

ASSESSING SUSTAINABILITY OF CONCRETE STRUCTURES USING THE SPANISH CODE EHE-2008. A CASE STUDY.

Gómez, D.º, del Caño, A., de la Cruz, Mª P.

University of La Coruña

Abstract

Two of the authors were part of the working group 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 pillars of sustainability: the environmental, economic and social ones. Sometimes, due to the complexity inherent to construction projects, it is not easy to answer all the questions that the Appendix proposes. Moreover, the initial computer program developed for facilitating the application of Appendix 13 has specific problems that lead to the authors to develop a new computer application for this purpose. The objective of this paper is to solve some doubts that can arise when applying the appendix, and explaining the way of using it, solving a case study with the help of the new computer application.

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

Resumen

Dos de los autores han participado en el grupo de trabajo que ha redactado el Anejo 13 de la nueva Instrucción de Hormigón Estructural EHE 2008. Esta norma ha incluido, por primera vez en España, y constituyendo una experiencia pionera internacionalmente, un anejo cuya misión es establecer los procedimientos necesarios para estimar un índice de contribución de la estructura a la sostenibilidad (ICES). Para calcular este índice, el Anejo 13 hace uso de una serie de criterios relacionados con los tres pilares básicos de la sostenibilidad: el medioambiental, el económico y el social. En ocasiones, y debido a la variedad de peculiaridades que hoy en día tienen los proyectos de construcción, y en particular las estructuras de hormigón, no resulta fácil responder a todas las preguntas que el anejo plantea. Además, el software inicial generado para facilitar la aplicación del Anejo 13 tiene ciertos problemas, que han llevado a los autores a desarrollar una nueva aplicación informática para ello. La misión de esta comunicación es despejar algunas dudas e instruir en la aplicación del Anejo 13 de la EHE 2008, a través de la explicación de un caso práctico, calculado con la nueva aplicación informática.

Palabras clave: *Sostenibilidad, estructuras de hormigón, norma española 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 (ICES), taking into account diverse criteria. Del Caño and de la Cruz participated in the working group that developed this appendix (Appendix 13 of EHE-08).

To calculate the ICES (“Índice de Contribución de la Estructura a la Sostenibilidad”; Rate of Contribution of the Structure to Sustainability), Appendix 13 is based on several criteria related to the three columns of sustainability: environmental, social and economic issues.

As far as the authors know, the EHE-08 Appendix 13 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 reflect on the use of Appendix 13 by explaining a case study. Using this case study, this paper will try to shed light on specific circumstances, not clarified in Appendix 13, that may arise when assessing a concrete structure.

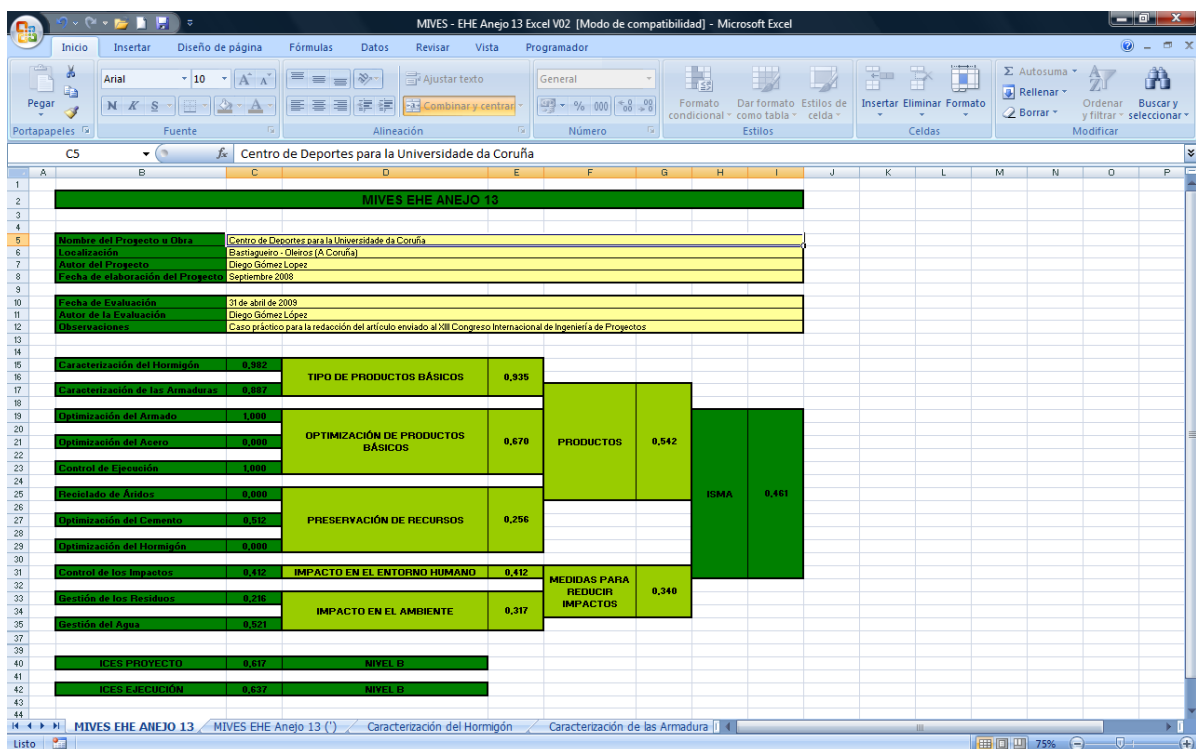


Figure 1. Results screen of the application developed by the authors.

The authors think that the implementation Appendix 13 is not excessively complex but, any way; the appendix text can be confusing in some cases, mainly because of the novelty 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 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 calculations.

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-logic models). The authors are currently preparing a report to the Spanish Body responsible for issuing the EHE Code, suggesting corrections and improvements to Appendix 13, ways of managing unclear or undefined circumstances, and solving other problems detected in its text; those suggestions have been already implemented in the new computer application.

3. Case Study.

To shorten the present paper, due to the large amount of questions that the Appendix 13 establishes, we will only refer here to the questions which response is positive (yes) or different from zero in our case study. When an issue is not here dealt with, the corresponding answer is always negative (zero for numeric parameters and “no” for other questions). 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	30	0	0,00
Central de Hormigón Preparado	Hormigones Alvedro	9026	80%	8,00	Distintivo	70	30	70	55,93
Instalación de Prefabricación	Prefabricados Castelo	2030	18%	70,00	Compromiso	50	20	50	8,98
	Norteph	241	2%	738,00	Compromiso	50	20	45	0,96
Empresa Constructora	FCC				Distintivo			20	0,00
Total / Media ponderada		11297	100%	34,71				27,88	27,88
Puntuación del Criterio 0-100: 93,76									
Valor del Indicador 0-1: 0,942									

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

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 rest). The building occupies an area exceeding 15.000 m², 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 Characterization of Concrete.

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

- Foundations, basement walls, columns and beams are in-situ 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 sign, 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 them is located far from the site (738 km) and, again, has not achieved an environmental sign but meets the 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 a ISO 14001 certification.

Taking all that into account, the score for this criterion is $P_1 = 0,982$. Before awarding the works, the user can not know the identity of the final contractor and suppliers, so it is difficult to answer the questions 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, studying the environmental conditions and locations of those companies. And finally, be prudent in estimating the environmental conditions and distances to use in calculations. This is also applicable to other criteria, except when the user is sure about the final identity of the contractor or suppliers. Nevertheless, the non-deterministic models under development by the authors will allow for establishing more complex answers, 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 companies could have with different environmental conditions. The Appendix 13 software not covers this possibility, but the new computer application developed by the authors does it.

3.2. Environmental Criterion Related to the Characterization of 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 in-situ concrete count for the 91% of the total steel reinforcement, and are prepared by a company located relatively near to the site (17 km). This company does not own an environmental distinctive, but it meets the 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 in situ elements the structural analysis programs 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 alluded in the previous criterion epigraph, related to the uncertainty about the final contractors and suppliers and to contracting several companies with different environmental conditions.

3.3. Environmental Criterion Related to Reinforcement Optimization.

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, which uses welded reinforcement (the system used by the chosen supplier). All the floor slabs include a top in situ concrete layer reinforced with large size steel meshes (normally used by the supplier).
- The other 20% is used in the precast hollow core slabs and stands. Again, the passive reinforcement is welded here.
- All reinforcements are produced following the standard UNE 36831.

For this criterion the score is $P_3 = 1,000$. A potential difficulty here is the one caused when a structure does not have slabs reinforced with meshes. It is not frequent, but is possible in civil engineering and structures restoration. The problem is that the Appendix 13 question related to this is: "*Percentage of slabs reinforced with large sized meshes? (0 to 100%)*"; in other words, the Appendix assumes that every structure will include slabs reinforced with meshes. In such cases, we recommend answering 100%; the authors think that EHE-08 should penalize the structures using small meshes, because the overlaps between them will cause an excessive steel consumption. So, if a structure does not have slabs (and therefore, does not have steel meshes), should not be penalized. This is the reason why the new computer application includes the case of structures without slabs, establishing here the maximum score for them.

3.4. Environmental Criterion Related to Steel Optimization.

This criterion assesses the environmental contribution associated with steel recycling, reduction of CO₂ 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 CI 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-08, allowing a structural analysis using the minimum steel safety coefficient γ_s . In this way, less materials are consumed (concrete and steel) and, thus, the score for this criterion is $P_5 = 1,000$.

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

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 of this criterion is $P_6 = 0,000$. 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 Optimization.

This criterion assesses the environmental contribution associated with the use of industrial sub-products and, particularly in the case of cement, incorporating these sub-products as well as employing other materials causing a reduction in the CO_2 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 CO_2 emissions. On the other hand the concretes to be used have not fly ash or silica fume additions. Under these circumstances, the score of this criterion is $P_7 = 0,512$. As in the case of the steel optimization 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 Optimization.

This criterion assesses the environmental contribution associated with the use of industrial sub-products in the form of additions directly incorporated into the concrete, according to the specifications contained in EHE-2008.

As we previously mentioned, in our case study the concretes to be used do not include additions. None of the cements to be used are CEM type I. With these data the score for this criterion is $P_8 = 0,000$.

Problems may arise here to respond some questions included in this criterion, because normally structural designs do not specify concrete dosages or additions. The information must to 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 the case-study building, it is necessary to use sprinklers and also to cover materials stored on site. Taking that into account, the score of this criterion is $P_9 = 0412$.

The reader should take into account that the referred to methods for reducing particles and dust emissions can be used both on site and also in the prefabrication plants. On the other hand, it is difficult to use in the same site the five impact reduction methods included since some methods are not compatible with others.

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 dug materials; for managing 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 digging 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 rest of the concrete is carried out using the normal cylindrical test specimens.

Taking all that into account, the score of 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 distinctive, 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 methods here mentioned for improving water management can be applied both on site and also in the prefabrication plants.

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

3.12. Social Contribution Coefficient.

The appendix also assesses the 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 can be considered as courses dealing with technical issues). On the other hand, the building will belong to a public University, so it is considered that it is a project of social interest. Responses to other questions of this criterion are negative, and the social contribution coefficient is 0,04. If finally the construction is performed following the design specs, the social contribution coefficient will be 0,06.

One problem here is to know when a structure can be considered part of a project of social interest. Normally public-sector projects should be considered as projects of social interest, but some problems can arise when assessing private-sector structures.

3.13. Criterion Related to the Life-Cycle of the Structure.

The last criterion to estimate the ICES parameter is associated with the duration of the life-cycle of the structure. Appendix 13 considers that a structure which life-cycle will be extended beyond the minimum durability periods established by EHE-08 for each type of structure, will save money and natural resources.

In our case study, the design specs consider a lifetime of 50 years, so the value obtained for the coefficient related to the life-cycle of the structure is $b = 1,25$.

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, $ICES = 0,617 =$ Level B for the design stage, and $ICES = 0,637 =$ Level B for the construction stage.

5. Conclusions.

Assessing sustainability using the EHE-08 Appendix 13 involves certain complexity. Using computer tools is recommended, to avoid miscalculation problems. The main problems are related to ignoring the potential final characteristics of the structure and its construction, 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 fairly good (B level). Probably taking into account these issues from the beginning, the assessment could be increased to an A level. This demonstrates that EHE-08 Appendix 13 is not particularly demanding, and that conceiving, designing, planning and constructing the concrete structure with a minimum care and control can lead to the highest levels of sustainability.

Despite of that, and taking into account other Appendix 13 applications performed by the authors, the assessment will be normally poor for other type of projects, as can be the industrial ones (manufacturing, process plants).

References.

Ministerio de la Presidencia (2008), Real Decreto 1247/2008, de 18 de julio, por el que se aprueba la instrucción de hormigón estructural (EHE-08). Boletín Oficial del Estado (BOE) Nº 203, de 22 de agosto de 2008, pp. 35176-8. Anexo 13 de dicha norma, pp. 487-504.

del Caño, A., de la Cruz, M^a P. "Bases y criterios para el establecimiento de un modelo de evaluación de la sostenibilidad en estructuras de hormigón.", *Cemento y hormigón*, Nº 913, abril de 2008, pp. 6-14.

Aguado, A., Alarcón, B., Manga, R. "Razón de ser del anejo ICES de la EHE y características del mismo.", *Cemento y hormigón*, Nº 913, abril de 2008, pp. 16-23.

San José, T., Josa, A. "Planteamiento MIVES para la evaluación. El caso de la EHE.", *Cemento y hormigón*, Nº 913, abril de 2008, pp. 26-34.

Burón, M., Carrascón, S., Carrau, José M^a. "Desarrollo de alguno de los indicadores: cemento y hormigón preparado.", *Cemento y hormigón*, Nº 913, abril de 2008, pp. 36-41.

Garrucho, I., Portas, I. "Manual de la aplicación del anejo ICES de la instrucción EHE.", *Cemento y hormigón*, Nº 913, abril de 2008, pp. 44-57.

Losada, R., Rojí, E., Cuadrado, J. "Evaluación del ICES en un edificio de 28 viviendas de VPO.", *Cemento y hormigón*, Nº 913, abril de 2008, pp. 58-65.

Pacios, A., Martos, G. "Estimación del índice de contribución de la estructura a la sostenibilidad en ejemplos de edificación.", *Cemento y hormigón*, Nº 913, abril de 2008, pp. 68-81.

Alavedra, P., Cuerva, E. "Aplicación del índice de sostenibilidad en la rehabilitación de un edificio industrial.", *Cemento y hormigón*, Nº 913, abril de 2008, pp. 82-91.

Vacas, A., Zornoza, B. "Aplicación del ICES a una obra de infraestructuras.", *Cemento y hormigón*, Nº 913, abril de 2008, pp. 94-103.

Acknowledgments

To the Xunta de Galicia (Regional Government of Galicia, Spain), for supporting this project (project MIVES-EH-I; code 08TMT011166PR; DOG Nº. 222 published 14-Nov-2008; years 2008-2011).

Correspondence (For more information contact to):

Diego Gómez López

Industrial Engineer, Researcher UDC

Escuela Politécnica Superior (Edificio de Talleres Tecnológicos)

Universidad de La Coruña - Campus de Esteiro

C/ Mendizábal, s/n 15.403 Ferrol (La Coruña, Spain)

Phone: +34 981 33 74 00 ext: 3867

Fax: +34 981 33 74 10

E-mail: diegogomezlopez@gmail.com

URL: <http://www.ii.udc.es/GRIDP>