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HIGH-PERFORMANCE INSPECTION VEHICLE FOR TUNNEL LININGS & RAILWAYS.

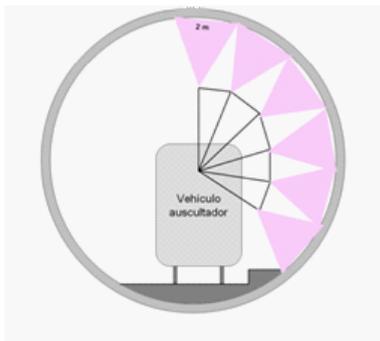
TUNNELINGS

INSPECTION - MAINTENANCE - MONITORING - SOLUTIONS

HIGH-PERFORMANCE INSPECTION VEHICLE FOR RAILWAYS AND TUNNEL LININGS.

The vehicle developed by Euroconsult and Pavemetrics and described below, is a tunnel inspection system based on cameras with laser line illumination that allows for the scanning of tunnel wall linings at speeds up to 30km/h. Compared to other equipment based on LiDAR (laser imaging) technology which operates at very low (walking) speeds, this system enables long tunnels to be inspected in short periods of time and with much higher resolutions. This rapid tunnel condition assessment capability allows inspections to be performed more frequently on a regular basis. The software of the Tunnelings system also allows the data from two different inspection runs to be rapidly compared, and structural changes and all types of wall lining defects to be assessed.

The measurement cameras for the condition survey are installed on a bimodal (road-rail) all-terrain truck approved by the railway authorities which provides rapid travel speeds



and flexibility to cope with different types of tunnels and infrastructures. The vehicle comprises all the systems necessary for safe road and rail travel (lane occupation indicator, speed governor, electric power supply for all systems, signalling equipment etc.). The structure which carries the laser cameras used for the inspection is fitted on the truck bed and a hydraulic system could be used to position its arms to that the system matches the geometry of the tunnel as the inspection progresses.



View of the side sensors which inspect the sidewalls.

The vehicle can hold up to 6 laser cameras. Each pair of “laser beam-digital camera” units, supplied by the Canadian company Pavemetrics, inspects a 2m wide section with an accuracy of 1 mm. Using the six cameras, tunnels 9 m in diameter can be inspected at the system’s maximum resolution. For example, using three pairs of units (i.e. six laser cameras) an arc with a circumference of 12 m, which is equivalent to virtually half the perimeter of the tunnel (side walls and keystone), can be completely covered, as demonstrated in the drawings and images.

The entire perimeter of the tunnel can be covered in two runs, one on each side. The bottom part of the tunnel where the track or road is located is currently not covered. An overlap occurs at

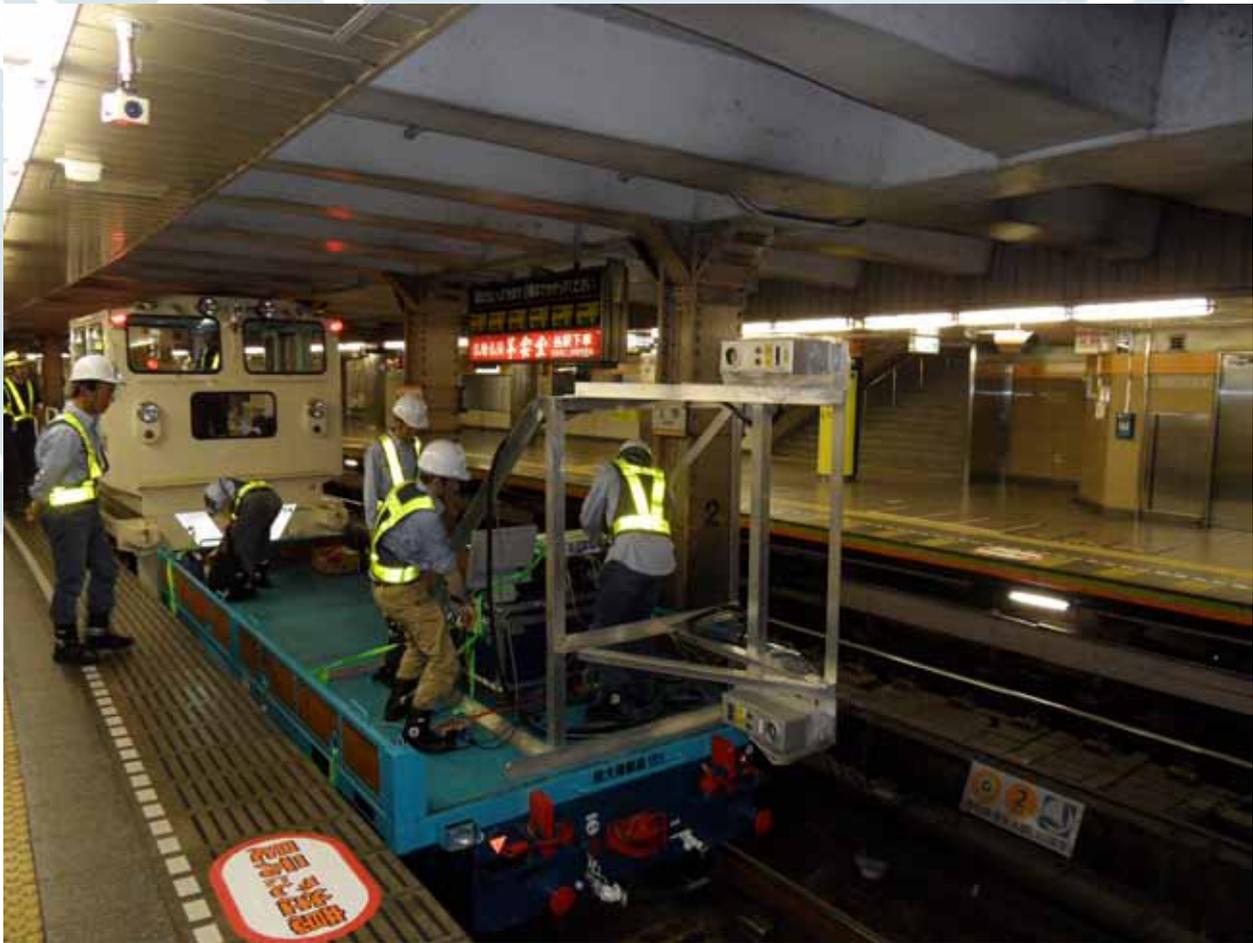
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the keystone so that the entire tunnel can be reconstructed and the two runs merged together with precision.

In addition to the system which enables the distance between the cameras and the tunnel lining to be continually modified, the sensors have also been configured so that they can scan curved surfaces and still operate within their measurement range.

In places where the geometry of the tunnel greatly differs from its theoretical geometry, the system adjusts its position during the acquisition run to ensure that high quality images continue and 3D depth data can always be obtained.

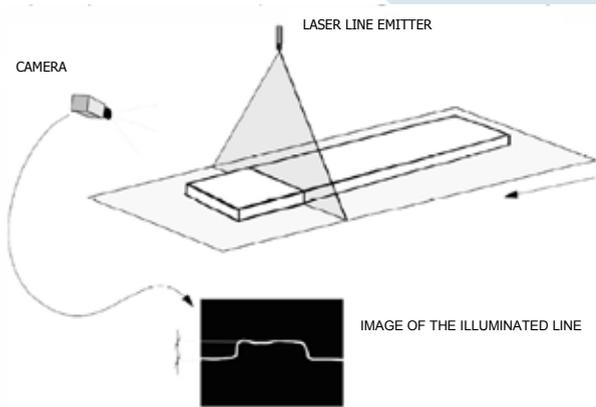


System installation for the inspection at Tokyo's underground wall, Japan.



PRINCIPLES OF THE INSPECTION SYSTEM

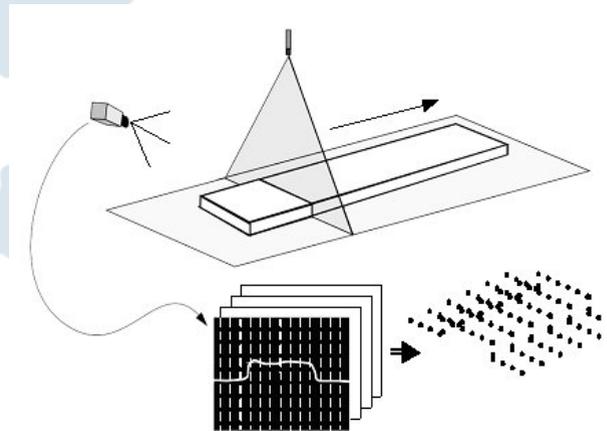
The software used to inspect the condition of the tunnel linings is based on image analysis and computer vision techniques. The captured high-resolution images of the surface of the lining illuminated by laser emitters enable cracks, damage, and moisture etc. to be detected and analysed. Relative displacements between assembled segments can also be monitored in both the longitudinal and transverse direction.



The 3-D information is extracted using the principle of triangulation which is shown in the previous image. Using this technique, a pattern of known illumination, a line in this case, is projected from the laser onto the object to be inspected. The line is recorded by a digital camera positioned a fixed distance away at an oblique angle relative to the projected light. The intersection between the pattern of emitted light and the field of view of the digital camera defines the range of operation of the 3-D sensor. The positions of the illuminated points on the surface of the object are displayed in the image obtained by the camera and the distance between these points and the camera can be calculated using trigonometry.

The system uses high-speed, high-resolution digital cameras in conjunction with high power laser line projectors aligned in the same transverse plane. This configuration offers various advantages compared with other, more conventional image analysis techniques.

Its most important feature is an optical configuration which facilitates the detection of cracks and damage ensured by the 3-D information obtained from the inspected surface.



The data collection process based on this measurement principle is summarised below:

- The surface to be inspected is illuminated by a line-emitting laser and an image of the area surrounding the illuminated line is captured by a high-resolution digital camera.
- The line on a horizontal plane surface is likely to be a horizontal straight line but if the surface has irregularities the line will deviate from the straight line.
- The transverse profile is obtained in the image and the surface is reconstructed in three dimensions by joining the profiles.

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Equipment being used on a track, front view.

This technique enables high-quality digital images and superimposed 3-D information to be obtained in a single capture, as shown in the following diagram of the inspected surface.

High-quality digital images and a 3-D reconstruction of the inspected area are obtained from the capture. The provision of 3-D information facilitates the analysis of the information when damage is found in the tunnel's surface and enables movements between assembled segments and deformations in sprayed or in situ concrete to be located and assessed.

The following are examples of defects which can be automatically detected using this 3-D image capture system in con-



junction with an intensity image:

- Cracks and areas with lining missing or spalling.
- Damp areas and seepage which could affect the lining.
- Areas with poorly assembled segments, protruding edges or poor workmanship.

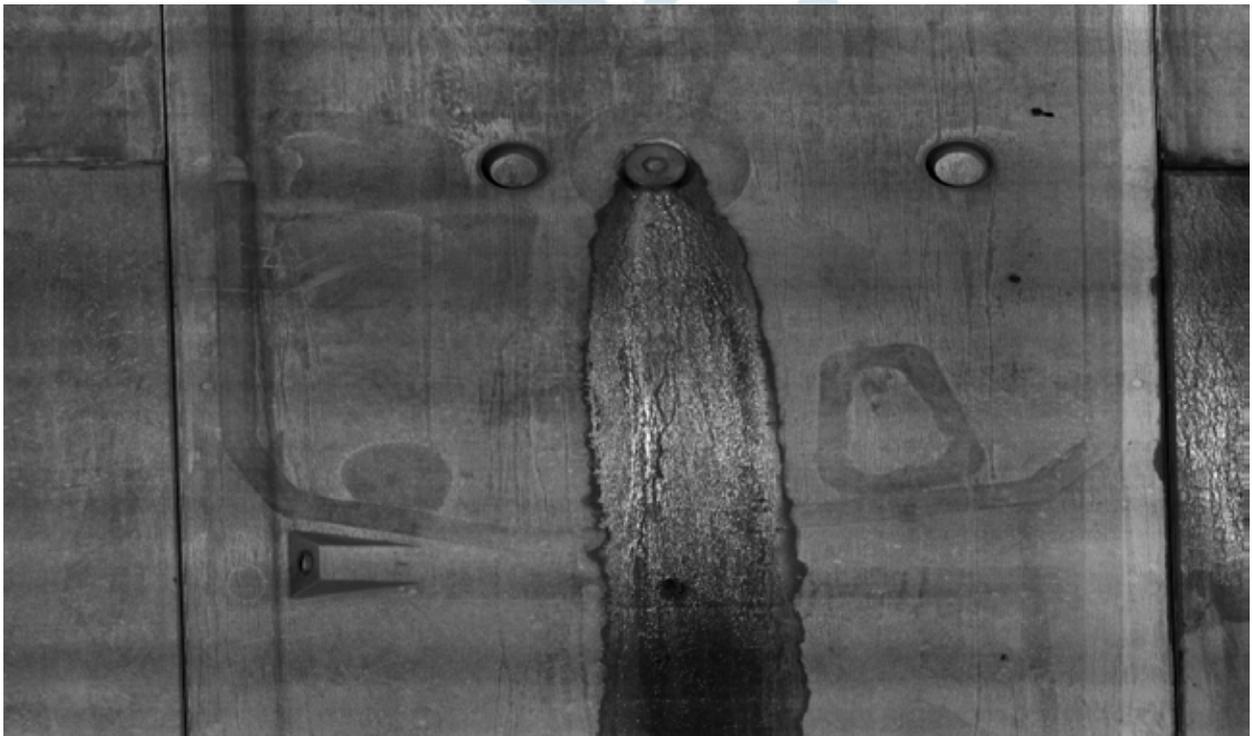
The following modifications have been made to the equipment in order to ensure that high quality images and profiles are obtained:

- The equipment has been altered so that measurements can be taken on both planer and curved tunnel surfaces such as circular assembled segments
- The sensor's sensitivity range has been modified so that, combined with the previous feature, the variation in distance

between the sensor and the lining can be significantly altered along the section to be inspected taking account of banking, galleries, sunk areas, etc.

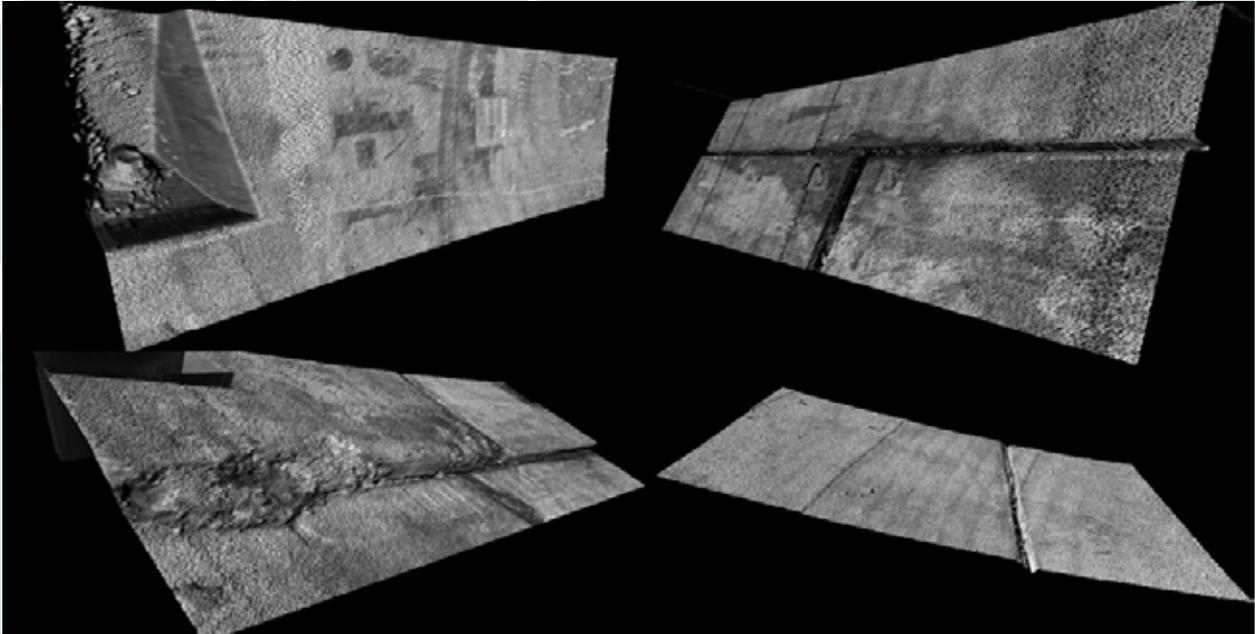
- Cameras have been installed so that they can pass over features such as catenary wires while maintaining a resolution of 1 mm x 1 mm in the image.

- Analysis and interpretation software has been developed so that results appropriate for tunnel condition surveys are obtained.



High-quality digital images of the tunnel's lining with a resolution of 1 mm.

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3D reconstruction



FEATURES OF THE SYSTEM

COMPONENTS

The standard data capture system comprises the following components:

- a. Laser line illuminator
- b. Digital scanning camera
- c. Control electronics

SPECIFICATIONS

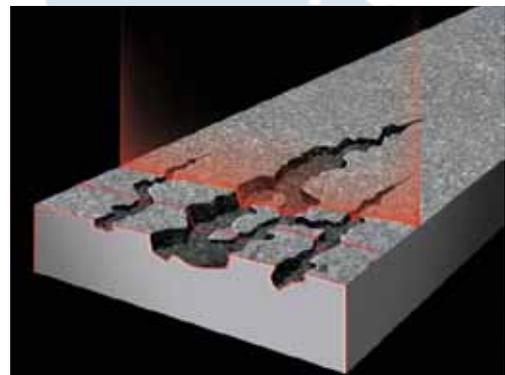
The system's main specifications are as follows:

- 2D area images of 1024 x 4096 pixels
- Capture speed : 28 images per second
- Image width: 4 m
- Transverse profiles: 4 m wide
- Capture speed: 2 800 profiles per second
- Number of points per profile: 4 096

The following resolutions are obtained with this system at 30 km/h, for example:

- For images:
 - Longitudinal: 1 mm
 - Transversal: 1 mm
- For profiles:
 - Longitudinal: 1 profile every 1 mm
 - Transversal: 1 point every 1.0 mm
 - Radial (depth): 0.5 mm

The final product comprises several 3-D images which, in addition to greyscale intensity information of any 2-D image, contain information in a radial direction relative to the direction of the condition survey.



Transverse resolution
The number of points defines a profile
2048 points/profile

Longitudinal resolution
Profile capture speed
2800 to 8400 profiles/second

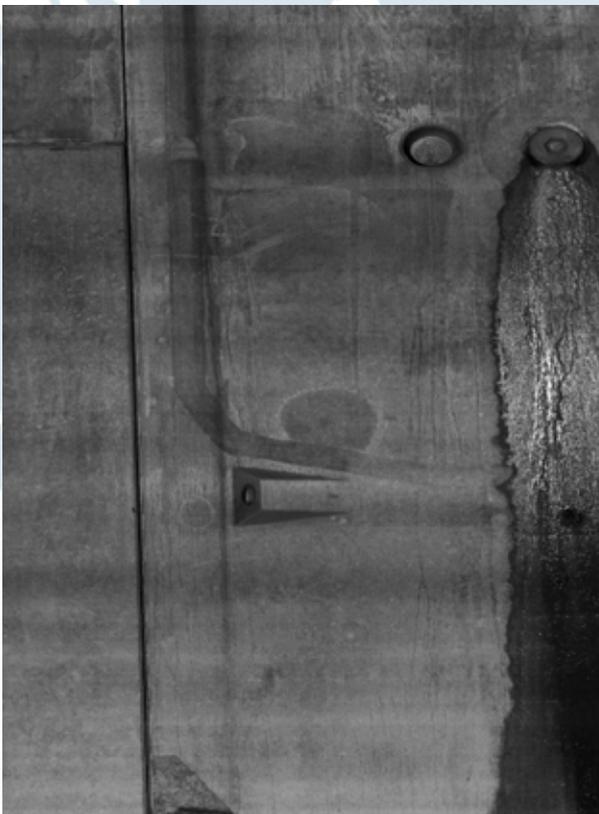
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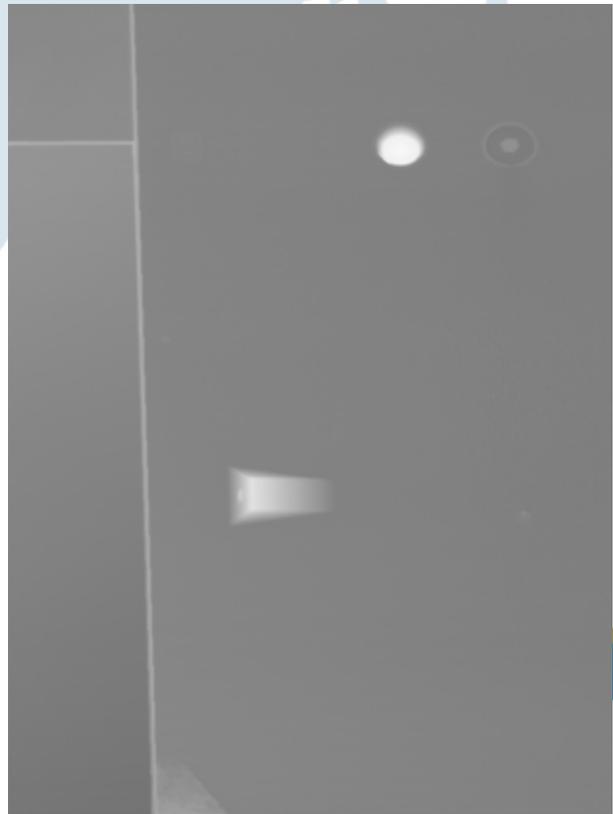
DATA PROVIDED BY THE SYSTEM

Several examples of the type of result obtained using the equipment during inspections are shown below:

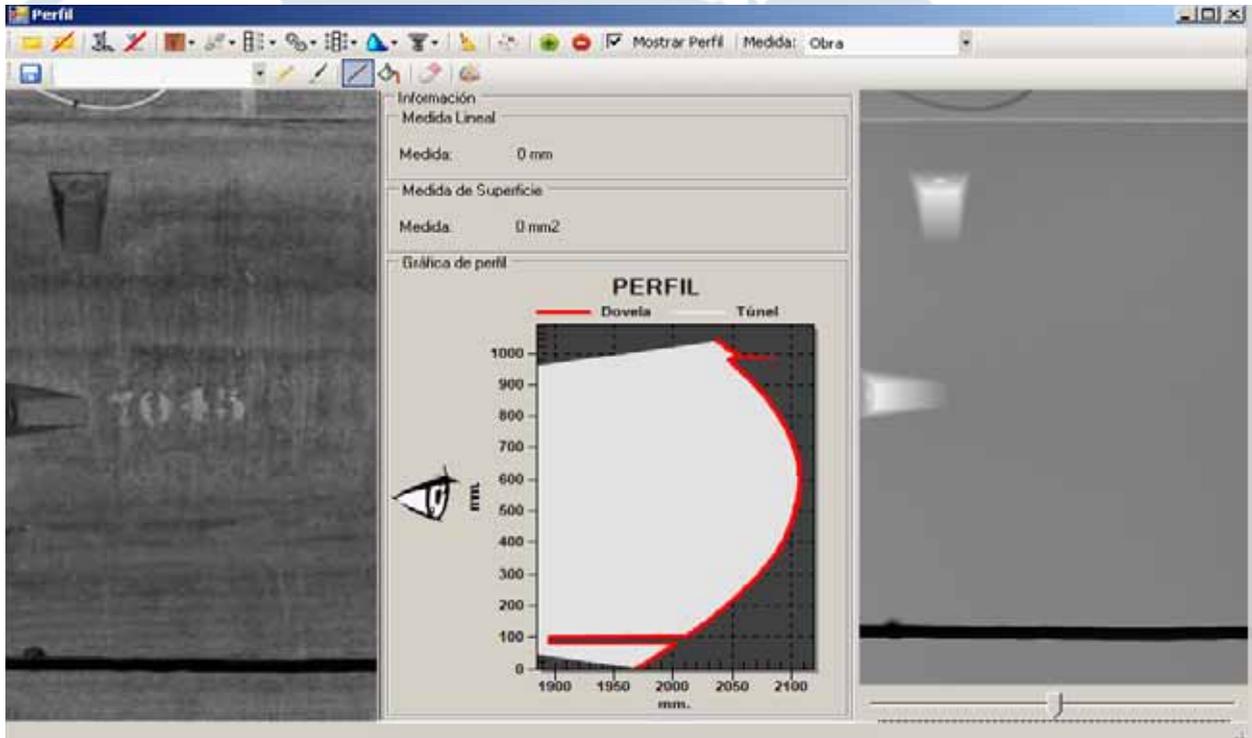
1.- High-quality digital images of the tunnel's lining with a resolution of 1 mm.



2. - Images showing the representation of the distance between the sensor as it moves along the tunnel and the lining every millimetre.



3.-Transverse sections of the lining (in the case of an image of assembled segments) obtained from the 3-D data information available.



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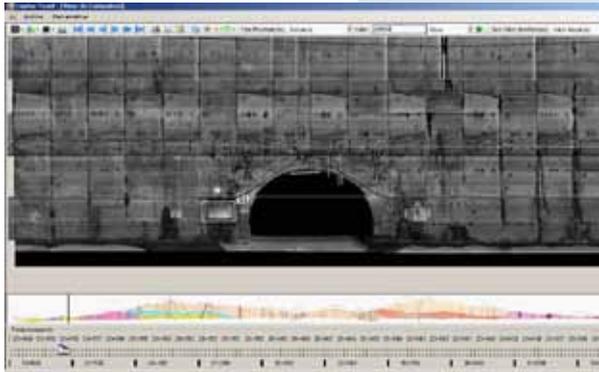


4. - Panoramic images taken using a camera positioned on top of the vehicle at the front synchronised with the collection of data from the laser sensors.

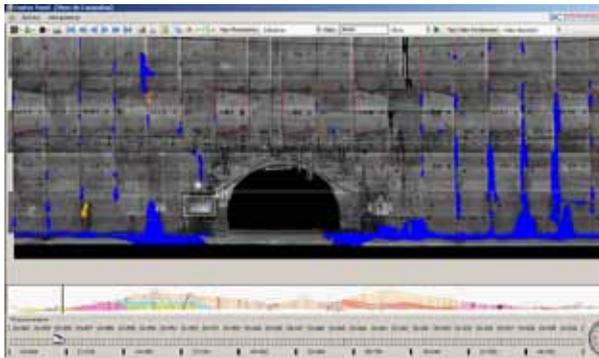


RESULTS DISPLAY SOFTWARE

An IT application comprising tools and utilities to combine all the images captured in both the longitudinal and transverse directions has been developed to display the results.



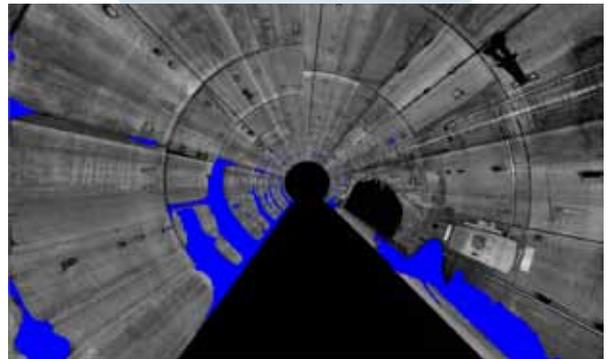
The following example shows how the complete middle section of the tunnel can be displayed following its inspection using six super-imposed cameras.



The application also enables the analysis of automatically analysed defects (protruding edges, damp, cracks etc.) and other defects manually entered following checking or verification by the engineer in charge of the inspection, to be super-imposed. All analysis data are stored in a database which can be rapidly consulted.



An option has also been included to produce a 3D representation of the tunnel and show the high-resolution digital images recorded during the capture together with the results of their analysis: cracks, damp and protruding edges, by changing the observation observer's view point to focus on sidewalls, shoulders or keystone.

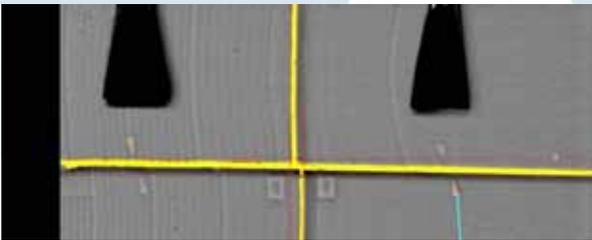


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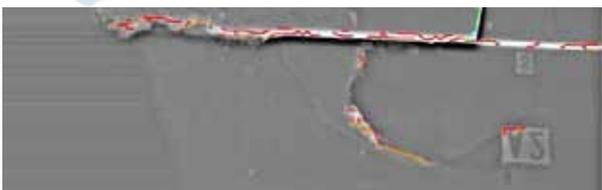
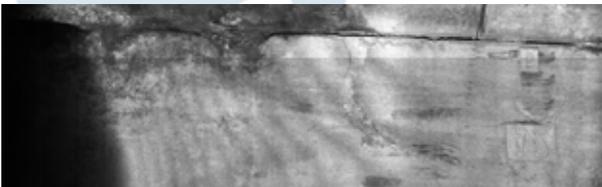
DATA ANALYSIS

Some of the algorithms developed to detect certain common defects in tunnels are shown as an example, but a very large number of options are available for detecting other defects using 3-D imaging.

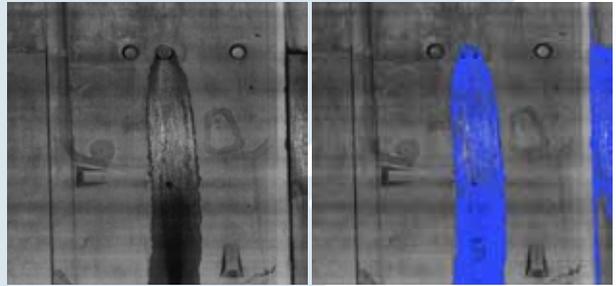
1. Joints between assembled segments so that the presence of protruding edges can be detected (and the offset of assembled segments calculated).



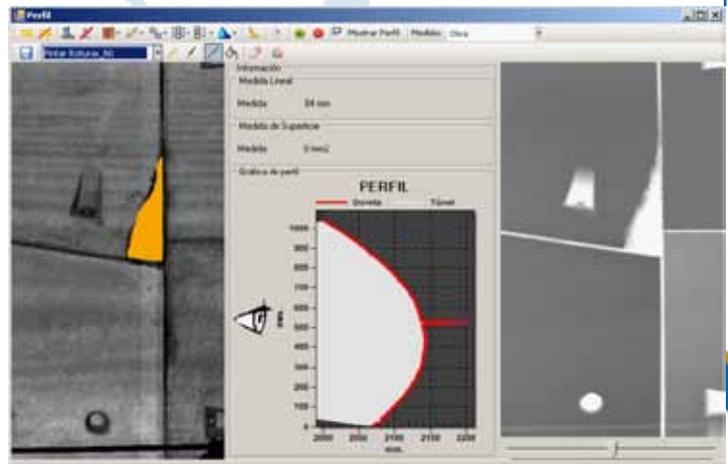
2. - Presence of fissures and cracks.



3. - Presence of damp.



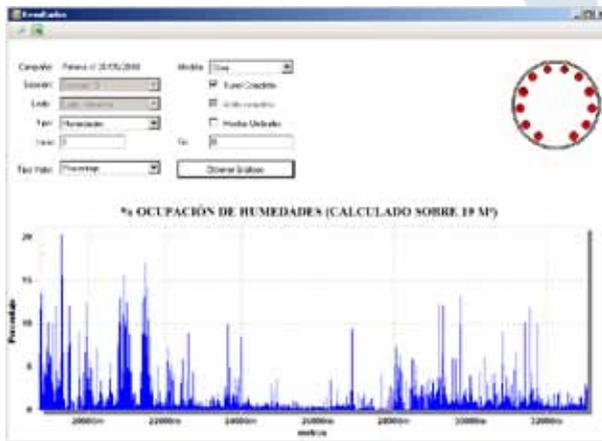
4.-Transverse sections for detecting “empty” areas in the interiors of the surfaces of assembled segments, for example, anchorages and injection tubes.



STATISTICAL ANALYSIS

Using the computer application developed, statistics can be extracted and displayed for the inspected tunnel as a whole or for individual sections, which can be subsequently used to draw conclusions about the overall condition of the tunnel. Results may be shown in graphic form or as reports in various formats. The presentation of results can be set by the user. Two inspections carried out on different days can be displayed and compared as captured images or analyses results.

The following figure shows an example of a calculation of the percentage of damp areas in the entire cross-section along the tunnel with distance related to the site's PPKK levels.

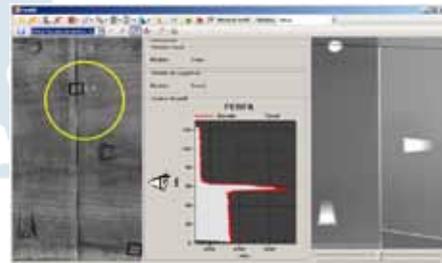


If several inspections are carried out, changes over time in the defects found can be studied.

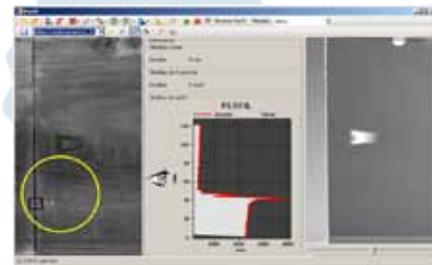
The following information may be obtained, for example, from a statistical analysis of the data collected:

1.-Sections in the tunnel where the protruding edges between assembled segments are the largest.

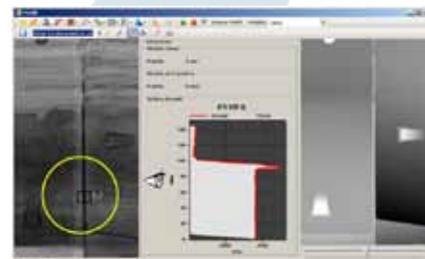
Low
(maximum offset between rings < 10 mm)



Moderate
(maximum offset between rings > 10 mm y < 30 mm)



High
(maximum offset between rings > 30 mm)



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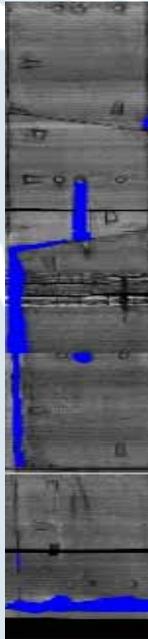
2.-Areas where the presence of moisture in the surface of the assembled segment is most relevant.

3.-Sections where most cracks have been found in assembled segments.

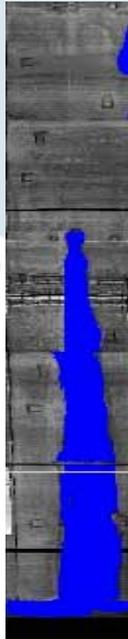
Low
(Damp area
< 5%)



Moderate
(Damp area
>5% y <15%)



High
(Damp area
>15%)



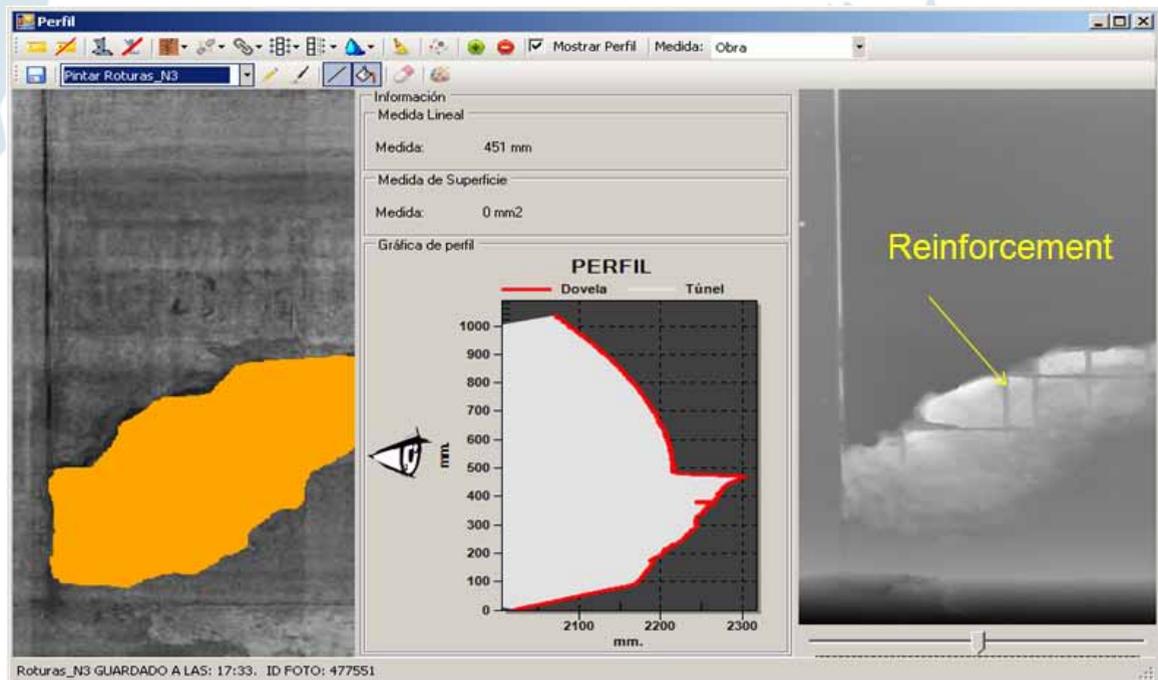
Low



Moderate



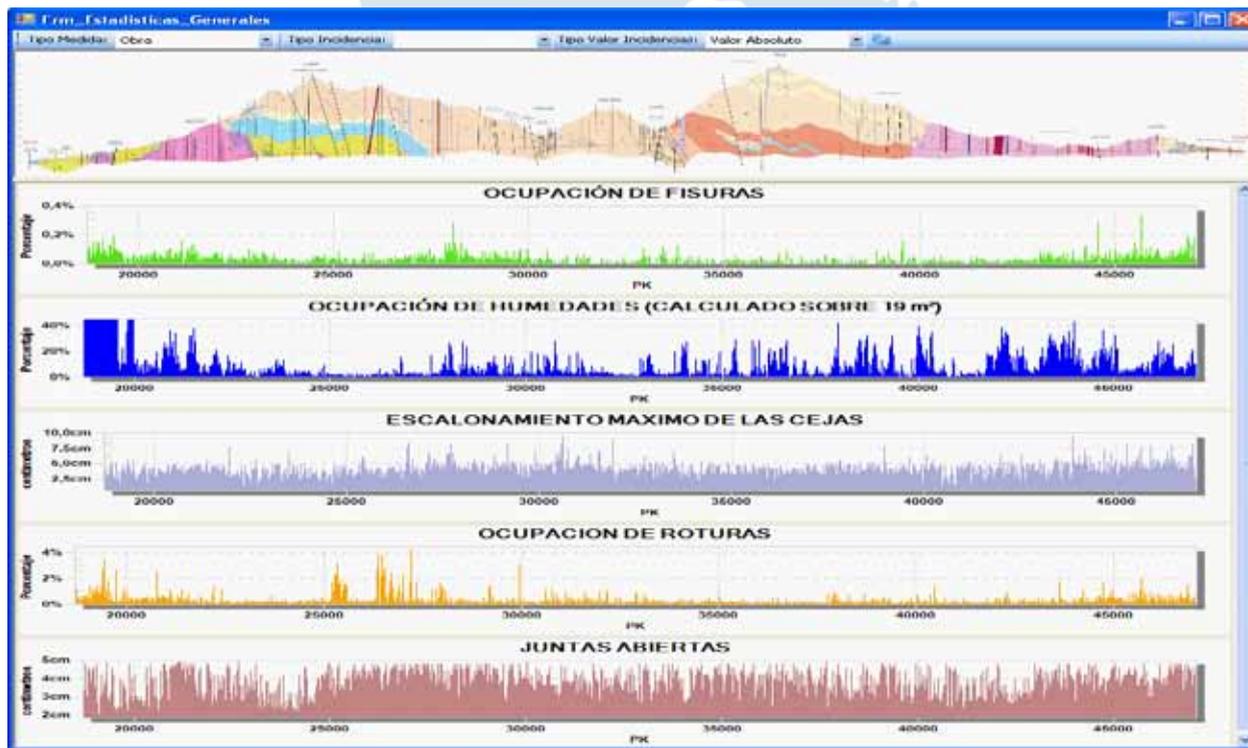
High



The results can be used to create tables that can help planning repairs of those defects observed and suggest solutions.

Euroconsult and Pavemetrics are companies specialised in the inspection, condition analysis and surveying of transportation infrastructures.

Tunnelings is a tool developed to aid Geotechnical engineering and tunnel project management and the maintaining of tunnels operational. Both capture and analysis were aimed at providing solutions to the large underground infrastructure industry, in particular the maintenance and monitoring of such infrastructure during its service life.



The same system allows the inspection of railways.



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