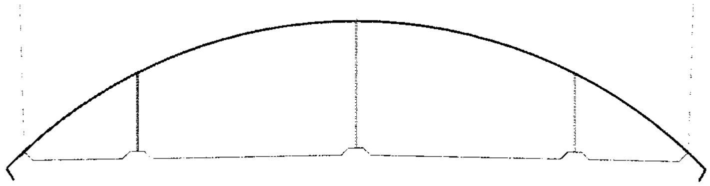
VENTILATION ADIT ARCH

VISTA RIDGE TUNNEL (WB)



09103B Oct. 2014





VENTILATION ADIT ARCH

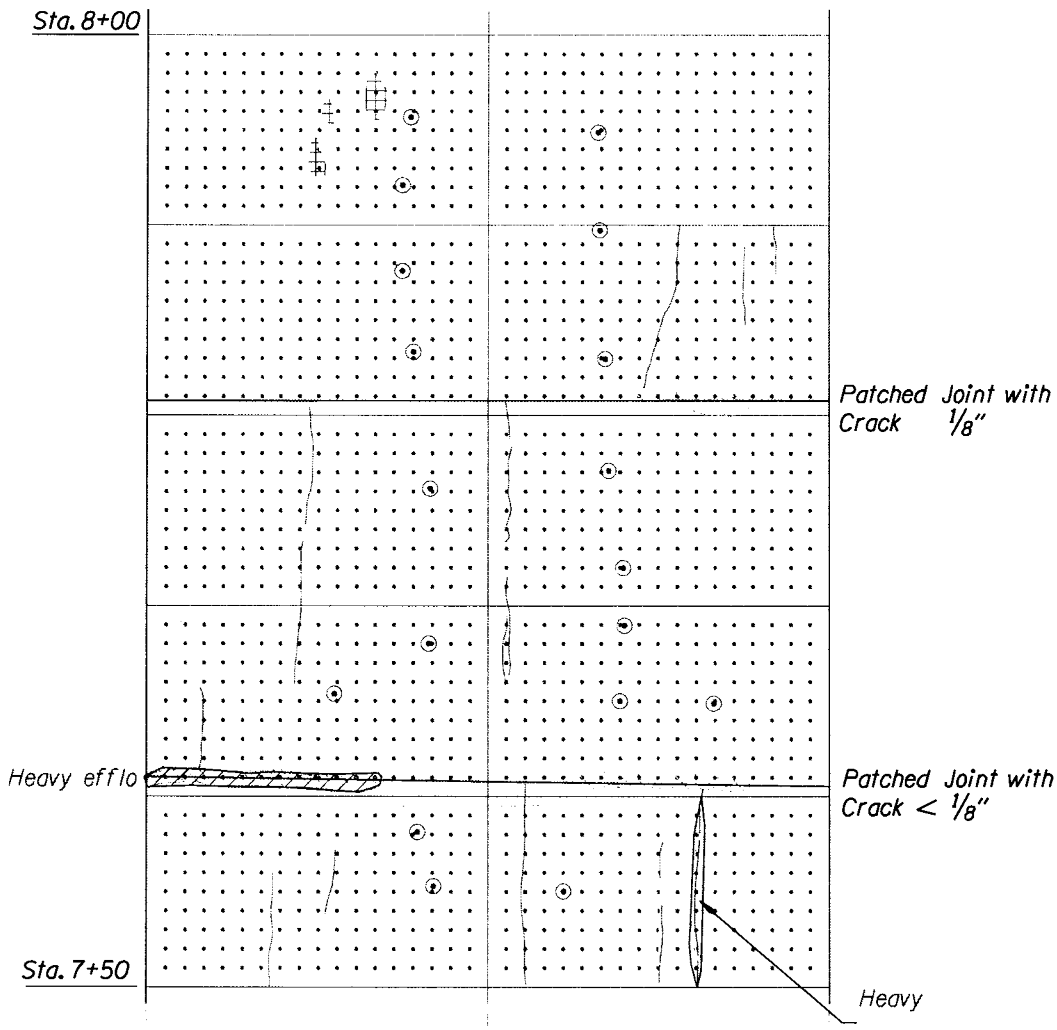
VISTA RIDGE TUNNEL (WB)

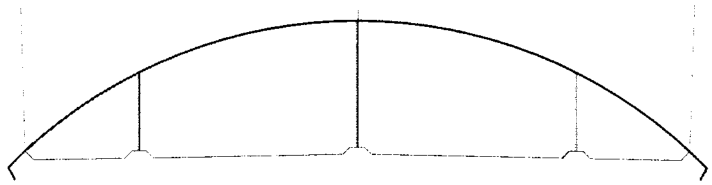
0 10 20

Scale in feet

09103B

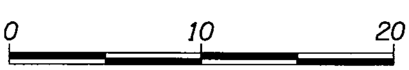
Oct. 2014



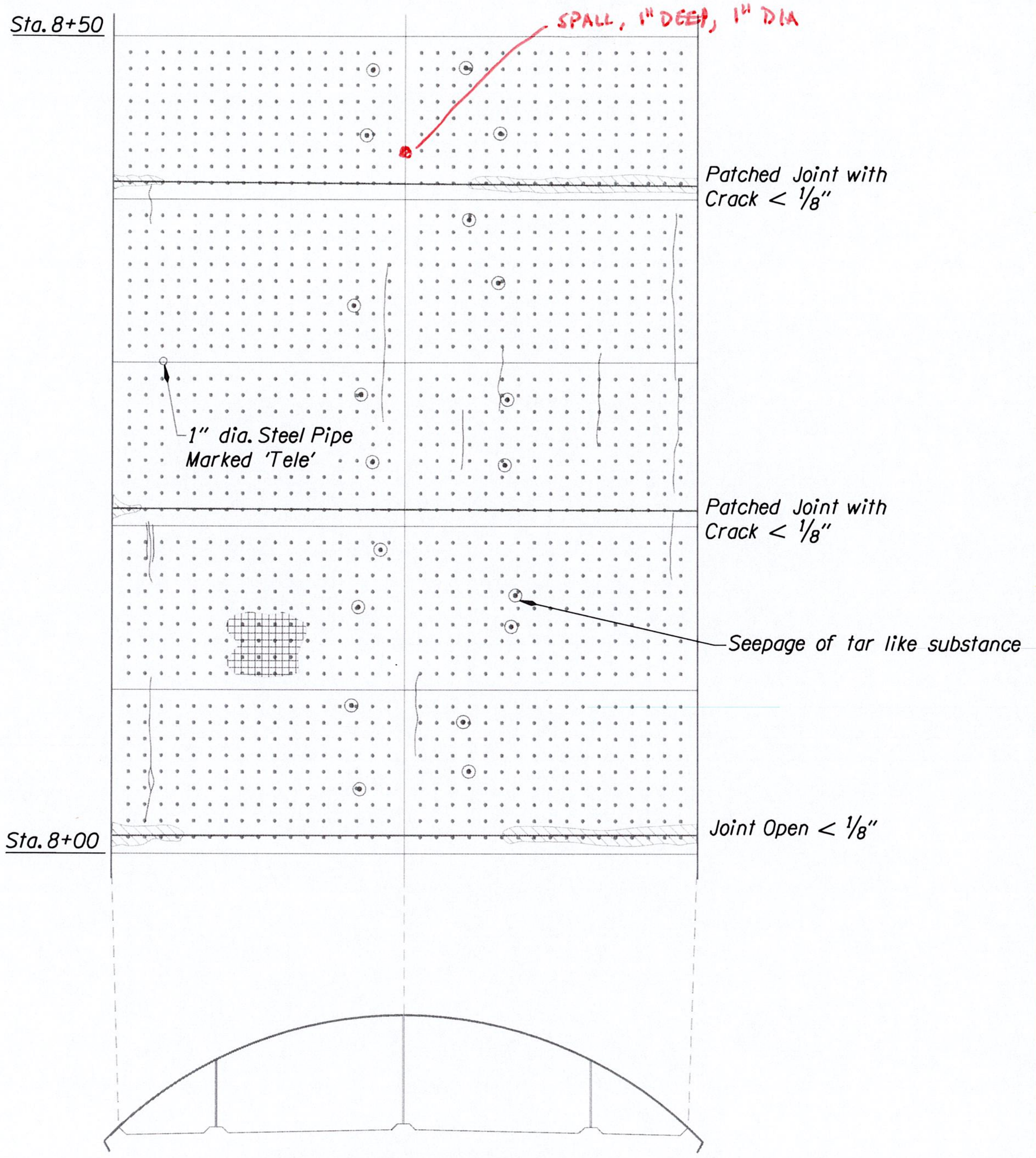


VENTILATION ADIT ARCH

VISTA RIDGE TUNNEL (WB)



09103B Oct. 2014



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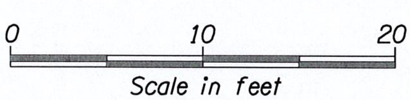
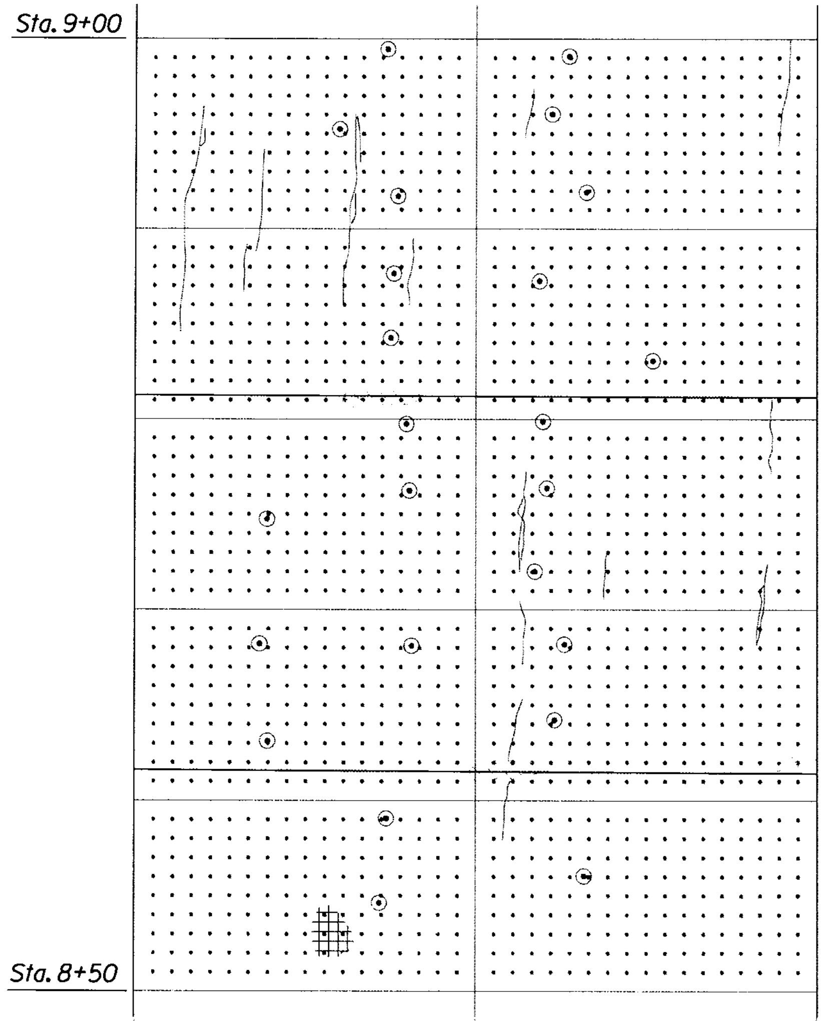


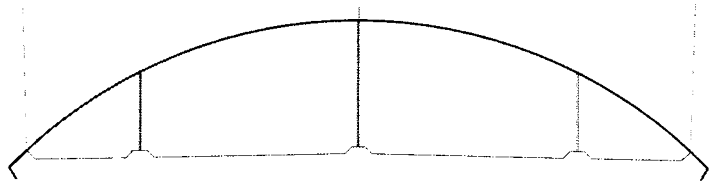
VISTA RIDGE TUNNEL (WB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No.	09103B	Last Update	Oct. 2014

Arch - Sta 8+00 to 8+50



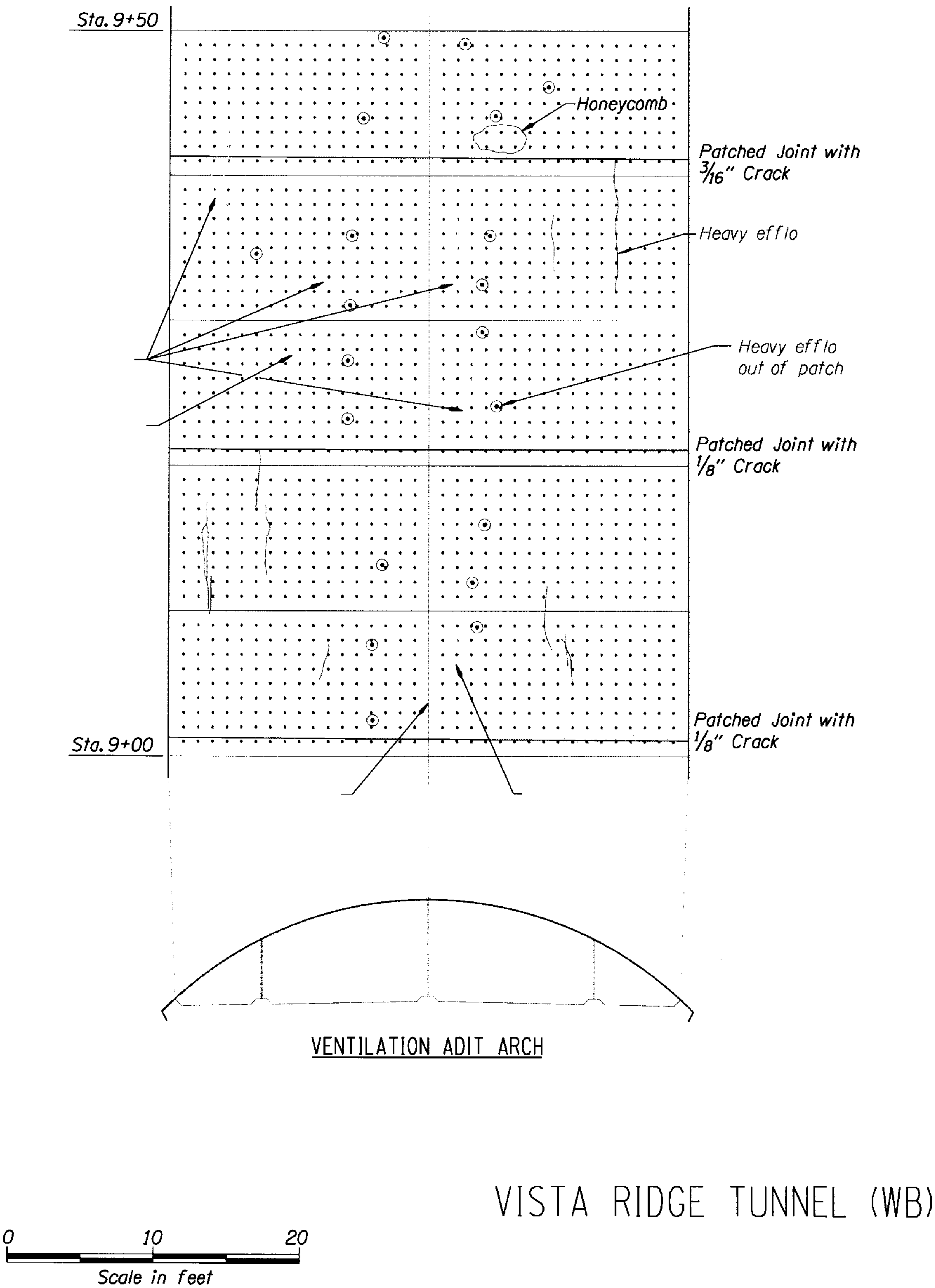


VENTILATION ADIT ARCH

VISTA RIDGE TUNNEL (WB)

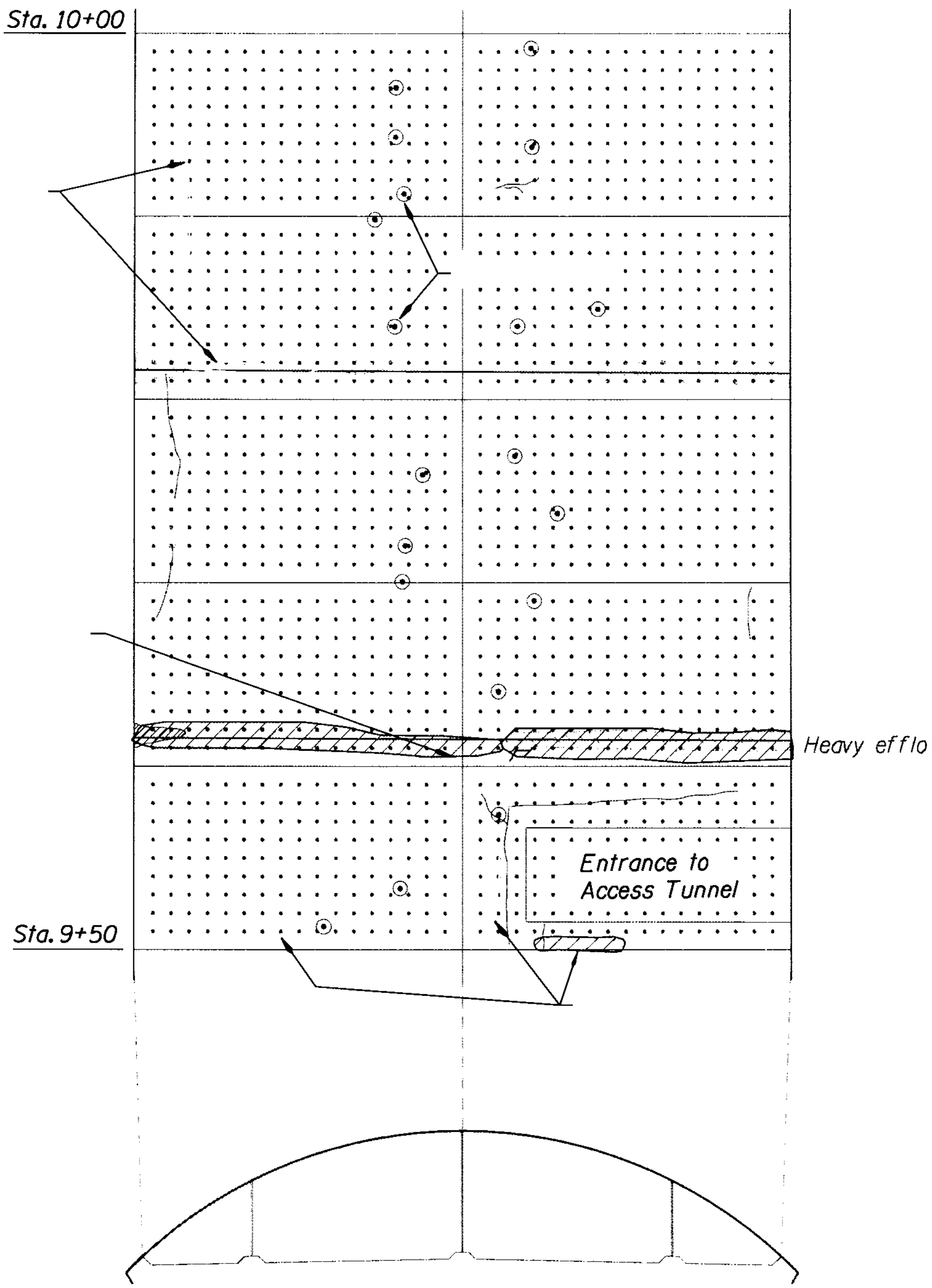
09103B

Oct. 2014



VISTA RIDGE TUNNEL (WB)

09103B Oct. 2014



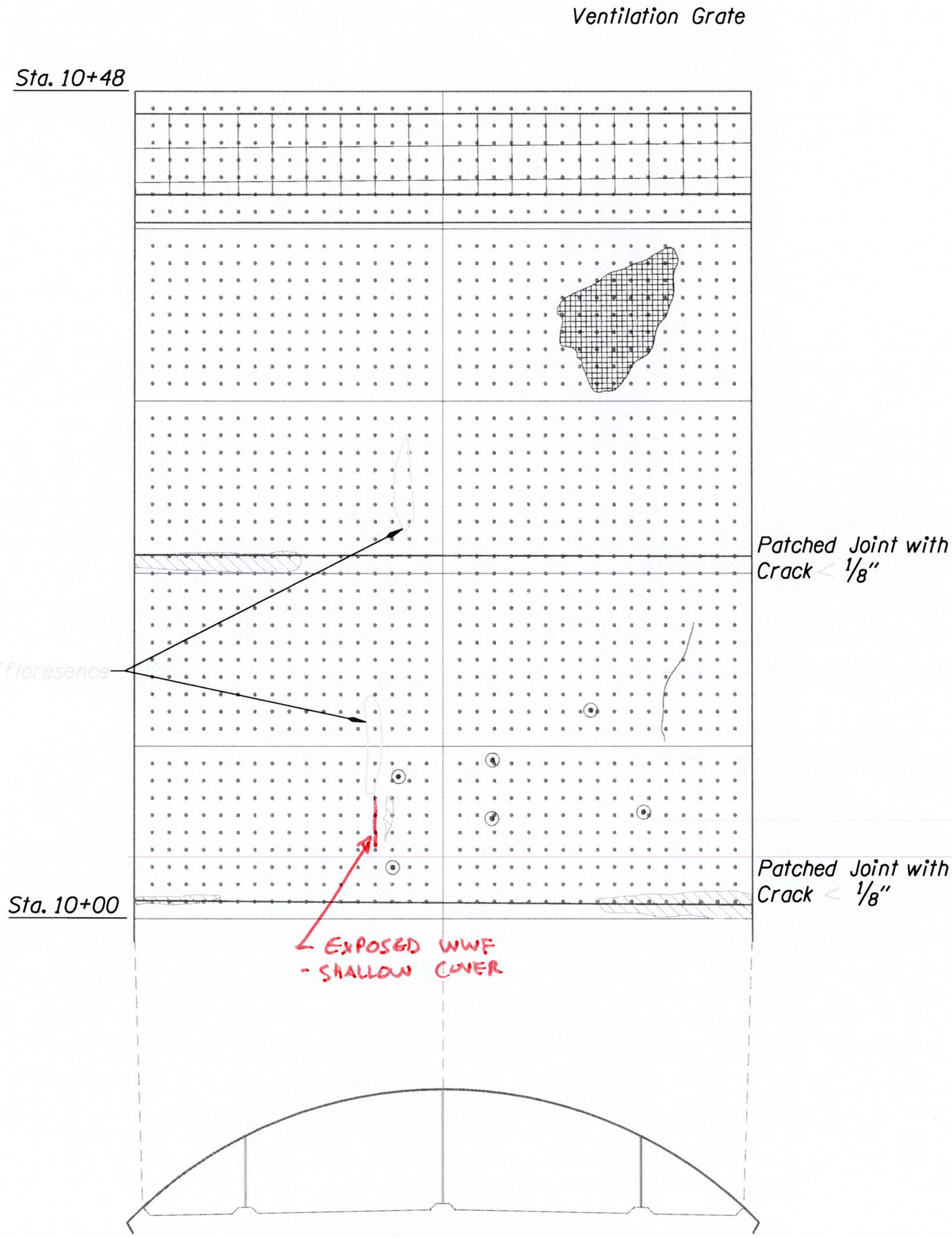
VENTILATION ADIT ARCH

VISTA RIDGE TUNNEL (WB)

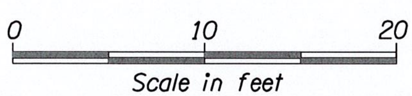
0 10 20
Scale in feet

09103B

Oct. 2014



VENTILATION ADIT ARCH



VISTA RIDGE TUNNEL (WB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No.	09103B	Last Update	Oct. 2014

Arch - Sta 10+00 to 10+61

Comb. 1206

TUNNEL MAP LEGEND

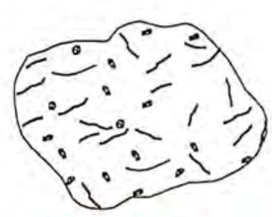
Scaling — *Scaling is light - loss of surface mortar without exposure of coarse aggregate unless otherwise indicated*

Moist to Wet Seepage Area/Stain

Dry Seepage Stains

Tile or Concrete Spall

Areas of Short Cracks and Small Spalls



DEBONDED TILE

Metal Plate or Box

Seep

Scrape or Gouge

Coreholes Patched Unless Noted Otherwise

Drain Inlets

Type 2 - Roadway 15 x 32 in.

NOTE New Defects outlined with red except debonded TILE

Tile and Concrete

Crack Fine

All cracks are fine (Cf. Δ1mm) unless otherwise indicated as Cm - medium, 1-2 mm or Cw - wide, >2mm

Tile and Concrete

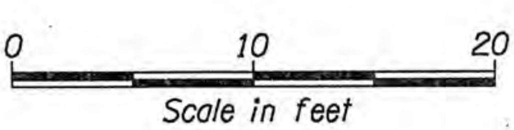
Construction Joint

VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103	Last Update Nov. 2010

Tunnel - Legend



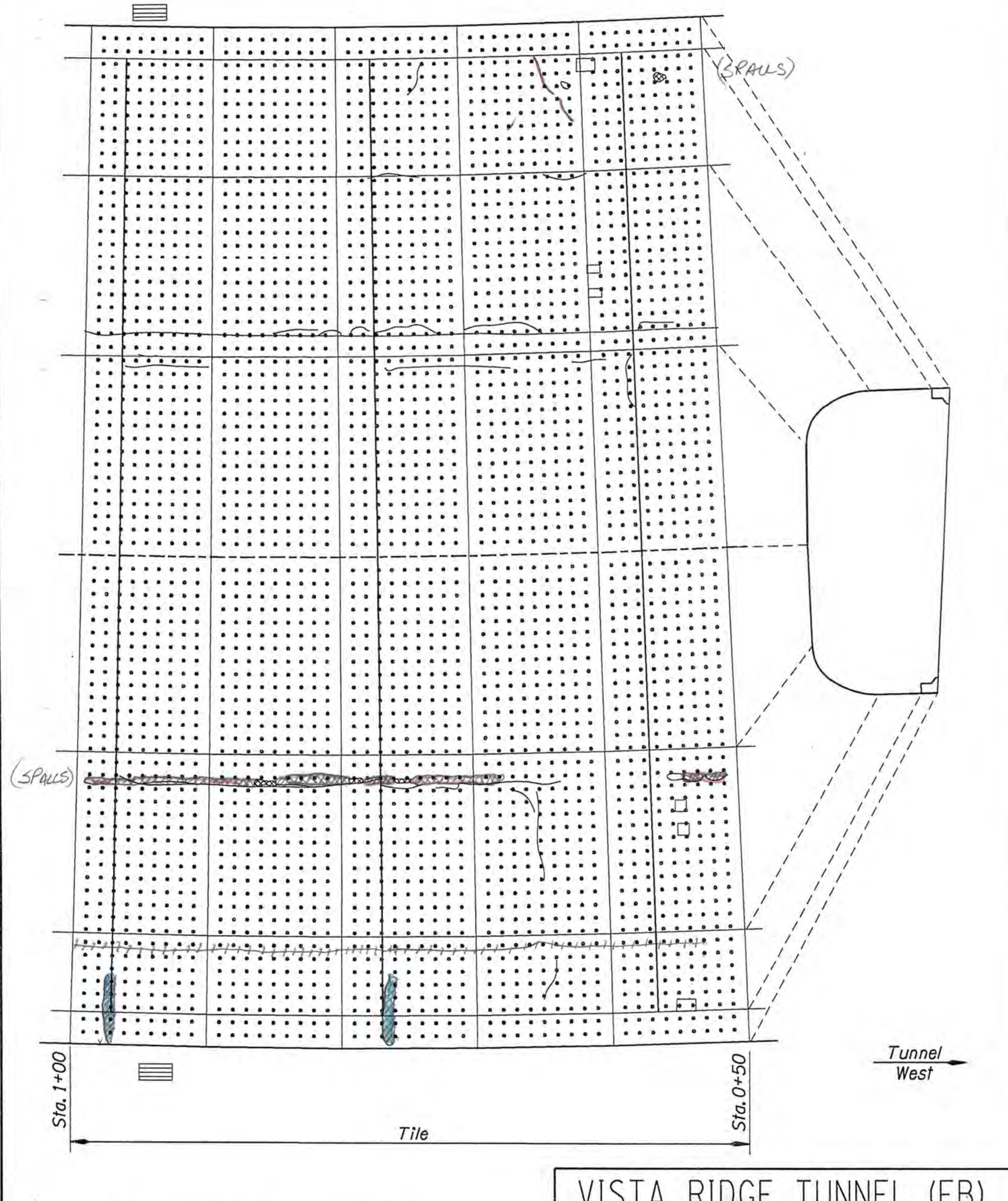
VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION

Bridge Operations Unit - Tunnel Maps

Structure No. 09103	Last Update Nov. 2010

Tunnel - Sta 0+00 to 0+50



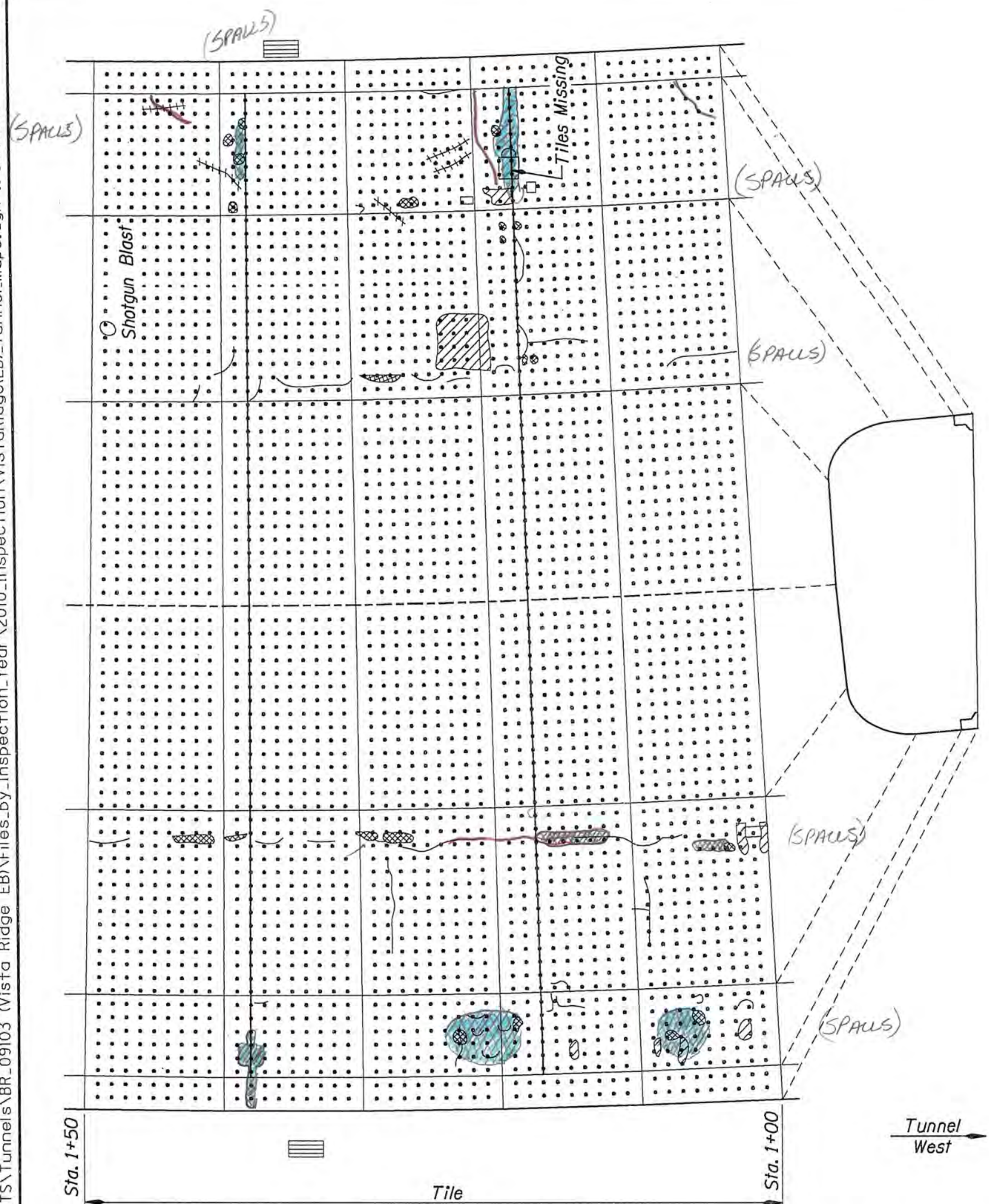
VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103 | Last Update Nov. 2010

Tunnel - Sta 0+50 to 1+00

F:\ODOT_DATA\PROJECTS\Tunnels\BR_09103 (Vista Ridge EB)\Files_by_Inspection_Year\2010_Inspection\VistaRidge(EB)_Tunnel_Maps.dgn :: Default 1/13/2011 12:32:25 PM



0 10 20
Scale in feet

VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103	Last Update Nov. 2010

Tunnel - Sta 1+00 to 1+50

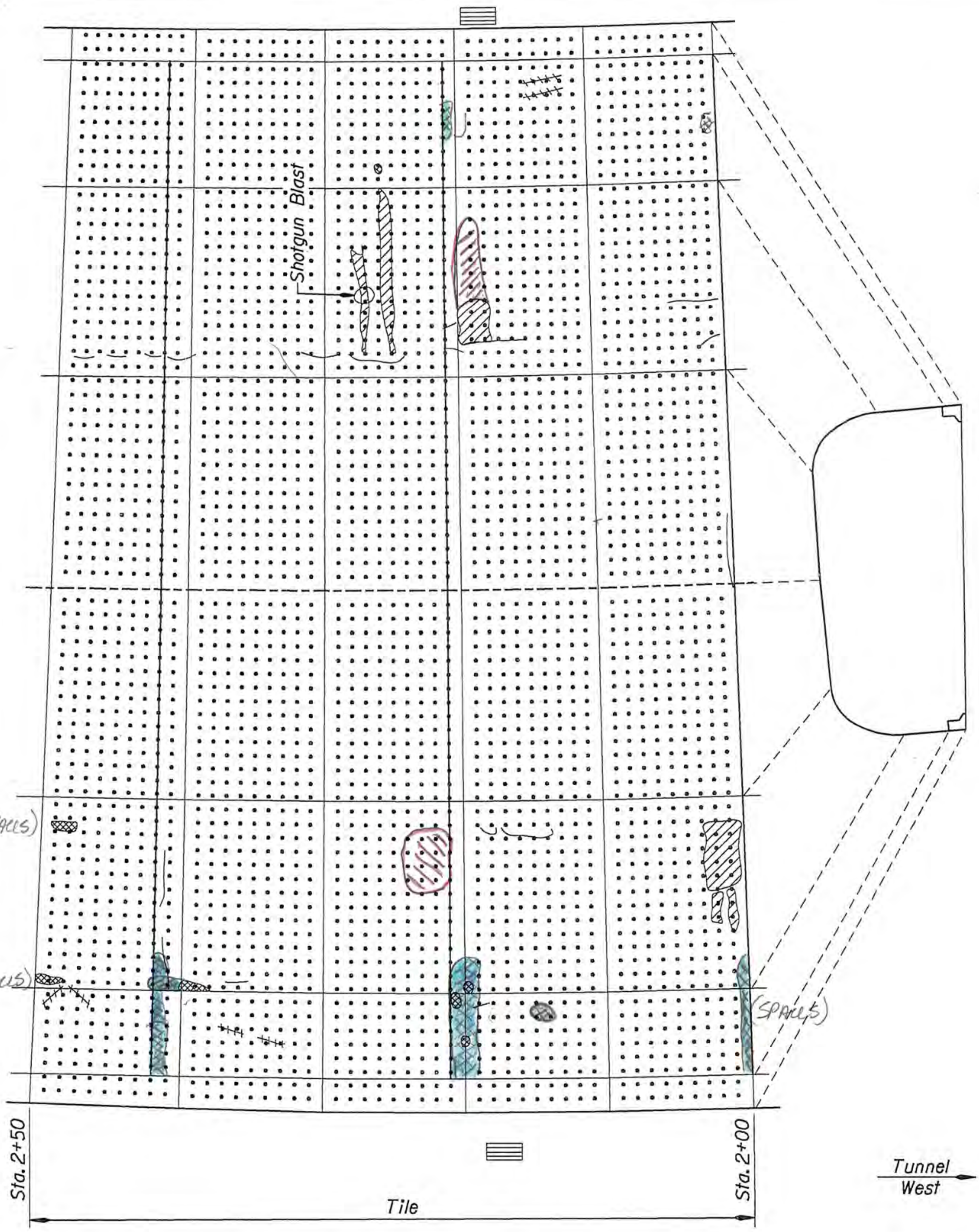
VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103 | Last Update Nov. 2010

Tunnel - Sta 1+50 to 2+00

F:\ODOT\...\PROJECTS\Tunnels\BR_09103 (Vista Ridge EB)\Files_by_Inspection_Year\2010_Inspection\VistaRidge(EB)_Tunnel_Maps.dgn :: Default 1/13/2011 12:32



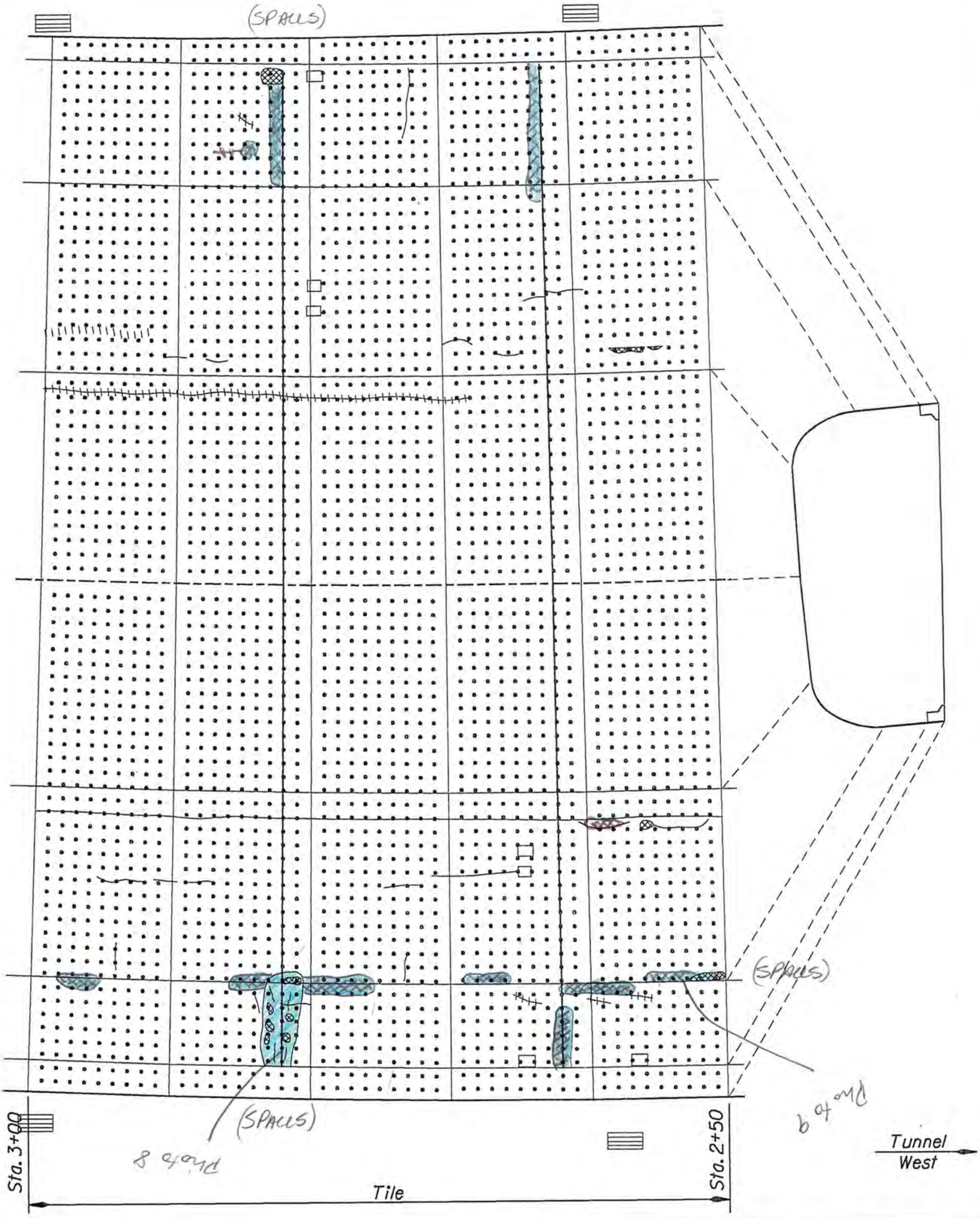
0 10 20
Scale in feet

VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103 | Last Update Nov. 2010

Tunnel - Sta 2+00 to 2+50



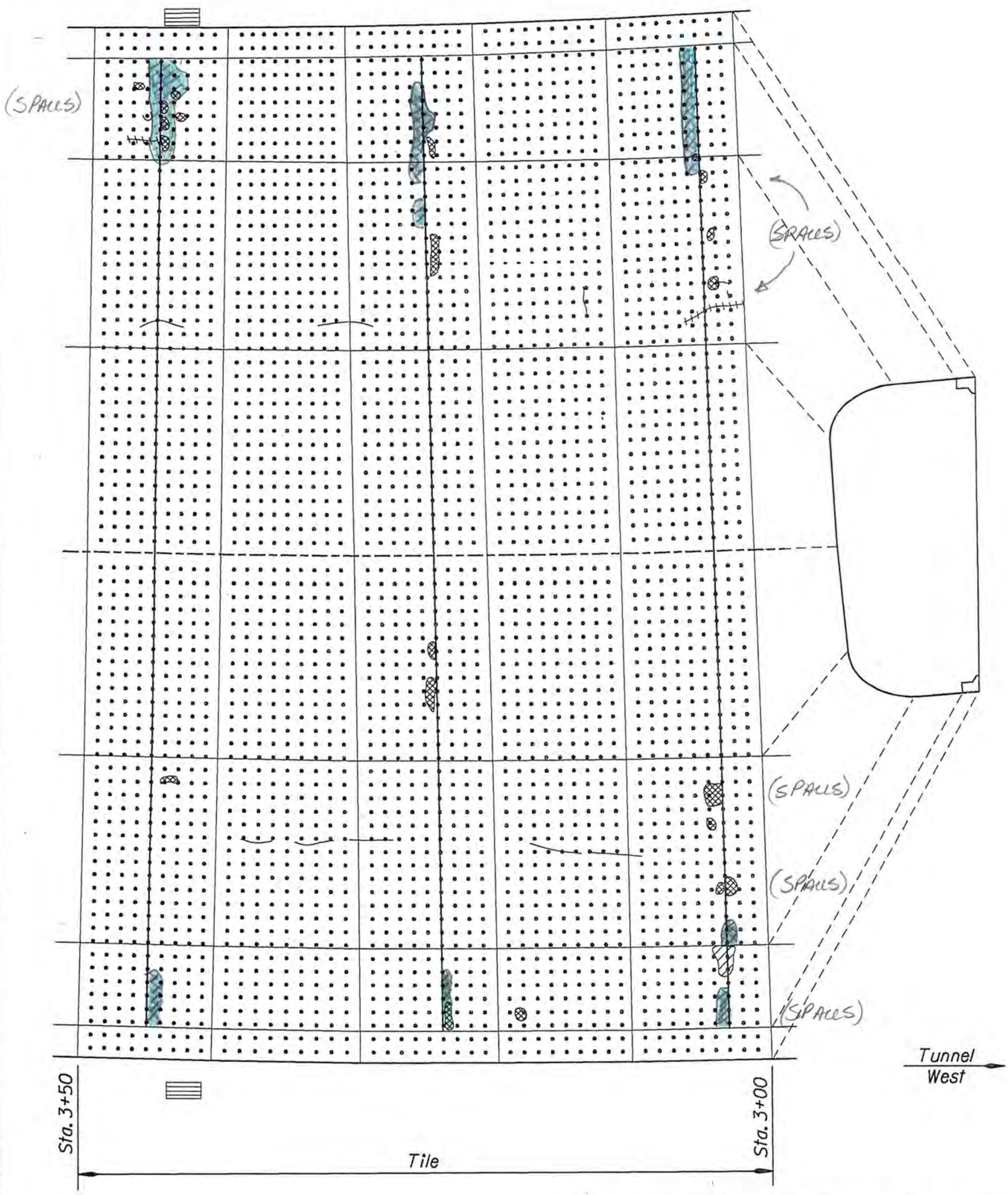
0 10 20
Scale in feet

VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103 | Last Update Nov. 2010

Tunnel - Sta 2+50 to 3+00



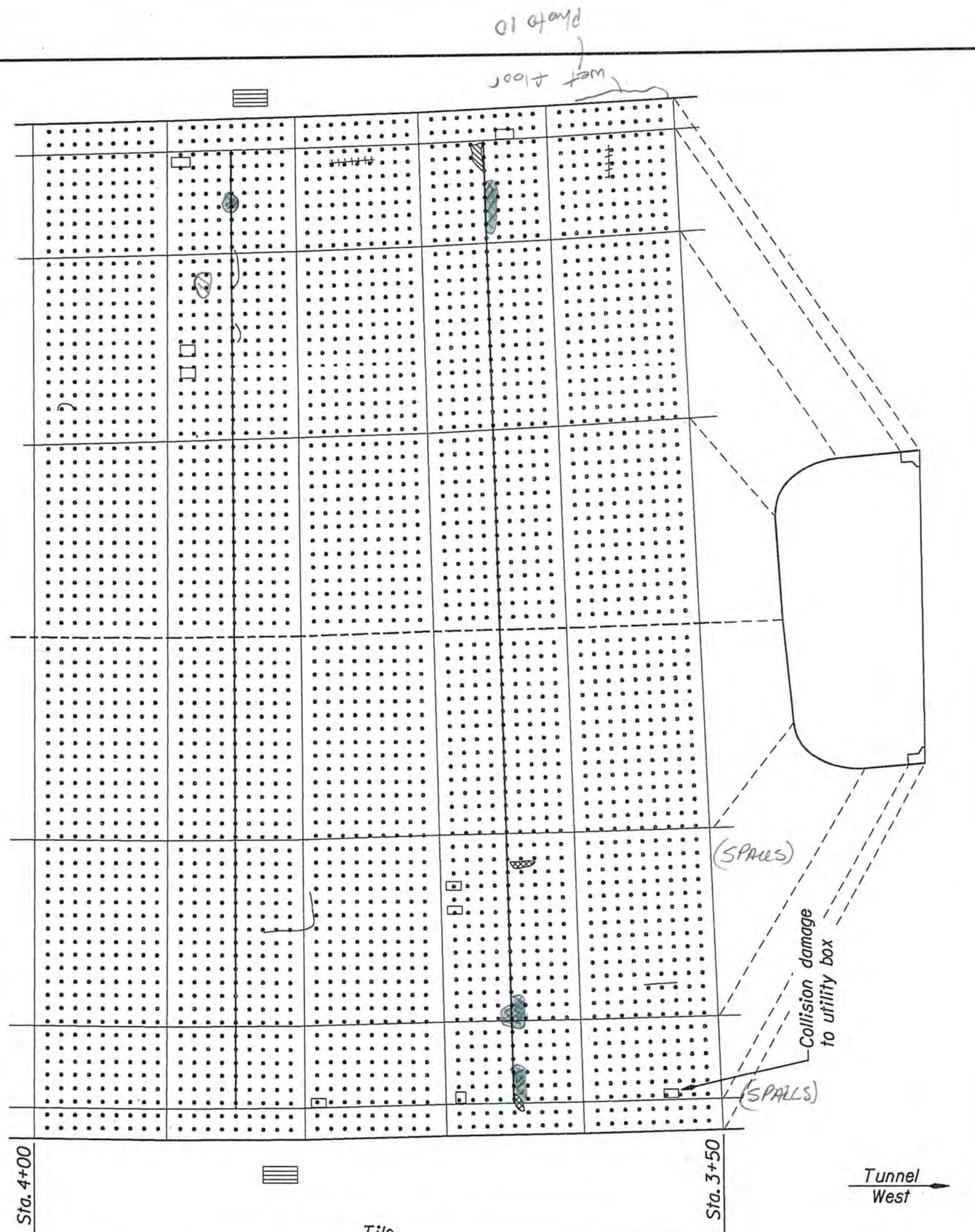
0 10 20
Scale in feet

VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103	Last Update Nov. 2010

Tunnel - Sta 3+00 to 3+50



0 10 20
Scale in feet

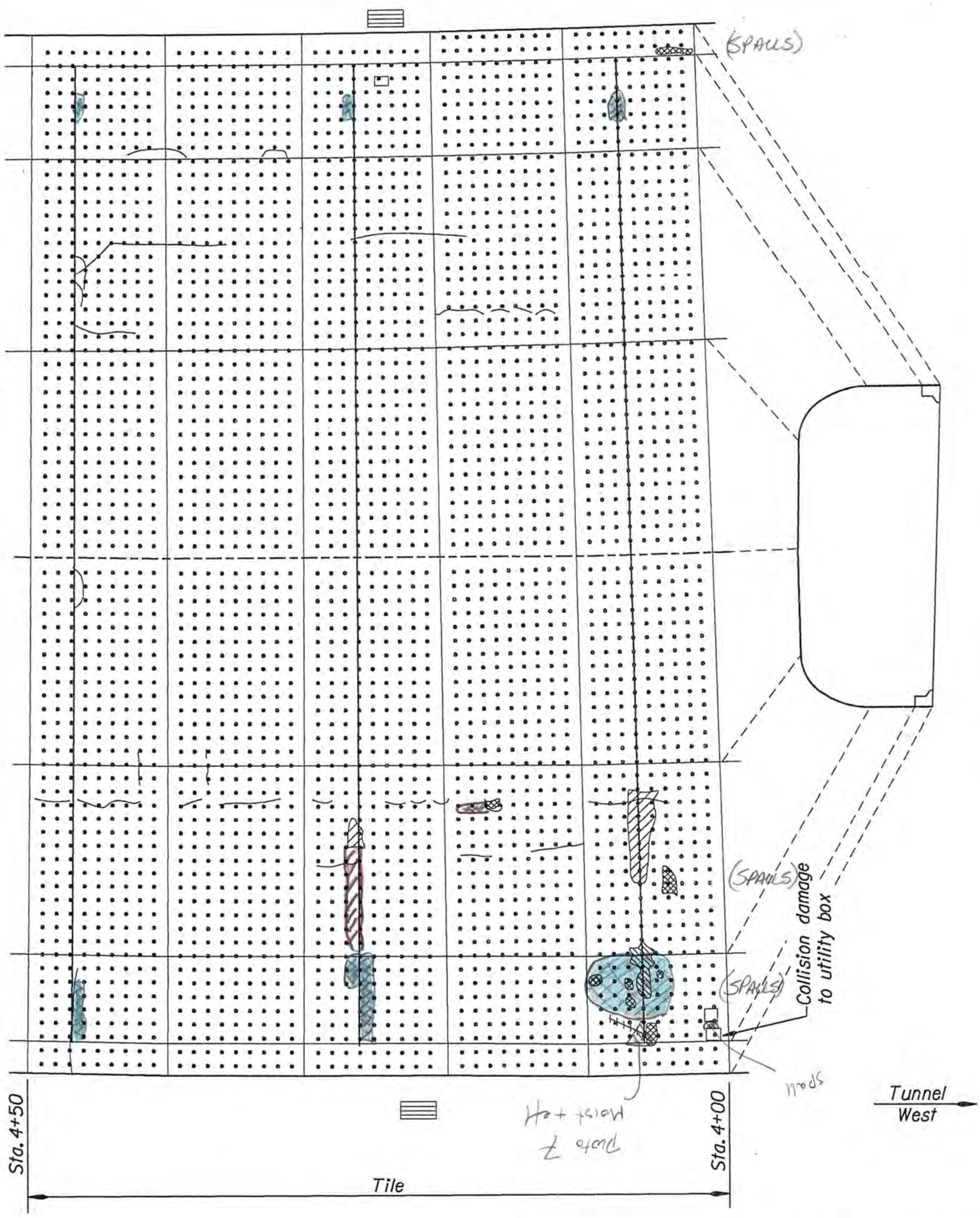
VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103 | Last Update Nov. 2010

Tunnel - Sta 3+50 to 4+00

F:\ODOT_DATA\PROJECTS\Tunnels\BR_09103 (Vista Ridge EB)\Files_by_Inspection_Year\2010_Inspection\VistaRidge(EB)_Tunnel_Maps.dgn :: Default 1/13/2011 12:33:20 PM



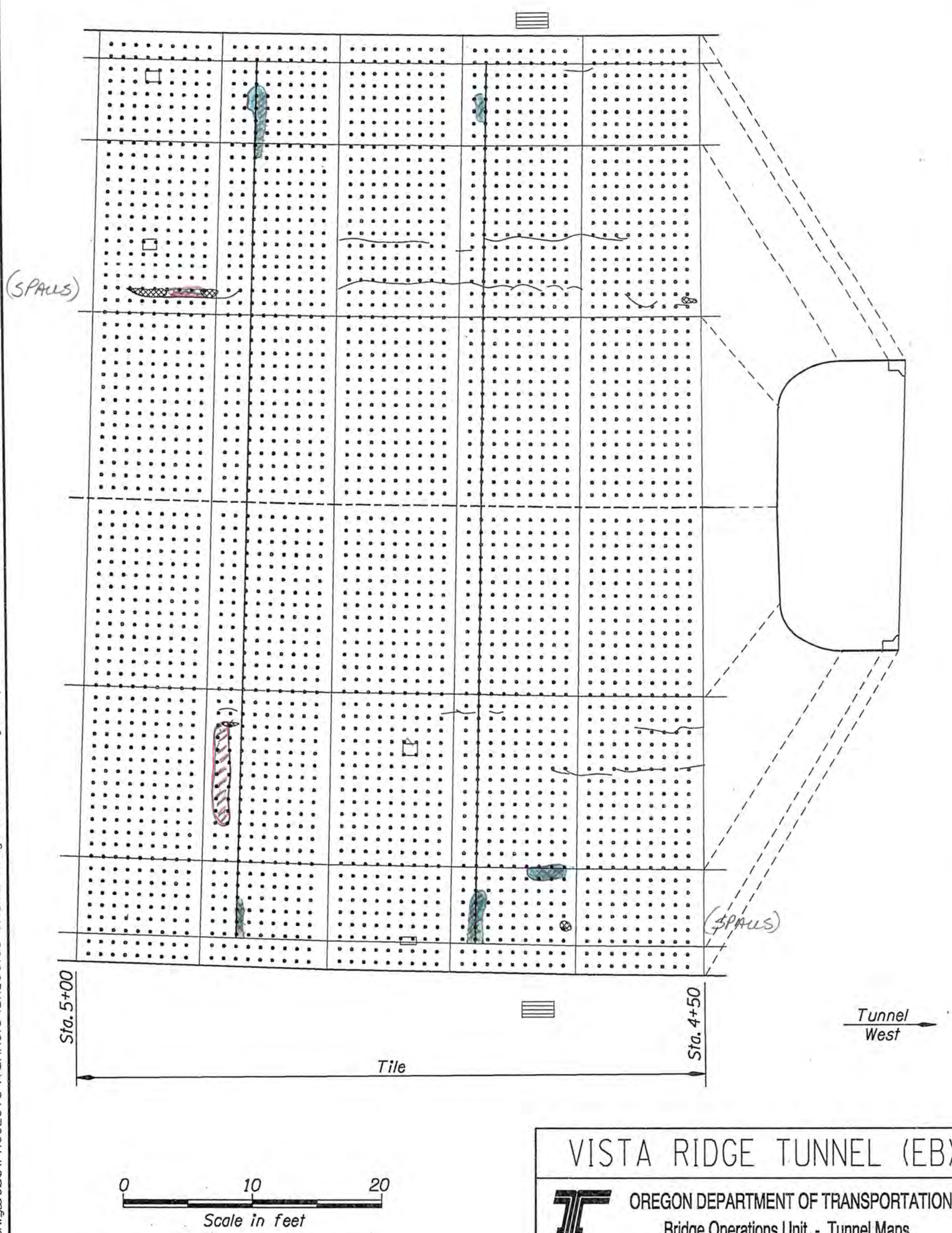
0 10 20
Scale in feet

VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103	Last Update Nov. 2010

Tunnel - Sta 4+00 to 4+50

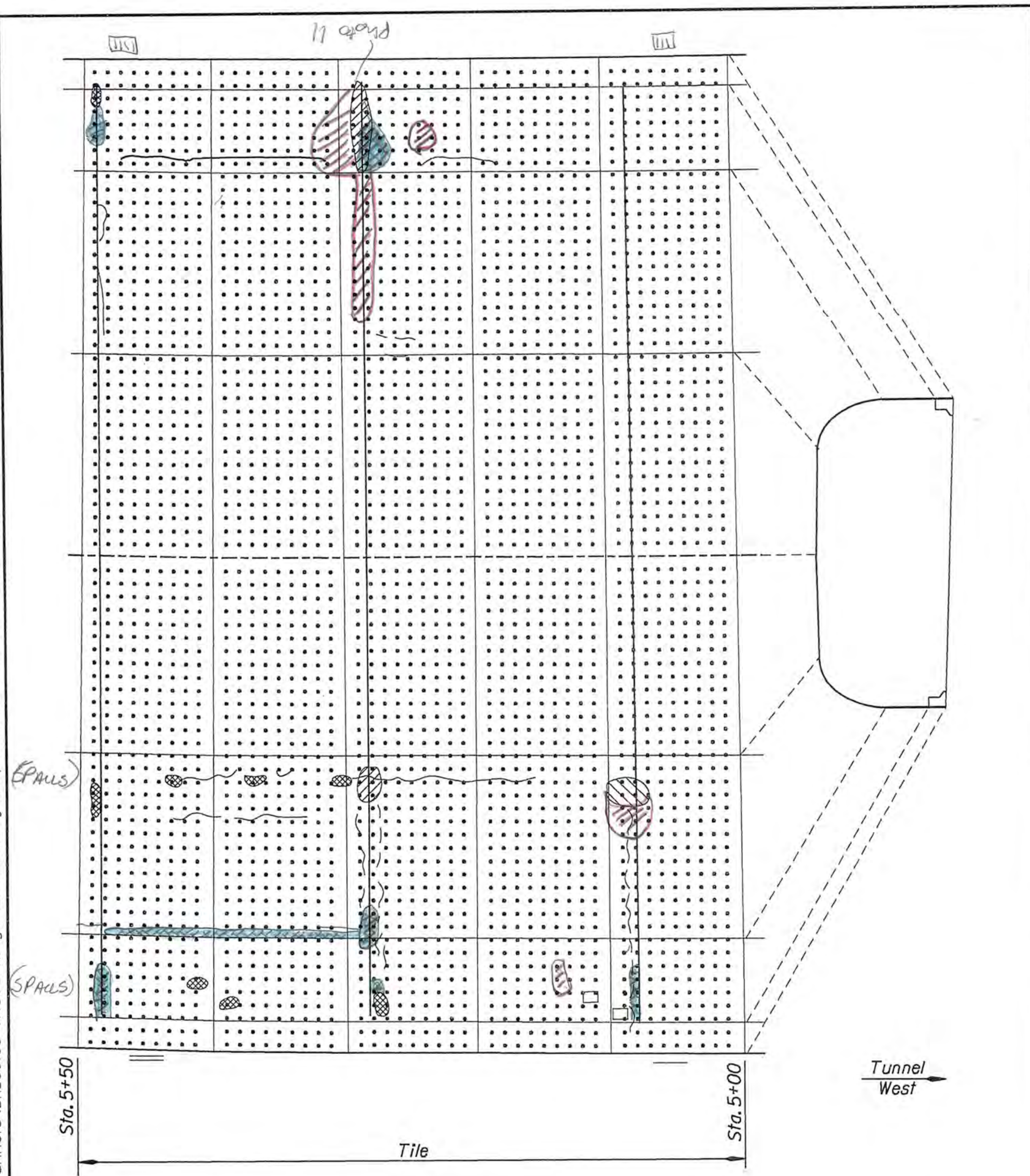


VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103 | Last Update Nov. 2010

Tunnel - Sta 4+50 to 5+00



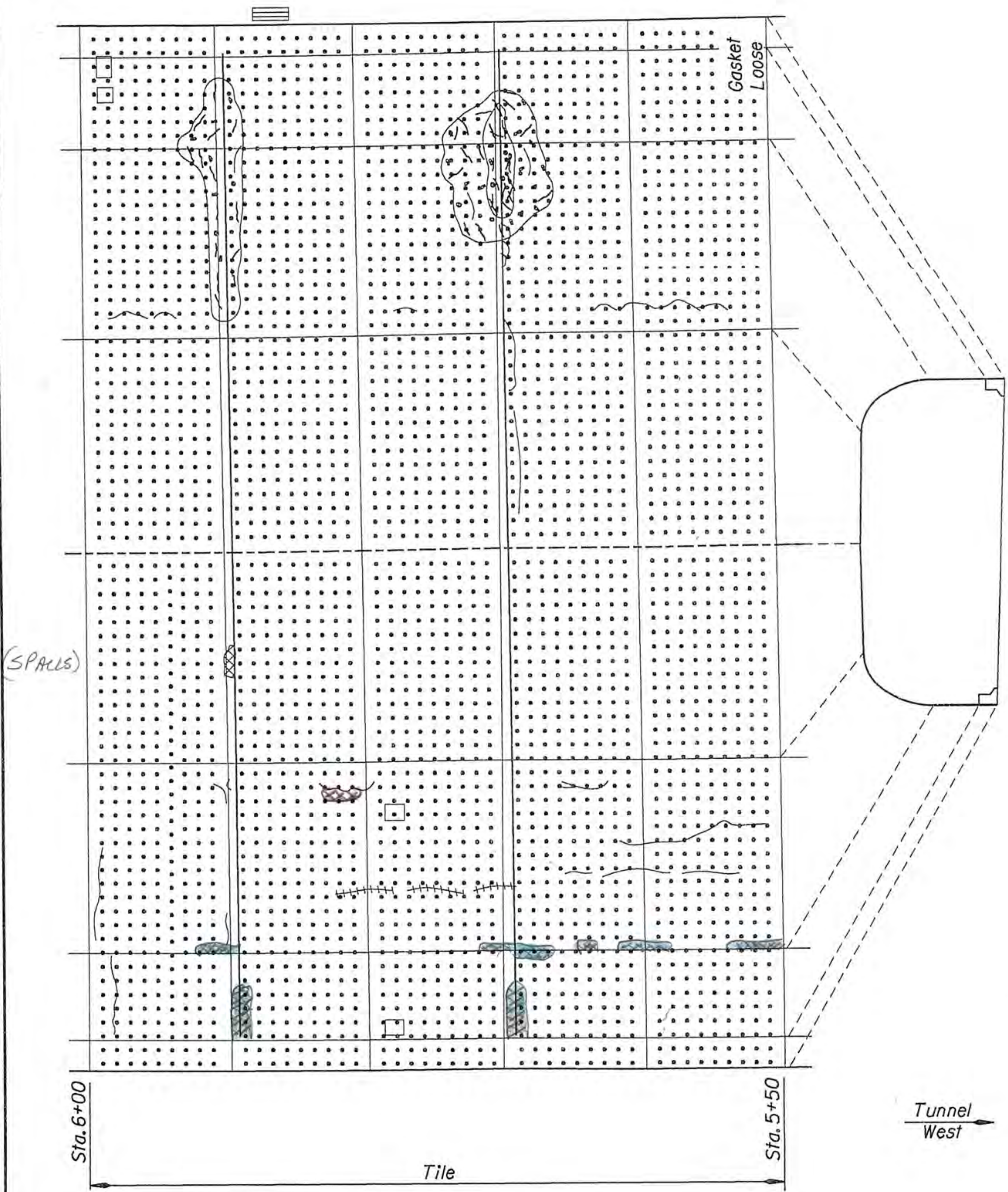
0 10 20
Scale in feet

VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103 Last Update Nov. 2010

Tunnel - Sta 5+00 to 5+50



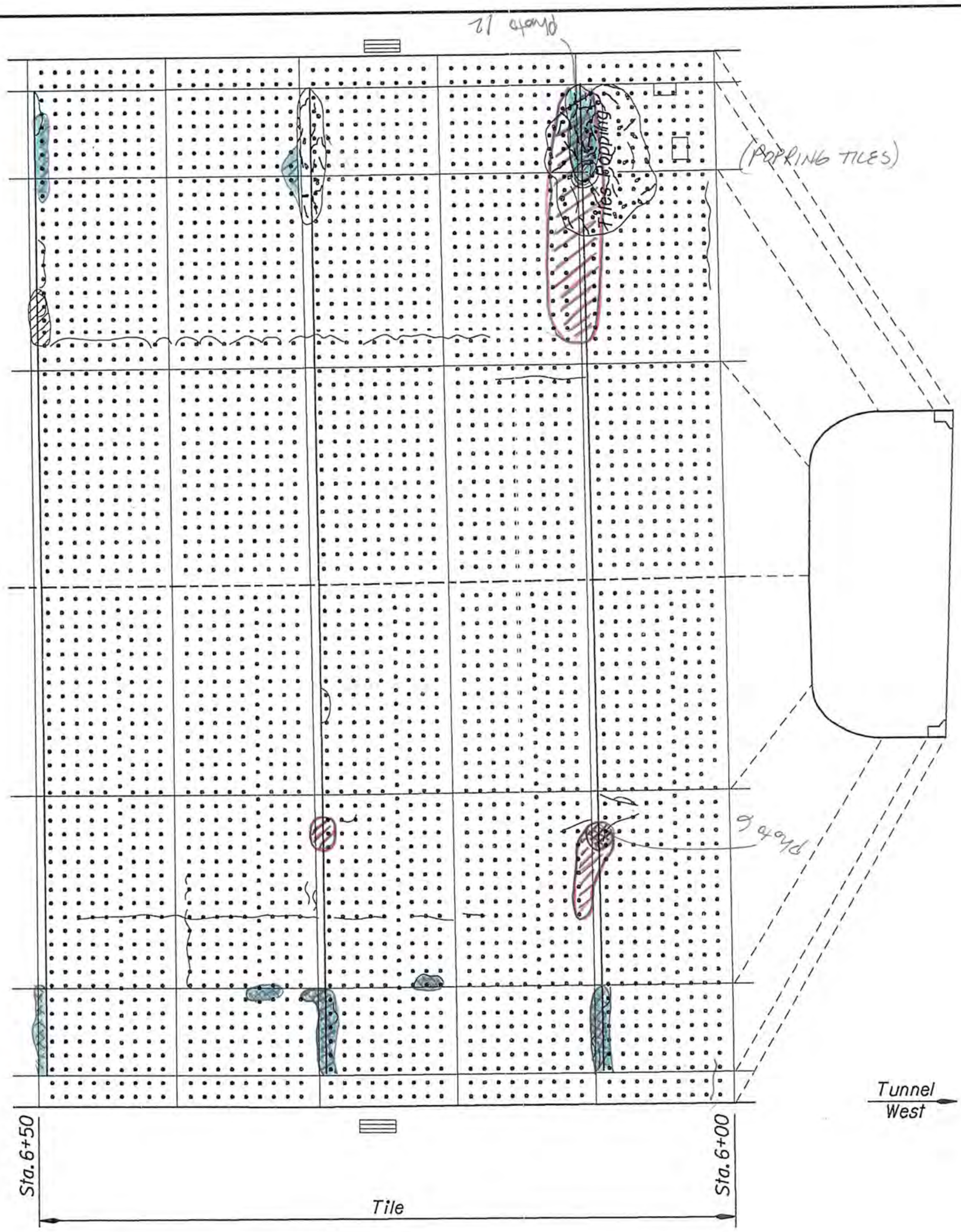
0 10 20
Scale in feet

VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103 | Last Update Nov. 2010

Tunnel - Sta 5+50 to 6+00



0 10 20
Scale in feet

VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103	Last Update Nov. 2010

Tunnel - Sta 6+00 to 6+50

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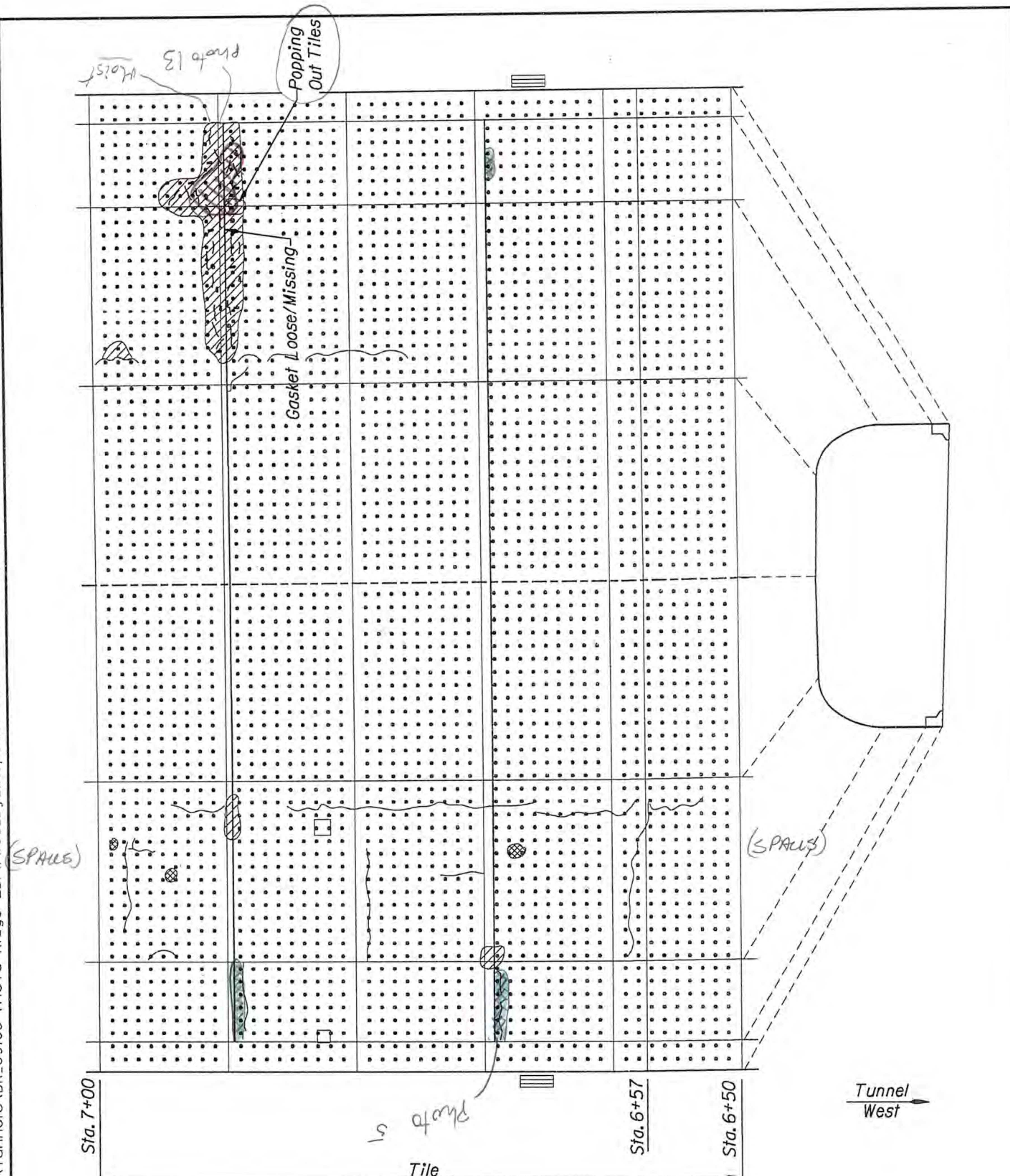

0 10 20

Scale in feet

VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION

Bridge Operations Unit - Tunnel Maps

Structure No. 09103 | Last Update Nov. 2010

Tunnel - Sta 6+50 to 7+00

F:\ODOT_DATA\PROJECTS\Tunnels\BR_09103 (Vista Ridge EB)\Files_by_Inspection_Year\2010_Inspection\VistaRidge(EB)_Tunnel_Maps.dgn :: Default 1/13/2011 12:34:
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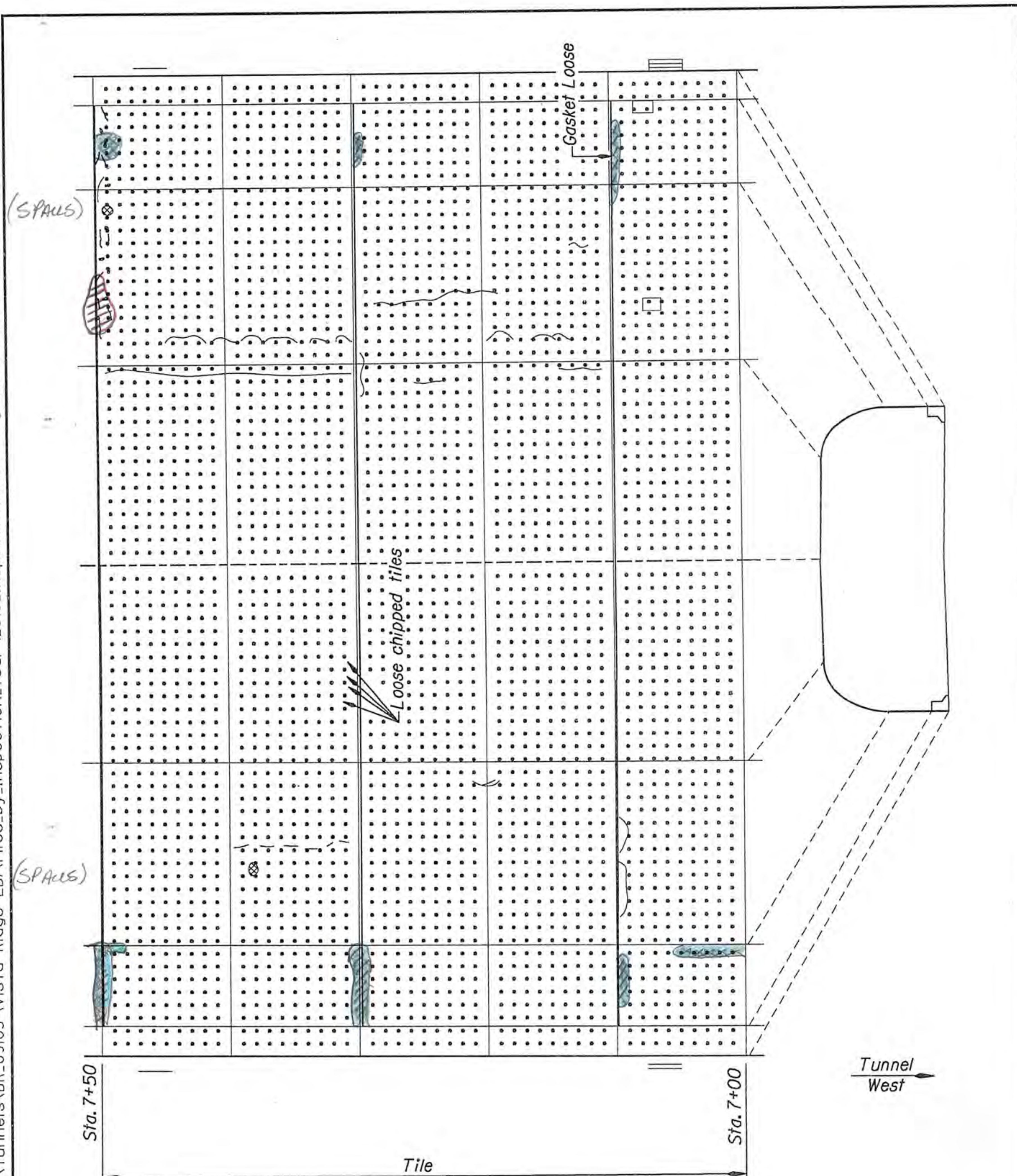


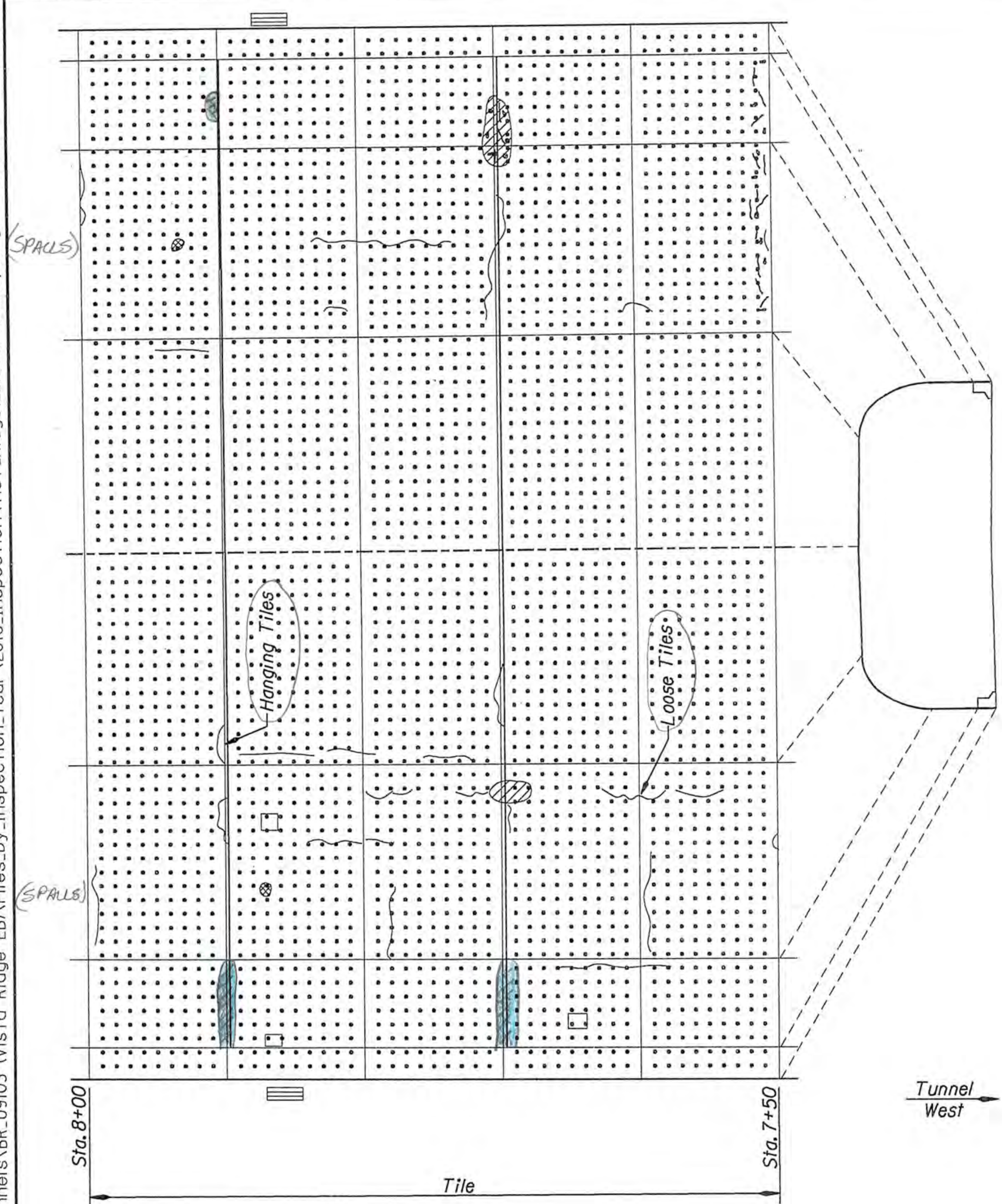
0 10 20
Scale in feet

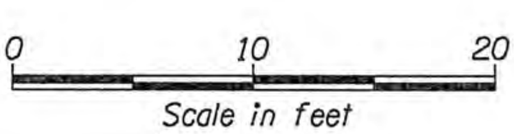
VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103	Last Update Nov. 2010

Tunnel - Sta 7+00 to 7+50



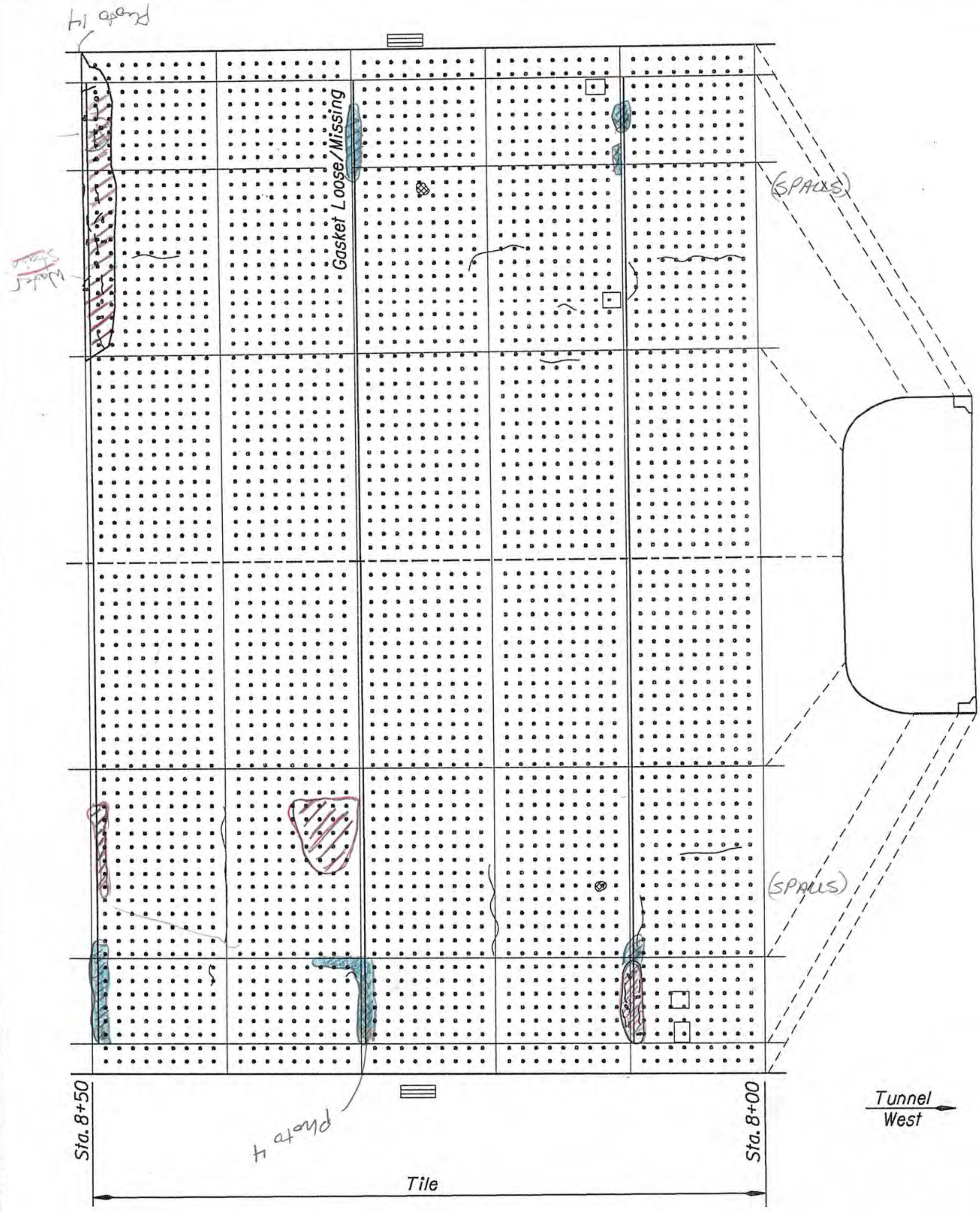


VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103	Last Update Nov. 2010

Tunnel - Sta 7+50 to 8+00



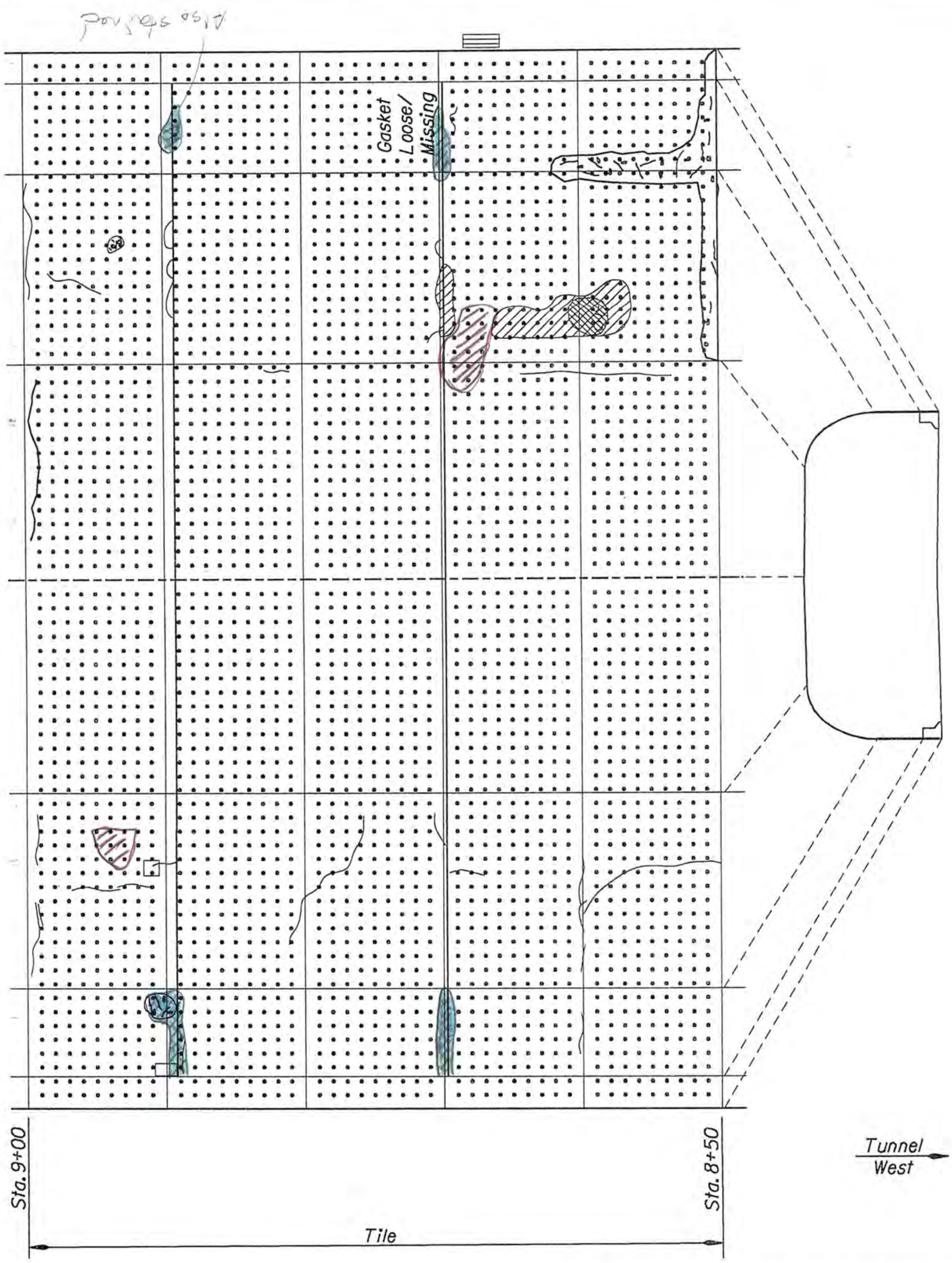
0 10 20
Scale in feet

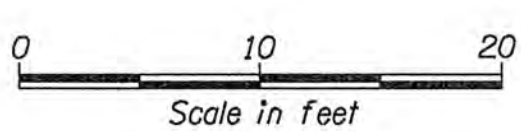
VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103 | Last Update Nov. 2010

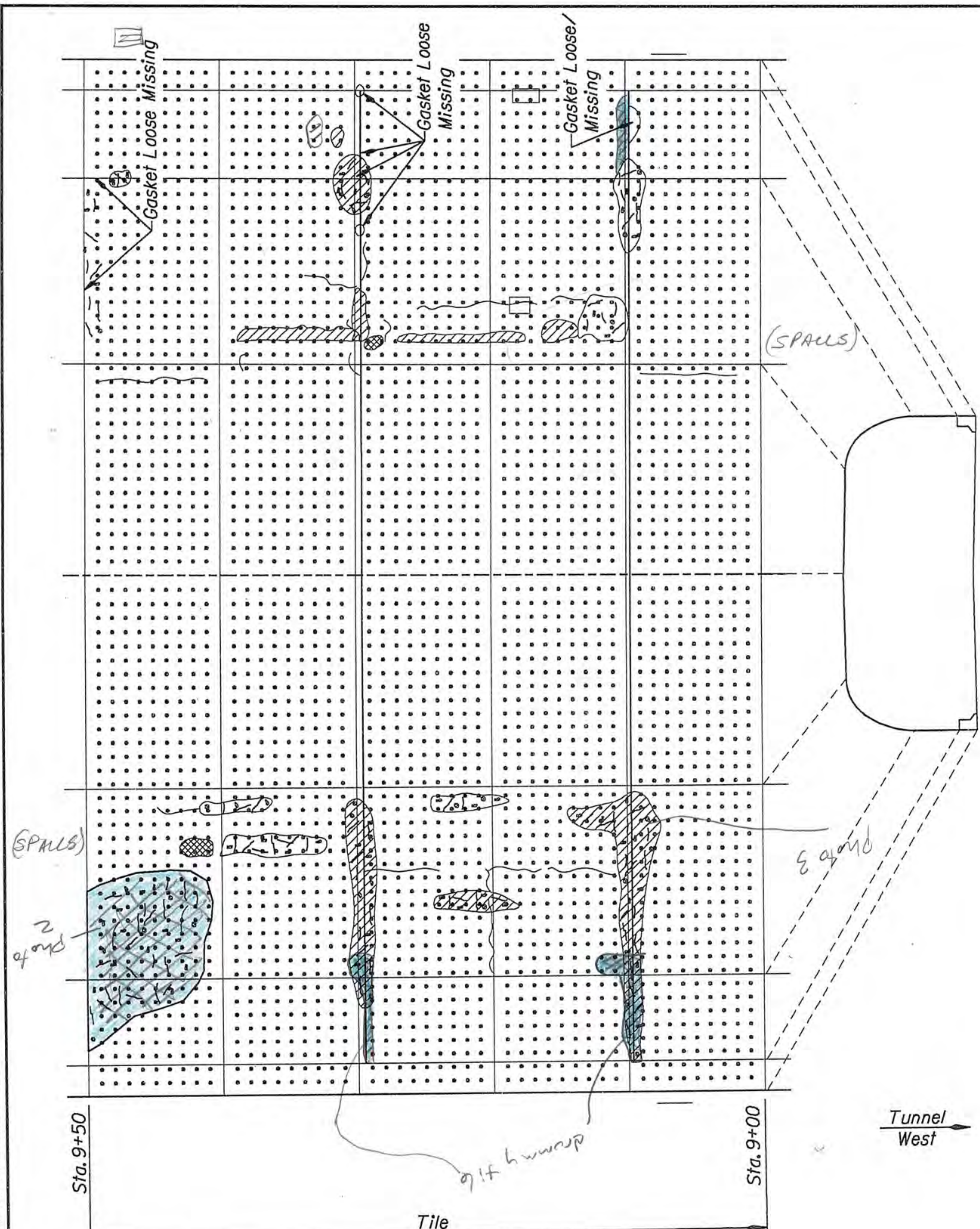
Tunnel - Sta 8+00 to 8+50





VISTA RIDGE TUNNEL (EB)	
OREGON DEPARTMENT OF TRANSPORTATION Bridge Operations Unit - Tunnel Maps	
Structure No. 09103	Last Update Nov. 2010

Tunnel - Sta 8+50 to 9+00



0 10 20
Scale in feet

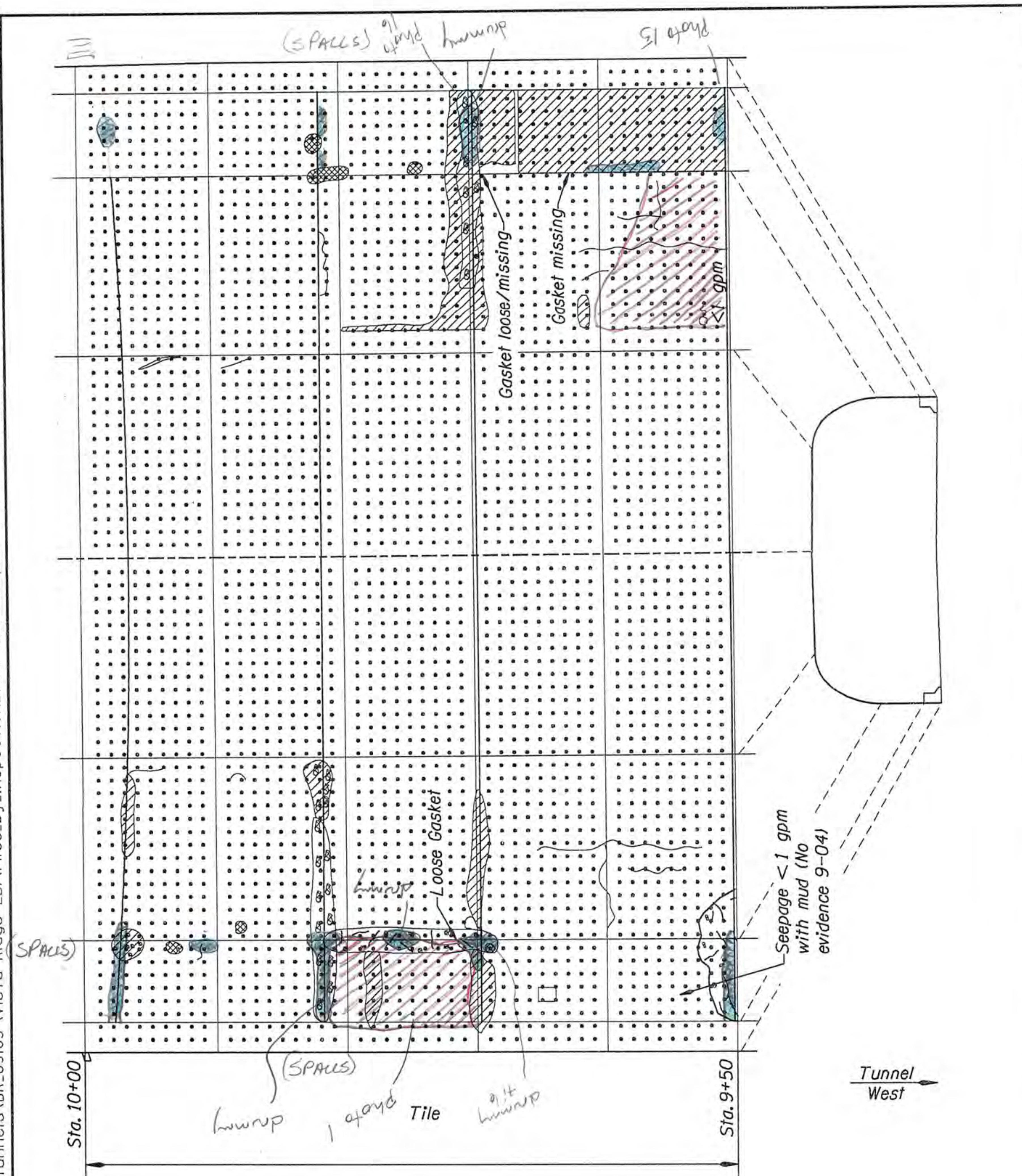
VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103 | Last Update Nov. 2010

Tunnel - Sta 9+00 to 9+50

F:\ODOT_DATA\PROJECTS\Tunnels\BR_09103 (Vista Ridge EB)\Files_by_Inspection_Year\2010_Inspection\VistaRidge(EB)_Tunnel_Maps.dgn :: Default 1/13/2011 12:34:52 PM



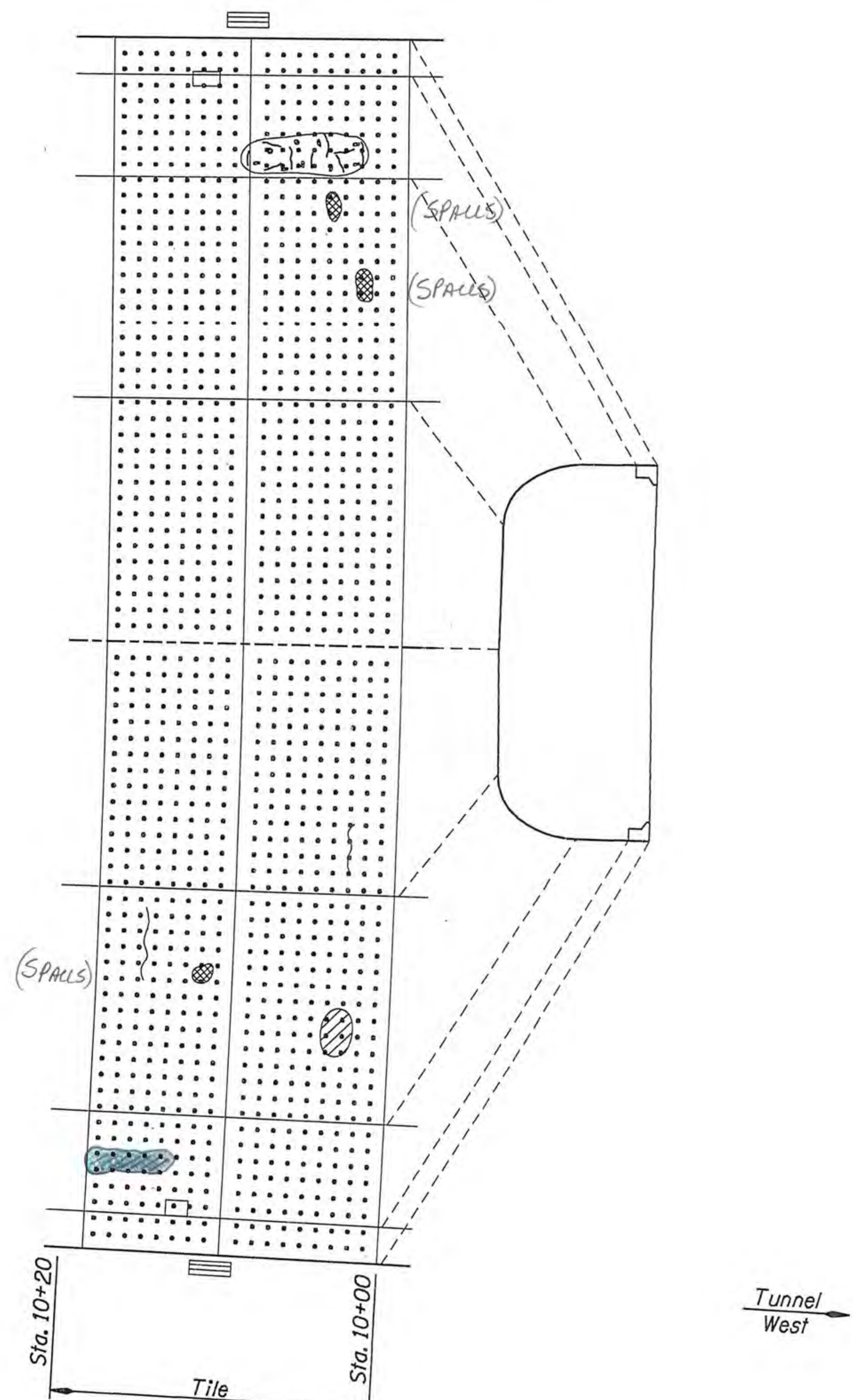
0 10 20
Scale in feet

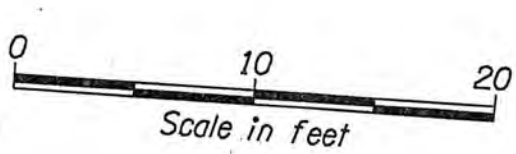
VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103	Last Update Nov. 2010

Tunnel - Sta 9+50 to 10+00





VISTA RIDGE TUNNEL (EB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103 | Last Update Nov. 2010

Tunnel - Sta 10+00 to 10+20

F:\ODOT_DATA\PROJECTS\Tunnels\BR_09103B (Vista Ridge WB)\Files_by_Inspection_Year\2010_Inspection\VistaRidge(WB)_Tunnel_Maps.dgn :: Default 1/13/2011 12:45

TUNNEL MAP LEGEND

Scaling		Scaling is light - loss of surface mortar without exposure of coarse aggregate unless otherwise indicated
Moist to Wet Seepage Area/Stain		
Dry Seepage Stains		
Tile or Concrete Spall		
Areas of Short Cracks and Small Spalls		
DEBONDED TILE		

Metal Plate or Box

Seep

Scrape or Gouge

Coreholes Patched Unless Noted Otherwise

Drain Inlets

Type 2 - Roadway 15 x 32 in.

Note: New defects outlined with red except DEBONDED TILE

Tile and Concrete

Crack Fine

All cracks are fine (Cf, Δ 1mm) unless otherwise indicated as Cm - medium, 1-2 mm or Cw - wide, >2mm

Tile and Concrete

Construction Joint

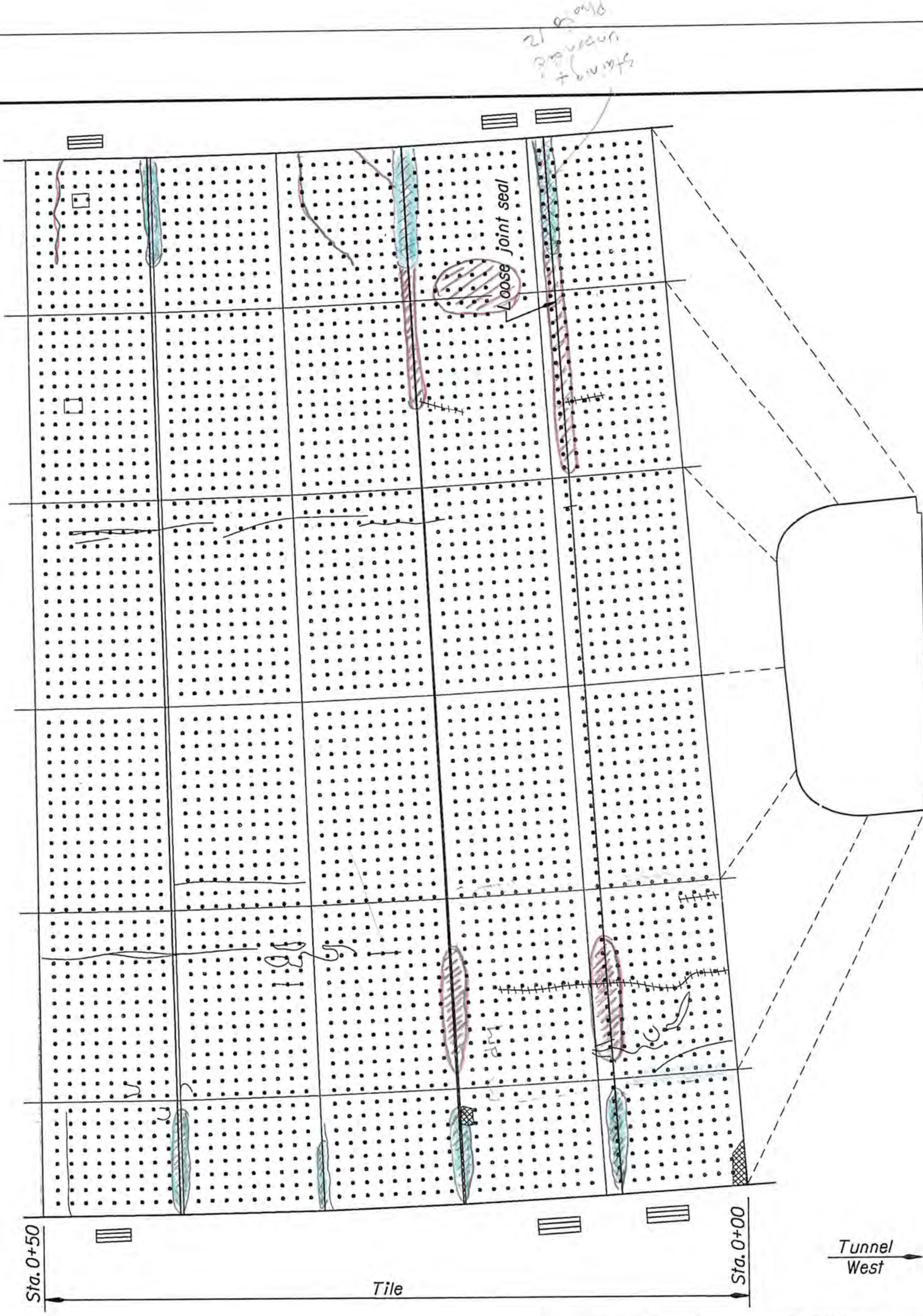
VISTA RIDGE TUNNEL (WB)

OREGON DEPARTMENT OF TRANSPORTATION

Bridge Operations Unit - Tunnel Maps

Structure No. 09103B Last Update Nov. 2010

Tunnel - Legend

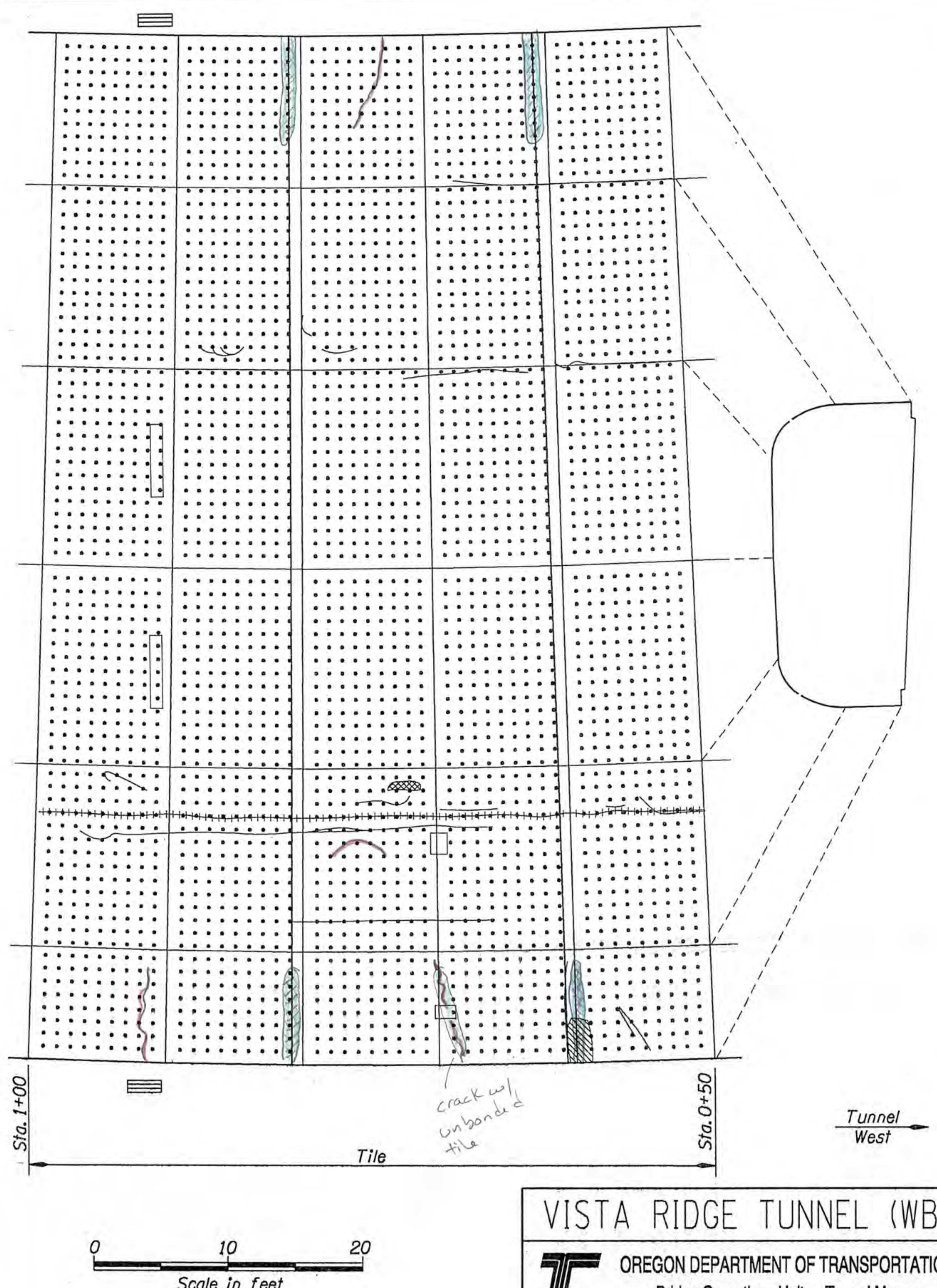


VISTA RIDGE TUNNEL (WB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103B | Last Update Nov. 2010

Tunnel - Sta 0+00 to 0+50



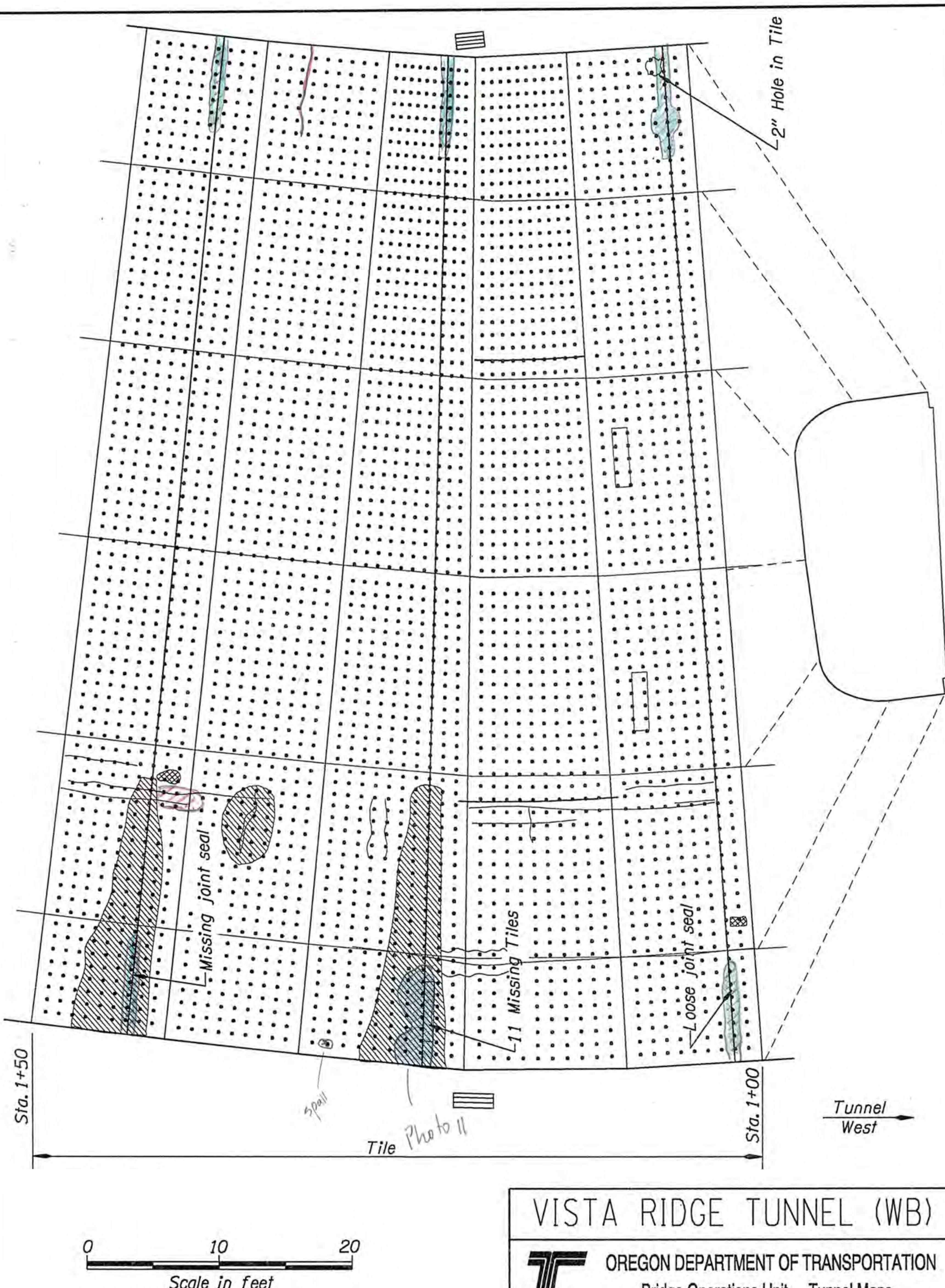
VISTA RIDGE TUNNEL (WB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103B	Last Update Nov. 2010

Tunnel - Sta 0+50 to 1+00

1/13/2011 12:46:04 PM F:\ODOT...\PROJECTS\Tunnels\BR_09103B (Vista Ridge WB)\Files_by_Inspection_Year\2010_Inspection\VistaRidge(WB)_Tunnel_Maps.dgn :: Default

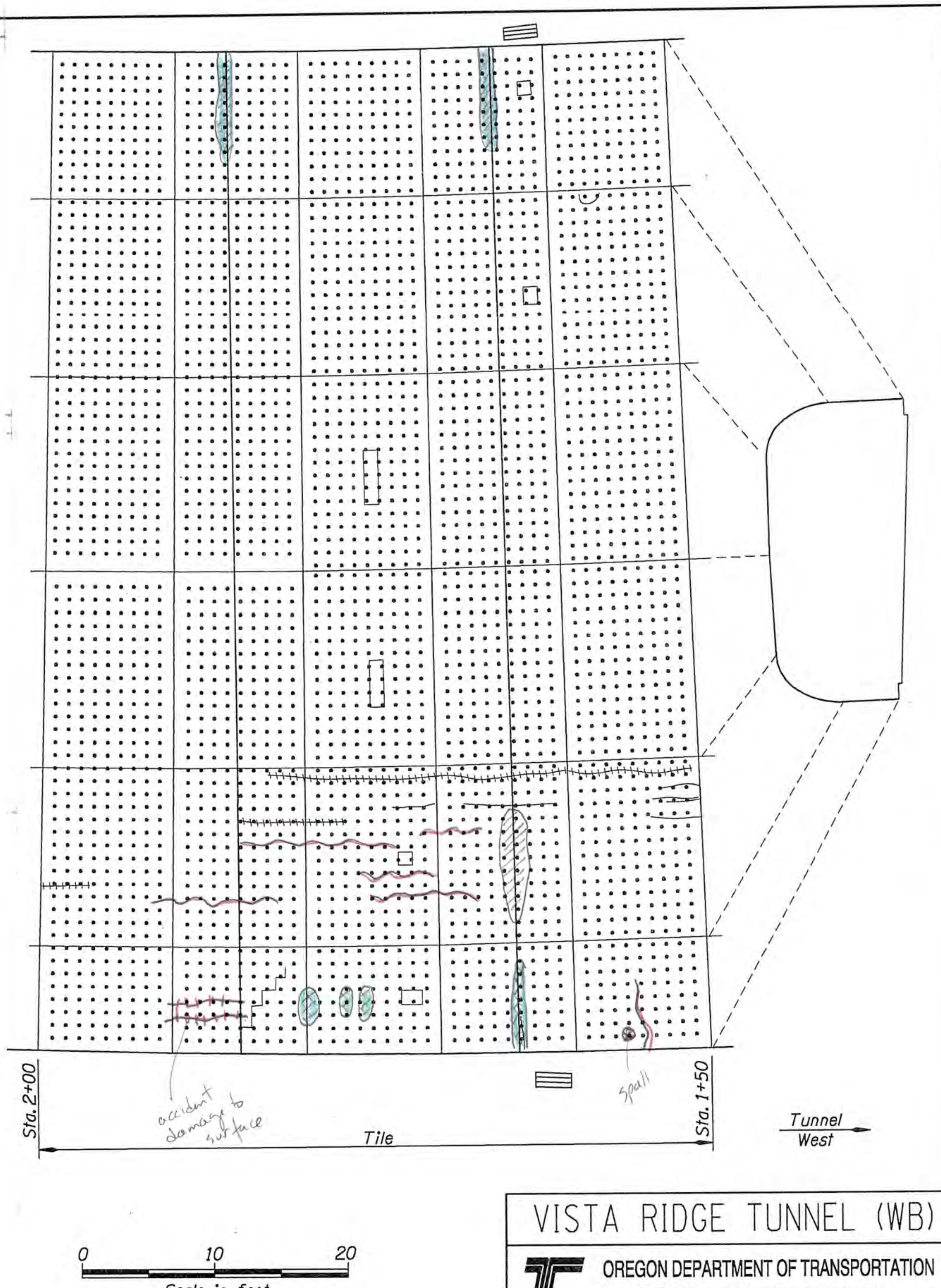


VISTA RIDGE TUNNEL (WB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103B	Last Update Nov. 2010

Tunnel - Sta 1+00 to 1+50

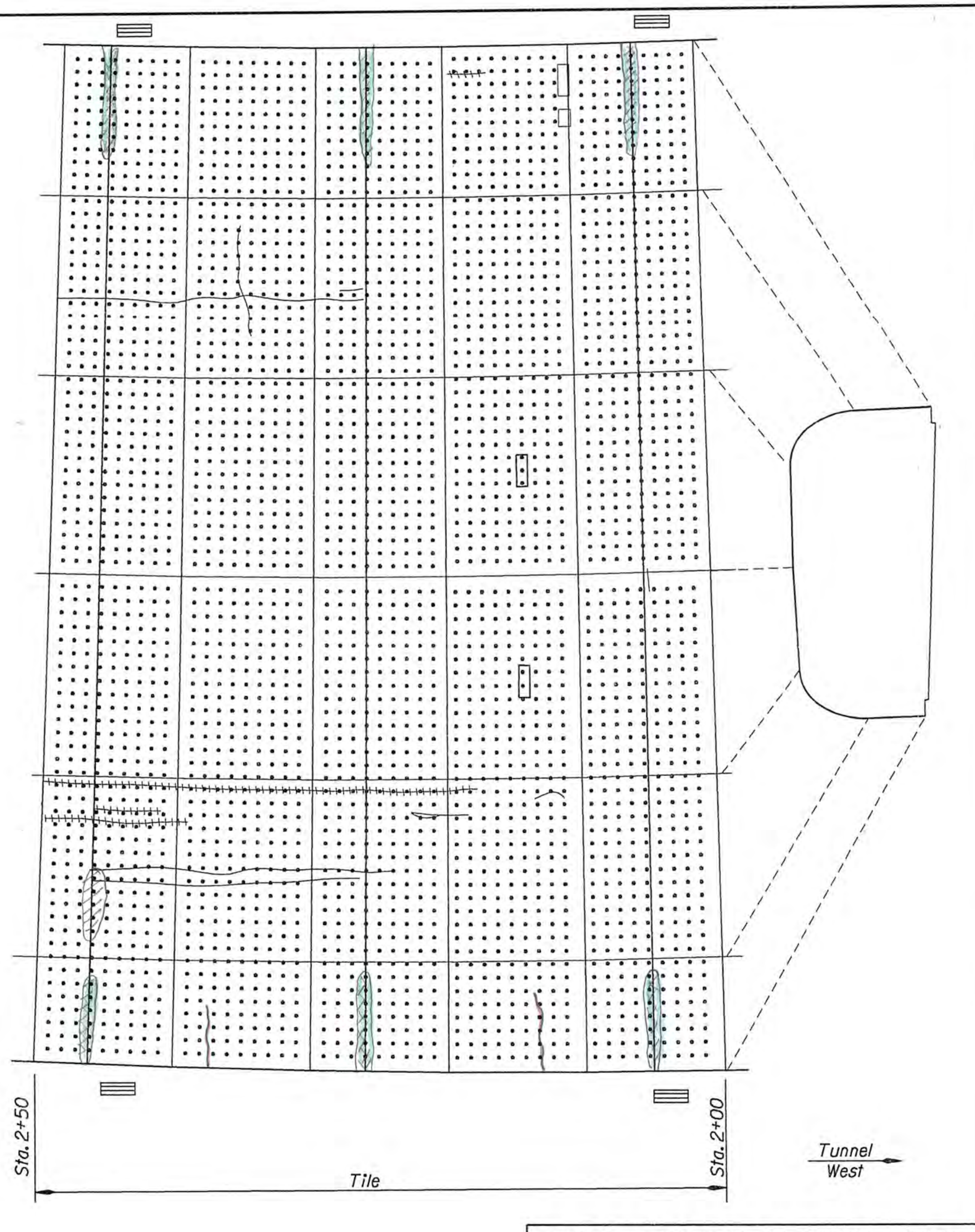


VISTA RIDGE TUNNEL (WB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103B	Last Update Nov. 2010

Tunnel - Sta 1+50 to 2+00

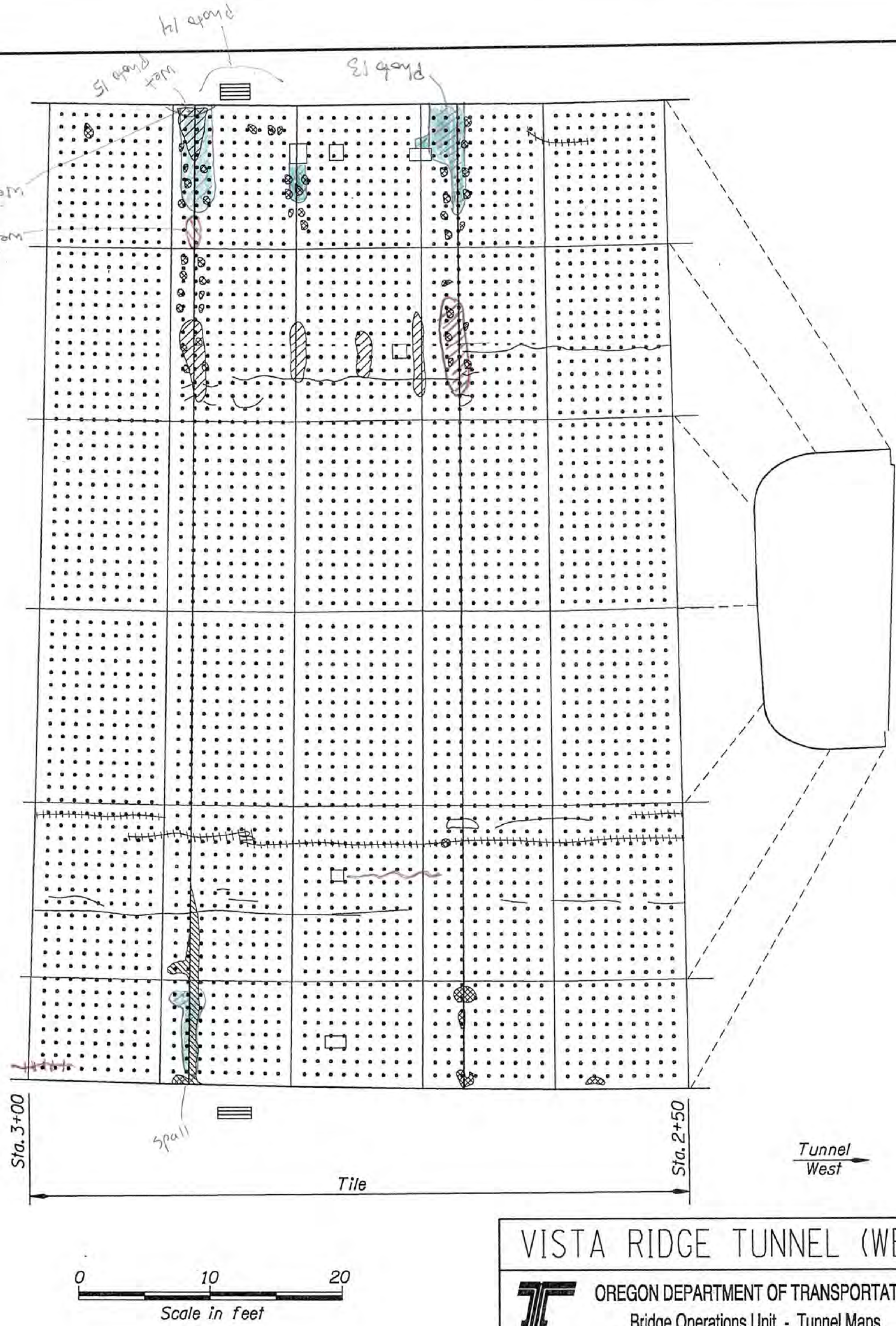


VISTA RIDGE TUNNEL (WB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103B | Last Update Nov. 2010

Tunnel - Sta 2+00 to 2+50

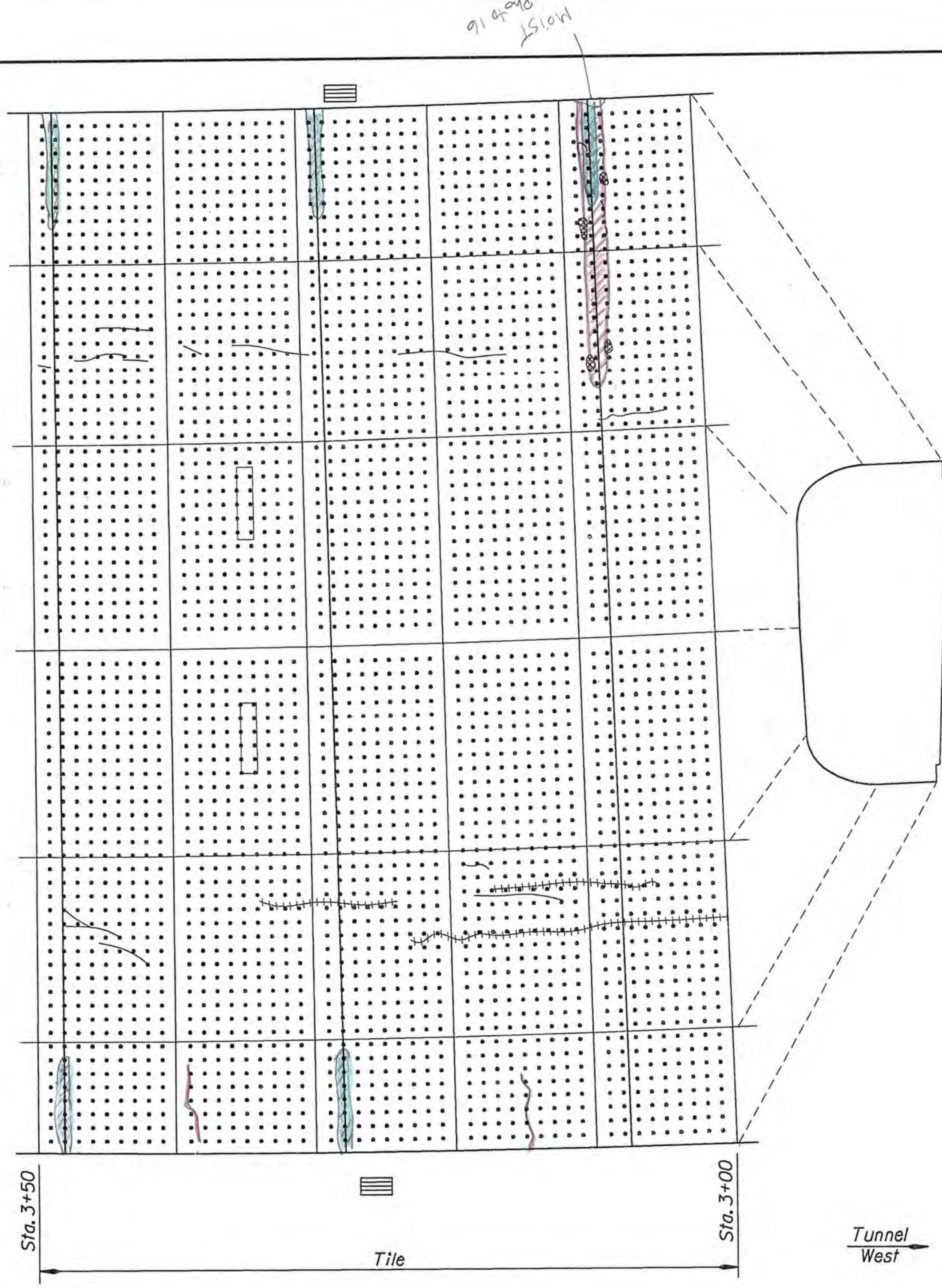


VISTA RIDGE TUNNEL (WB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103B	Last Update Nov. 2010

Tunnel - Sta 2+50 to 3+00



0 10 20
Scale in feet

VISTA RIDGE TUNNEL (WB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103B | Last Update Nov. 2010

Tunnel - Sta 3+00 to 3+50

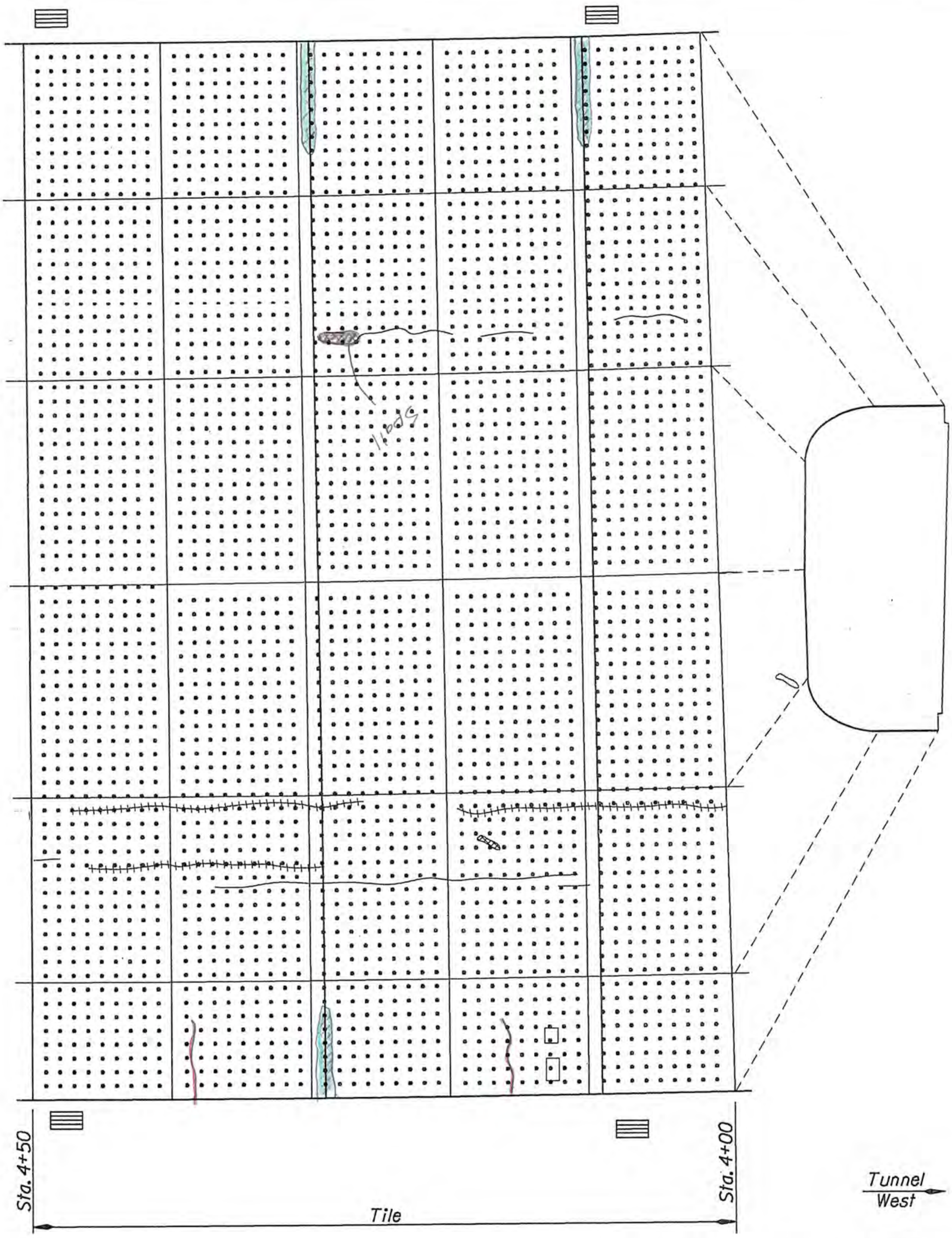
0 10 20
Scale in feet

VISTA RIDGE TUNNEL (WB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103B | Last Update Nov. 2010

Tunnel - Sta 3+50 to 4+00



0 10 20
Scale in feet

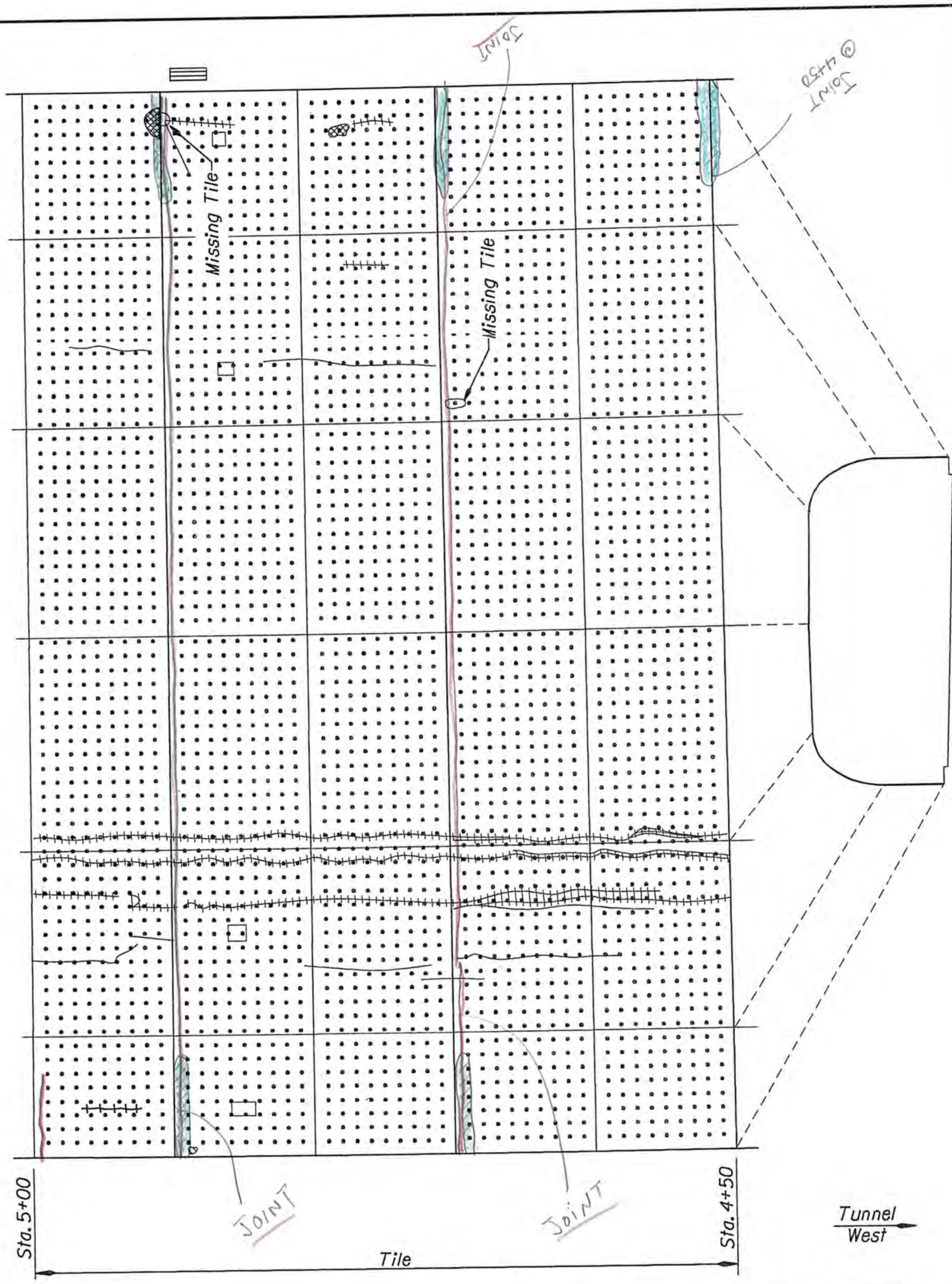
VISTA RIDGE TUNNEL (WB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103B	Last Update Nov. 2010

Tunnel - Sta 4+00 to 4+50

F:\ODOT_DATA\PROJECTS\Tunnels\BR_09103B (Vista Ridge WB)\Files_by_Inspection_Year\2010_Inspection\VistaRidge(WB)_Tunnel_Maps.dgn :: Default 1/13/2011 12:47:08 PM

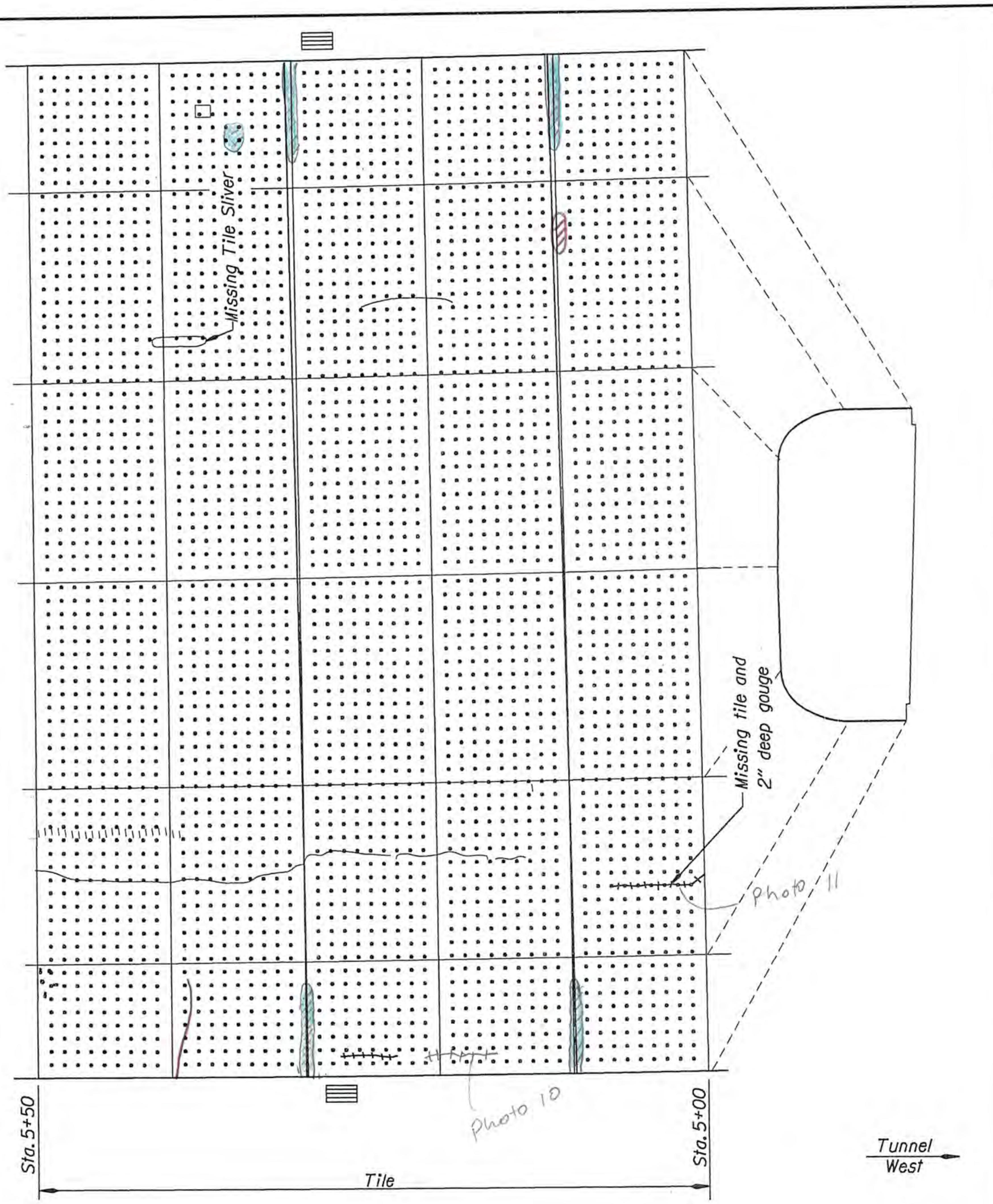


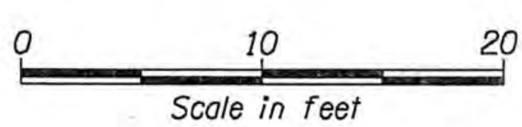
VISTA RIDGE TUNNEL (WB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103B	Last Update Nov. 2010

Tunnel - Sta 4+50 to 5+00



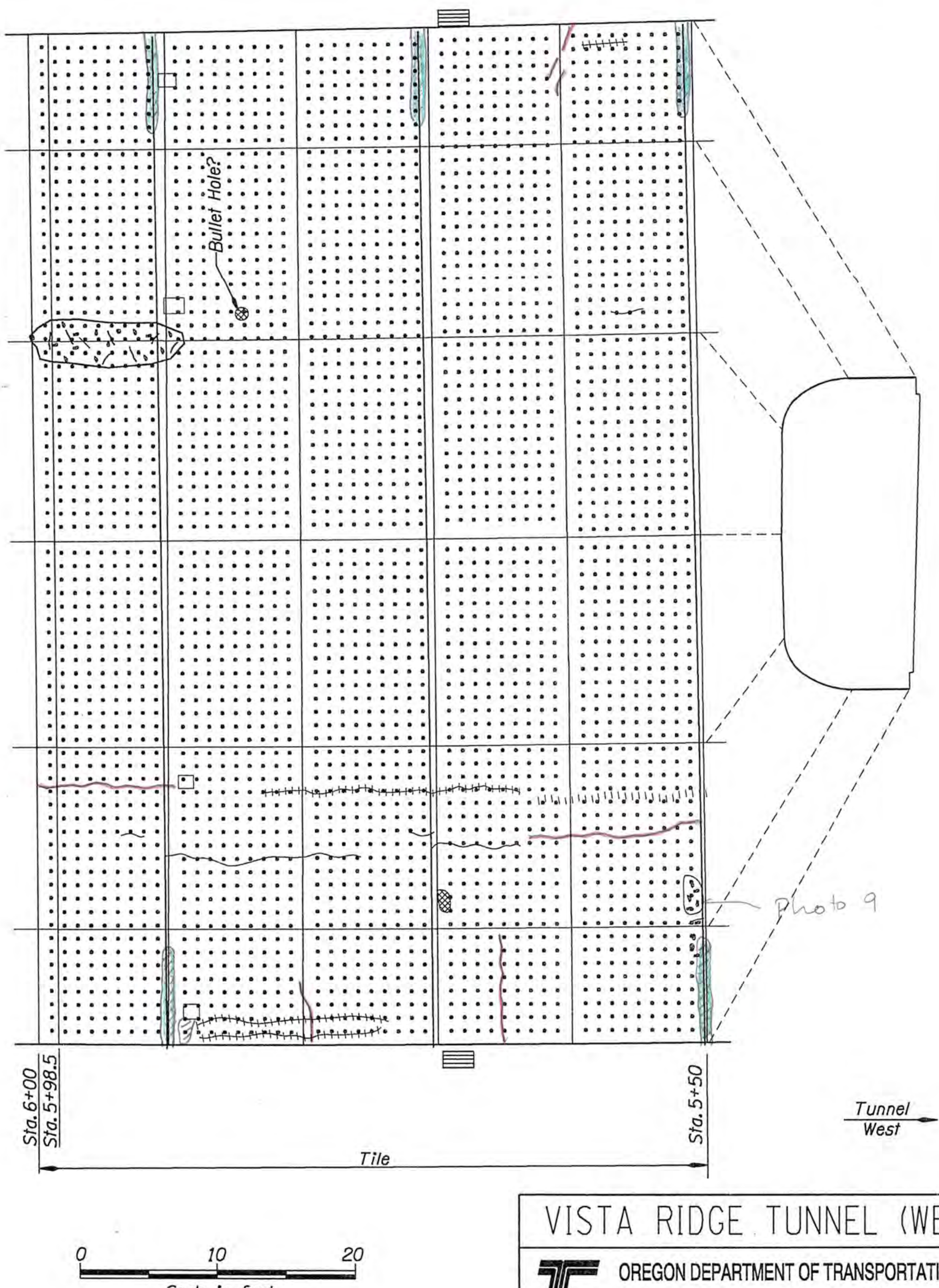


VISTA RIDGE TUNNEL (WB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103B | Last Update Nov. 2010

Tunnel - Sta 5+00 to 5+50

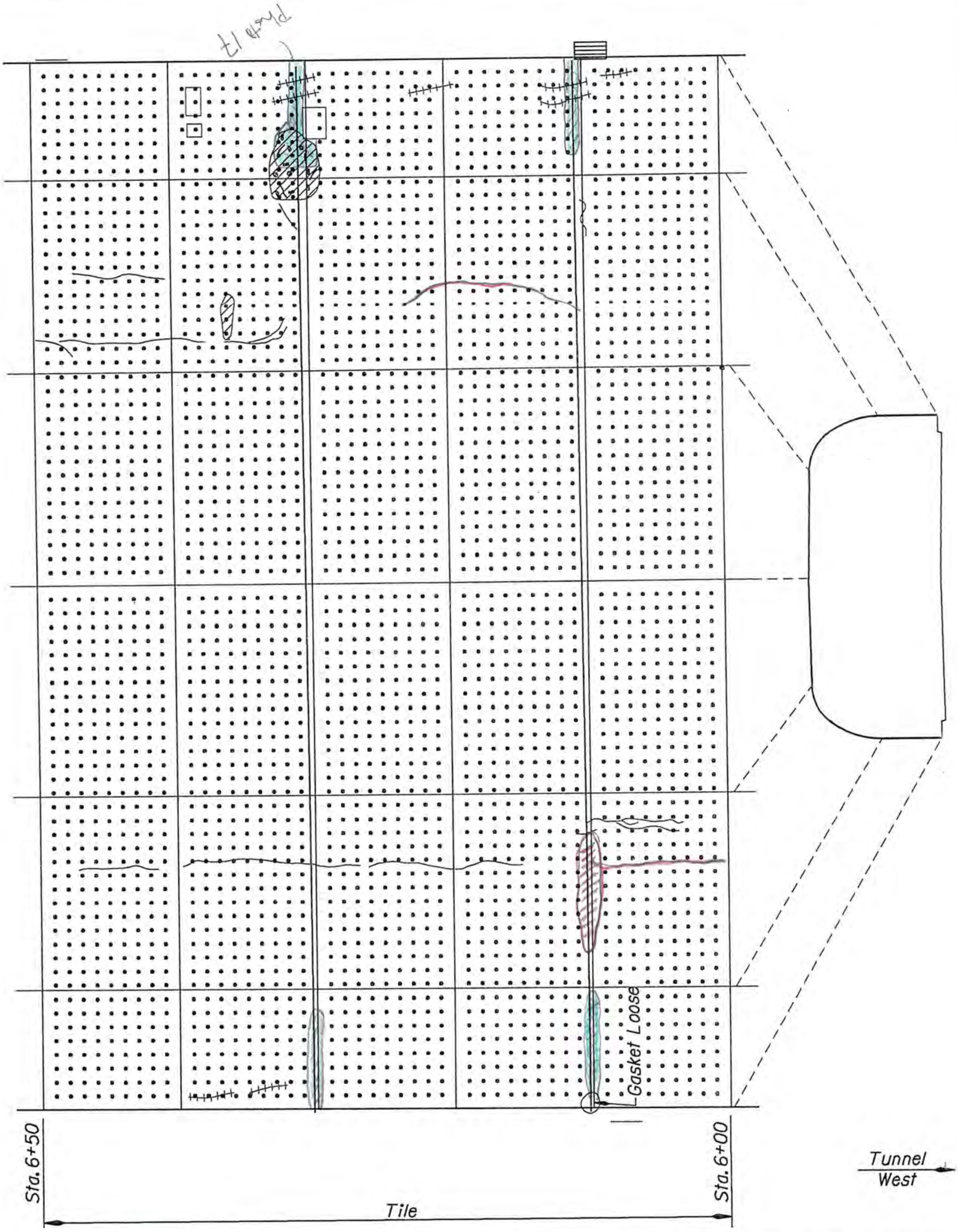


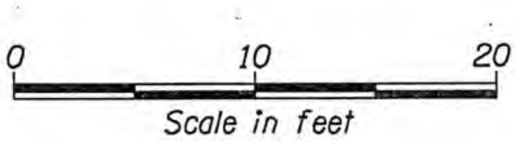
VISTA RIDGE TUNNEL (WB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103B	Last Update Nov. 2010

Tunnel - Sta 5+50 to 6+00



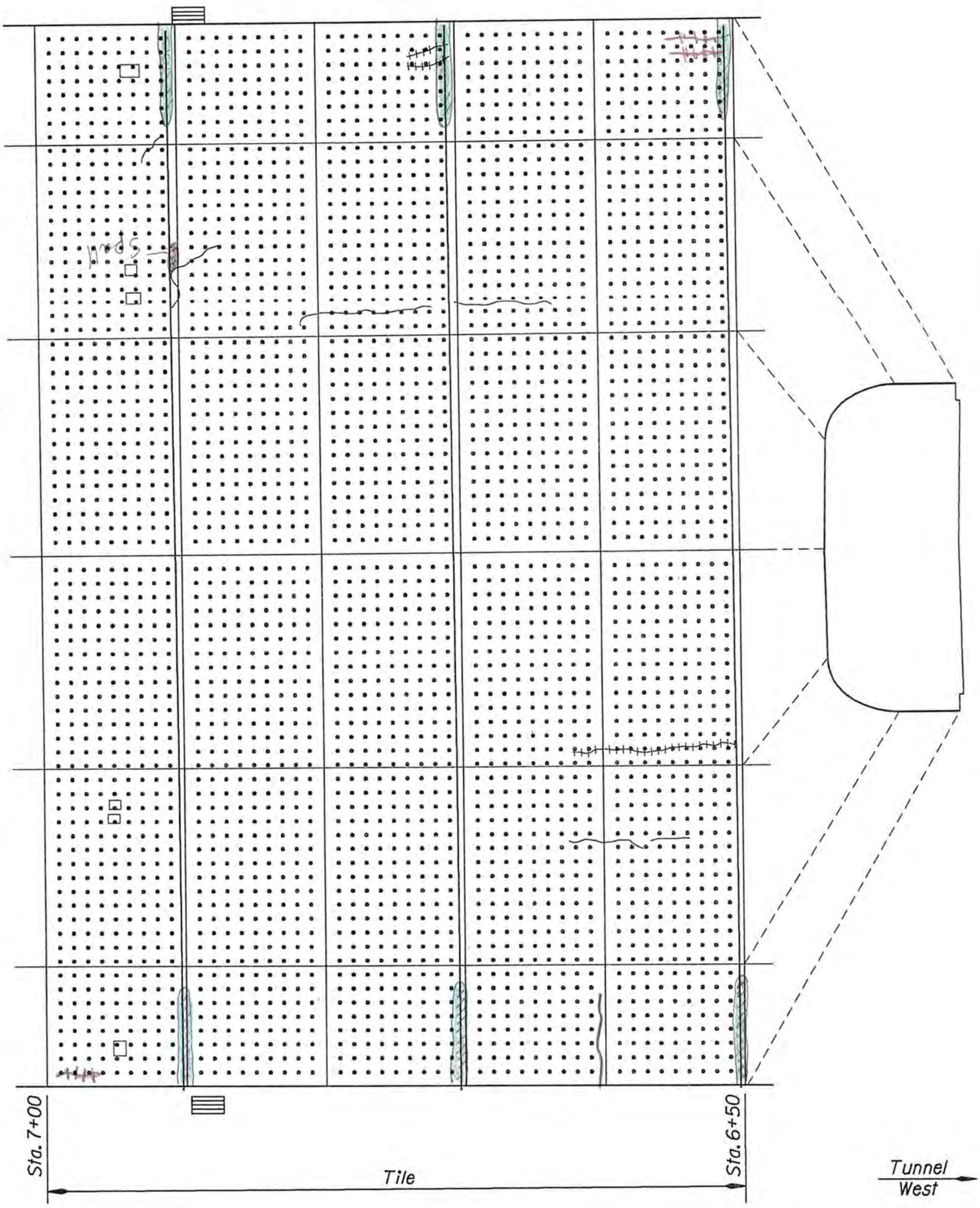


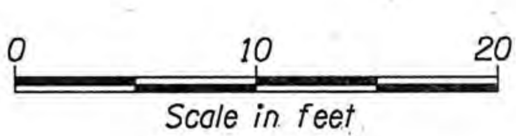
VISTA RIDGE TUNNEL (WB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103B | Last Update Nov. 2010

Tunnel - Sta 6+00 to 6+50



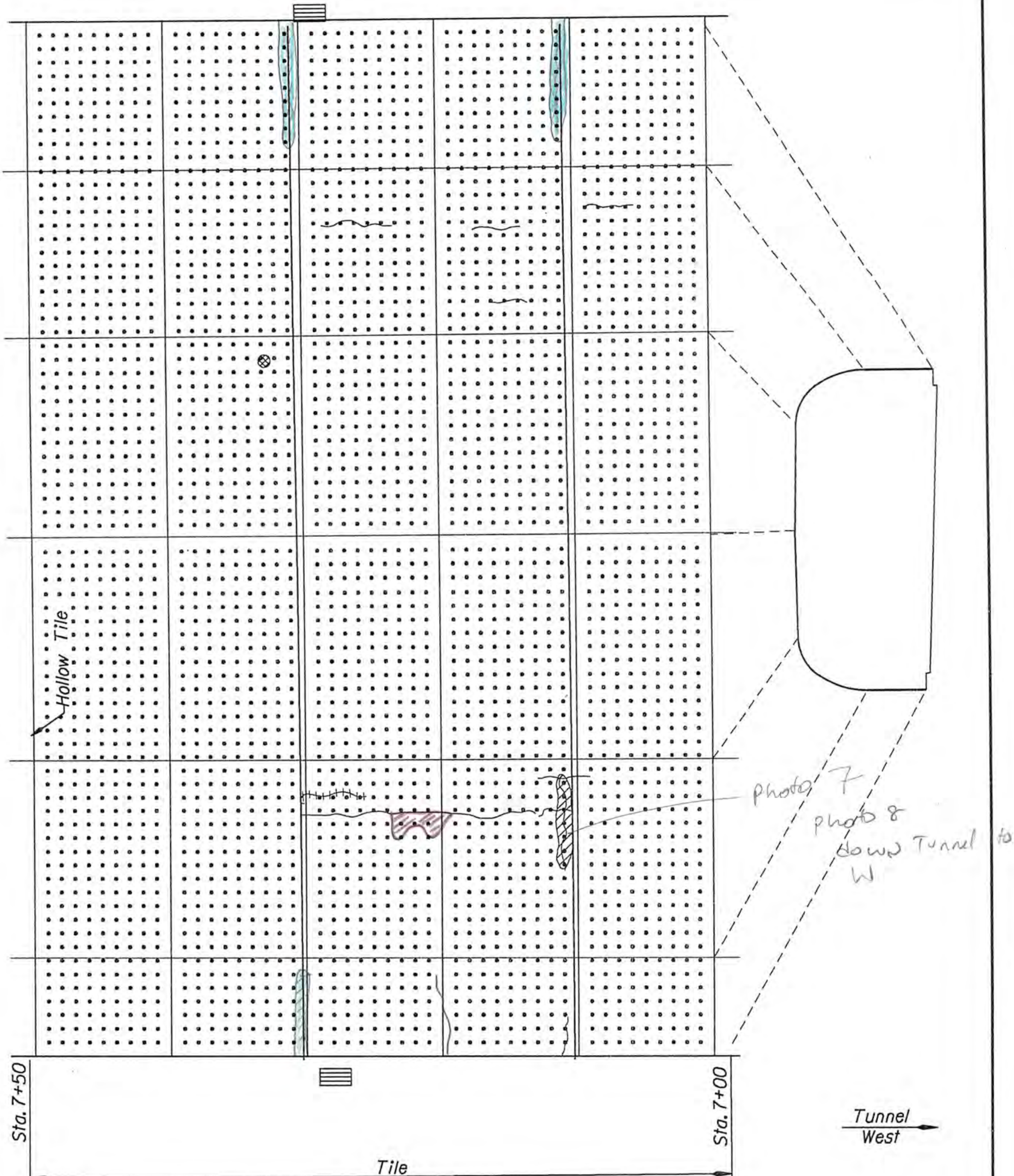


VISTA RIDGE TUNNEL (WB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103B	Last Update Nov. 2010

Tunnel - Sta 6+50 to 7+00



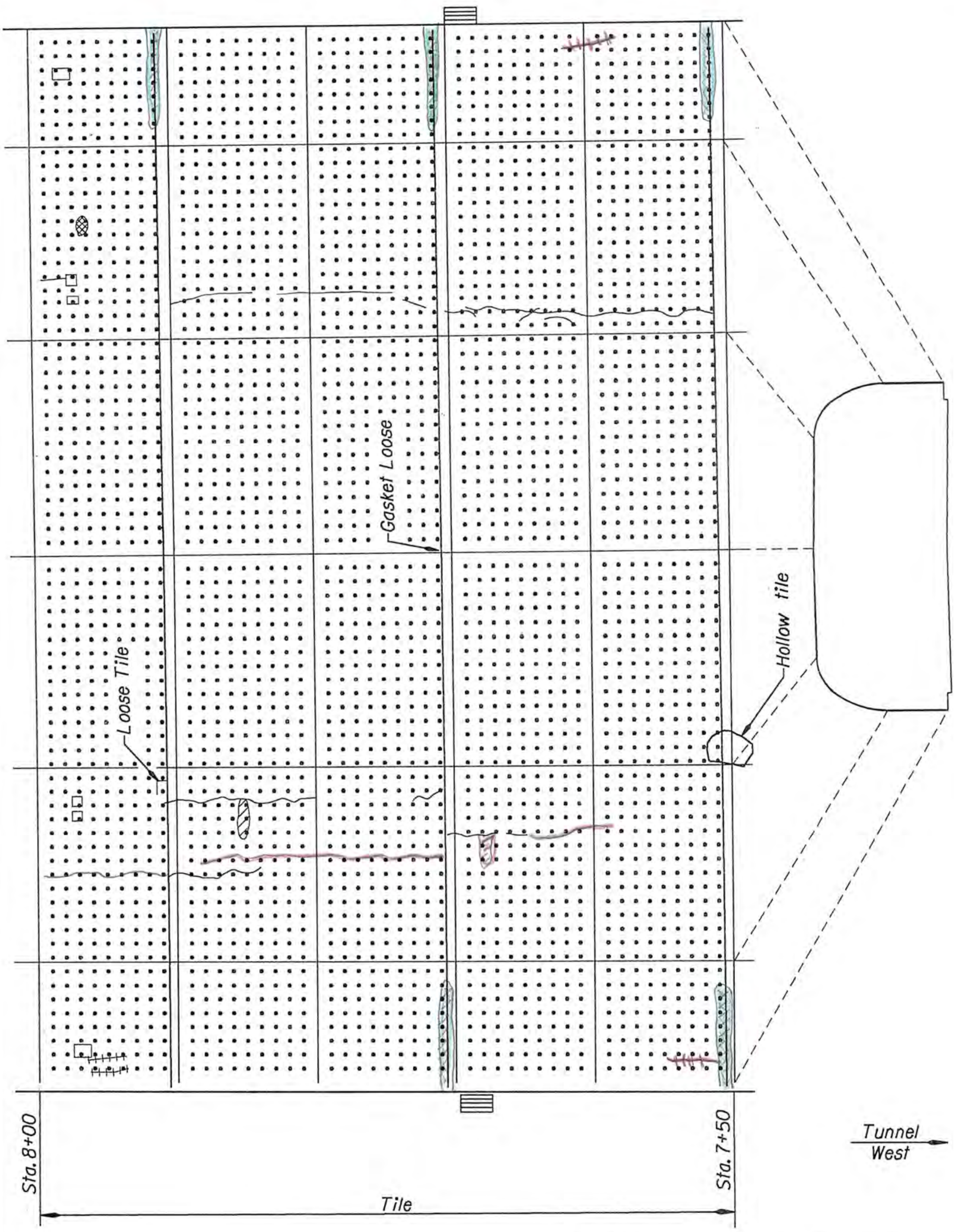
0 10 20
Scale in feet

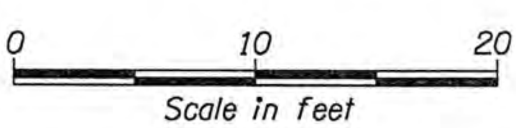
VISTA RIDGE TUNNEL (WB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103B | Last Update Nov. 2010

Tunnel - Sta 7+00 to 7+50



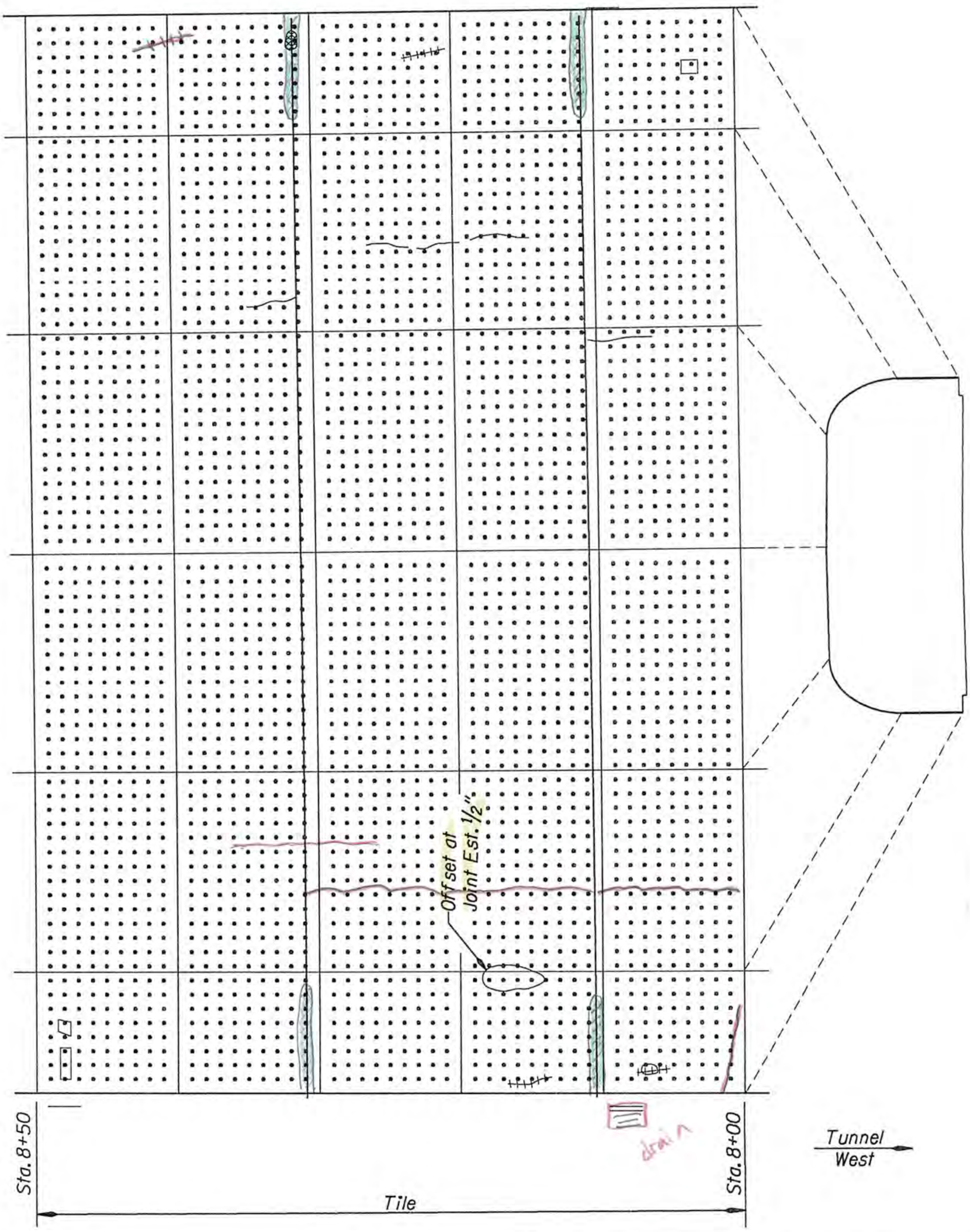


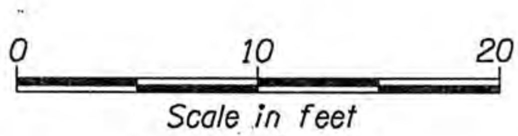
VISTA RIDGE TUNNEL (WB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103B	Last Update Nov. 2010

Tunnel - Sta 7+50 to 8+00



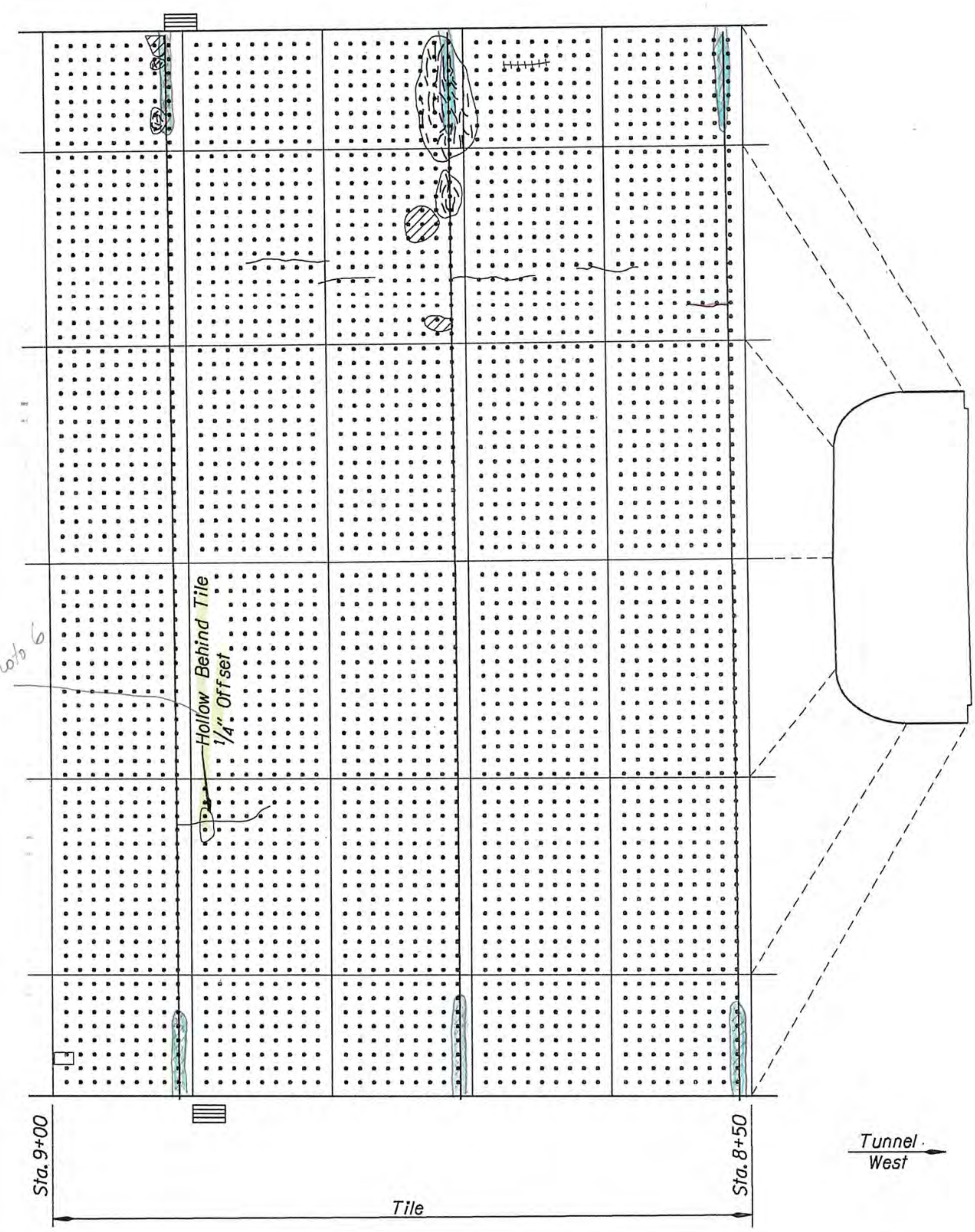


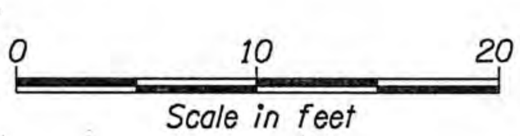
VISTA RIDGE TUNNEL (WB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103B | Last Update Nov. 2010

Tunnel - Sta 8+00 to 8+50



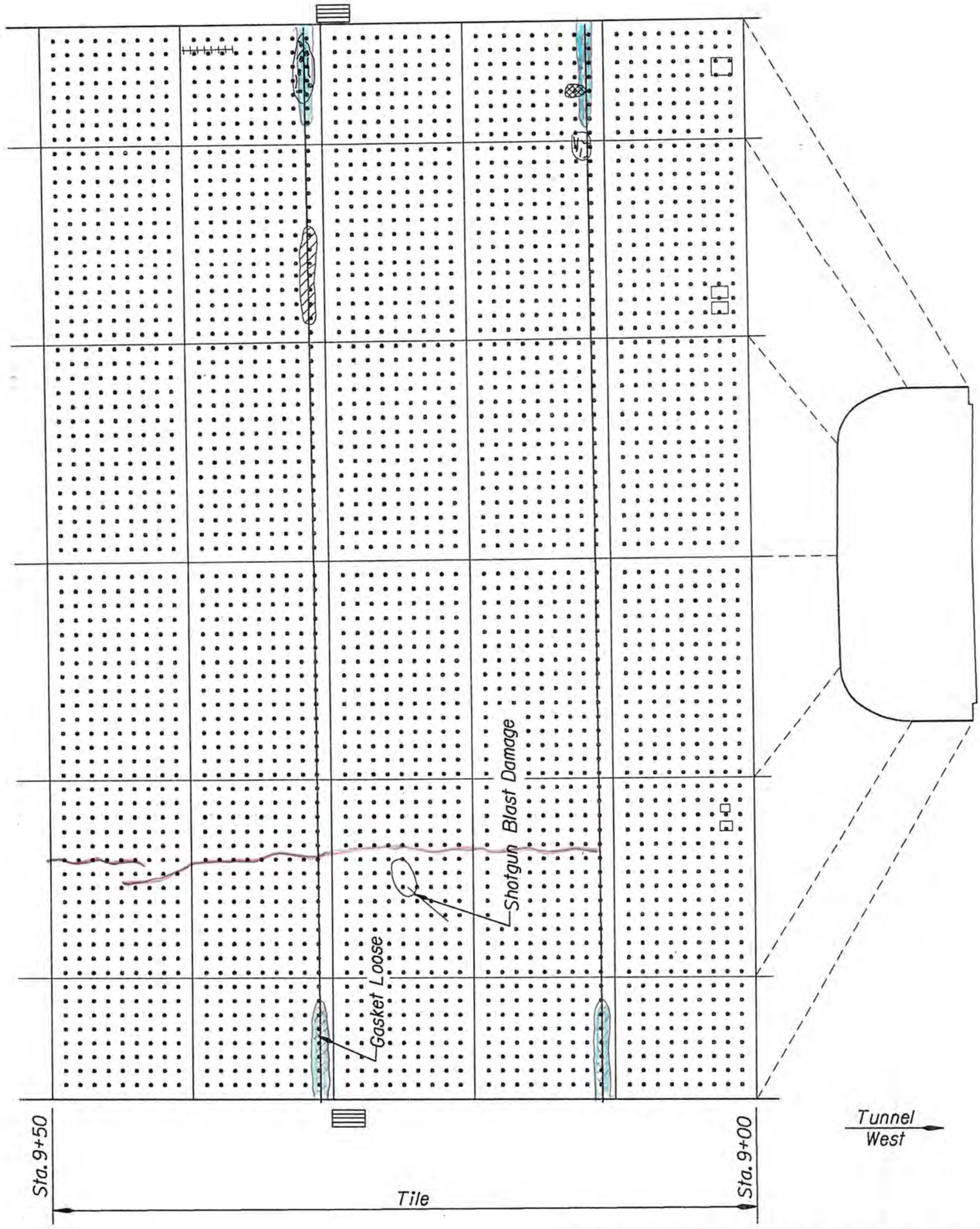


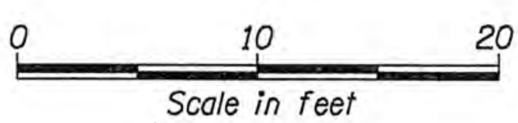
VISTA RIDGE TUNNEL (WB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103B	Last Update Nov. 2010

Tunnel - Sta 8+50 to 9+00





VISTA RIDGE TUNNEL (WB)

OREGON DEPARTMENT OF TRANSPORTATION

Bridge Operations Unit - Tunnel Maps

Structure No. 09103B	Last Update Nov. 2010

Tunnel - Sta 9+00 to 9+50

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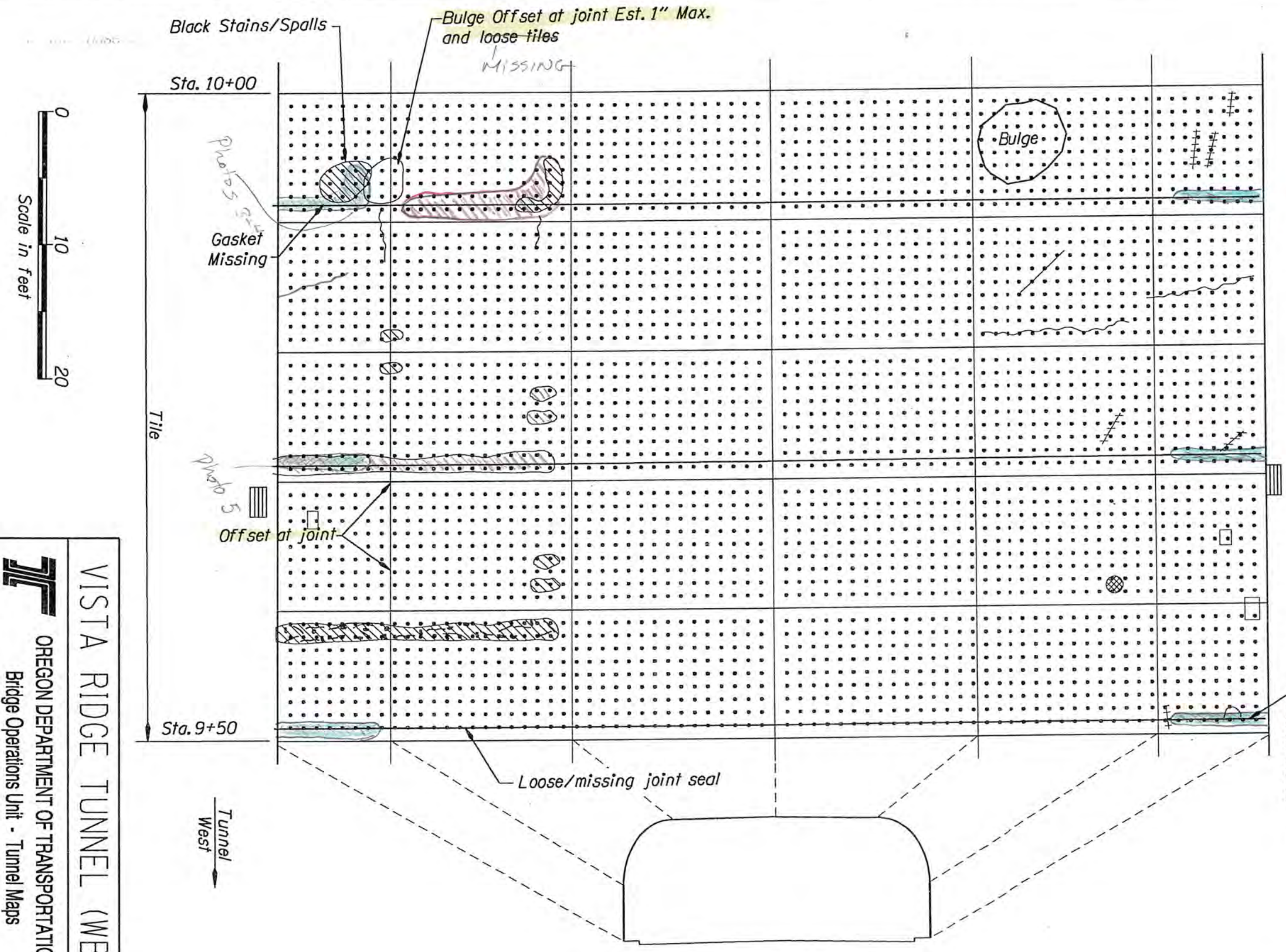
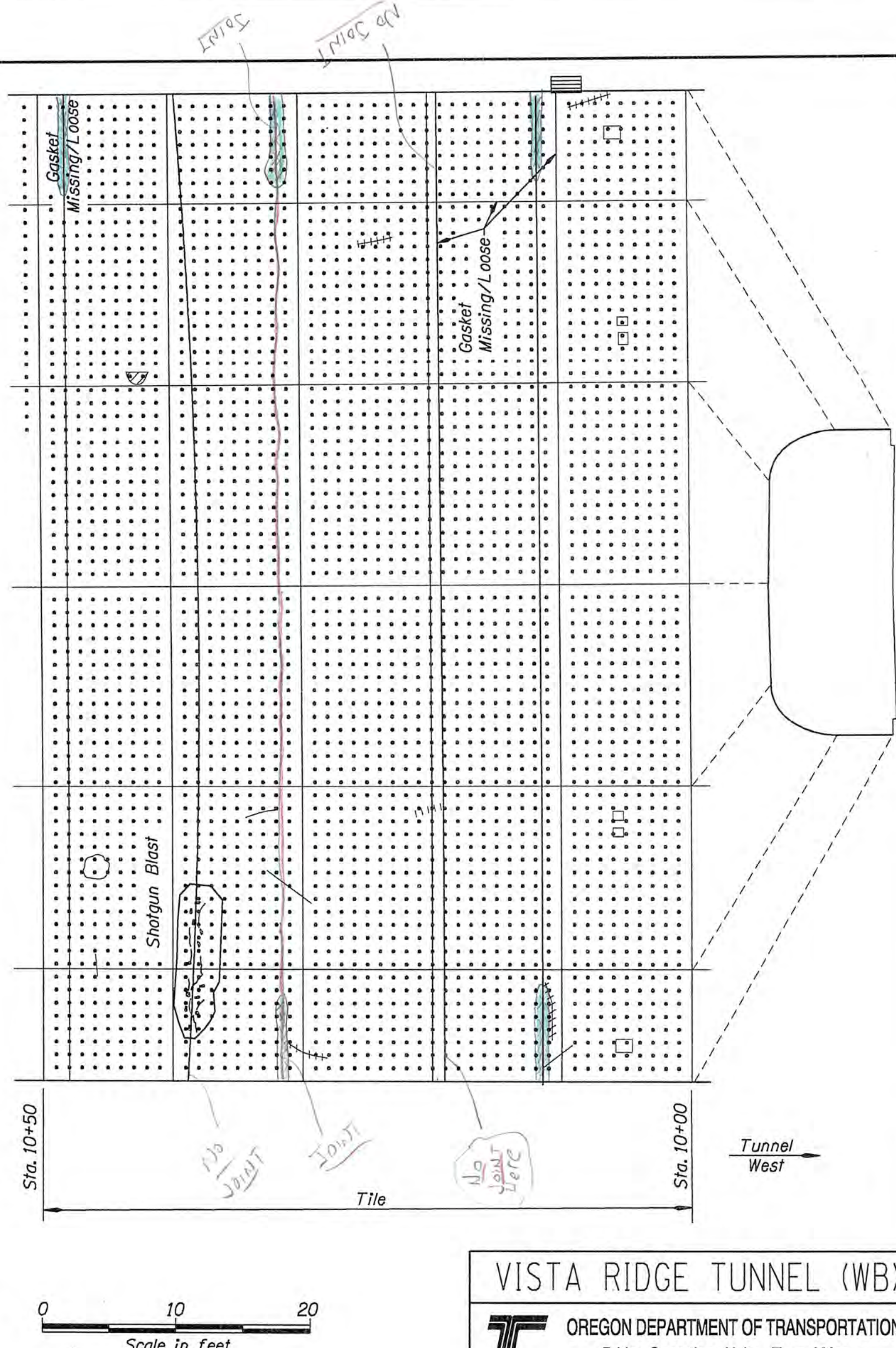


VISTA RIDGE TUNNEL (WB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103B | Last Update Nov. 2010

Tunnel - Sta 9+50 to 10+00

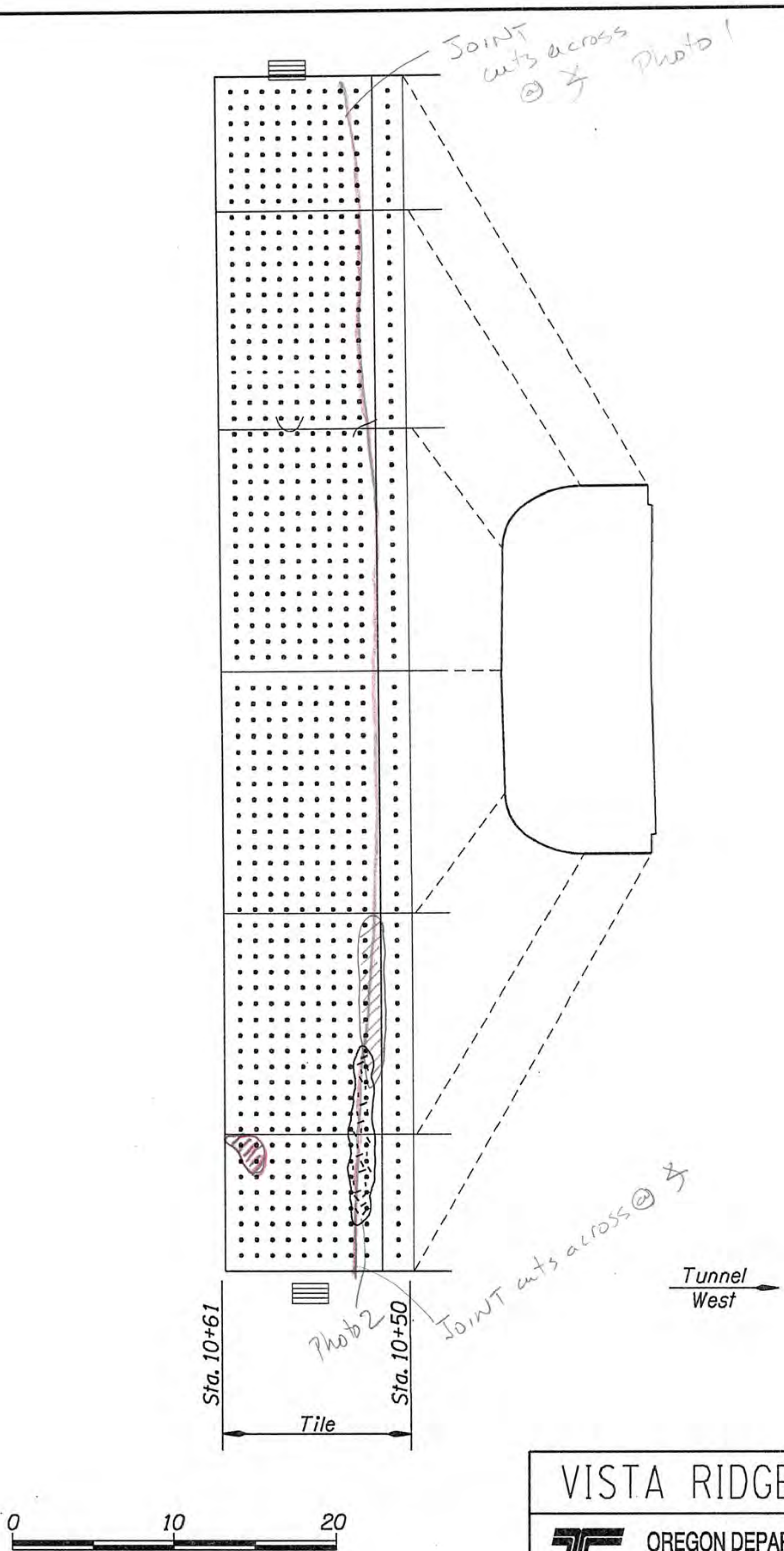


VISTA RIDGE TUNNEL (WB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103B	Last Update Nov. 2010

Tunnel - Sta 10+00 to 10+50



VISTA RIDGE TUNNEL (WB)

OREGON DEPARTMENT OF TRANSPORTATION
Bridge Operations Unit - Tunnel Maps

Structure No. 09103B	Last Update Nov. 2010

Tunnel - Sta 10+50 to 10+61