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QUALITY OF ROAD INFRASTRUCTURE

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ABSTRACT

With a view to improving the quality of road infrastructure, over the 2002 to 2006 period Spain carried out a comprehensive study not only of the regulations but also of the methods in this field.

The first action to highlight in this respect is the 2003 revision of the pavement and road surface regulations. This optimised the structural pavement sections, adapting them to current traffic conditions and to the technological advances that have occurred concerning both materials and construction systems.

Likewise, the Ministerial Order covering the utilisation in road works of marginal soils (expansive, collapsible soils and types with a high soluble salt content, etc.) was passed in 2002. Application of this type of material involved a more rational utilisation of natural resources, thereby achieving an optimum employment of local materials and consequently reducing the impact on the areas through which road works pass.

The Circular Order on recommendations for the design and construction of underground drainage systems in road works came into force in 2004. This regulation set up the basic criteria for the design of underground drainage systems, defining the characteristics of the works units to be employed most frequently and the details and rules of good practice to be taken into account during their construction and subsequent maintenance.

On the subject of structures, this National Report includes the account of an application for assessing the potential risk of undermining on bridges spanning water channels. To this end, it sets up methods to be adopted for carrying out bridge inspections, as also criteria for assessing their vulnerability to the scouring action of water. The Directorate General of Roads of the Spanish Ministry of Development applied these methods to an inspection campaign carried out over the 2000-2003 period involving 1,818 water bridges, all of which were on Spain's State-run Road Network.

The following index was used for reporting on this ST IV Strategic Direction Session on *Quality of Road Infrastructure*.

1. - “Innovations concerning Structural Sections and Surfacing” within Section 4.3.1, *Selecting Adequate Pavement Types and Road Techniques*.
2. - “The New Spanish Instruction on Sub-soil Drainage” within Section 4.3.3, *Minimising the Impact of Road Works on the Areas Traversed*.
3. - “Innovations in Promoting and Use of Local, Residual and Marginal Materials” within Section 4.5.1, *Promoting Optimum Use of Local Materials.*
4. - “Assessing the Potential Collapse Risk in Bridges over Water Courses” within Section 4.4.2. *Evaluating the Condition of Structures in connection with Asset Management Methods*.

1. INNOVATIONS CONCERNING STRUCTURAL SECTIONS AND SURFACING

Over the 2002-2006 period, a series of highly significant innovations appeared in Spain in relation to road pavements, with particular reference to structural sections, materials employed and the use of recycling in rehabilitation road works.

The experience acquired in works carried out in Spain in recent years dictated that the time was right for drawing up Standards 6.1.I.C and 6.3.I.C (they came into force on 13/12/03).

Standard 6.1.I.C on the one hand covers the new structural sections for pavements, adapting them to the traffic conditions existing in Spain and, on the other, the technological evolution of the materials and construction systems for road paving and surface treatment.

The following modifications included in this Standard are worth highlighting.

- With a view to optimising the pavement sections to be designed, heavy vehicle categories were distributed more comprehensively. In this respect, a new category of heavy vehicle traffic was created, the T00 (over 4000 HGV/lane/day) in order to reflect the increase in HGVs that has taken place on Spanish roads. Likewise, two HGV subcategories were created, namely T3 (50-200 HGV/lane/day) and T4 (less than 50 HGV/lane/day) in order to adapt the pavement sections better to the real traffic scenario on roads with low heavy vehicle rates.
- A commitment was made to obtain subgrades with greater guarantees in respect of structural uniformity, durability and insensitivity to water action by adopting a parameter for determining the most demanding subgrade category (modulus of compressibility in the second load cycle) and generalising the use of soil stabilisation with hydraulic binders to obtain subgrades. For the better quality Type E3 subgrades, the Standard requires them to be stabilised with hydraulic binders.
- The number of structural sections possible was reduced. Similarly, the new structural sections provide a significant increase in durability and useful life as compared to their predecessors.
- The use of natural graded aggregate as subbase was eliminated from pavement sections. This elimination was based on two accounts - for their poor structural contribution and for environmental reasons.
- New materials were incorporated into pavement design and particular attention should be drawn to the high modulus asphalt mixes for base courses and hot-mixed gap-graded asphalts for wearing courses.
- With regard to rigid pavements, it became compulsory to use continuous reinforced concrete surface treatments for heavy vehicle traffic categories T00 and T0 (over 2000 HGV/lane/day).

Standard 6.3.I.C sets out the basic criteria to be taken into account in pavement rehabilitation projects, designed to provide rehabilitated pavements with the structure and characteristics as if they were new pavements. Section 7.4 of Standard 6.3.I.C refers to criteria for applying recycling techniques. It also stipulates that rehabilitation work on pavements with a surface area greater than 70,000 m^2 must take into account (fundamentally for environmental and economic reasons) pavement recycling in the analysis of rehabilitation design solutions for road pavements.

Circular Order 8/2001 “*Pavement Recycling*” came into force on 18 January, 2002. This legislation came about as a result of the experience acquired in recycling work carried out in Spain in the 1990s. Choice of recycling technique depended on the type of structural pavement and surfacing sections involved and their state of wear. These consist of in situ recycling with emulsion for bituminous layers, in situ recycling with cement for pavement layers or hot plant recycling for asphalt layers.

Owing to their importance, two of the most significant innovations to have taken place in Spain in recent years are described below. These are hot-mixed gap-graded asphalts for wearing courses and in situ stabilised soils for creating subgrades.

1.1. Hot-mixed Gap-graded Asphalts for Wearing Courses

Hot-mixed gap-graded asphalts for wearing courses are covered in Article 543 of the General Technical Specifications for Road and Bridge Works (PG-3) which was passed on March 1st, 2004.

Table 1 - Grading Envelopes of Gap-graded bituminous mixes

GRADING ENVELOPES, ACCUMULATED PASSING FRACTION (% by Mass)

MIX TYPE	SCREED APERTURE (mm)						
	12.5	10	8	4*	2*	0.500	0.063
M8	-	100	75-97	14-27	11-22	8-16	5-7
M10	100	75-97	-	14-27	11-22	8-16	5-7
F8	-	100	75-97	23-38	18-32	11-23	7-9
F10	100	75-97	-	23-38	18-32	11-23	7-9

(*) The aggregate fraction passing a 4-mm UNE-EN 933-2 screed and retained by a 2-mm UNE-EN933-2 screed will be less than eight per cent (8%).

These mixes are defined as possessing materials consisting of a combination of a hydrocarbon binder, aggregate with really pronounced gap grading in the screeds admitting less than coarse aggregates, mineral dust and possibly additives in a way that all the aggregate particles are coated by a uniform film of binder.

In Spain, the Standard distinguishes two mix types (F and M) each involving two grading envelopes with a nominal maximum size of 8 and 10 mm and wearing course thicknesses of 2 and 3 cm respectively. The Standard lays down the use of M-type gap-graded mixes for stretches of road handling heavy traffic at rates of over 800 HGV/lane/day.

These wearing courses are generally used for roads with a high ADT and in these cases the Spanish Standard requires the use of a modified bitumen as hydraulic binder.

Tables 1 and 2 give the most significant characteristics of these mixes.

Table 2 - General Characteristics of Gap-graded bituminous mixes
MIX TYPE, COMPOSITION AND DOSAGE

<table>
<tr><th colspan="2" rowspan="2">CHARACTERISTIC</th><th colspan="4">MIX TYPE</th></tr>
<tr><th>M8</th><th>M10</th><th>F8</th><th>F10</th></tr>
<tr><td colspan="2">AVERAGE MIX DOSAGE (kg/m²)</td><td>35-50</td><td>55-70</td><td>40-55</td><td>65-80</td></tr>
<tr><td colspan="2">MINIMUM BINDER DOSAGE (*) (% by mass of total dry aggregate, including mineral dust)</td><td colspan="2">5</td><td colspan="2">5.5</td></tr>
<tr><td rowspan="2">RESIDUAL BINDER IN TACK COAT (kg/m²)</td><td>New pavement</td><td colspan="2">> 0.3</td><td colspan="2">> 0.25</td></tr>
<tr><td>Old pavement</td><td colspan="2">> 0.4</td><td colspan="2">> 0.35</td></tr>
</table>

(*) Including the tolerances specified in Section 543.9.3.1. Corrections for specific gravity and absorption of the aggregates, where necessary, must be taken into account.

1.2. Stabilised Soils for Subgrade Formation

In respect of defining pavement structure, Standard 6.1.I.C lays down three subgrade categories, denominated E1, E2 and E3 respectively. These categories are determined as a function of the modulus of compressibility in the second load cycle (E_{v2}), obtained in accordance with NLT-357 “Plate Bearing Test” Standard, the minimum values of which are given in the table below.

Table 3 – Subgrade Categories

– SUBGRADE CATEGORY -	– E_1	– E_2	– E_3
– E_{v2}(MPa)	– ≥ 60	– ≥ 120	– ≥ 300

For subgrade formation, the Standard recommends design engineers, for reasons of durability and uniformity of the structural capacity throughout the alignment, to give preferential consideration to soils stabilised in situ with lime or cement as against the direct use of untreated borrows materials. For the formation of Type E3 better quality subgrades, the Standard stipulates that their top layer should be comprised of stabilised soils except for subgrades in rock.

Table 4 - Soil Classification

SYMBOL	MATERIAL DEFINITION	PG-3 ARTICLE	COMPLEMENTARY DIRECTIVES
IN	Inadequate or marginal soil	330	- Use only possible if stabilised with lime or cement to achieve S-EST1 or S-EST2
0	Tolerable soil	330	-CBR ≥ 3 (*). -Organic matter content < 1% -Soluble sulphate content (SO_2) < 1%. -Unconfined swelling < 1%.
1	Adequate soil	330	- CBR ≥ 5 (*) (**)
2	Selected soil	330	- CBR ≥ 10 (*) (**)
3	Selected soil	330	- CBR ≥ 20 (*)
S-EST 1 S-EST 2 S-EST 3	Soil stabilised in situ with cement or lime	612	-Minimum thickness: 25 cm -Maximum thickness: 30 cm

(*) The CBR rate must be determined in line with the conditions specified for laying and its value only used for the acceptance or rejection of the materials utilised in the different layers in accordance with Figure 1.
(**) In the top layer of those used to form the subgrade, the adequate soil defined as Type 1 must have, in the laying conditions, a CBR of 6 and the selected soil defined as Type 2, a CBR ≥ 12. Likewise, these minimum CBR rates will be required when a Category E1 subgrade is formed on Type 1 soils or a Category E2 subgrade on Type 2 soils, respectively.

The instructions for forming in situ stabilised soils are provided in Article 512 of the General Technical Specifications for Road and Bridge Works (PG-3) passed on March 1st, 2004.

Table 5 – In Situ Stabilised Soils

SPECIFICATIONS FOR IN SITU STABILISED SOILS

CHARACTERISTIC	UNIT	STANDARD	STABILISED SOIL TYPE		
			S-EST1	S-EST2	S-EST3
LIME OR CEMENT CONTENT	% PER MASS OF DRY SOIL		≥ 2	≥ 3	
CBR at 7 days (*)	----	UNE 103502	≥ 6	≥ 12	
UNCONFINED COMPRESSION at 7 days (*)	MPa	NLT – 305	---	---	≥ 1.5
DENSITY (Modified Proctor)		UNE 103501	≥ 95 (**)	≥ 97	≥ 98

(*) For carrying out these tests, the cores must be compacted according to NLT-310 with the density specified in the work formula.
(**)For the top course of EI subgrades as defined in Standard 6.1. I.C on Pavement Sections, this value must be ninety-seven per cent (97%).

Stabilised soils are defined as the uniform mix on the actual road alignment of a soil with lime or cement and possibly with water which, when correctly compacted, is designed to lower the soil's susceptibility to water or increase its strength with a view to utilising it in the formation of subgrades.

Depending on its end characteristics, the Spanish Standard specifies three types of in situ stabilised soil, known respectively as S-EST 1, S-EST 2 and S-EST 3. The first two can be obtained with lime or with cement whereas the third type needs to be made with cement.

The conditions these stabilised soils should comply with are laid down in the abovementioned Article 512, as a function of the soil type and subgrade category intended, as included in Table 5.

2. THE NEW SPANISH INSTRUCTION ON SUB-SOIL DRAINAGE

The Spanish regions have sharp *pluviometrical contrasts*. While average annual rainfall in the North-East of the Spanish Mainland can go above 2200 mm/year, in the South-East it scarcely reaches 300 (a 1:7 ratio), and some weather stations even record less than 130 mm/year, almost certainly representing the lowest average value in continental Europe.

Furthermore, the temporal distribution of the pluvial regime is extremely irregular since in some parts of the country the average number of days with rainfall (over 1 mm/day) scarcely reaches 50 days/year whereas in others it is over 190 (1:4 ratio).

The average annual *hours of bright sunshine* range, depending on the region, between 1500 and 2900 h/year, signifying a 1:2 ratio. The situation is even more extreme in relation to the *frost regime* as on the South coast, the average numbers of days with frost is between 0 and 2 days/year while in certain specific inland zones it is over 120.

Spain's State-run Road Network passes through all these zones, forming part, as indicated above, of exceedingly variable climatic coordinates affecting the conditions in which its *underground drainage* takes place.

In early 2004, Circular Order 17/2003 "*Recommendations for the Design and Construction of Underground Drainage in Road Works*" came into force, which includes basic instructions related to the design, construction and maintenance of State-run roads, aimed at serving this entire network. To this end and in certain specific aspects, it was necessary to divide the country into relatively uniform regions in order to distribute the climatic variables referred to.

Bearing constantly in mind the above determining factors, this document applies to the State-run roads with some of the pavements covered by the new Standard on *Pavement Sections* (2003), excluding drainage of tunnels and of structures and specific geotechnical work (ground improving techniques and impervious diaphragm walls, etc.).

The new Standard is an attempt to lay down the *basic criteria* for the design of underground drainage, defines the characteristics of the work units most frequently employed in this field and states issues that can be tackled from the design stage referring to aspects related to construction and maintenance.

2.1. Need for Underground Drainage and Basic Planning

The *need* for underground drainage on roads is based on the fact that the increased moisture content in the materials comprising pavement and subgrade layers is usually linked to a decrease in their bearing capacity and may give rise to physical and chemical phenomena capable of modifying their structure and behaviour in a detrimental fashion, for instance, erosion, meteorisation, dissolution, expansion and collapse, etc.

These issues are even more important at the present time since as from the publication in 2002 of the new General Technical Specifications for Road and Bridge Works (PG-3) relating to *subgrades, drainage and foundations*, the use is permitted in certain specific circumstances of so-called marginal materials tending to be sensitive to water (expansive and soluble soils, etc.) in order to take the maximum advantage of local materials.

In an attempt to prevent the abovementioned problems, the Standard starts from a number of *basic premises*:

- Drainage of *pavement layers* and elements comprising the roadway:
  - an effort should be made to prevent surface water from penetrating by filtering through the carriageway, hard shoulders, berms, central reserves and exceptional elements in order to prevent any rise in the moisture content of the pavement layers;
  - treatment of central reserves, berms and any possible unpaved verges is compulsory in order to prevent, or at least decrease the volume of, water filtering in through them;
  - water filtering in for any reason must be helped to evacuate.
- Drainage of *subgrades* (fills and cuts):
  - subgrades must be protected from the inflow of groundwater;
  - subgrades should be placed at the greatest possible distance from the groundwater table. Minimum distances are set in the new Standards on *Pavement Sections and Rehabilitation* (2003) as a function of the type of materials comprising the supporting ground.

Having stated these basic technical premises, the Standard deals with the issue from a *practical approach*, based to a large extent on the observation of the problems affecting roads in service.

2.2. Brief Summary of the Content

The following problems are included in the *design criteria*:

- maximum prevention of *vertical filtration*: introducing aspects complementary to the new *Pavement Sections* Standard on joint sealing in concrete surfacing, covering questions related to the characteristics of the materials stipulated on central reserves and unpaved berms, etc.;
- analysis of the possibility of *horizontal* (or lateral) *filtration*: developing questions related to its possible consideration and measures to attempt to mitigate it;
- *evacuation of any water* that has managed to filter in: the basic assumption being that surface treatments are impervious, in spite of which, measures are stipulated to ensure water evacuation in the event of any filtration.

A theoretical model is set up for the path of any water filtering into the cross-section for whatever reason. This behaviour model assumes that the infiltration is vertical as far as the stage where the water reaches a poorly pervious layer in which the flow can be assumed to be subhorizontal. If all the layers crossed were sufficiently pervious, vertical flow would continue until the water encountered a more impervious material deeper down.

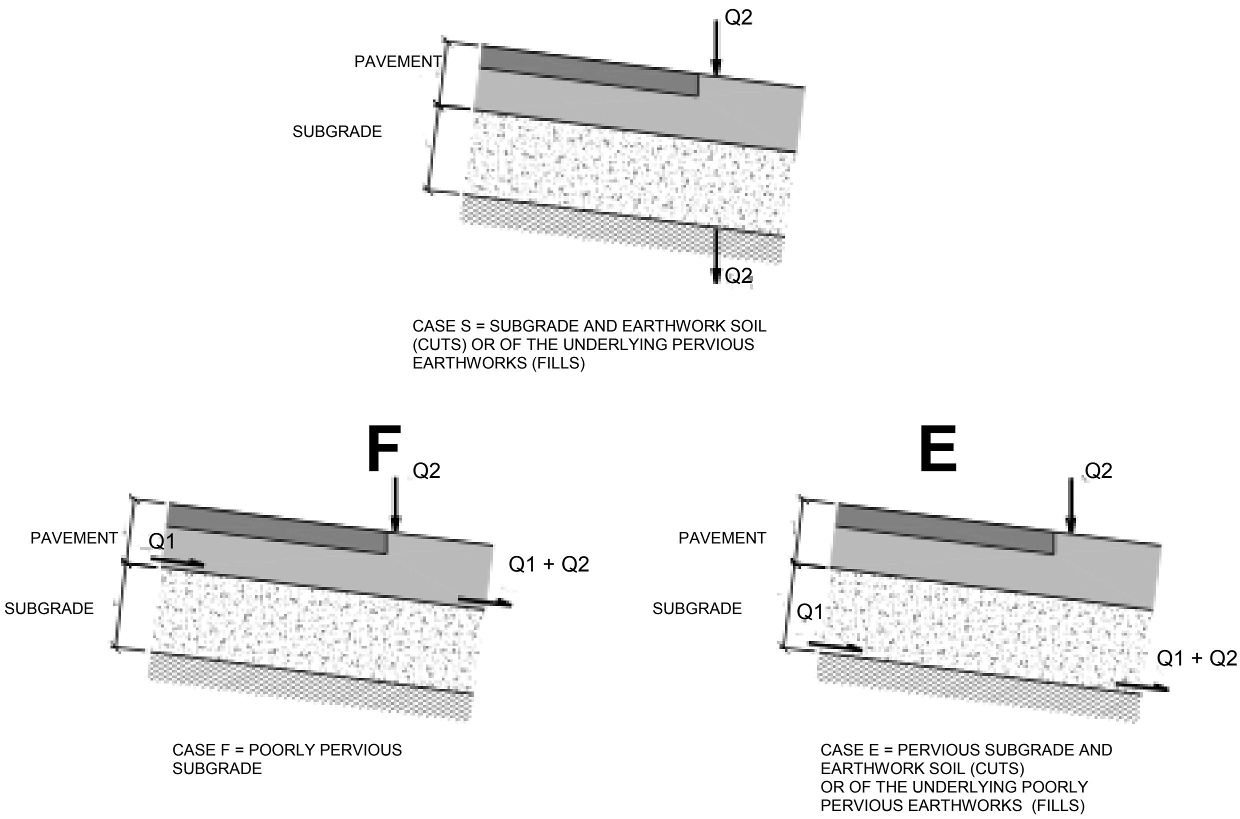

Figure 1 – Subgrade drainage cases

Based on the pavement section catalogue of the new Spanish Standard and applying the recently indicated theoretical approach, the possible paths of vertical and subhorizontal filtered water are studied for each individual standard road cross-section.

To this end, three possible cases are established *(F, E, S),* denominated as a function of the Spanish initial of the name of the layer through which the majority of the filtered water is assumed to run.

These three cases need to be selected on the basis of a *flow diagram* based on contrasting permeability criteria (qualified in certain cases by climatic aspects) between the layers forming the road cross-section. Figure 2 reproduces the appearance of this diagram.

Having determined the case for application out of the three possibilities, the theoretical path of the water that could have filtered into the cross-section needs to be followed, checking that water is not accumulating or being retained anywhere and that it is not running through soils or rocks that should be classed as marginal or adequate on the basis of the criteria laid down in the new version of the PG-3 on *subgrades, drainage and foundations* (2002).

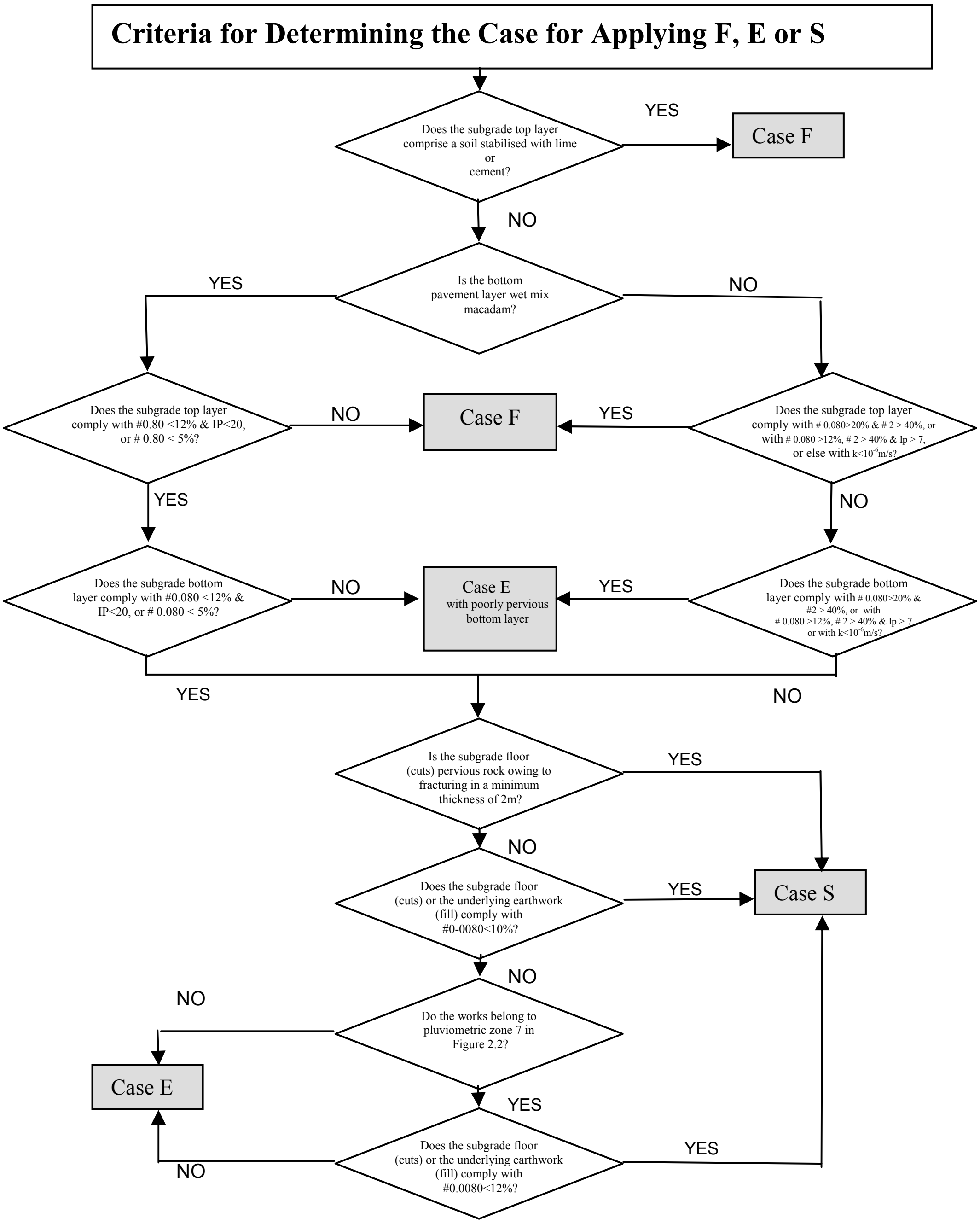

Figure 2 - Flow Diagrams

Furthermore, a series of *geometrical criteria* are set up, intended to encourage lateral outflow and hamper inflow.

The document goes on to cover matters related to the different *types of drain* and their most typical *locations*, insisting on the need not to drain runoff water or water from surface drainage into specific underground drainage elements or systems, due to the fact that differences of varying degrees of magnitude tend to exist in the run-offs circulating through the two, to which must be added the difficulty usually involved in subsequent inspection and repair work on these elements.

A possible classification of the drains proposed is determined by their location, distinguishing between drains at the foot of cuts, in central reserves and verges and also in relation to two special cases, namely for concrete surfacing and for collecting longitudinal flows, entailing a very specific set of problems that the Standard develops in greater detail.

- In relation to *subgrade drainage* (fills and cuts), it stipulates the need for hydrogeological explorations prior to execution of the works and deals separately with the matter of groundwater table proximity and so-called stabilisation drainage, intimately linked to the geotechnical behaviour of subgrades.
- It also formulates criteria for calculating *drain pipes*, distinguishing between whether they are located above or below the groundwater table and dealing with some questions on the underground drainage for so-called *exceptional elements* such as conducting for utility services and arrester beds.
- It also covers the phenomenon of *frost*, using a series of maps to define three geographical regions (H1 to H3). In each of these regions, it stipulates a frost penetration depth within which materials susceptible to ice should not be installed. It also prescribes minimum depths for underground drainage elements in each of these zones.

It subsequently includes a chapter, designed as an open-ended catalogue, indicating the main characteristics and basic requisites to be met by the *underground drainage elements* most frequently encountered in road works.

It specifically deals with cut-off drains, fin drains, filters and drain pipes; main drains, catchpits and manholes; impervious sheeting; sills, heels and draining buttresses; Californian drains, interception drains and fishbone drains as also sumps, drainage galleries and specific geotechnical works. In addition, it indicates the questions that a design should take into account when the particular element under study does not come in the above list.

Later on in the chapter on *construction and maintenance* it draws attention to the aspects needing to be taken into account in designs and considered most significant for the adequate functioning of the underground drainage systems during the construction and operation stages of a road and which normally consist of good practice rules and details that are easy to comply with.

The Standard ends by including a series of *annexes* dealing with a total of fifty underground drainage details applicable to the design of standard cross-sections, depending on which case for application (F, E or S) is involved for evacuating filtered water, on whether the detail is relative to cuts, fills or central reserves and on whether the carriageway slope encourages run-off towards the proposed system or not. These details are accompanied by a number of additional notes relative to miscellaneous items, namely the possible placement of topsoil in certain areas of the section, minimum thicknesses for certain specific granular layers and the need to line ditches, etc.

3. INNOVATIONS IN PROMOTING AND USE OF LOCAL, RESIDUAL AND MARGINAL MATERIALS

The Official State Gazette dated 11 June, 2002 published Order FOM/1382/02 updating certain articles of the General Technical Specifications for Road and Bridge Works (PG-3) relating to the construction of subgrades, drains and foundations.

Articles 330 on Embankments, 331 on Rockfills and 333 on Random Fills introduce the concept of *marginal materials* for the first time in Spain, referring as such to materials that, while not being able to be utilised directly in road works, are eligible for use in certain specific areas of fills, provided that an explicit study for each specific circumstance determines the viability of their use, defining whatever instructions are necessary for such utilisation.

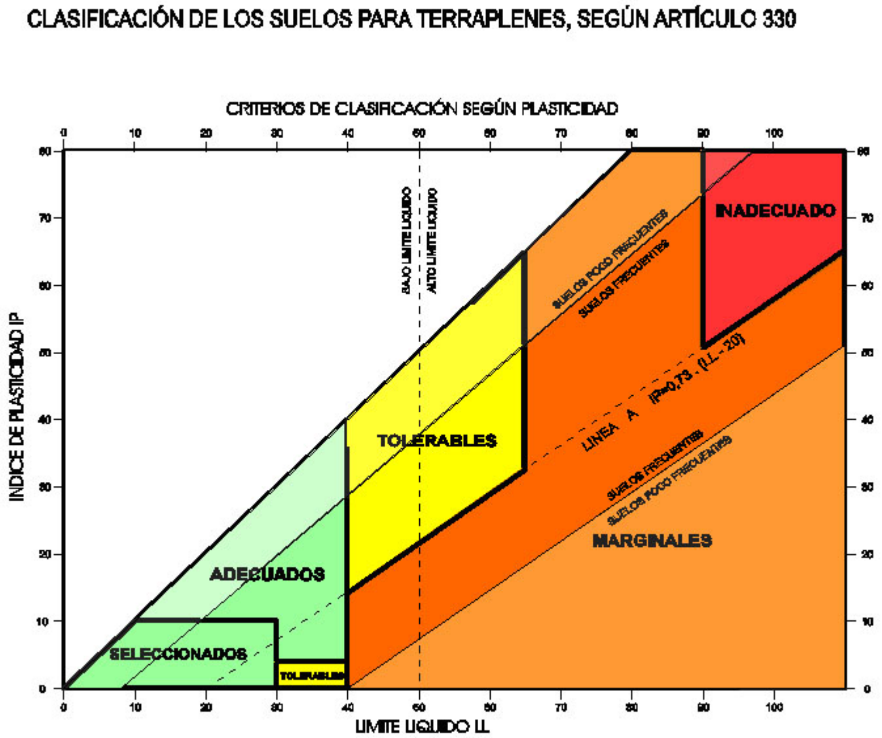

Figure 3 – Classification of soils by plasticity

The use of these types of material involves a more rational employment of natural resources, reducing the impacts in the areas affected by road works and an optimum utilisation of local materials - preferably from along the actual road alignment - which would otherwise be rejected.

This new regulation, introduced in 2002, divides fills into foundation, core, top, shoulders and special zones where applicable, calling for different instructions for each of them, and details the characteristics determining that a particular type of *soil* or *rock* material is considered marginal.

For soils, these properties are linked to conditions of plasticity, content of organic matter, soluble salts, expansivity, collapsibility and CBR for the compaction conditions for site laying.

Figure 3 and Table 6 give the criteria for classifying *soil* materials in Order FOM/1382/02. Where rocks are concerned, it is their specific mineral characteristics, water stability and inadequate shape that can determine their classification as marginal.

Table 6 – Spanish Soil Classification

<table>
<tr><th colspan="2">SELECTED</th><th>ADEQUATE</th><th>TOLERABLE</th><th>MARGINAL</th><th></th></tr>
<tr><td colspan="2">< 0.2%</td><td>< 1%</td><td>< 2%</td><td>Art. 330.4.4.5</td><td>Organic matter</td></tr>
<tr><td colspan="2" rowspan="2">< 0.2%</td><td rowspan="2">< 0.2%</td><td>GYPSUM < 5%</td><td>Art. 330.4.4.3</td><td rowspan="2">Soluble salts</td></tr>
<tr><td>OTHERS < 1%</td><td>Art. 330.4.4.4</td></tr>
<tr><td colspan="2">---------</td><td>---------</td><td>< 3%</td><td>< 5%
Art. 330.4.4.2</td><td>Unconfined swelling</td></tr>
<tr><td colspan="2">---------</td><td>---------</td><td>< 1%</td><td>Art. 330.4.4.1</td><td>Settlement in collapse test</td></tr>
<tr><td colspan="2">≥ 100</td><td>≥ 100</td><td>---------</td><td>---------</td><td>Maximum size (mm)</td></tr>
<tr><td rowspan="3">(*)
0.4 ≥ 15%</td><td># 2 < 80%
#0.4 < 75%</td><td># 2 < 80%</td><td>---------</td><td>---------</td><td>Other grading conditions</td></tr>
<tr><td>< 25%</td><td>< 35%</td><td>---------</td><td>---------</td><td>Fines content
(# 0.08)</td></tr>
<tr><td></td><td colspan="2">AS PER ATTACHED GRAPH</td><td></td><td>Plasticity</td></tr>
</table>

(*) Soils fulfilling the condition indicated are exempt from the other grading and plasticity checks
#n = A% percentage in weight passing an n UNE screed
(#n = number of UNE set screed)

The use of marginal materials is only permitted in the core of fills, a necessary requisite for their use being a *special study*, which must be passed by the Works Manager and must include the following aspects:

- determination of the properties giving the soil its marginal nature;
- study of the behaviour of these properties in the use for which the material is intended;
- study justifying the strength of the compilation and the total and differential settlement expected, making reference to its evolution over time;
- construction arrangements and technical specifications that must be adopted for the use to which the material is to be put.

Logically, these requisites must be justified by means of a sufficiently representative exploration campaign.

The marginal soils most usually found include types that are collapsible, expansive, contain organic matter, gypsums and other soluble salts.

Possible actions permitting the use of marginal materials include the following most significant types standing out for their number and importance in Spain:

- utilisation of materials with a high soluble salt content, especially embankment cores built of gypsipherous materials (not in vain is Spain the number three producer in the world of commercial grade gypsum and extensive zones of the territory contain it in substantial quantities) where their isolation from atmospheric action, groundwater and road drainage systems, normally by the use of synthetic waterproofing sheeting and pipe encasing, etc., is of upmost importance;
- maximum use of soils combining high plasticity and expansivity values with a low bearing capacity (measured by the CBR test) where stabilisations (mainly with lime) play a relevant role;
- in other more isolated cases, the leading role is played by the use of by-products from human processing treatments and rocks that are unstable in the presence of water action, etc.

To sum up, the Spanish commitment to studying the rational utilisation of marginal materials is clear and resolute, endeavouring to achieve an optimum use of local materials capable of redounding in greater respect for the environment, all of which meeting strict criteria and quality controls.

Two actions are reported below, one involving the use of gypsipherous materials in embankments and the other, the lime-based stabilisation of a highly plastic soil.

- The highway known as Saragossa's *Fourth Beltway (Cuarto Cinturón)* constitutes a motorway ring road for the capital city of Aragon (which will host the 2008 Universal Exhibition). The city stands on the River Ebro basin with a predominance of Tertiary evaporitic materials, fundamentally gypsums.
  One of the first applications of the new regulations was execution of some 14 km of core for an embankment with an average height of 10 m and a 36-m wide top using gypsums from the actual road alignment, which were confined by installing waterproofing sheets and built using 3.50-m wide non-structural confining shoulders.
- Another recent case is located in the vicinity of the city of Gerona, very close to its airport, where construction of a motorway section some 6 km long, all of which is on an embankment with an average height of around 5 m, utilises local plastic clays with unconfined swelling close to 3% and a CBR of < 3 in all cases.
  The contractors opted for an in situ stabilisation adding some 2% of lime and entirely satisfactory results have been achieved to date.

4. ASSESSING THE POTENTIAL COLLAPSE RISK IN BRIDGES OVER WATER COURSES

The fundamental function of a bridge is to provide continuity for a road, overcoming any natural or artificial obstacles encountered along its alignment. This obvious remark takes on particular relevance if the obstacle to be overcome is a water course. It must be taken into account that the dynamic equilibrium of water courses is affected not only by human intervention involving direct actions - construction of dams, extraction of aggregates and channel invasion, etc. - but also indirectly as a result of changes in the hydrological balance of the inflow basin, essentially owing to variations in land use. Then, to recover its balance, the channel responds by acquiring a balancing slope providing it with the minimum energy required to transport the water load. This natural phenomenon is achieved through erosion, transport and sedimentation.

In water bridge scenarios, the process of erosion is a relevant aspect insofar as re-establishment of the dynamic balance of the river channel can become a vulnerability factor for a bridge, essentially associated with scour phenomena in its foundations.

Bearing these considerations in mind, it would seem logical to assume that assessing the safety of a bridge not only depends on its structural conditions but that a certain degree of vulnerability also exists in the river channel it spans. The question is how to estimate the risk in the channel-bridge interaction. It would seem that the immediate initial response could be based on carrying out an inspection of the channel to be able to record the variables capable of making the bridge vulnerable in relation to the channel. This requires an objective estimation of the potential risk of the bridge collapsing under an extraordinary flood, considering river hydraulics, based on the geomorphological parameters of the channel and on the bridge hydraulics actually involved. The extent of freedom and uncertainties that can be acquired in these parameters is undoubtedly high, insofar as the river dynamics involved do not, unlike bridges, allow systematic criteria to be set up capable of making the inspection accurate. In addition, it may happen that no signs are evident at the time of the inspection (slight scour, light undermining and silt or alluvion deposits, etc.) capable of indicating in an obvious way that risk exists. This leads us to consider a potential and not an accurate risk, in the assessment of the bridge-channel combination, governed by the qualitative and quantitative relations between the variables under study.

All this appears to be very promising, but is it technically viable and sufficiently reliable?

In order to answer this question and, above all, to solve the problem of assessing the potential risk of scour in water bridges, a set of methods for inspecting bridges and their surroundings has been developed and criteria defined to allow this risk to be quantified.

4.1. Methods for Inspecting Bridges and Their Surroundings

The first task needed for studying the vulnerability of a bridge in relation to action from the water course it spans is to carry out a meticulous inspection of the bridge and its immediate surroundings. Based on our experience, a reasonably valid scope is four times the length of the bridge upstream and downstream, approximately.

An assessment of the potential flood risk is based on two parameters - the vulnerability of the bridge and the geomorphology of the water course. These two descriptors give rise to a large number of records that, under a calculation algorithm, enable the risk condition to be established in numerical form.

4.1.1. Bridge Vulnerability

Bridge vulnerability is determined by the possible effects of local scour of the understructure. The parameters framing this descriptor only relate to the implementation of the bridge and its foundation characteristics. Consequently, inspections should cover the aspects described below.

a) Existence of Scour due to Channel Contraction or to Obstacles Interposing Water Flow

The potential risk shows up in the form of scour, either local in nature, at the foot of buttresses and piers, or else throughout the cross-section, owing to contraction of the channel caused by a structure interposing.

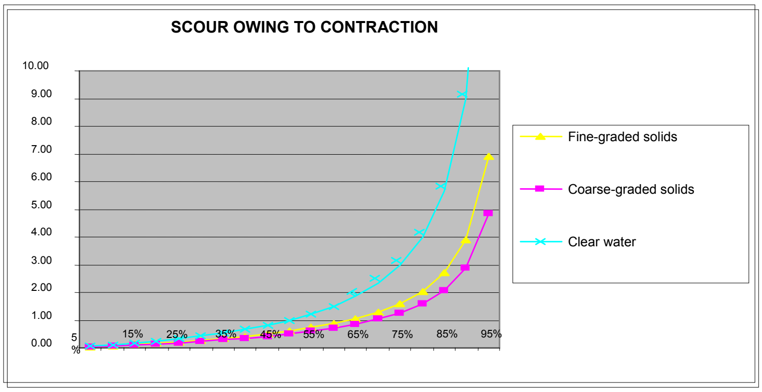

Figure 4 - Scour depth variation as a function of the percentage of contracted section

If the buttresses are embedded in the channel, this produces a reduction of the section, which in turn produces a concentration of flow giving rise to a phenomenon of contraction erosion. This effect can be estimated using Laursen's Law Its calculation is not the subject of this article nor of the proposed channel inspection, although for information purposes a graph is included representing the variation of scour depth as a function of the percentage of contracted section (Fig. 4).

b) Pier Orientation

In addition, the orientation of piers and buttresses in relation to water flow, the shape of the attack front and the number of shafts (single or multiple) are parameters with a substantial effect on the vulnerability conditions in relation to the risk of local scour at the foot of the understructure.

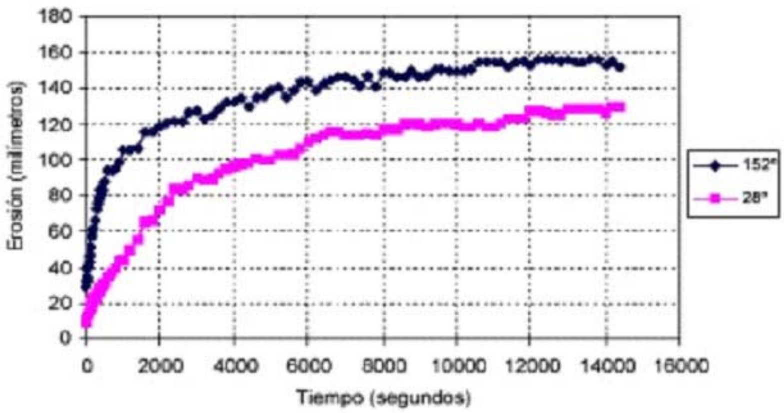

Figure 5 - Scour depth in buttresses as a function of the angle of attack

Figure 5 illustrates the effect on erosion of buttress orientation in relation to flow, according to an experimental study in a uniform flow regime and under the same hydraulic conditions. Figure 6 is a qualitative illustration of the shape of scour pits generated in a pier orientated in the same direction as the flow and in another pier with a specific angle of attack.

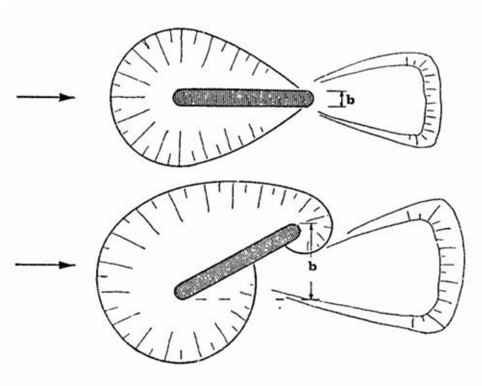

Figure 6 - Effect of angle of attack on pier scouring

c) Foundation Type

The type of foundations, deep or direct, and the material comprising the competent substratum equally constitute parameters to be taken into account. A bridge with piered foundations may have suffered undermining due to scour and not prove potentially dangerous if its design took these conditions into account (Fig. 7).

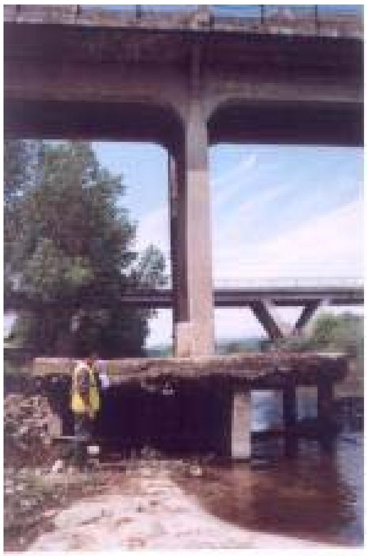

Figure 7 - Foundation with deep scour

d) Examining Scour Pits

Scour pits can prove to have a devastating effect in direct or short-piled foundations or those with an alluvial or similar type of poorly competent substratum. Special attention should be paid to the fact that a scour pit reaches its maximum exponent during an extraordinary flood, but once the river's uniform regime is restored, this pit can accumulate sediments and partially mask the real depth of the scour.

e) Other Factors

Other parameters affect scour in the understructure but are difficult to quantify in a visual inspection. Some depend on the fluid properties, density and viscosity, etc. while others depend on the flow characteristics, velocity and depth, while still others, on bed properties such as slope and sediment grading. None of these parameters is registered on the scene of the proposed inspections but inspectors need to be aware of all the influential factors.

4.1.2. Channel Geomorphology

This descriptor really assesses the state of equilibrium in the channel thanks to geomorphological parameters. The inspection should consequently record the following aspects:

- existence of bars or islands, obstructions or build-ups of silt or alluvion indicating the first signs of the way a river will behave under a flood regime;
- type of channel, whether rectilinear, braided, anastomosed, meander or torrential, etc., and the bed and bank material indicating the degree of channel stability;
- protection systems and their state of preservation allowing certain erosion risks to be distinguished;
- existence of tributaries or confluents making it possible to take into account discharge rises and nape overflows under an extraordinary regime.

All these constitute recordable data in accordance with a specific nomenclature making it possible to carry out calculations post process.

4.2. Assessing the Risk Factor

As in the case of the so-called Main Inspection for bridges, the aim of inspecting the bridge-channel combination is to obtain a factor capable of representing and, to the extent possible, quantifying the potential risk of a bridge under threat of scour phenomena. This factor means that the actions to be carried out can be prioritised, in this case geared to protection work to reduce the channel's erosive capacity. This assessment starts by grouping the data collected in the inspection under the following headings:

- data observed from the bridge deck:
    - flow regime
    - bridge built on the flood plain
    - angles of approximation and deviation
    - surface vegetation (woodland, scrubland, crops, etc.);
- data observed from under the bridge:
    - bed material (concrete, rock, boulders/pebbles, gravels, sands, etc.)
    - existence of isolated or intermediate bars (with vegetation or without)
    - existence of obstructions (channel invasions, impairment caused by other structures, waste dumping, buildings, etc.)
    - build-up of entrained material (shrubs, trees, refuse, rubble, etc.)
    - evidence of structure overburden
    - evidence of flow under load;
- data observed in piers and buttresses:
    - location (left/right bank, channel, flood plain, etc.)
    - angle of attack
    - shape of attack front (pointed, rounded, square-shaped, H-shaped, etc.)
    - orientation of wings
    - construction material (concrete, steel, stone, brick, etc.)
    - maximum water level reached
    - silt and alluvion
    - scour pits
    - understructure bed material (rockfill, alluvial soil, rock, concrete, etc.)
    - existing protection systems (gabions, dykes, encasings, weirs, etc.);
- data observed upstream and downstream in the channel:

- channel width
- channel type (rectilinear, braided, anastomosed, torrential, etc.)
- vegetation on the banks
- material of banks and bed (concrete, rock, boulders/pebbles, gravel, sand, etc.)
- bank erosion (mild, severe, sliding, etc.)
- existence of tributaries or confluents (natural or artificial)
- meander impact
- existence of isolated or intermediate bars (with vegetation or without)
- existence of obstructions
- channel and bank protection systems (rockfills, gabions, dykes, breakwaters, encasings, etc.) and state of preservation
- contraction erosion upstream and expansion erosion downstream.

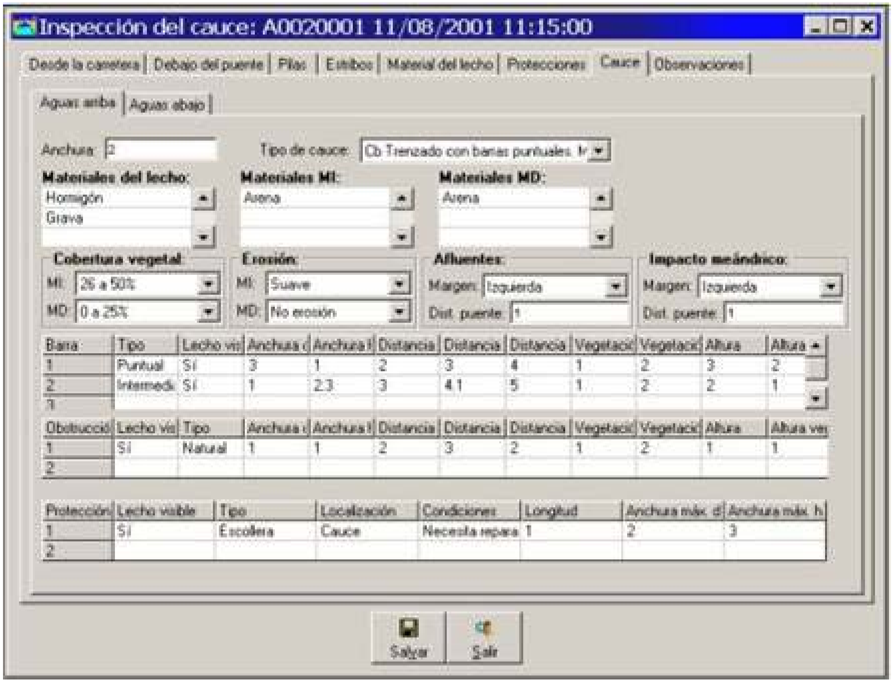

Figure 8 - Grouping of data collected during a Main Inspection

All these data are put into a data base (Figure 8) where they are processed using a specific algorithm aimed at quantifying the four parameters characterising bridge vulnerability, namely:

- the *bridge vulnerability descriptor*, which is a function of:
  - the installation of buttresses
  - the installation of piers
  - the frontal shape of pier shafts
  - the type of foundations
  - the foundation material
  - the understructure attack angle;
- the *channel descriptor*, which depends on:
  - the existence of bars or obstructions
  - the existence of deposit build-ups
  - the channel type
  - the evidence of meander impact
  - the bank erosions
  - the bed and bank material

  - the effect of tributaries
  - the type of channel protection systems and their condition
  - the effect of ocean tides;
- the *channel-structure interaction descriptor*, determined on the basis of:
  - the channel bed material in the understructure
  - the evidence of flow under pressure
  - the angle of deviation under a high water regime
  - the existence of understructure protection systems in the bridge area
  - the condition of this protection
  - the ratio between the width of silt or alluvion deposit and the shaft width
  - the evidence of erosion due to expansion;
- the *bridge scour descriptor*, quantifying the existence of scour, undermining or rotations already produced in the structure inspected.

Integrating these descriptors and also taking into account the importance of the bridge category provides the RISK FACTOR characterising the bridge-channel combination as a function of its vulnerability to any scour that a possible future flood could produce. Bridges can consequently be grouped into five categories as a function of the risk factor obtained.

- *Structures with a risk factor less than or equal to 20*
  These are bridges over water courses with a vulnerability index that is virtually zero. They should be re-inspected at a sensible interval marked by the limit periods defined as standard intervals up to the next Main Inspection.
  They are not likely to be affected by extraordinary floods although, given river dynamics, it could prove chancy to corroborate this statement.
- *Structures with a risk factor over 20 and under 50*
  Works in this group have an acceptable vulnerability index in the short term and the following evidence has been detected in them:
  - a minor indication of moderate scour and/or
  - some relatively significant negative parameter such as the attack angle of the understructure, the existence of expansion erosion (channel contraction), meander impact or bank erosion.

  In these cases, the general procedure should be to continue monitoring the scour parameters that have generated the bridge's risk factor.
- *Structures with a risk factor over 50 and under 70*
  Works generally come under this category when they have a moderate short-term vulnerability index and where a combination of several negative parameters have been detected or considerable scour found in some element of the understructure.
  In these cases, the general procedure should be to carry out periodic monitoring of the scour parameters that have generated the bridge's risk factor or, where appropriate, to install the relevant protection systems.
  A factor of 70 can be taken as the acceptance threshold.
- *Structures with a risk factor over 70 and under 100*
  Works in this group have a short-term severe or very severe vulnerability index in which a combination of several negative parameters have been detected and also advanced or pronounced scour found in some element of the understructure.
  In these cases, the general procedure should be to protect the understructure properly as also the channel where necessary.
- *Structures with a risk factor equal to or greater than 100*

These are always bridges where settlement has been detected or rotation of some element of the understructure. Their state of vulnerability is high and the potential risk unacceptable.

For bridges with this case history it is mandatory to carry out a detailed study of the understructure with a view to providing an underpin or, in some cases, proceeding to do immediate repairs that may even be classed as urgent.

4.3. Some Application Results

The inspection methods highlighted and the evaluation criteria for the scour risk factor indicated above constitute an innovative treatment for the problem of the vulnerability of bridges over water courses. Over the 2000 to 2003 period, the Directorate General of Roads belonging to Spain's Ministry of Development carried out a visual inspection campaign of the so-called 2nd and 3rd category routes that include some 4,800 bridges on the State-run Network of General Interest Roads (known by its Spanish acronym RIGE). Close to 38% of these are water bridges on which the channel-structure combination was inspected and the risk factor assessed in consistence with the criteria reported above.

Some representative results are given below concerning the 1,818 water bridges that were assessed.

- 152 bridges have their buttresses in the water course and in 248, their piers form an angle greater than 30º with the direction of water flow.
- 261 bridges span torrential channels and 380 are built in the vicinity of meanders. 34 of the first group show some type of scour while some type of meander impact was detected on 53 of the second group.
- Out of the total bridges inspected, 23 suffered advanced scour in piers or buttresses and 75 suffered moderate scour.

Twenty bridges had a risk factor higher than 100 and in 22, it was between 70 and 100.

4.4. Conclusions

A large part of the bridge collapses to have occurred recently were due to defective foundations in bridges built in water courses and produced by local erosion or scour. In addition, it is difficult to ascertain the condition of these foundations as they tend to be inaccessible or, at the very least, hard to see. Furthermore, it is not easy to ascertain the risk of collapse as it can happen that, at the time of the inspection, signs of deteriorations are not yet apparent on the basis of which a certain risk for the structure could be assumed to exist.

It therefore becomes indispensable for inspections of water bridges to be completed by a study of these tendencies in order to ascertain the potential risk of scour existing. This risk should be quantified based on the observations of the condition of the bridge itself and on the geometrical, physical and evolutionary conditions and characteristics of the actual channel in the area where the structure is located.

This paper provides a brief and succinct report on the main outlines of a set of methods for carrying out inspections on bridges, their understructure and the channel surroundings they span. It also presents criteria for a somewhat objective assessment of the vulnerability of bridges to scour action from the water course they span. It ends with a summary of the results obtained from the 1,818 inspections carried out on bridges spanning water courses under the scope of the Bridge Management System implemented by the Directorate General of Roads of Spain's Ministry of Development.