An aerial photograph of a road network, likely a highway interchange or a complex road system, with a grid overlay. The roads are shown in various colors (blue, green, orange) and the grid is composed of thin white lines. The background is a blurred orange and white pattern.

REPA **RA**^{2.0} **FIRMES**

ASPHALT PAVEMENT DESIGN SOFTWARE

User guide



Asphalt pavement design software

User guide

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1. INTRODUCTION

In the XXI century the use of computer tools in the field of engineering is a generalized fact to such an extent that it would be difficult to find any project in which they were not used. However, this development has not been homogeneous in the different fields of civil engineering. While in structural engineering or hydraulic engineering there are powerful software tools capable of solving complex problems, however in the field of road engineering it is difficult to find a program or application that efficiently performs the calculation and sizing of pavements covering all the particularities and phases of it, even less in the Spanish language.

It is at this point, within the REPARA 2.0 project co-financed by the Ministry of Economy and Competitiveness through the Center for Industrial Technological Development -CDTI-, through the "Strategic Program of Consortiums of National Business Research -CIEN", this need was detected, and it is proposed to develop a computer calculation tool that covers the different phases of the road sizing project.

In this way, the REPARA Firms application is born, which comes to fill this gap in the computer science tools of the engineering, and which integrates in a single environment for all the phases of the sizing of pavement sections. This is a multi-device web application that allows access to it through any web browser.

In addition, because of the results of the REPARA 2.0 project, the application allows the design of sections with some of the new technologies of recycled mixtures resulting from the results of this project.

Access to the application is through a web browser and can be opened by any user through the address: <https://firms.cemosa.es>



2. OBJECTIVE AND SCOPE OF APPLICATION

2.1. OBJECTIVE

The purpose of this application is to offer the designer a flexible calculation tool that allows the dimensioning and validation of pavement sections sequentially, in a common environment and without the need to use additional applications.

The design of the application is made in an intuitive way, so that anyone familiar with the dimensioning of pavements can sequentially walk through the different stages of the calculation of a pavement.

The application without explicitly being normative, can be used with almost any prescription or calculation procedure that is based on the elastic multilayer method. The wide database of materials with their respective fatigue laws, the different procedures for calculating calculation loads and the possibility of using different configurations of axes, gives a flexibility and breadth to the calculation that allows the validation of sections of pavement under a great multitude of different hypotheses.

Given the flexibility of the application, its use will allow to overcome the usual and classic catalogs of pavement sections, which offer preconceived solutions and which in many cases can be optimized.

Finally, one of the main innovations of the application lies in the form of access to it, through a web browser and its ability to be used from different types of electronic devices such as computers, tablets or mobile phones. This widens the horizon of possibilities to be able to be used in different situations, not restricting its use in a project office.

2.2. SCOPE OF APPLICATION

The application is designed to dimension pavement sections with bituminous pavement, including those that are traditionally known as flexible, semi-flexible and semi-rigid pavements.

The application will be used for the validation of a section of the pavement whatever the normative or legislation used, provided that it is based on the analysis by the multilayer elastic method.

Regarding the determination of traffic requests, the application allows the choice between various criteria depending on the availability of data, all based on the concept of equivalent axis of 13 t used in Spain and most European countries. Complementarily, it includes the calculation of the requests according to the methodology of the AASHTO for the equivalent axis (ESAL) of 18 kips so that it can also be used in the countries where this method is extended, such as the United States or Hispanamerican countries.

In search of greater applicability, a module of load configurations has been defined that allows the choice and configuration of various types of axes such as the tandem or tridem which are not usually used in the usual regulations but which nevertheless can be subject to particular analyzes for exceptional cases.

Along with these particularities of the calculation, the application includes a wide catalog of materials together with its mechanical characteristics and its associated fatigue laws, covering the different materials used in the layers of pavement, layers of foundation of the pavement and the subbase.



3. STRUCTURE OF THE APPLICATION

3.1. SCHEME

The application is designed in a modular structure, so that, independently and through a sequential process, the different parameters needed for the thickness of the different layers of the pavement are calculated, so that the process ends with the validation of a considered section.

The procedure begins with a form that allows the introduction of the general information of the project, and in which the main identification data of the project are defined. From there, the series of different modules (see Figure 1) allow an assisted design of the different necessary or complementary parameters for the calculation.

The modules correspond to the following procedures:

- **Geolocation module:** allows the location of the project through the introduction of its geographic coordinates, UTM, or directly with the postal address. It is a module assisted by using the Google TM Maps tool.
- **Climatological data module:** in which the main climatic characteristics of the project area are defined. It is also assisted by climatic maps loaded in the application itself and by downloading real data from different agro climatic stations spread across the national territory and that are in the vicinity of the project.
- **Traffic module:** this module is used to calculate the traffic requests that will condition the road section. It is a complex module that allows the choice between different methodologies for the determination of the number of equivalent axes based on the available data or the regulations considered.
- **Module for defining the pavement sections:** where the definition of the pavement section is defined by distinguishing between the esplanade and the pavement package itself. It has a wide database of materials that include mechanical characteristics and fatigue laws according to the main regulations. In addition, the recycled materials developed during the REPARA 2.0 project stand out, facilitating design work for the designer.
- **Module for defining the load model:** it requests information about the type of axis considered in the dimensioning, giving a choice between different types of axes. Allows the definition of different geometric definitions of them and contact pressures.
- **Results module and calculation validation:** in which the results of the multilayer elastic calculation are shown, and where after applying the fatigue criteria considered for each material and the calculations previously calculated, the section considered is validated or not.
- **Final report:** downloadable in pdf format and where the entire calculation process is collected.

At the schematic level, the structure and flow of the process defined in the application is shown in the following figure (Figure 1):

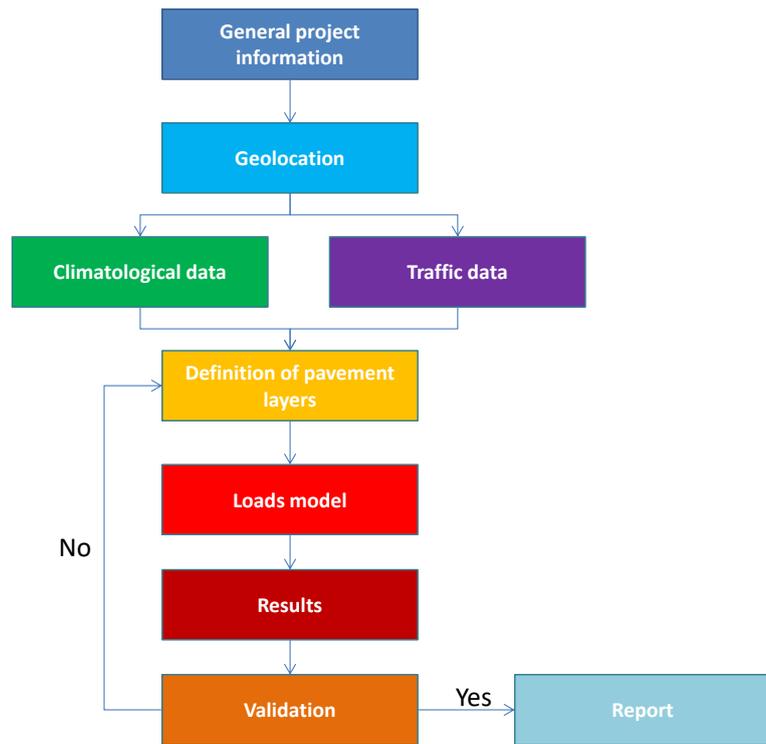


Figure 1. Scheme of operation for the application

3.2. DATABASE

Starting from the internal functioning of each one of the different defined modules, and from the requirements thereof, architecture has been designed for the different databases with which the application has to count, as well as the relationships between them.

In this way, 18 databases are defined within the application itself that allow the user to use during the different phases of the calculation (see Annex II):

- Type of user
- Project data
- Locations
- Weather data
- Traffic data
- Types of vehicles
- Specters
- Distribution of load spectra
- Spectra for double and triple axes
- Simple axle loads
- Double axle loads
- Triple axle loads
- Traffic categories
- Load models
- Type of loading model
- Layers of pavement
- Materials
- Laws of fatigue

Each of the databases contains the different parameters necessary to complete the calculations corresponding to the various modules that make up the application. The interrelations between the different databases are expressed in the following UML class diagram (see Figure 2).

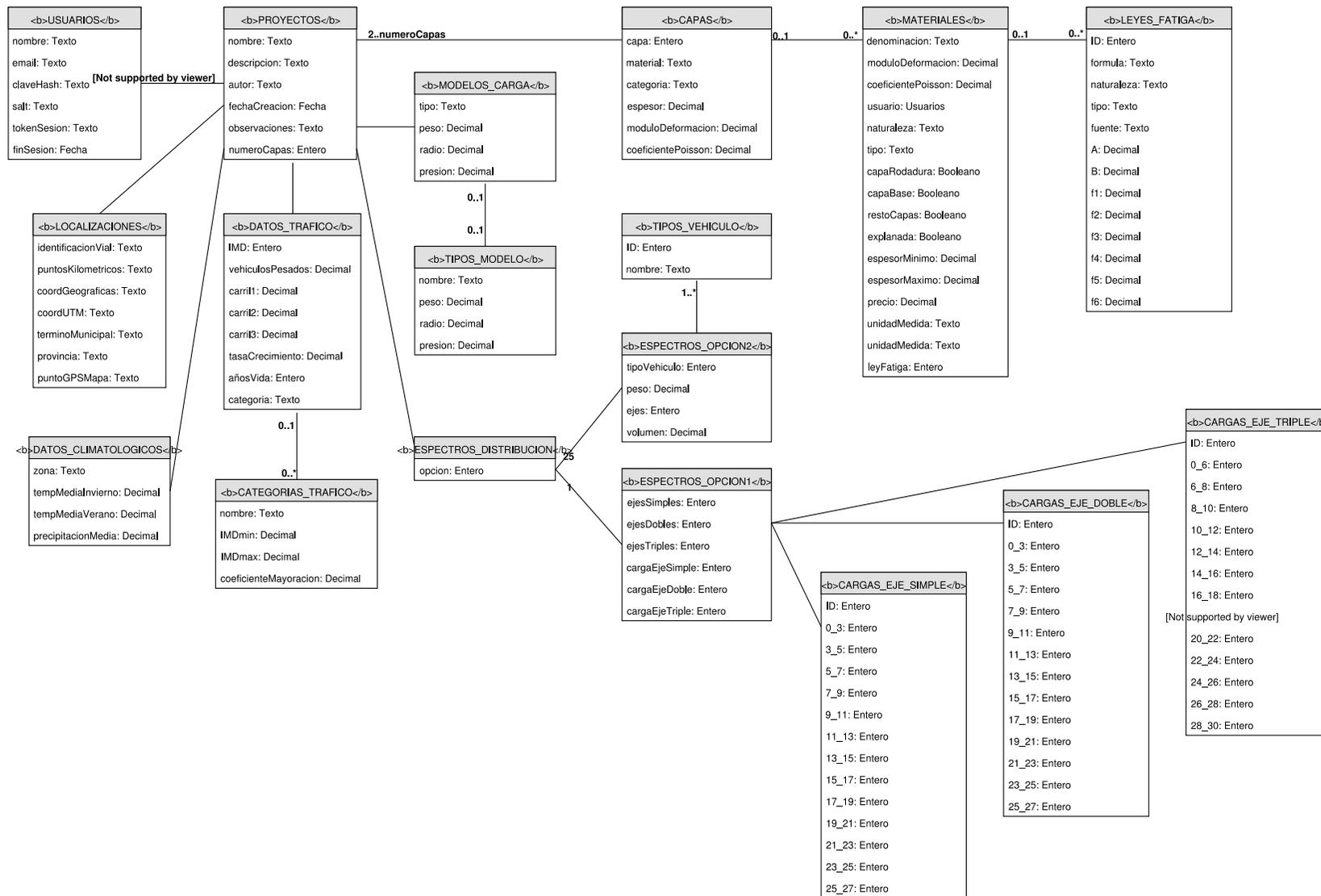


Figure 2. UML class diagram of the different databases of the application

4. GENERAL INFORMATION MODULES

4.1. STARTING THE APPLICATION

The REPARA Firms bituminous pavement application is implemented in the form of a web application, which can be accessed through any web browser, in the same way that it would be done to access any domain.

The appearance of the application is the one that can be checked in Figure 3. At this moment, a series of options are presented:

- *User*
- *Password*
- *Log in*
- *Check in*
- *Access as a guest*
- *Language*

The application is designed for access as a registered user. This requires the introduction of a user and a password prior to registration. In addition, it offers the possibility to start accessing it in the form of a guest (Access as a guest), although in this case the application has a series of limitations.



Figure 3. Application start

The registration process to access as a registered user can be done from this initial screen by just tapping the green button Register. After accessing it, the application requests some registration data to proceed to it. These are based on standard registration forms like those made in other applications in the environment. Among them are:

- *Username*
- *Qualification*
- *Company*
- *Position*
- *Address*
- *How did you get to know the REPARA Firms software?*

- *Password*
- *Email*

In addition, during this registration process, you will be asked to choose the language in which you want to continue with the application, with Spanish and English as the default languages.

Once the registration is complete, it will be enough to go back to the initial screen, enter the username and password chosen and press the blue button to Login.

4.2. MAIN MENU

Once the registration procedure and access to the application via registered user have been completed, the application presents the general menu (Figure 4) in which the following series of possibilities are presented:

- *Create Project*
- *See my projects*
- *See personal data*
- *Help*
- *Delete user*
- *Sign off*



Figure 4. Home screen

4.2.1. Create project

Through the *Create project* tab, you will access the different modules that make up the calculation core of the application in the way that was defined in the previous chapter. The depth definition of these modules requires a greater depth and will be analyzed in later sections.

4.2.2. See my projects

The *View my projects* tab (see Figure 7) allows access to a historical record of the different projects carried out by the user. Within it, the different projects previously carried out are organized by name. Next to the name it is possible to carry out a series of actions on said projects such as:

- download the completed projects report through the *View report* tab 
- proceed to the elimination of the project with the Delete option 

- edit completed projects 
- complete projects that are not finished 

In addition, the state in which the project is located distinguishes between completed projects or those that are not. It is the latter which indicates the next step to be taken.

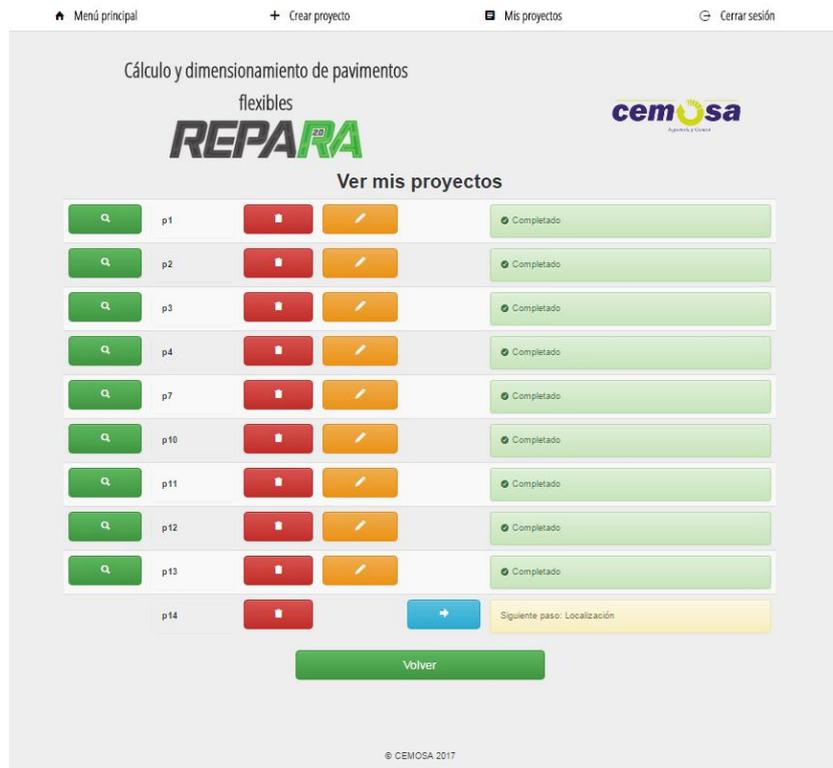


Figure 5. Image of the section *See my projects*

The return to the main menu will be done through the lower *Return* tab or by using the top menu.

4.2.3. See my personal data

This option allows the access and visualization of the personal registration data that were introduced in the application at the time of registration along with the modification thereof (Figure 6).

The modification of said data is possible through the *Edit* option.

The password change will can made through the *Change password* tab.

The return to the main menu will be done through the *Return* tab or by using the top menu.



Figure 6. Image of the section *See my personal data*

4.2.4. Help

The return to the main menu will be done through the *Return* tab or by using the top menu.

4.2.5. Delete user

This option allows you to delete the registered account which will mean the loss of all registered projects.

4.2.6. Close session

The closing and exit of the application will be done through this option.

4.3. CREATION OF PROJECT. GENERAL DATA

Once the option to carry out a new calculation has been chosen, the flow diagram or calculation procedure schema is launched, which appears in the first steps established in the general project scheme presented in Figure 1.

The first step of said flow chart is based on the consideration of some general data or starting data, necessary for the definition of the initial project situation. Among these data are:

- *Project name*
- *Project description*
- *Project author*
- *Date of completion of the project*
- *Itinerary considered for the calculation of the pavement*
- *Observations*

In Figure 7 you can graphically check the appearance in which these data are presented within the

Datos generales del proyecto

Nombre:
Proyecto de acondicionamiento y mejora

Descripción:
Calculo de pavimento

Autor:
Proyectista

Fecha:
Jueves 20 / 4 / 2017 dd/mm/yyyy

Itinerario:
Madrid-Granada

Observaciones:

Guardar cambios

Figure 7. Image of the general data module of the Project

Once all the fields have been completed, the *Save Changes* tab allows you to save the established changes and through the arrow you can sequentially continue with the next phase of the application flow diagram.

4.4. GEOLOCATION AND CLIMATOLOGICAL DATA

4.4.1. Location

Once the general project data has been introduced, and after saving the changes, the next step of the application leads to the geolocation module and territorial determination of the scope of action of the road project.

This location has a crucial importance in the dimensioning of the pavement section since depending on the climatology or atmospheric conditions to which the pavements are subjected, the properties of the materials may vary and in this way the design will be affected. These climatic conditions will in turn determine the validity or not of the use of different types of pavement, such as, for example, drainage pavements in areas of high rainfall or those in which the availability of certain material discourages their use.

Once access to this calculation module, the application requests the introduction of a series of identifiers that will allow the determination and geolocation of the scope of action of the road project. The required information can be entered in two different ways, either by completing a series of information fields that will be defined below or by selecting the location on a real map (see Figure 8).

The first of the options requires completing a series of fields among which are:

- *Identification of the highway or road:* which must include the nomenclature and coding of the existing or planned road for which the sizing of the pavement will be carried out
- *Kilometric points (PKs):* in which the initial and final kilometric points of the performance will be defined in XXX + XXX format.
- *Municipality*
- *Province*
- *Coordinates:* in the section you can enter both the geographic coordinates or the UTM

coordinates. Any of the two types of coordinates will be possible since the application performs the instantaneous translation of each other reciprocally.

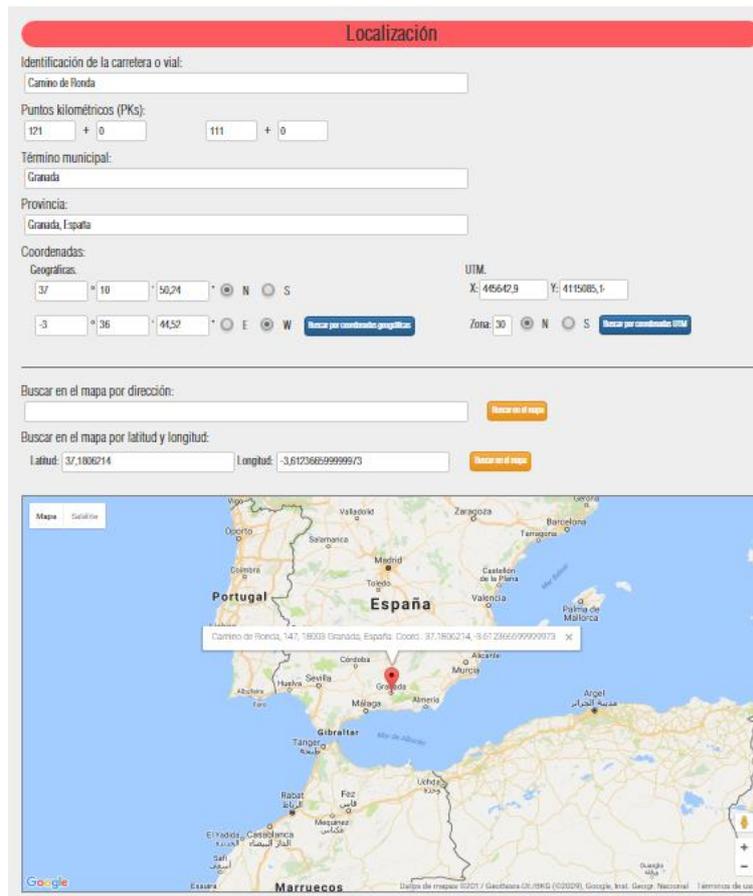


Figure 8. Image of the application location module

Regarding the selection of the location by means of a map, the application uses Google™ Maps technology so that simply with the selection on the map the required information fields are completed, as well as the geographical coordinates and UTM.

Once the localization process is completed, once again a tab allows you to save the data and continue with the calculation process.

4.4.2. Climatological data

The module is complemented by the introduction of climatological data that will be associated with the territorial environment of the project.

In this way the application presents a new screen where through the connection with different climatic stations in the project environment, you can import the data referring to average temperatures in summer, average temperatures in winter, rainfall history, together with a Climogram in which you can see the annual historical evolution of temperatures and rainfall (see Figure 10).

In addition, a series of climatic maps of the National Geographic Institute [1] are presented that will emerge when the user clicks on the variables of temperature and annual precipitation.

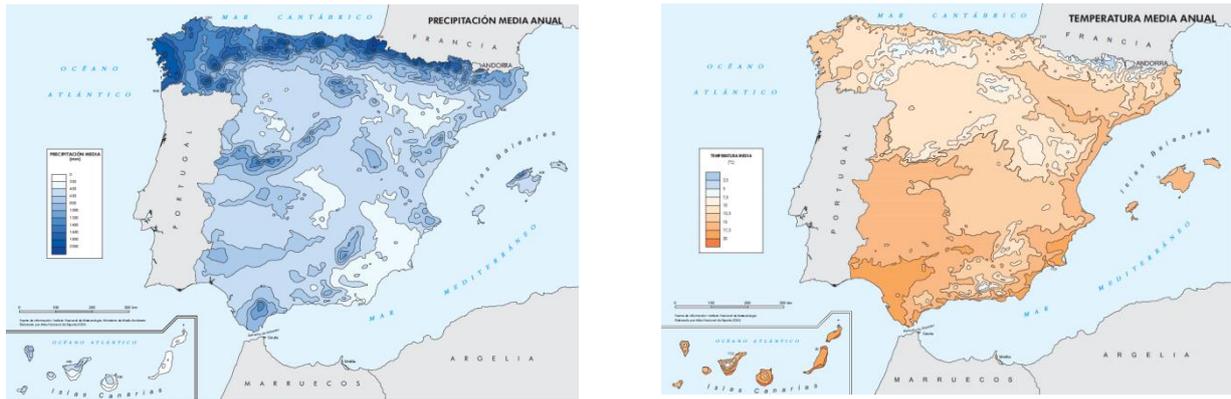


Figure 9. Climatic maps used in the application

The climatological information is considered essential when adjusting the values of the deformation modules of the different bituminous materials considered in the calculation, and when considering the use of certain types of draining mixtures. At the same time it allows the inclusion in the report of information about the climate in the surroundings of the project area, which can facilitate complementary tasks to the designer, such as the determination of drainage networks.

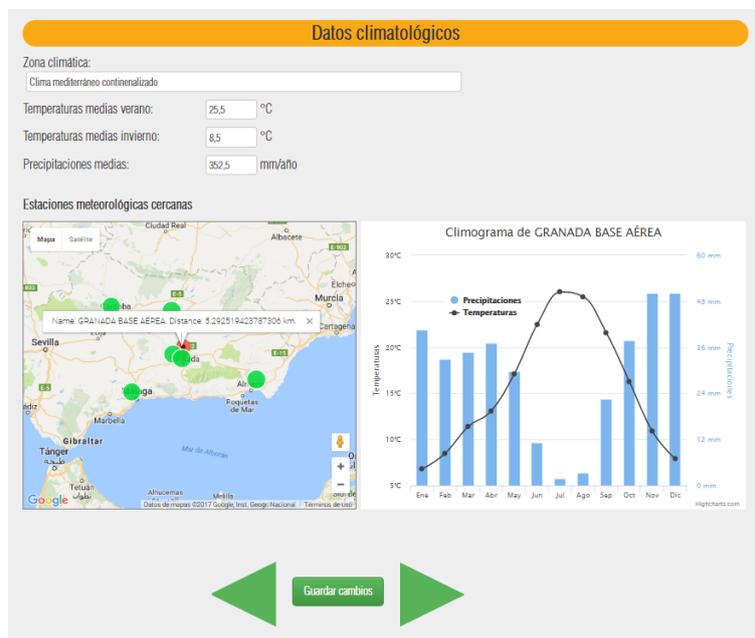


Figure 10. Image of the climatological data import module

5. TRAFFIC MODULE

5.1. INTRODUCTION

The traffic module of the REPARA Firmes application is one of the most complex and relevant of the application itself, since from the functional point of view it allows determining one of the critical parameters of the project, such as project traffic solicitations. These requests will be given through the number of equivalent axes, which will be later used as a criterion to validate or not the section of the road considered.

As a particularity and novelty, the procedure implemented in the application allows the calculation of the number of equivalent axes according to different methodologies depending on the starting data that are available at the time of sizing. These methodologies range from the hypothesis of a total absence of input data, to the availability of complete gauging considered load spectra. In addition, in addition and taking into account the global nature of today's engineering, the method of the AASHTO standard is presented for the sizing of sections in countries where such regulations are valid.

5.2. ENTRY DATA

First, the application requests some common general input data (Figure 11), together with the determination of the capacity limit of the track which is based on the High Capacity Manual HCM - 2000 [2] under the assumptions of 50% of trucks, factor of rush hour - FHP - equal to the unit, the proportion of average daily traffic in the period of analysis or k-factor equal to 0.10 and the distribution by lanes in a proportion of 60/40 (see annex II).

This first form is common to all calculation procedures and a series of input data is requested:

- *Year of project*: year in which the road project is carried out
- *Year of commissioning*: year in which the opening of the dimensioned section is scheduled
- *Project period*: period or estimated useful life of the pavement project
- *Type of road*: distinguishing through a drop-down menu between main network (or basic network), secondary network with shoulder (or complementary network) and secondary network without shoulder.
- *Type of section*: distinguishing between flat, undulating or mountainous.
- *Limit capacity of the road*: to be calculated according to the hypothesis previously exposed or that may well be directly entered by the user
- *Calculation method*: where you can choose between the different calculation methodologies that will be defined below.



Figure 11. General input data for the calculation of equivalent axes

In order to determine the calculation demands, the application considers the following methods of determination of equivalent axes:

- Case 1: no gauging data available, therefore the equivalent axes are calculated from the traffic classification.
- Case 2: capacity data is available from a coverage station, based on the value of the average daily intensity (ADI) from a single annual capacity.
- Case 3: capacity gauging data of a permanent station (continuous gauging) or of a control station is available, which allows evaluating the intensity taking into account the cycles and fluctuations of traffic -daily, weekly and annual- as well as the tendencies for long term.
- Case 4: gauging data is available for a permanent station that has state-of-the-art equipment that allows determining the load spectra per axis.
- Case 5: the calculation is made according to the American regulations presented in the AASHTO [1] by which the value of the equivalent axes expressed in 18 / kips ESAL is deduced.

Once the method has been chosen and the rest of the fields have been completed, once again a tab allows you to save the data and continue with the calculation process.

The calculation process will be based on the concept of project equivalent traffic (TP), which will be given by the following expression:

$$TP = IMD_p \cdot CE \cdot 365 \cdot F \cdot \gamma_t$$

where:

- IMD_p is the average daily intensity of heavy vehicles in the project lane in the year of traffic opening
- CE is the coefficient of equivalence of heavy vehicles in number of applications of the equivalent axis of 13 t
- F is the growth factor of heavy vehicle traffic
- γ_t is the security coefficient for the charge increase established in 1.10.

One of the novelties of this application is based on the consideration of exhaustion by capacity of the road in the determination of traffic solicitations. In this sense, the first corresponds to the direct calculation without considering the depletion by the capacity of the road, and the second one has the particularity that it is considered in the calculation of said parameter. If, due to the growth of traffic at some point in the useful life of the road, the capacity limit of the road is reached, which was previously determined, the algorithm considers that this growth cannot continue taking place due to what it considers constant traffic to the year of the end of the useful life of the pavement, so

the value is lower than the figure that does not take into account this limit. The application allows the option to choose which of the two parameters to take reference and continue the process.

5.3. NO GAUGING DATA

In the case of choosing the option *Without gauging data*, the application requires the generic information for the determination of the equivalent number of axes in the form of an expression based on a constant annual growth rate of the form:

$$IMD_{futura} = IMD_{actual} \cdot (1 + F)^n$$

Where:

n is the estimated life or project period

F is the average annual growth rate or growth factor

To do this, a form is presented (see Once these fields are completed, pressing the *Calculate and save* button proceeds to calculate the number of equivalent axes.

This presents two different values for said number of equivalent axes. The first corresponds to the direct calculation without considering the capacity depletion of the road, and the second one has the particularity that it considers this parameter in the calculation. Therefore, if, due to the growth of traffic at some point in the useful life of the road, the capacity limit of the road is reached, which was previously determined, the algorithm considers that this growth cannot be continued due to what it considers the constant traffic until the year of end of the useful life of the pavement, so the value is lower than the data that does not take into account this limit. This particularity is also present in the rest of the methods of calculation of traffic.

The application allows the option to choose which of the two parameters to take as reference and continue the process with just press the option *Save N and continue*.

) in which the following data are required:

- *Traffic category*: category of heavy vehicles based on the categories (T00, T0, T1, ...) of the IMDp of the road instruction IC 6.1 [2].
- *Average annual growth rate*
- *Typology of the pavement*: distinguishing between pavement with bituminous or granular base, pavement with base treated with cement or pavement with vibrated concrete pavement (see annex).

The project period, is necessary for the calculation, and has already been entered in the previous screen for General input data.

Tráfico

Sin datos de aforo

Categoría de tráfico:

Tasa anual de crecimiento: %

Tipo de firme:

Número de ejes equivalentes (N)

Sin considerar el agotamiento por capacidad:

Considerando agotamiento por capacidad de la carretera:

Once these fields are completed, pressing the *Calculate and save* button proceeds to calculate the number of equivalent axes.

This presents two different values for said number of equivalent axes. The first corresponds to the direct calculation without considering the capacity depletion of the road, and the second one has the particularity that it considers this parameter in the calculation. Therefore, if, due to the growth of traffic at some point in the useful life of the road, the capacity limit of the road is reached, which was previously determined, the algorithm considers that this growth cannot be continued due to what it considers the constant traffic until the year of end of the useful life of the pavement, so the value is lower than the data that does not take into account this limit. This particularity is also present in the rest of the methods of calculation of traffic.

The application allows the option to choose which of the two parameters to take as reference and continue the process with just press the option *Save N and continue*.

5.4. GENERAL OR COVERAGE ADAPTATION DATA

The calculation option for *Generic (or Coverage) Gauging Data* is based on the results obtained by a coverage type station in which the ADI is estimated from a minimum annual capacity of no more than 24 hours. In order to analyze the details of the results, manual counts are usually carried out to identify the composition of the traffic.

In the case of choosing this option, the application requests a series of necessary fields (see Figure 12) for the calculation as:

- *Average daily intensity or IMD*: intensity of traffic passing through a given road section for 24 hours
- *Percentage of heavy vehicles*: percentage of heavy vehicles over the total of vehicles that cross a road section during a day.
- *Annual growth rate*
- *Type of road*: with the same distinction that was made for the option No gauging data
- *Type of road*: where a drop-down menu appears that classifies them according to the number of lanes and the direction of circulation (see annex) and that will allow a distribution of traffic to determine the traffic in the project lane.



Tráfico

Datos de aforo genéricos

Intensidad media diaria (IMD): 5000 %

Porcentaje de vehículos pesados: 2 %

Año de datos de aforo: 1999

Tasa anual de crecimiento: 5

Tipo de firme: Firme con base bituminosa o granular

Tipo de vía: Calzada de dos carriles por sentido de circulación

Calcular y guardar

Datos guardados

Número de ejes equivalentes (N)

Sin considerar el agotamiento por capacidad: 383.443

Considerando agotamiento por capacidad de la carretera: 383.443

Figure 12. Image of the calculation method Generic gauging data

The output of the application again presents the two values of equivalent axes depending on whether or not the capacity limit of the track is considered. To continue the process, simply select the value of the number of equivalent axes and press the option *Save N and continue*.

5.5. CONTINUOUS OR CONTROL ASSESSMENT

This option presents the possibility of using the gauging data obtained through intense campaigns in the field and which are based on the data and fluctuation coefficients from a permanent station of a control station.

In this case, the amount of data required by the application increases substantially as it is a more complete typology, in which there is a detailed count of vehicles according to their typology and in which a series of coefficients mainly related to variations or fluctuations in traffic at different points of the day, week or month.

This option has an aspect like the one that can be checked in Figure 13. Regarding the data requested by the application are:

- *Year of capacity data*: year in which the capacity data is taken
- *Month of capacity*: month in which the capacity is carried out
- *Duration of the capacity*: duration in hours of capacity
- *Annual growth rate*
- *Type of road*: in the same way as for the previous cases
- *Night N Factor for month of gauging*: factor of fluctuation of traffic between day and night obtained by means of a permanent gauging or control station.
- *L factor or monthly variation for the month of gauging*: factor of fluctuation of traffic between different months obtained by means of a permanent gauging or control station.
- *Factor S or Saturdays and Sundays for the month of capacity*: factor of fluctuation of traffic between working days and weekends obtained by means of a permanent gauging or control station.

Tráfico

Aforo de cobertura

Año de datos de aforo:

Mes de aforo:

Duración del aforo:

Tasa anual de crecimiento: %

Tipo de vía:

Factor N o coeficiente de nocturnidad para mes de aforo:

Factor L o variación mensual para mes de aforo:

Factor S o de sábados y domingos para mes de aforo:

Datos de aforo

Tipo de vehículo	Clase de vehículo	N° de vehículos pesados totales
Autobuses	Autobús Clase A o B	<input type="text"/>
Autobuses	Autobús urbano (Clase I)	<input type="text"/>
Autobuses	Autobús interurbano (Clase II)	<input type="text"/>
Vehículos a motor	Vehículo a motor 2 ejes	<input type="text"/>
Vehículos a motor	Vehículo a motor 3 ejes	<input type="text"/>
Vehículos a motor	Vehículo a motor rígido 4 ejes	<input type="text"/>
Trailers	Trailer de cuatro ejes (1-1-2)	<input type="text"/>
Trailers	Trailer de más de cuatro ejes (1-1-3)	<input type="text"/>
Trailers	Trailer de más de cuatro ejes (1-2-3)	<input type="text"/>
Trenes de carretera	Tren de carretera de 4 ejes	<input type="text"/>
Trenes de carretera	Tren de carretera de >4 ejes (1-2-1-1)	<input type="text"/>
Trenes de carretera	Tren de carretera de >4 ejes (1-2-1-2)	<input type="text"/>

Calcular y guardar

Figure 13. Image of the calculation method Control capacity

Once these fields have been completed, the calculation again presents the number of equivalent axes considered and without considering the capacity depletion of the road, so that the considered option is selected and the road sizing process can be continued.

5.6. FULL ADOPTION WITH LOAD SPECTRUM

In the case of selecting the option Full capacity with load spectrum the application will present the possibility of performing the calculation through the introduction of data from a latest generation capacity, in which through a pressure sensor or another class of device, the gauging station is able to record and obtain the full load spectrum by axis of the total of vehicles traveling on the road.

In this option the data entry form is the most extensive and is oriented to the determination of the coefficient of equivalence -CE- real of heavy vehicles in number of applications of the equivalent axis of 13 t. For the other methodologies, this coefficient is estimated at 0.6 for pavements with bituminous pavement and in its case granular base, 0.8 for pavements with bases treated with cement and 1 for pavements with concrete pavement.

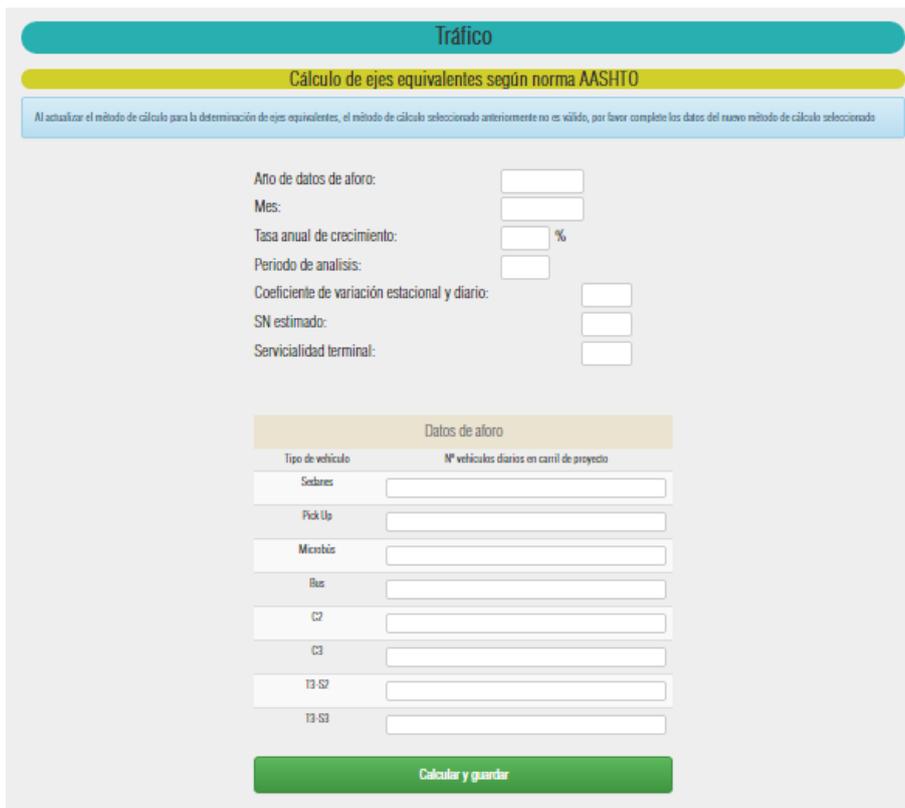
In the case of roads with a special incidence of heavy vehicles, it is possible that the average value of this coefficient varies significantly with respect to the values previously expressed, so that the calculation of the real value is highly recommended, especially if the load spectra necessary for its determination.

In this way, this option requests the following parameters:

- *Year of capacity data*
- *Annual growth rate*
- *Average daily intensity (IMD)*
- *Percentage of heavy vehicles*
- *Percentage of heavy vehicles in project lane*
- *Heavy simple axes*
- *Heavy double axles*
- *Heavy triple axles*

- *Annual growth rate*: average annual growth rate of estimated traffic
- *Period of analysis*: project life span in years
- *Coefficient of seasonal and daily variation*: according to AASHTO
- *Estimated SN*: structural number estimated according to AASHTO
- *Terminal service*: according to AASHTO

In addition, the capacity data is requested according to different categories of vehicles considered according to the AASHTO. In this sense, it would be necessary to complete these fields with the number of vehicles registered daily in the project lane.



Tráfico

Cálculo de ejes equivalentes según norma AASHTO

Al actualizar el método de cálculo para la determinación de ejes equivalentes, el método de cálculo seleccionado anteriormente no es válido, por favor complete los datos del nuevo método de cálculo seleccionado

Año de datos de aforo:

Mes:

Tasa anual de crecimiento: %

Periodo de analisis:

Coefficiente de variación estacional y diario:

SN estimado:

Servicialidad terminal:

Datos de aforo	
Tipo de vehículo	N° vehículos diarios en carril de proyecto
Sedanes	<input type="text"/>
Pick Up	<input type="text"/>
Microbús	<input type="text"/>
Bus	<input type="text"/>
C2	<input type="text"/>
C3	<input type="text"/>
T3-S2	<input type="text"/>
T3-S3	<input type="text"/>

Calcular y guardar

Figure 15. Image of the method Calculation of equivalent axes according to AASHTO standard

Once these fields are completed, just by clicking on the *Calculate and Save* tab, the application shows on this occasion the number of equivalent axes according to the AASHTO which are referred to the axis of 18 kips (8.1647 t), being called ESAL w18.

6. DIMENSIONING MODULES

6.1. INTRODUCTION

After the process of calculating traffic loads, the next step in the workflow diagram of the application (see Figure 1) is the definition of the sizing modules composed of the module for defining the pavement model and the module of definition of the model of loads or type of axis.

The module for defining the pavement model presents the option of defining the structure and composition of the pavement package under study. It will be a definition at the level of number of layers, mechanical properties, layer thicknesses, fatigue laws, etc. On this composition will

proceed to perform the multilayer elastic calculation with which to obtain the values of deformations and stresses that will allow the validation or not for the considered traffic.

In the module for defining the load model it is possible to choose different configurations for different types of axes, giving a choice between the consideration of individual wheel, simple axis, double axis or tridem axis.

6.1. DEFINITION OF THE PAVEMENT MODEL

6.1.1. Definition of the subbase layer of the pavement

For the definition of the structure of the pavement, the application begins by requesting a classification of the subbase layer or foundation of the pavement on which the asphalt folder will be sized.

The application presents by default the option to select the esplanades presented in the highway instruction I.C.-6.1 [3] In addition, the introduction of any other type of esplanade is allowed just by modifying the values of the Young's Module and the Poisson's coefficient.

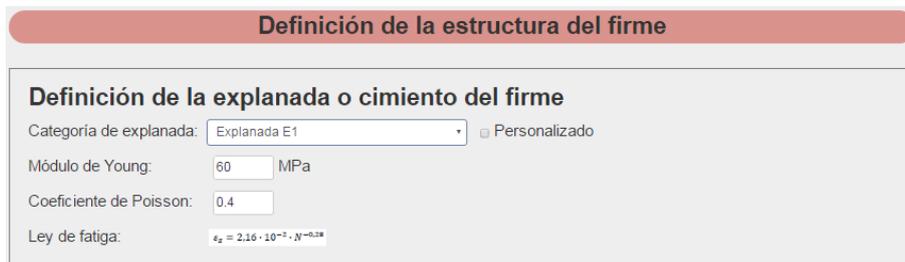


Figure 16. Image of the form Definition of the subbase layer or foundation of the pavement

In turn, if one of the concourses of the standard is selected, along with the mechanical properties such as the Young's Module and the Poisson's Coefficient, the fatigue law by default is considered and will be used for the validation of the section.

6.1.2. Definition of the layers of the pavement

Once the esplanade is defined, the application continues with the definition of the pavement section. To make this definition, the application previously requests the determination of the number of layers to be considered. Once the total number of layers is entered, a table appears to be completed in which each of these layers is defined one by one. The definition of each layer includes:

- *Type of layer*: distinguishing between the tread layer, intermediate layer, base layer and other non-bituminous types (gravel, soil, stabilized floors, gravel, etc.).
- *Denomination*: where you can choose between the catalog of materials stored in the database of the application (e.g. AC 16 D) or if you select the Custom option you can enter a new material to its characteristics.
- *Thickness*: thickness in centimeters of the layer
- *Young's module*: expressed in megapascals (MPa).
- *Poisson's coefficient*
- *Fatigue Law*: for each material in order to evaluate the fatigue resistance capacity after a certain number of cyclic loads.

The application has a broad database that includes most types of materials used in road construction, including bituminous mixtures, gravel and cement-treated materials. Each cataloged material has associated mechanical values and fatigue law, in this way the user only has to select the material and enter the thickness of the layer. These values can be modified by the user through the *Custom* tab, while it is possible to incorporate some new material that does not appear in the

database.

The design of the database is partially assisted, so that erroneous configurations or those that do not meet the standards are notified by alert messages. At the same time, a dynamic graphic window will allow the complete visualization of the section considered as it is verified in the following figure (Figure 17).



Figure 17. View of the application window where the structure of the pavement is defined

6.2. SELECTION OF AXIS TYPOLOGY

One of the most important novelties of the application is the possibility of choosing the load model considered in the calculation. This load model is based on the consideration of the type of axis. Most programs and applications only allow the option of the single or double twin wheel [4]. On the other hand, the application REPARA Firmes implements a wider range of axes typologies, so that the user is able to choose among the different models among which are:

- *Individual wheel*
- *Simple axis*
- *Tandem axis*
- *Tridem axis*

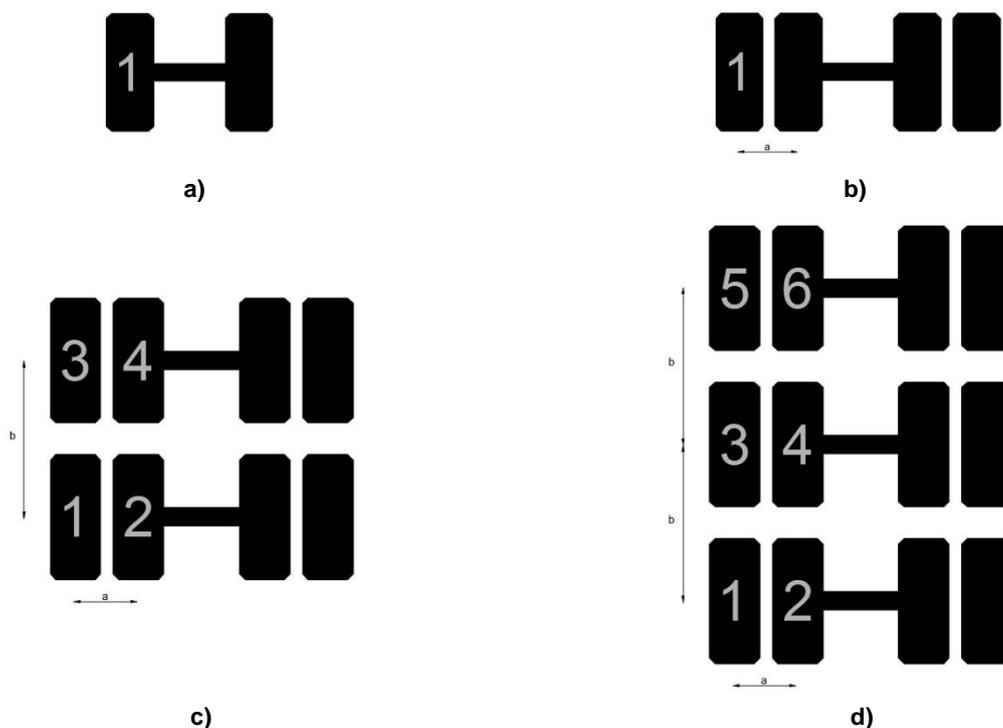


Figure 18. Schemes of the considered axes: a) individual wheel; b) simple axis; c) tandem axis; d) tridem axis

The choice of one or the other model will depend on the standard heavy vehicle considered in the reference regulations. In addition, the definition of the chosen axis model is completed through a series of parameters such as:

- *Distance between the axle wheels*
- *Shaft distance*
- *Contact pressure*
- *Radius of the equivalent circular Wheel*

The default values for each of the above parameters will be those that appear in the Highway Road Construction of Andalusia [5], with a contact pressure of 0.8 MPa, wheel tread radius of 11.35 cm and distance between wheel centers of 37.5 cm. These may be modified by the user to be adapted to the various existing regulations.

Each load model will have associated to it a series of points in which the evaluation of the mechanical parameters necessary to determine the number of admissible axes of the section will

be made. These have been determined according to the points where it is expected that the critical mechanical parameters will acquire their maximum values. In the following table you can check the coordinate and description of these points according to the load model considered.

Table 1. Evaluation points in the different axis models

Model of load	Assessment point	Coordinate X	Coordinate Y	Description
Individual wheel	1	0	0	Under unique load
Simple axis	1	0	0	Under load 1
	2	$a/2$	0	Between loads
Tandem axis	1	0	0	Under load 1
	2	$a/2$	$b/2$	Center of loads
	3	$a/2$	0	Between load 1 and 2
	4	0	$b/2$	Between load 1 and 3
Tridem axis	1	0	0	Under load 1
	2	0	b	Under load 3
	3	$a/2$	0	Center of loads
	4	$a/2$	0	Between load 1 and 2
	5	0	$b/2$	Entre cargas 1 y 3

7. MODULE OF RESULTS AND VALIDATION

7.1. OUTPUTS OF RESULTS

Once the calculation is done, the application displays on the screen the results obtained for the parameters vertical unit strain, unit radial strain and maximum tension (this parameter is only for materials treated with cement) in the upper and lower bound of each of the layers that they form the section and in the different evaluation points (Table 1) which will depend on the model of loads selected.

The form of presentation of the results is organized for each one of the evaluation points for the selected load model (see Figure 19).

Tipo de eje: Eje simple						
Punto de evaluación 1: Bajo rueda 1 Coordenadas: x=0; y=0						
Tipo de capa	Denominación	Cota	ϵ_t	ϵ_z	σ_t	
Capa1	Rodadura	AC 22 S	0,00	-7,62e-5	-2,75e-5	-
			0,11	1,18e-5	-8,46e-5	-
Capa2	Base	AC 32 S	0,11	7,15e-5	-8,43e-5	-
			0,26	7,87e-5	-7,18e-5	-
Capa3	Otra (No bituminosa)	Zahorra artificial sobre explanada E2	0,26	1,13e-4	-1,80e-4	-
			0,51	7,96e-5	-1,17e-4	-
Capa4	Explanada	Explanada E2	0,51	8,00e-5	-1,86e-4	-
Punto de evaluación 2: Entre cargas Coordenadas: x=a/2; y=0						
Tipo de capa	Denominación	Cota	ϵ_t	ϵ_z	σ_t	
Capa1	Rodadura	AC 22 S	0,00	-2,69e-5	4,07e-5	-
			0,11	1,30e-6	2,07e-6	-
Capa2	Base	AC 32 S	0,11	2,28e-5	-5,04e-6	-
			0,26	8,00e-5	-6,35e-5	-
Capa3	Otra (No bituminosa)	Zahorra artificial sobre explanada E2	0,26	1,18e-4	-1,69e-4	-
			0,51	8,36e-5	-1,25e-4	-
Capa4	Explanada	Explanada E2	0,51	8,43e-5	-1,99e-4	-

Figure 19. Output of application results

7.2. VALIDATION OF THE PAVEMENT SECTION

Based on these results, the application selects the most unfavorable values and applies the fatigue criteria obtaining the value of equivalent axes admissible by the section considered. With these calculated, and using the value of the admissible axes from the traffic module, calculate a safety factor that must be greater than 1 for all the fatigue criteria considered in order to validate the section.

Evaluación		
Criterio de fatiga	Ejes máximos de cálculo según criterio (N')	Coficiente de seguridad respecto a ejes calculados
Fatiga de la mezcla bituminosa	9.902.889	N'/N = 1,4
Fatiga del cemento del firme	18.641.234	N'/N = 2,6
Fatiga para material tratado con cemento	0	N'/N = 0,0

Sección válida

Figure 20. Validation evaluation of the section

Once a valid section has been obtained by simply clicking on the *Finish project* option, the entire calculation procedure will be saved so that the registered user can subsequently revise it if desired (see Figure 5) and proceed to generate the results report.

8. RESULTS REPORT

The REPARA Firms application presents the option, once the validation of a pavement section has been reached, to obtain a final report of results in which all the different stages followed during the sizing process are collected. This report, in the form of a project annex, allows the collection of hypotheses, parameters, validations, etc. so that its analysis will allow to quickly check all the methodology used.

For viewing and downloading, after clicking the *Finish project* tab within the validation module, a new screen will appear, such as the one shown in Figure 21

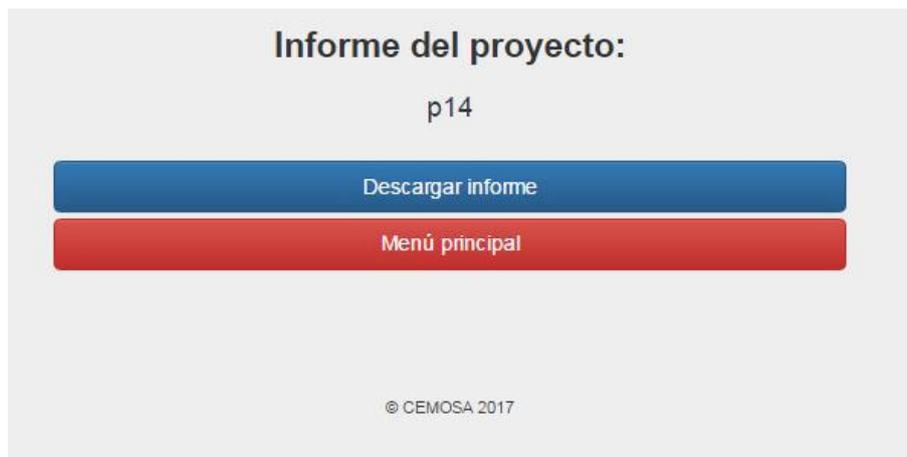


Figure 21. Image of the report download option

When clicking on the *Download report* tab, a file in pdf format will be displayed on the screen, which can be downloaded and saved to the computer that is being used to perform the calculation.

If instead, you want to exit, just press the *Main Menu* tab to return to the main menu of the application.

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ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
AC	<i>Asphalt concrete</i>
CDTI	Center for Industrial Technological Development
CE	Equivalence coefficient
CIEN	National Business Research Consortiums
ESAL	<i>Equivalent Single Axle Load</i>
FHP	Rush hour factor
IMD	Average daily intensity
IMD _p	Average daily intensity of heavy vehicles
HCM	<i>High Capacity Manual</i>
MPa	Megapascal
N	Number of equivalent project axes
PK	Kilometric point
PDF	<i>Portable Document Format</i>
SN	<i>Structural number</i>
TP	Project traffic
UML	<i>Unified Modeling Language</i>
UTM	<i>Universe Transverse Mercator</i>

ANNEX I. Definitions

Automobile: motor vehicle that circulates without lanes and without connection to an external source of energy. This definition excludes mopeds, vehicles for people with disabilities and tractors and other agricultural machinery.

Base layer: layer of the pavement located under the pavement whose mission is eminently structural.

Berma: longitudinal strip, affirmed or not, included between the outer edge of the shoulder and the gutter or inner edge of the slope closest to the platform.

Causeway: part of the road destined to the circulation of vehicles. It consists of one or more lanes

Cement floor: homogeneous mixture of granular materials (gravel, granular soil or inert waste products), cement, water and possibly additives made in the plant, which is conveniently compacted as a structural layer on road surfaces.

Cold open bituminous mixture: combination of a bituminous emulsion, aggregates with a very low content of fines and additives, so that all the aggregate particles are coated with a binder film. Its manufacturing process does not involve heating the binder or the aggregates, and its commissioning is carried out at room temperature.

Embankment: part of the grading located on the natural terrain.

Esplanade categories: types of esplanade that are established, depending on their resistant capacity, for the purposes of sizing the structural section of the pavement.

Pavement semi-flexible: pavement constituted by layers of bituminous mixture, of total thickness or greater than 15 cm, on untreated granular layers.

Pavement semirigid: pavement constituted by a bituminous pavement of any thickness on one or more layers treated with hydraulic binders, with a joint thickness equal to or greater than 20 cm for the IC-6.1 [3] or 18 cm for the IC-6.3 [5].

Flexible pavement: pavement consisting of untreated granular layers and a bituminous pavement less than 15 cm thick (may be a surface treatment).

Gravacement: homogeneous mixture of aggregates, cement, water and exceptionally additives, made in central, which is conveniently compacted as a structural layer on road surfaces.

Heavy traffic categories: intervals that are established, for the purposes of dimensioning the structural section of the road, for the average daily intensity of heavy vehicles (IMDp).

Heavy vehicle: for the purposes of the highway instruction 6.1-IC, trucks of more than 3 tons of more than 4 wheels and without a trailer are included in this denomination; trucks with one or more trailers; articulated vehicles and special vehicles; and vehicles dedicated to the transport of people with more than 9 people.

High modulus bituminous mixture: hot bituminous mixture in which the value of the dynamic module at twenty degrees Celsius (20 ° C), according to NLT-349 [6], is higher than eleven thousand megapascals (11,000 MPa).

Horizon year: year to which certain prognoses of situations related to the road public service refer.

Hot bituminous mixture: combination of a hydrocarbon binder, aggregates (including mineral powder) and additives, so that all aggregate particles are coated with a binder film. Its manufacturing process involves heating the binder and the aggregates, and putting it on site must be done at a temperature far above the ambient.

Hot discontinuous bituminous mixture: hot bituminous mixture for rolling layers whose

aggregates have a very pronounced granulometric discontinuity in the lower sieves of the coarse aggregate.

Intermediate layer: layer of a bituminous mix floor located under the tread layer.

Law of fatigue: mathematical expression that allows estimating the number of applications of load that a material can support until its exhaustion, based on a certain parameter characteristic of its structural behavior.

Modulus of elasticity: in a material of essentially elastic behavior is the quotient between the tension applied in a uniaxial test and the unit deformation produced in the same axis.

Natural terrain: existing land under the vegetation layer.

Partial reconstruction of the road surface: partial removal and replacement of the existing road surface that does not affect the entire thickness.

Pavement: upper part of a road surface, which must withstand the stresses produced by the traffic, providing it with a comfortable and safe rolling surface.

Period of service: period of time considered for the project and dimensioning of the structural rehabilitation of a pavement.

Platform: zone of the highway destined to the use of the vehicles, formed by the road, the median, the hard shoulders and the affirmed berms.

Project lane: lane through which the largest number of heavy vehicles circulates on a road.

Recycling in situ: recycling technique in which the materials raised for their use do not move away from the road

Recycling in the plant: recycling technique in which the raised materials are taken to a manufacturing plant to mix them, hot, with a certain proportion of input materials.

Recycling: rehabilitation of a pavement consisting of the lifting, normally by milling, of the materials that have been in service, their mixing with materials of contribution and their application in the same place or in a different one.

Reposition of the road surface: removal of the deteriorated layer or layers of the road surface to the necessary depth, replacing them with another or other suitable materials, which may not be those of the existing road surface.

Residual life: period of time that remains of useful life to a pavement or any of its layers.

Rolling layer: top or single layer of a bituminous mix floor.

Structural rehabilitation: increase in the structural capacity of the existing road surface, adapting it to foreseeable traffic conditions during its useful life.

Subbase: surface on which the pavement rests, not belonging to its structure

Surface rehabilitation: restoration or improvement of the surface characteristics of a pavement. Unlike structural rehabilitation, it is not intended to increase the strength of the pavement, even if in certain cases can improve it.

Total reconstruction of the road surface: complete replacement of the existing road surface with a new one in the whole of a section, or area of the road.

Useful life: period of time in which the pavement (or the pavement layer considered) does not present a generalized structural degradation.

Zahorra: granular material, of continuous granulometry, used as a pavement layer. It is called artificial sandpaper consisting of totally or partially crushed particles. Natural zahorra is the material formed basically by non-crushed particles.

ANNEX II. Database

PARAMETERS FOR THE CALCULATION OF THE NUMBER OF EQUIVALENT AXLES

Table 2. Traffic categories [4]

Heavy traffic category	IMDp (min)	IMDp (max)	IMDp (cal.)	Allowance coefficient for traffic [5]
T00	4000	-	8000	1,2
T0	2000	4000	4000	1,2
T1	800	2000	2000	1,2
T2	200	800	800	1,1
T31	100	200	200	1,1
T32	50	100	100	1,1
T41	25	50	50	1
T42	0	25	25	1

Table 3. Maximum capacity of a road [2]

Type of road	Type of stretch		
	Level	Wavy	Mountainous
Main network	9000	4000	2000
Secondary network (with shoulder)	7000	3000	1500
Secondary network (without shoulder)	5000	2000	1000

Table 4. Asignation parameters for lanes

Type or road	Percentage over project lane
Two lanes and double direction of circulation	0,5
Two lanes per direction of circulation	1
Three or more lanes for direction of circulation	0,85

Table 5. Coefficient of equivalence to 13 tn axles

Type of pavement	Coefficient of equivalence
Bituminous or granular base	0.6
Cementitious base	0.8
Concrete base	1

Table 6. Usual values for *factor-k* [2]

Type of área	Value
Urbanised	0.091
Urban	0.093
Transition/ urban	0.093
Developed rural	0.095
Non-developed rural	0.100

FEATURES OF CONSIDERED HEAVY VEHICLES

Table 7. Type of considered vehicles for european and spanish standards

Type of vehicle	Class of vehicle	Weight per axle (tn.)	Type of axle
Buses	Bus class A o B	11,5	Simple
		10	Simple
	Urban bus (Class I)	13	Simple
		10	Simple
	Interurban bus (Clas II)	12,6	Simple
		10	Simple
Motorised vehicles	Motorised vehicle 2 axles	8	Simple
		10	Simple
	Motorised vehicle 3 axles	8	Simple

Type of vehicle	Class of vehicle	Weight per axle (tn.)	Type of axle
	Motorised vehicle 4 axles	18	Tandem
		16	Tandem
		16	Tandem
Trailers	Four axle trailer (1-1-2)	8	Simple
		11,5	Simple
		18	Tandem
	More than 4 axles trailer (1-1-3)	8	Simple
		11,5	Simple
		20	Tridem
	More than 4 axles trailer (1-2-3)	8	Simple
		11	Tandem
		21	Tridem
Road trains	Four axle road trains (1-1-1-1)	8	Simple
		10	Simple
		9	Simple
		9	Simple
	More than four axle road trains (1-2-1-1)	8	Simple
		18	Tandem
		7	Simple
		7	Simple
	More than four axle road trains (1-2-1-2)	8	Simple
		18	Tandem
		6	Simple
		8	Tandem

Table 8. Types of considered vehicles for AASHTO standards [3]

Class of vehicle	Type of axle	Weight per axle (tn.)	Weight per axle (kips)
Sedanes	Simple	0,5	1,1023
	Simple	0,5	1,1023
Pick Up	Simple	0,5	1,1023
	Simple	1	2,2046
Microbus	Simple	1	2,2046
	Simple	2,8	6,1729
Bus	Simple	5	11,0231
	Simple	7	15,4324
C2	Simple	7	15,4324
	Simple	11	24,2508
C3	Tandem	16	35,2440
	Simple	7	15,4324
T3-S2	Tandem	17	37,4786
	Tandem	14	30,8647
	Simple	6	13,2227
T3-S3	Simple	7	15,4324
	Tandem	18	39,6832
	Tridem	25	55,1156

FEATURES OF THE INCLUDED MATERIALS IN THE APPLICATION

Table 9. Database for materials

Name	Description	Type	Surface layer	Base layer	Others layers	Subbase	Elastic modulus	Poisson coefficient	Fatigue law	Minimum thickness (cm)	Maximum thickness (cm)
AC 16 D	Bituminous asphalt	Dense	Yes	-	-	-	6000	0,33	4	5	10
AC 22 D	Bituminous asphalt	Dense	Yes	-	-	-	6000	0,33	4	5	10
AC 16 S	Bituminous asphalt	Semi-dense	Yes	Yes	-	-	6000	0,33	4	5	15
AC 22 S	Bituminous asphalt	Semi-dense	Yes	Yes	-	-	6000	0,33	4	5	15
AC 32 S	Bituminous asphalt	Semi-dense	Yes	Yes	-	-	6000	0,33	4	5	15
AC 22 G	Bituminous asphalt	Coarse	-	Yes	-	-	5000	0,33	3	7	15
AC 32 G	Bituminous asphalt	Coarse	-	Yes	-	-	5000	0,33	3	7	15
AC 22 S MAM	Bituminous asphalt	High modulus asphalt	-	Yes	-	-	11000	0,3	5	7	13
BBTM 8A	Bituminous asphalt	Non-continuous	Yes	-	-	-	4000	0,35	-	2	3

Name	Description	Type	Surface layer	Base layer	Others layers	Subbase	Elastic modulus	Poisson coefficient	Fatigue law	Minimum thickness (cm)	Maximum thickness (cm)
BBTM 11A	Bituminous asphalt	Non-continuous	Yes	-	-	-	4000	0,35	-	3	-
BBTM 8B	Bituminous asphalt	Non-continuous	Yes	-	-	-	4000	0,35	-	2	3
BBTM 11B	Bituminous asphalt	Non-continuous	Yes	-	-	-	4000	0,35	-	3	-
PA 16	Bituminous asphalt	Draining	Yes	-	-	-	4000	0,35	-	4	-
PA 11	Bituminous asphalt	Draining	Yes	-	-	-	4000	0,35	-	4	-
AF 8	Bituminous asphalt	Porous asphalt	Yes	-	-	-	1500	0,35	3	-	3
AF 12	Bituminous asphalt	Porous asphalt	Yes	-	-	-	1500	0,35	3	4	5
AF 20	Bituminous asphalt	Porous asphalt	Yes	-	-	-	1500	0,35	3	6	7
AF 25	Bituminous asphalt	Porous asphalt	Yes	-	-	-	1500	0,35	3	8	-
Zahorra natural	Aggregate	-	-	-	Yes	-	350	0,35	-	15	30
Zahorra sobre	Aggregate	Zahorra	-	-	Yes	-	180	0,35	-	15	30

Name	Description	Type	Surface layer	Base layer	Others layers	Subbase	Elastic modulus	Poisson coefficient	Fatigue law	Minimum thickness (cm)	Maximum thickness (cm)
explanada E1											
Zahorra sobre explanada E2	Aggregate	Zahorra	-	-	Yes	-	360	0,35	-	15	30
Zahorra sobre explanada E3	Aggregate	Zahorra	-	-	Yes	-	600	0,35	-	15	30
Suelo seleccionado tipo 2	Aggregate	Soil	-	-	Yes	-	150	0,35	-	-	-
Suelo seleccionado tipo 3	Aggregate	Soil	-	-	Yes	-	200	0,35	-	-	-
Suelo seleccionado tipo 4	Aggregate	Soil	-	-	Yes	-	250	0,35	-	-	-
Todo-uno	Aggregate	-	-	-	Yes	-	350	0,35	-	-	-
Suelo estabilizado S-EST1	Aggregate	Stabilised Soil	-	-	Yes	-	100	0,35	-	25	30
Suelo estabilizado S-EST2	Aggregate	Stabilised Soil	-	-	Yes	-	200	0,3	-	25	30
Suelo estabilizado S-	Aggregate	Stabilised Soil	-	-	Yes	-	1000	0,25	-	25	30

Name	Description	Type	Surface layer	Base layer	Others layers	Subbase	Elastic modulus	Poisson coefficient	Fatigue law	Minimum thickness (cm)	Maximum thickness (cm)
EST3											
Suelocemento SC-3	Cementitious material	Cementitious soil SC-3	-	-	Yes	-	2000	0,25	8	20	30
Suelocemento SC-4	Cementitious material	Cementitious soil SC-4	-	-	Yes	-	8000	0,25	9	20	30
Gravacemento	Cementitious material	Cementitious gravel	-	-	Yes	-	20000	0,25	10	20	25
Explanada E1	Sub-base	Low category	-	-	-	Yes	60	0,4	11	-	-
Explanada E2	Sub-base	Medium category	-	-	-	Yes	120	0,4	11	-	-
Explanada E3	Sub-base	High category	-	-	-	Yes	300	0,4	11	-	-