Managing Data from Instrumentation in the CEDEX Test Track

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Abstract

One of the main objectives of the Test Tracks is to determine the structural response of the pavements under particular load and environmental conditions. Structural response can be measured in terms of different variables, like deflection, stress or strain at certain significant points of the pavement structure. Other related environmental variables as temperature or moisture condition are typically measured as well.

A minimum number of sensors are required for any variable to be measured, since the variability of the response can be significant. Consequently, the number of sensors used in a pavement structural response assessment can be very high.

Response is typically determined for different conditions of load, speed, offset, temperature, number of cycles etc. This requires a very comprehensive planning for the measurements.

This paper presents the Software Program used in CEDEX Test Track to measure and manage the data from the six pavement sections of the facility. The Program enables the planning of measurements for specified conditions of speed, offset, pavement temperature, date or number of cycles, and the later treatment of the registered signals.

The Program can manage up to 256 sensors, and typically around 250.000 measurements are carried out in a complete test. This way, a detailed knowledge of pavement behavior under a wide variety of environmental or load conditions can be achieved.

Introduction

Accelerated Pavement Testing can be defined as the "controlled application of wheel loading to pavement structures for the purpose of simulating the effects of long-term in-service loading conditions in a compressed time period". There are twelve full-scale facilities operating in Europe and a similar number in the United States of America, besides other facilities in Mexico, Brazil, South Africa, Australia, New Zeeland, China and Japan. It can be stated that nowadays the Accelerated Pavement Testing constitutes a basic pillar of road research worldwide. There are two kinds of test facilities: circular and linear shaped.

Figure 1. Circular Test Track (LCPC France)

Figure 2. Linear Test Track (LINTRACK, Delf, Netherlands)

The CEDEX Test Track is in between, having two straight sections of 75m each, joined by two additional curved sections with a radius of 25 m. A rail beam located on the inside perimeter of the track serves as a guide for two automatic vehicles.

Considering that the six sections of pavements under test are installed on the straight segments of the track, this facility could be classified from the test point of view inside the second group of linear-shaped facilities. The total length traveled by the load test wheel is of 304 meters by cycle. The curved segments are not used for test purposes and are assigned to other studies like surface materials, surface treatments, paints, wearing paths, etc.

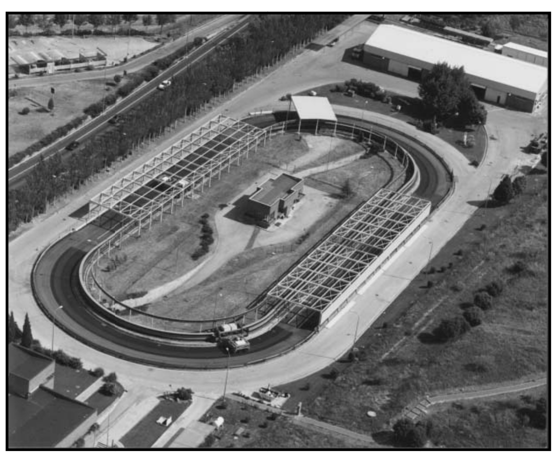

Figure 3. CEDEX Test Track

The testing of the pavement sections is carried out in the straight stretches, and therefore the results are comparable to those obtained in other linear test tracks. Six 20-25 m long complete pavement sections can be tested simultaneously.

Meanwhile the curved segments are based on the terrain; the straight segments are installed inside two watertight U-shaped test pits made out of reinforced concrete. The concrete test pit, 2.6 m deep and 8 m wide, enable the building of embankments of at least 1.25 m in height as well as the use of conventional machinery and the usual road-building procedures. The purpose of using concrete test pits is to isolate the performance of the pavements from that of the surrounding ground, allowing homogeneous support to the pavements throughout each test and between different tests in such a way that the results are comparable. It also allows the subgrade to be flooded for testing under different groundwater conditions.

The two test vehicles apply the load by gravity through a half heavy axle. The load can be fixed in between 5.5 and 7.5 Tons and is fixed at 6.5 Tons, equivalent to the maximum allowed load in Spain for a single axis (13 Tons). The suspension system is pneumatic. The test wheel is equipped with two twin wheels or one single balloon-shaped wheel at 8,5 Kg/cm2 inflating pressure. Both the suspension system so as the traction test wheels are conventional ones used in Roads' Transport. The circulating speed is of 40 Km/h, with a maximum allowable speed of 60 Km/h.

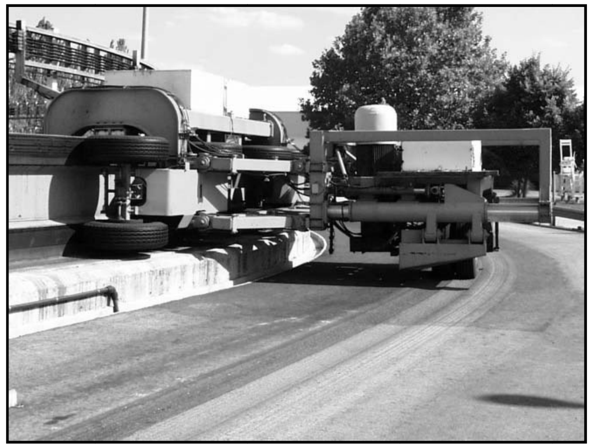

Figure 4. Vehicle for Traffic Simulation

Thanks to a hydraulic actuator, the test wheel can be positioned in seven different transversal paths, producing in this way a footprint band of 1.0 to 1.3 m width. The automatic control of this position allows reproducing a real statistical distribution of passages according to real traffic.

This test facility is fully controlled from a centralized Control Center, situated in the geometrical center of the test track. The control program has been specifically developed for this application. In this way the whole facility can work unattended once programmed. The test frequency is higher than 1x106 cycles by year. The automation process was mainly considered during the design phase of the facility with the aim of reaching a test life cycle with minimum interruptions.

Measuring Parameters

When a wheel moves along a road, stresses and strains develop at any point of the pavement structure; this stresses and strains depend on the type, magnitude and direction of the load, pavement structure, type of subgrade, temperature, depth, etc.

The instrumentation of the pavement makes possible the measurement of the stresses and the strains that appear in different parts of the pavement under the pass of a load, and especially those that are considered to be critical.

For each layer, the critical points as well as the tensodeformational variables are different, and that has to be considered when choosing the type of sensor and its placement.

Horizontal tensile strain at the bottom of the bituminous layer is considered the most important response variable for flexible pavements. Consequently, the instrumentation of the asphalt mixture layers is mainly focused on measuring horizontal strain at the bottom of the layer.

Granular layers and soils fail mainly due to accumulation of vertical strains. Therefore, the instrumentation of the soils is especially focused on measuring vertical stresses and strains.

Pavement deflection sensors are also placed in order to measure the transient response under the pass of the moving wheel. These sensors are placed on the top of the asphalt layer and anchored to the bottom of the test pit.

Finally, a series of sensors are installed in order to collect data from environmental and load related variables: temperature, moisture and water table, speed, transverse position, etc.

Description of the Control System of the Facility

In the Test Track facility, there are two control systems related to one another and both of them are managed by a single system (PC Computer). The first one (PLC Computer) is in charge of the steering of vehicles and it controls the following key test parameters: speed, load transverse position, air pressure of the tires, etc., and also all the required variables for the maintenance of the vehicles and safety of the facility, including: electricity consumption, puncture detectors, position detectors, and so forth. The other system (Micro Computer) manages the instrumentation covering the tasks mentioned above.

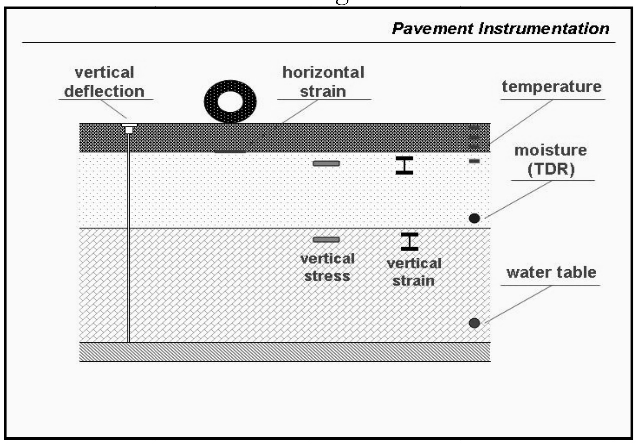

Figure 5. Example of the instrumentation

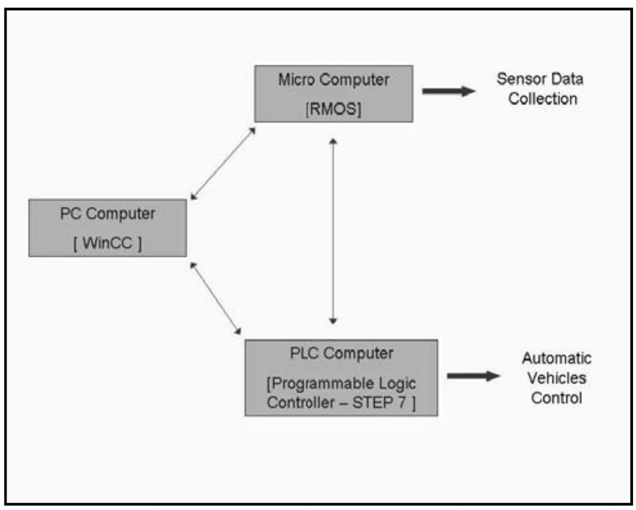

Figure 6. Communication system

Both systems are in permanent communication. The system that controls the instrumentation needs at all times the data regarding the position of the vehicles on the track, the speed and the transverse position. On the other hand, the vehicles control system has to obey the orders issued by the measurement system to achieve the vehicle speed and transverse position required by the measurement.

In the Test Track, a gallery is available on the straight stretches next to the test sections where the power supply and conditioning devices of the sensors are located. It was thus designed to achieve the minimum distance possible between the sensor and the conditioning device to avoid distortion of the output signal and to amplify this signal to reach the Control Center, where the signal will be converted from analog to digital.

Instrumentation Management Tasks

The system for data acquisition of the sensors, which is fully automated, has been designed and developed by CEDEX and makes real-time measurement and storage in database possible for up to 300 sensors on every measurement test.

The management tasks are divided into three processes:

- Management sensor process.
- Measurement process.
- Data storage and analysis.

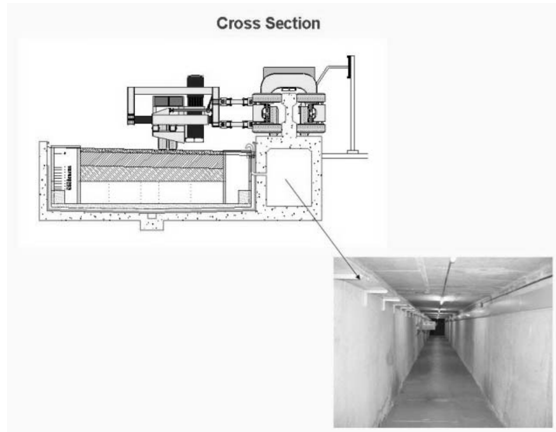

Figure 7. Cross section and instrumentation gallery

Management Sensor Process

Once the plan of instrumentation for each test has been designed and the supply of each sensor has been carried out, the next step is to register it into the system database. It is then time to include all the data which define the sensor, its location, the plate and channel of the measurement chain where the sensor is connected, the optical measurement startup sensor, calibration data of the sensor, relevant dates and state of activity.

After the sensor has been registered in the database, the next step is carrying out the calibration. During the calibration process, the transducer must be calibrated and also the whole measurement chain, including wiring, the conditioning plate and the ADC board. Calibration is performed from the system itself and the results are incorporated into the system database.

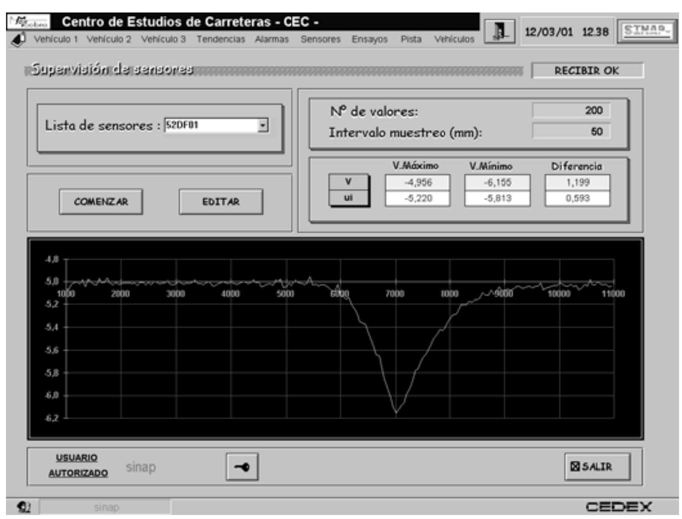

Figure 8. Example of sensor graphical monitoring

There are also additional tasks which simplify the instrumentation maintenance work and feature graphical and numerical real-time monitoring functions of the readings.

Measurement Process

Within the data acquisition system, there are two distinct types of tests:

- Dynamic tests.
- Special tests.

The dynamic test refers to the systematic measures taken with the instrumentation while the vehicle is in motion. When carrying out this kind of tests, the sensors being measured have to be previously defined, up to a number of 256 per test. Besides, a results file (ASCII) is created to include all the variables required for the analysis of curves, such as pavement temperature, ambient temperature, number of cycles, transverse position, vehicle speed, date and time.

Dynamic tests are activated automatically. They can be activated by means of three different events, which are selected when the test is being scheduled. These three events are the following:

- Number of cycles. The test begins when the vehicles cover a predetermined number of cycles.
- Time. The date and time of the beginning of the measurement are indicated.
- Temperature. It begins when the pavement temperature (defined by the user) reaches a certain value.

The presence of staff at the facility is not required for this kind of tests, which are performed 24/7.

When the event that triggers a test takes place, the computer in charge of the measurement management (Micro computer) instructs the computer in charge of the steering of vehicles (PLC computer) to position the vehicles on the conditions required for the test. Once the vehicles are placed in the right position for the scheduled test, an OK signal is sent to the Micro computer, which activates the beginning of the data collection.

The vehicles will complete one cycle, in which the vehicle speed is measured and the sampling speed is calculated in order to storage 5 cm-distance readings which begin 5 m before the vehicle arrives to the vertical position of each sensor and finish when the vehicle moves 5 m onwards the location of the sensor. In the subsequent cycle, a measurement per sensor is carried out, which stores 200 values that define the curve. Once every piece of data is stored, the test finishes and the computer in charge of the steering of the vehicles regains control. This test can be scheduled cyclically depending on the number of cycles, after a determined period of time or when the desired temperature values occur.

We would like to highlight the following three types of tests as special tests:

- Temperature traces. The test starts and finishes automatically at a specified time and is repeated after an elapse of time. In this test, the daily temperature traces are measured for each of the sensors located on the Test Track, which are used to analyze not only the instrumentation but also the damages of the pavement.
- Manual Start. These tests can be performed not only with vehicles in motion but also with vehicles stopped. They begin when a trigger is sent. This kind of test is used to study in detail some specific variables when the vehicle is passing by and, unlike the dynamic tests; they are made with a sample frequency up to 5000 samples per second. This test is also used to measure the response of one or various sensors to equipment other than the test vehicles, e.g. FWD devices.
- Start by optical sensor. It has the same features as the Manual Start test, but, in this case, the measurement is triggered by one of the optical sensors on the Test Track.

Data Storage and Analysis

All the files generated by the measurement process are included in an ORACLE database for subsequent analysis. The only measurements that are stored come from the systematized dynamic tests, thus the special tests results are kept for the user personalized processing. At this stage, the system has the three following distinct processes:

- Data entry
- Curve display
- Parameter analysis

Data entry

The data measured during the measurement process are not always correct and are subject to wrong readings caused by the failure of the system, a broken sensor, incomplete readings, etc. Therefore, the inclusion of these data into the database requires special attention. Moreover, the manual inclusion of a great amount of data generated by the system is a very slow process. For instance, in a regular day of standard operation of the facility, 8000 curves can be measured, that is why it is virtually impossible to keep a daily control of the manual inclusion into the database.

The system has a feature for automatic inclusion of the measurement files. The design of this inclusion process is the result of a thorough experience and is being constantly updated with increasingly effective improvements, because this stage is remarkably important in order to avoid the inclusion of wrong data that can hinder the work of analysis.

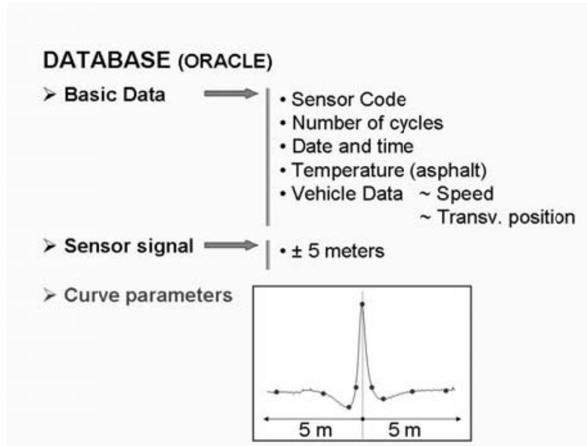

Figure 9. Registered data in a dynamic test

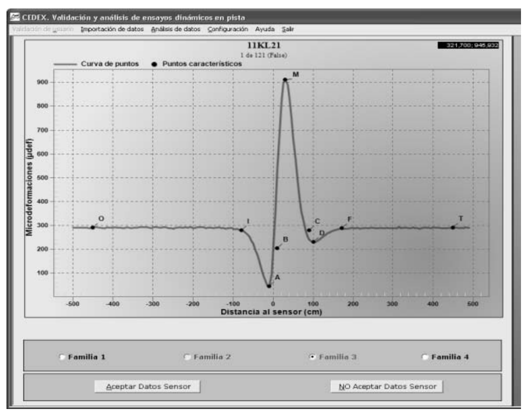

Figure 10. Example for the validation of a curve and its singular points

Prior to the data entry, the application displays the pavement temperatures assigned to each curve. The temperature at which the variable has been measured is very important in the case of pavements with asphalt mixture. If the temperature is incorrectly assigned, afterwards that will be difficult to identify, except when talking about wrong data, which will generate errors in the analysis stage. In the manual inclusion, there is no problem, because it is easy to detect it and it is corrected manually. In the automatic inclusion, the application is programmed to identify errors in the temperature measurements and it is able to correct them. This mathematical algorithm is based on a comparison by section and by stretch where the different sensors are placed.

Then, the program analyzes each type of curve measured and compares it with the type of variable that it is being measured. If there is a coincidence, the program calculates the singular points of the curve, as shows in Figure 13, and everything is stored in the database. In the automatic inclusion, if a difference arises between the measured curve and the expected typical curve, this curve is stored in a provisional file until the user evaluates it.

Curve Display

Every curve stored in the database can be displayed. Therefore, we can ensure the proper inclusion of these curves into the database; we can use it for instrumentation maintenance tasks and mainly to carry out the analysis of the measured variables.

To access the information, a form is required to be completed with additional data:

The type of sensor, the section, the range of transverse position, the range of vehicle speed, the range of temperature and the cycles period for which the records are required. The program then automatically displays the readings as can be seen in Figure 14, and the user can select any of the curves and print them as needed.

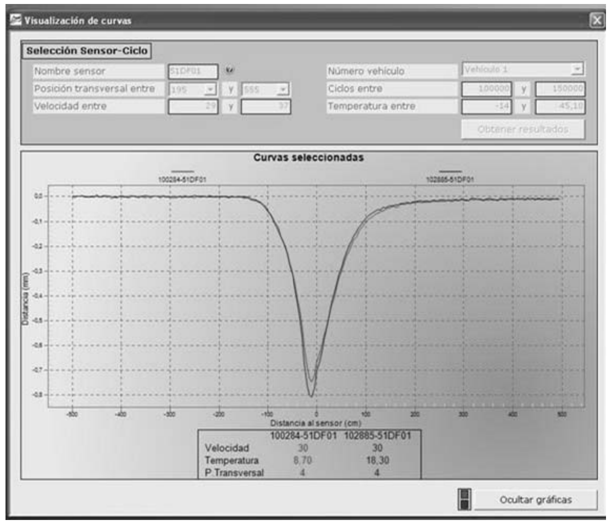

Figure 11. Example of display. Deflection at different temperatures

The restrictions when searching for curves are essential for a correct operation of the application, thus the application is opened to a large number of variations and that is why the user carrying out the analysis is also responsible for delimiting them depending on the required task.

Parameter Analysis

In the validation process of the curves measured by the sensors, the singular points are calculated for each curve. The database stores not only the curves and all the variables defining them, but also the coordinates of the singular points.

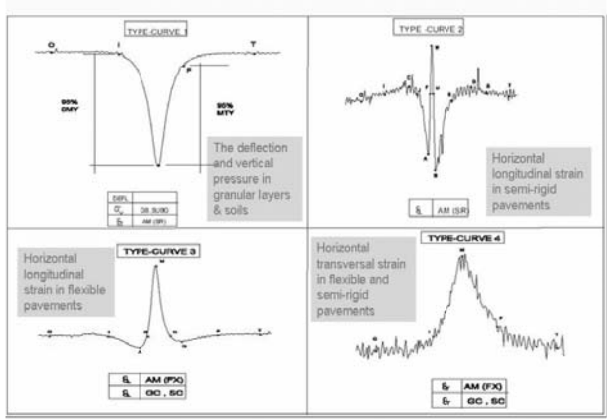

Figure 12. Singular points for the typical curves

In this part of the application, we can obtain graphical and numerical values for the different parameters versus the following variables: temperature, transverse position of the vehicles, vehicle speed and number of cycles. We define parameters such as the relative difference in the Y-axis or X-axis between two singular points of the same kind of variable. OMY value is typically used, since it represents the maximum peak response.

During the search process in the database, once the type of curve to be studied has been selected, the application displays the list of all the sensors of this precise kind. The next step is to select the parameter to be analyzed. Then, the system provides the ranges of temperature, speed, number of cycles and transverse position of the vehicle, in order to delimit the analysis as desired. The application provides the graphical evolution of the parameter with the selected variable. The search results can also be retrieved in an Excel file, in order to use the data in other computer applications.

The following figure shows a typical example of parameter variation with one of the variables:

- Type of sensor: Load cell.
- Variation relative to the pavement temperature.
- Parameter of search: In this case, OMY corresponds to the maximum vertical tension.
- Transverse position of the vehicle: 305, which corresponds to the central position in the transverse distribution of the vehicle movement.
- Between cycle 125000 and 200000.
- Vehicle speed: between 33 km/h and 37 km/h.
- Pavement temperature: between -3.9 °C and 40.5 °C. (The complete range with available data).
- Sensor: 52CT31, which corresponds to a load cell located at the top of the subgrade in section 5.

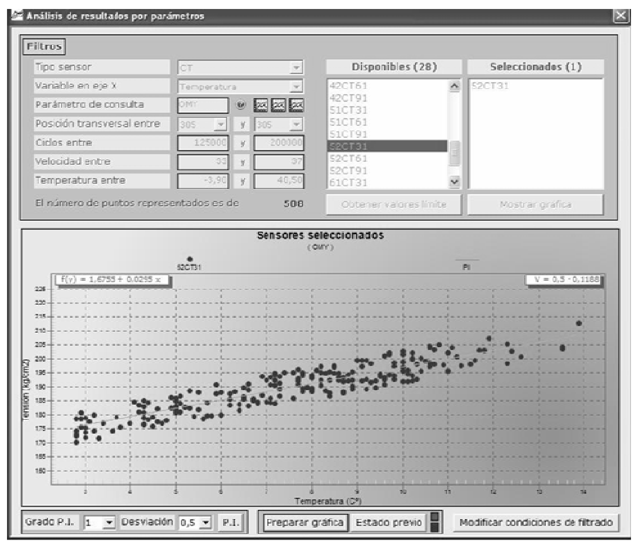

Figure 13. Example of parameter variation with temperature

Once all the values have been represented, the application offers the possibility to eliminate the outliers through a statistical procedure. For this purpose, the points are adjusted through a polynomial up to its third grade and we define a band consisting of that polynomial plus/minus the standard deviation multiplied by a number that ranges between 0.5 and 2. All the values that are out of this band will be eliminated.

Conclusions

- The facility is designed so that the traffic simulation vehicles move continuously, 24 hour a day, seven days a week. That is achieved by two control systems (micro computer and PLC) related to one another and both of them managed by a PC computer.
- The data acquisition system enables the full-automatic sensor measurement, based on different environmental and load related variables as well as number of cycles.
- The system allows the simultaneously managing of up to 256 sensors and typically, more than 250000 curves of the sensors are collected in a complete test.
- Records are stored in a Database together with the singular points of each one; e.g. maximum peak value, zero reference etc.
- A program enables the treatment of the stored data, so that the response of any sensor can be plot against test-related variables such as pavement temperature, vehicle speed or transverse position. The evolution versus the number of cycles can be displayed as well.
- Output ASCII files can be also generated so that data can be treated by a more specific software, like statistical packages or pavement design programs.

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