SUSTAINABILITY ASSESSMENT OF CONCRETE STRUCTURES USING THE SPANISH CODE EHE-2008. REFLECTIONS AND RECOMMENDATIONS.

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Abstract

Two of the authors of this paper were part of the team responsible for developing the new Appendix 13 to the Spanish Code for the Design of Concrete Structures (EHE-08). This code includes, for the first time in Spain, an Appendix (Appendix 13) for assessing the level of sustainability of a concrete structure. This has been an international pioneering experience. Appendix 13 uses a set of criteria related to the three columns of sustainability: the environmental, economic and social ones. Sometimes, due to the complexity inherent to construction projects, it is not easy to collect all the entry data needed for applying the Appendix. The objective of this paper is to solve some doubts that can arise when applying the appendix, presenting a computer application developed by the authors for this purpose, and explaining the way of applying the Appendix 13 by means of a case study solved with the new computer application.

Keywords: *sustainability, concrete structures, Spanish code EHE 2008*

1. Introduction

At the end of 2008, the new Spanish Code for the Design of Concrete Structures (EHE-08) came in force in Spain. The Code has included, for the first time in Spain, a non compulsory appendix that can be used for estimating a sustainability index, taking into account diverse criteria, and called Índice de Contribución de la Estructura a la Sostenibilidad (ICES; Index of Contribution of the Structure to Sustainability). Del Caño and de la Cruz participated in the team that developed this appendix (Appendix 13).

To calculate the ICES, Appendix 13 is based on several criteria related to the three columns of sustainability: the environmental, social and economic ones. As far as the authors know, this Appendix is a pioneering experience not undertaken in other countries. The reader can find a very detailed explanation on the development of this appendix in del Caño and de la Cruz (2008), Aguado et al. (2008), San José and Josa (2008), Burón et al. (2008), Garrucho and Portas (2008), Losada et al. (2008), Pacios and Martos (2008), Alavedra and Cuerva (2008), and Vacas & Zornoza (2008).

2. Objectives

The aim of this article is:

- To solve some doubts that can arise when applying the appendix, in specific cases, not clarified by the Appendix 13.
- Presenting a computer application developed by the authors for this purpose.

- And explaining the way of applying the Appendix 13 by means of a case study solved with the new computer application.

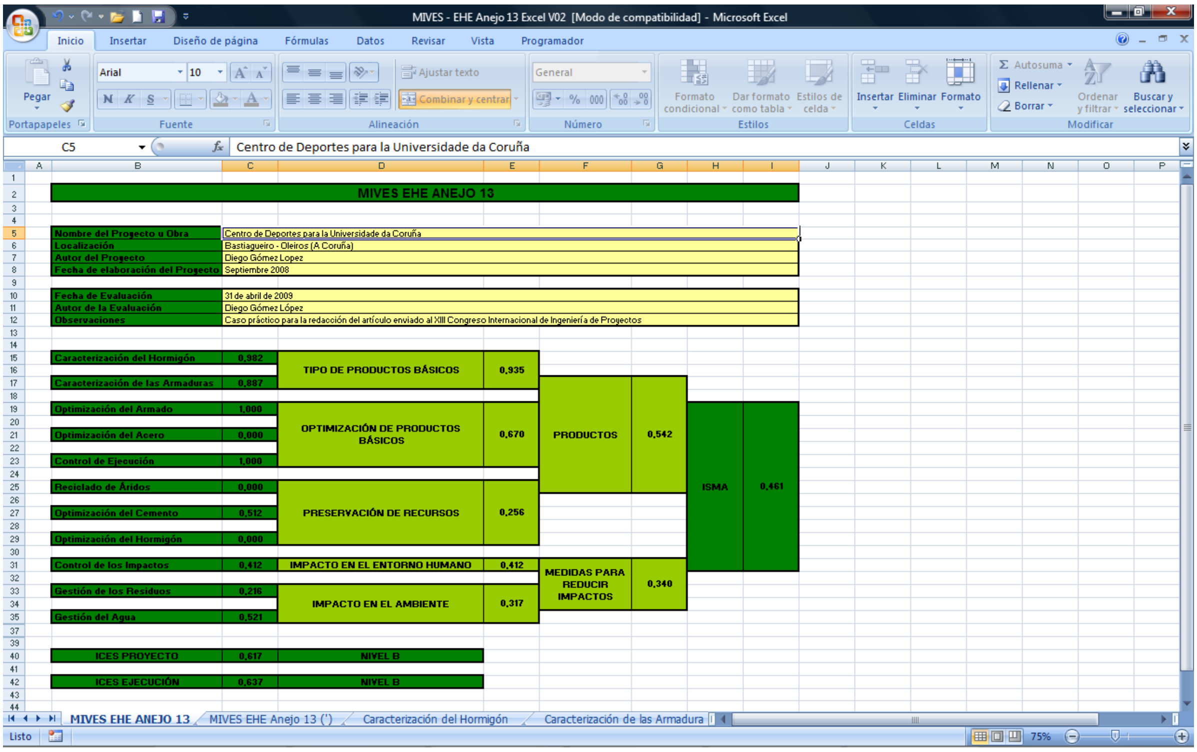


Figure 1. Results screen of the computer application developed by the authors.

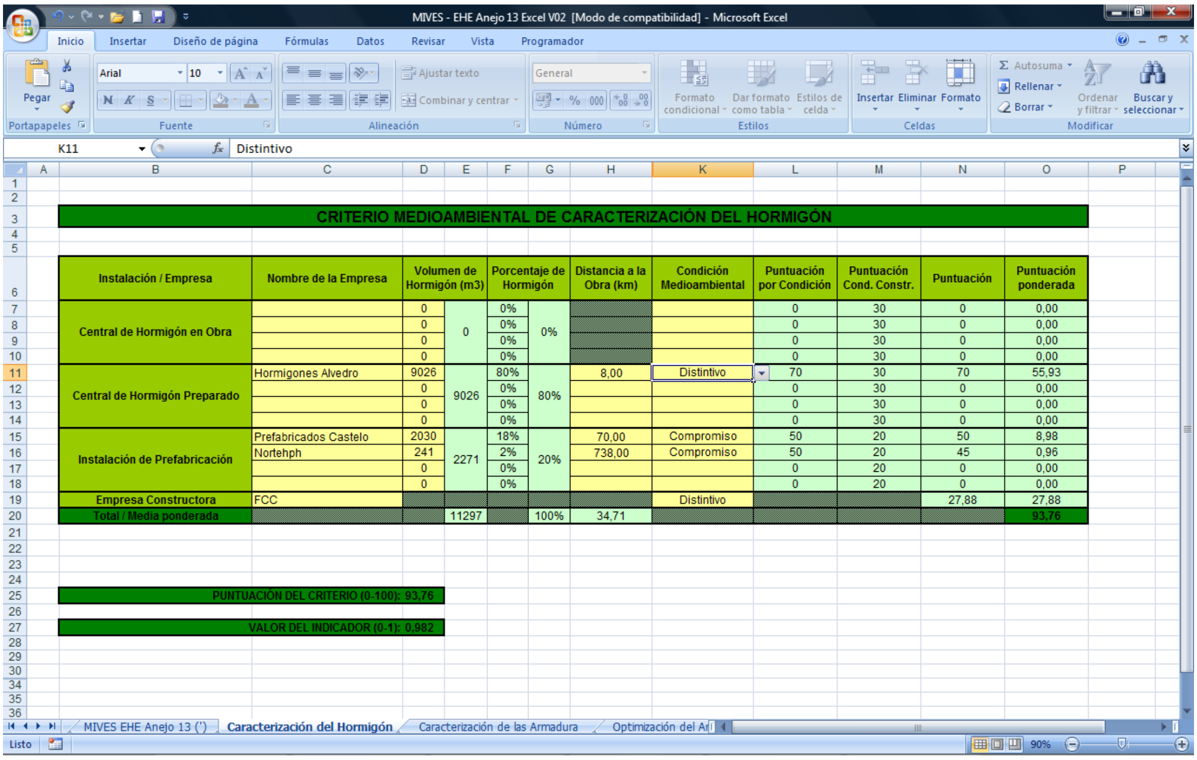
The authors consider that the application of Appendix 13 is not excessively complex but, any way, its text can be confusing in some cases, mainly because of the novelty of its approach and also because a part of the mathematical formulae to be used are complex enough to cause problems in specific circumstances.

For this reason, the Spanish Ministry of Public Works commissioned a professional for developing a software application to automate these calculations. Despite of that and after some time applying the appendix and using that software, the authors detected some problems, both in the appendix text and the software application.

Although that software could be used without excessive problems, the authors have developed a new computer application (a spreadsheet-based one; see figures 1 and 2), in the framework of a research project for conceiving and implementing computer models for assessing sustainability of concrete structures taking into account uncertainty (probabilistic and fuzzy-math models). The authors are currently preparing a report to the Spanish Body responsible for issuing the EHE Code, suggesting amendments and improvements to Appendix 13, ways of managing unclear or undefined circumstances, and solving other problems detected in its text; some of those suggestions have already been implemented in the new computer application.

3. Case Study

To shorten the present paper, due to the large amount of calculations that the Appendix 13 includes, we will only refer here to the variables which value is "yes" or is different of zero, in our case study. When a variable is not dealt with here, the corresponding value is always negative (zero for numeric parameters and “no” for other variables). The interested reader can find additional information in Ministerio de Fomento (2008).



Instalación / Empresa	Nombre de la Empresa	Volumen de Hormigón (m3)		Porcentaje de Hormigón		Distancia a la Obra (km)	Condición Medioambiental	Puntuación por Condición	Puntuación Cond. Constr.	Puntuación	Puntuación ponderada
Central de Hormigón en Obra		0	0	0%	0%			0	30	0	0,00
		0		0%				0	30	0	0,00
		0		0%				0	30	0	0,00
		0		0%				0	30	0	0,00
Central de Hormigón Preparado	Hormigones Alvedro	9026	9026	80%	80%	8,00	Distintivo	70	30	70	55,93
		0		0%				0	30	0	0,00
		0		0%				0	30	0	0,00
		0		0%				0	30	0	0,00
Instalación de Prefabricación	Prefabricados Castelo	2030	2271	18%	20%	70,00	Compromiso	50	20	50	8,98
	Nortehph	241		2%		738,00	Compromiso	50	20	45	0,96
		0		0%				0	20	0	0,00
		0		0%				0	20	0	0,00
Empresa Constructora	FCC						Distintivo			27,88	27,88
Total / Media ponderada			11297		100%	34,71					93,76

PUNTUACIÓN DEL CRITERIO (0-100): 93,76

VALOR DEL INDICADOR (0-1): 0,982

Figure 2. Screen related to the environmental characterization of concrete criterion.

On the other hand, the case study deals with the design of a concrete structure designed by one of the authors (Gómez), for a Sports Centre building. The structure includes different elements in steel (roof) and prestressed (stands and hollow core concrete floor slabs) and reinforced concrete (the other structural elements). The building occupies an area exceeding 15.000 m^2, including an indoor pool and a multi-purpose sports field (basket, handball, etc.).

The variation of structural elements means that this is an interesting case study because it brings together some of the most frequent structural elements in use today in Spain. It should be noted that when this structure was designed, the author did not paid special attention to issues related to sustainability.

3.1. Environmental Criterion Related to the Companies Supplying Concrete.

This criterion assesses the environmental contribution of the industrial plants manufacturing the utilized concrete, as well as the on-site construction procedures. In our case study:

- Foundations, basement walls, beams and columns are on site reinforced concrete elements with the concrete supplied by a ready-mix plant. All these elements account for 80% of the concrete structure and the supplier is a company located near the construction site (8 km), holding the ISO 14001 certification.
- The prestressed floor slabs count for 18% of the concrete structure. The supplier is relatively near the site (70 km), has not achieved an environmental certificate, but meets the environmental commitment requirements established by Appendix 13.

- The stands are made of prestressed concrete "L" beams. They represent only the 2% of the concrete structures. The supplier is located far from the site (738 km) and, again, has not achieved an environmental certificate but meets the EHE (Appendix 13) environmental commitment requirements.
- Because of the size and importance of the building, it has been considered that the construction should be contracted to a large company owning an ISO 14001 certification.

Taking all that into account, the score for this criterion is P_1 = 0,982. Before the procurement process, frequently the user doesn't know the identity of the final contractor and suppliers, so it is difficult to collect the data here mentioned. What can be done is, first, exploring potential companies who can perform the work, looking for contractors adequate for the building characteristics, and for suppliers located near to the site. Then, analyzing the locations and environmental characteristics of those companies. And finally, be prudent when estimating those distances and environmental characteristics to be used in calculations. This is also applicable to other criteria, except when the user is sure about the final identity of a contractor or supplier. Nevertheless, the non-deterministic models under development by the authors will allow for establishing more complex entry data, for instance estimating optimistic, expected and pessimist values, or even simpler answers, as can be "I don't know".

In large construction projects is frequent to contract two or more suppliers for the same product (for instance, ready-mix companies), and these suppliers could have different environmental characteristics. The Appendix 13 software doesn't cover this possibility, but the new computer application developed by the authors will do it.

3.2. Environmental Criterion Related to the Companies Supplying Steel Reinforcement.

This criterion assesses the environmental contribution of the companies manufacturing the steel bars and preparing the reinforcement. In our case study:

- The reinforcements of the concrete poured on site count for the 91% of the total, and are prepared by a company located relatively near to the site (17 km). This company does not hold an environmental certificate, but it meets the EHE environmental commitment requirements.
- The remaining steel relates to prefabricated elements (8% of the hollow core slabs and 1% of the stands).

The score obtained for this criterion is P_2 = 0,887. A potential difficulty here is to estimate the percentages by weight of each type of reinforcement. In case of elements constructed on site, the structural analysis programs will provide the quantities. However, in case of prefabricated elements we must ask the supplier; anyway, these companies should normally inform us about those data.

Other problems that can arise here are the already mentioned ones related to the uncertainty about the features of the final contractors and suppliers, and to the possibility of contracting several companies with different environmental characteristics.

3.3. Environmental Criterion Related to Reinforcement Reduction.

This criterion assesses the environmental contribution associated with reducing the natural resources consumed for the production of reinforcement, promoting the use of structural solutions that minimize the amount of steel needed and simplify the on-site works. In our case study:

- We have an 80% of reinforced concrete poured on site, which uses welded reinforcement (the system used by the chosen reinforcement supplier). All the floor slabs include a top concrete layer, reinforced with steel meshes (established by the designer).
- The other 20% is used in the precast hollow core slabs and stands. Again, the passive (normal, non prestressed) reinforcement is welded here.
- All reinforcements are produced following the UNE 36831standard.

For this criterion the score is P_3 = 1,000. One of the issues taken into account in this criterion is the use of steel meshes in slabs larger than 6 m x 6 m, as a way of reducing steel consumption. A potential, rare pitfall here is the one caused when a structure does not include thin kind of slabs, since the Appendix 13 assumes that every structure will incorporate them. It is not frequent, but this circumstance is possible in specific industrial plants and civil engineering structures. In such cases, we recommend to do the calculation using a “100% of slabs larger than 6 m x 6 m reinforced with steel meshes” (despite of the absence of them), because in other case the EHE will unnecessarily penalize the structure. This is the reason why the new computer application includes the case of structures without slabs, establishing for them here the maximum score related to this issue.

3.4. Environmental Criterion Related to Steel Characteristics.

This criterion assesses the environmental contribution associated with steel recycling, reduction of CO_2 emissions when producing steel, and also the use of sub-products generated in steel production. In this case study there are two types of steel (passive: B-500S; active: Y1670 Cl 1). In both cases the design specs did not included a steel quality mark, so the score for this criterion is P_4 = 0,000.

3.5. Environmental Criterion Related to Construction Control.

This criterion assesses the environmental contribution associated with reducing the amount of steel needed through implementing an adequate construction control and the use of products with an official quality mark. In our case study all the structure elements are designed to be constructed with the highest level of construction control established by EHE, allowing a structural analysis using the minimum steel safety coefficient □s and, so, reducing the amount of steel needed. The score for this criterion is P5 = 1,000.

In case of using precast elements a problem could arise, for obtaining the suppliers information, but normally this can be easily acquired.

3.6. Environmental Criterion Related to Recycled Aggregate.

This criterion assesses the environmental contribution associated with the use of recycled aggregate. In our project all the companies will use normal aggregate for preparing concrete, so the score for this criterion is P6 = 0,000. In Spain, today, it is still rare to include the use of recycled aggregate in the design specs, and even when it is included, the chief superintendent could generate a change order for using normal aggregate, to avoid any problem.

3.7. Environmental Criterion Related to Cement Characteristics.

This criterion assesses the environmental contribution associated with incorporating industrial sub-products (fly-ash or silica fume additions, for instance) to cement, as well as employing other materials causing a reduction in the CO2 emissions; or producing cement using industrial processes that consume less energy, especially through the use of alternative fuels; or increasing the value of waste materials.

In our case study the cement used is a CEM III 42.5 one, manufactured by a supplier that has not an environmentally certified production; anyway, its product has a quality mark and additions above 20%. There is not information on the implementation of the Kyoto Protocol and the reduction of CO2 emissions. Under these circumstances, the score for this criterion is P7 = 0,512. As in the case of the steel characteristics criterion, the main difficulty here lies in knowing all the necessary information about of the cement to be used.

3.8. Environmental Criterion Related to Concrete Characteristics.

This criterion assesses the environmental contribution associated with the use of industrial sub-products (fly-ash or silica fume) in the form of additions directly incorporated into the concrete. In our case study the several types of concrete to be used doesn't include this kind of additions, so the score for this criterion is P8 = 0,000.

Problems may arise here, because normally structural designs do not specify concrete proportioning or additions. The information must be gathered contacting the ready-mix suppliers.

3.9. Criterion Related to Environmental Impacts Caused by Construction Processes.

This criterion assesses the environmental contribution associated with adequate construction processes that minimize impacts on the environment, particularly dust generation and the emission of other kind of particles.

Taking into account the size of our case-study building, it is necessary to use sprinklers and also to cover materials stored on site. Taking that into account, the score for this criterion is P9 = 0,412.

The EHE only takes into account the potential methods for reducing particles and dust emissions that can be used on site. A problem arises here, since it is difficult to simultaneously use the five impact reduction methods included in Appendix 13, since some methods are substitute for others. Consequently, it is difficult to reach the maximum score (and perhaps, impractical).

3.10. Environmental Criterion Related to Waste Management.

This criterion assesses the environmental contribution associated with an adequate management of waste produced during construction. Particularly, it takes into account the potential existence of a management plan for excavation materials and construction and demolition waste; and the reduction of waste caused by the use of concrete cube test specimens. In our case study:

- An 11% of the excavation products are reused for filling trenches; this could be considered in the same way as recycling. The rest of the digging and construction waste will be sent to a dumping site.
- The 80% of the concrete to be used (the in situ concrete) will have a quality mark. Quality control for the remainder of the concrete is carried out using the normal cylindrical test specimens.

Taking all that into account, the score for this criterion is P_{10} = 0,216.

3.11. Environmental Criterion Related to Water Management

This criterion assesses the environmental contribution associated with an adequate water management during construction. Particularly, it takes into account the efficient curing of concrete; the use of specific devices to save water; and the use of rainwater.

In our case study, effective curing techniques are used for producing precast concrete. On the other hand, since the supplier has an environmental certificate, the score for this criterion is P_{11} = 0,521.

In the same way than for the criterion related to environmental impacts caused by construction processes, the EHE only takes into account the potential water management methods used on site.

The sum of all scores estimated for the eleven environmental criteria multiplied by the corresponding weighting factors leads to an ISMA = 0,461.

3.12. Social Issues.

The EHE also assesses the potential contribution of the structure to the social issues of sustainability. In our case study, the design specs establish that workers must receive health and safety courses. In the authors' opinion, the health and safety courses should be considered as courses dealing with technical issues, which are promoted and positively assessed by the Appendix.

On the other hand, the building will belong to a public University, so the project will be in the public interest. To consider that a project is in the public interest, a specific Government statement is needed.

The Appendix establishes two ICES values, one for the moment of finishing the design, and the other when the construction has concluded. In our case, the social contribution coefficient is respectively, 0,04 and 0,06 for those moments.

3.13. Criterion Related to the Structure Life-Cycle.

The last criterion to estimate the ICES parameter is associated with the life-cycle of the structure. Appendix 13 promotes expanding the structural life-cycle beyond the minimum durability periods established by EHE for each type of structure, since this will save money and natural resources.

In our case study, the design specs consider a lifetime of 100 years, so the value obtained for the coefficient related to the life-cycle of the structure is b = 1.

4. Assessment Results.

The ICES parameter is a number between 0 and 1 that, finally, is transformed in a label similar to the ones used for classifying electrical appliances taking into account their energy efficiency (A, B, C, D, E). There are five levels of sustainability, being A the higher one, and E the other extreme label. In our case study, using the new computer application developed by the authors, ICES = 0,501 = Level C for the design stage, and ICES = 0,521 = Level C for the construction stage.

5. Conclusions.

Assessing sustainability using the EHE involves certain complexity, so using computer tools is recommended. The main identified problems are related to ignoring the potential final characteristics of the structure and its construction process, and also the uncertainty about specific issues.

On the other hand, the reader should take into account that, for our case study, a structure designed without paying special attention to sustainability issues, the assessment is not low (C level). Probably taking into account these issues from the beginning, the assessment could be increased to a B or even A level. This demonstrates that EHE is not extremely demanding, and that conceiving, designing, planning and constructing the concrete structure with a minimum care and control can lead to medium or medium-high levels of sustainability.

Despite of that, and taking into account the author’s experience when applying Appendix 13 to small industrial buildings, the assessment will be normally poor or even very poor for the most frequent small buildings constructed by small and medium companies.

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