euroCADcrete, a Computer Aided Learning tool for education in reinforced concrete

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ABSTRACT: euroCADcrete is an interactive design exercise in structural engineering with reinforced concrete. The level of this exercise aims to reflect the abilities a student should have at the end of a bachelor course in civil or structural engineering. The exercise addresses the design process, the structural integrity of the design and the economy. As an interactive Computer Aided Learning tool, euroCADcrete can be used as courseware on an institute network and individually at home. It will be a sufficient self-explaining program using tutors on several levels, to guarantee a minimum of staff attendance and a maximum of learning effect.

1 EUROCADCRETE, INTRODUCTION

Students in Civil engineering should not only have theoretical knowledge, they also need practice in designing and detailing components of concrete structure to enhance their work experience. EuroCadcrete is especially designed to fulfill these goals; therefore it has been part of the curriculum for the education of civil engineers at the Delft University of Technology for a long time.

To reduce the costs and time of university education staff, an AutoCAD based computer program was developed in the late eighties. This CAD exercise was developed in order to support students in dimensioning, analyzing and detailing concrete structures, after the introductory lecture in designing and constructing concrete in their third academic year. During 10 years more than 1500 students used these exercises for training. Although the exercise was quite successful in the beginning, the success decreased in time because equipment and software went out of date, as well as the didactic unwanted situations, this was reason to improve the program.

In 1999 Matrix Software BV, supplier of MatrixFrame®, a commercial software tool for structural analysis and the design of concrete, steel and timber structures, which already has been used for the structural analysis education at the university, was invited to develop a complete new exercise. In cooperation with the educational staff of the department of Civil Engineering and an educational technologist of the Educational Development Unit of the university, Matrix Software developed a new exercise, called euroCADcrete, as an extension on MatrixFrame. In March 2000 the first group of 110 students from the Delft University performed their exercise with euroCADcrete successfully. Now, three years later, roughly 400 students worked with euroCADcrete, accompanied this year, after a trial previous year, with 40 students from the Polytechnics of Utrecht.

2 LEARNING OBJECTIVES

Before starting the software development of the new euroCADcrete exercise in 1999, first objectives, also been based on the experiences with the old CAD-Concrete exercise where formulated. The objectives are (Galjaard, Vos & Kunst 2000):

- Students should design a concrete beam according to the relevant codes. This design should be checked and corrected without human interference.
- The design should leave some ‘engineering judgement’ to the student. More specific: checks, which could have been included to prevent uneconomic designs, should be avoided as much as possible.
- The judgment on the economy of the design compared to other possible designs should be left to the student by showing him a cost comparison of some alternatives.
- Giving the student the possibility to get context-related help, varying from a hint to the correct answer should prevent solving the exercise by trial and error. Asking too much help should however be discouraged.
- At the start of the exercise the students should determine the correct sequence of the steps of the design process.

- Students should size the structure by global rules of thumb before doing any detailed calculations.
- The student will only be allowed to proceed to the next step of the design process when the current step is fully correct. In this way it will be immediately clear where errors are made, and misleading error messages which are the result of the subsequent stacking of errors in a number of steps can be avoided.

Table 1. Learning objectives

	A Task	B Product	C Students activity	D Computer activity	E Learning objective
1	Fixing a static scheme, from a drawing with a tunnel-roof or a continuous beam in a prefab building.	Static scheme with sizes and loads and other design parameters.	Making sketches, static scheme, loading scheme with EC 1 and common sense, and exposure class.	Only administrative generating of a unique set of design parameters.	Training the relation in between the constructed world and a structural scheme for analysis.
2	Selection geometry of structural concrete and final static scheme.	Shape (including possible haunches) and depth, width, cover and concrete quality of the cross section.	Simple trial & error hand analysis, for moment and shear capacity of cross section. Prepare input.	Fixes data from student. Analyses and shows range of valid parameters. Depth for min. and max. ζ.	To analyze by hand shape, sizes and concrete specifications from a beam type concrete member.
3	Analysis from ruling external and internal forces.	Ruling bending moment and shear diagrams.	Analysis by Frame program on PC.	Automatic analysis and showing results to student for comparison.	Understanding from force-distribution in a structure. Using a frame program in practice.
4	Check ruling cross sections on moment and shear for check on SLS and ULS.	Reinforcement % longitudinal reinforcement and stirrups in ruling cross-sections.	Analyzes with intermediate steps (depth compression zone etc.) the reinforcement. Checks for crack-width.	Analyzes and shows intermediate steps after student has provided his intermediate data.	Getting acquainted step by step with the complete process of analyzing a cross section and the influence of the relevant parameters.
5	Designing a practical and economic reinforcement.	Full drawing of a rational reinforcement as far as structurally required.	Input of reinforcement cover diagram, choice of diameters, basic reinforcement and secondary bars.	Automatic analyzing and showing of reinforcement cover diagram, commenting students. Analyzing students diagram on consequences. Just the same for stirrups, c.t.c. distances of bars and diameters.	Exercising steps required to arrive at a rational reinforcement from a cross section analysis only.
6	Find reinforcement details.	Complete reinforcement drawing.	Indicate all other required reinforcement.	Check per component being used as input and comment deviations from rules with consequences. Generate and comment answers on some interactive questions on detailing.	Getting a complete picture of detailing reinforcement.
7	Cost estimate.	Estimate, being build up from unit prices.	Estimate unit costs per cum of concrete for the whole structure. (Concrete, casing and reinf.) Use these quantities as input and give the present the price.	Analyze and show the exact price of the structure after the student has given his figures.	Obtaining an idea on the cost structure of a concrete construction.
8	Parameter-study.	Influence of important design parameters on the costs of a concrete construction.	What is the price difference for a 50% higher loading, or when paint is being used, that bridges cracks.	Analyzes and shows these answers exact after student has presented his estimates. Presents a way of improved guessing, when required.	Obtaining an idea of the influence of different parameters on the costs of a concrete structure.

These objectives have led to a schedule comprising all the necessary steps of the exercise. In this schedule a differentiation is made between:

1. The task to be done
2. The product of this task
3. The required activity of the student for this task
4. The required activity of the computer for this task
5. Learning objective of this task

This schedule is presented below and formed a starting point for the development of the euro-CADcrete exercise.

3 BACKGROUNDS OF DEVELOPMENT

Before starting the design of reinforcement, the engineer should calculate forces and deflections first. In the same way the euroCADcrete exercise is divided into a general structural analysis part, based on the student version of MatrixFrame, and a concrete part, to perform with the euroCADcrete wizard.

Users of MatrixFrame can select a template, related to their skills. The *Professional*-template for advanced users is common to the usual structural analysis software, with a full graphical window, a lot of toolbars, pop-up windows and a free workflow.

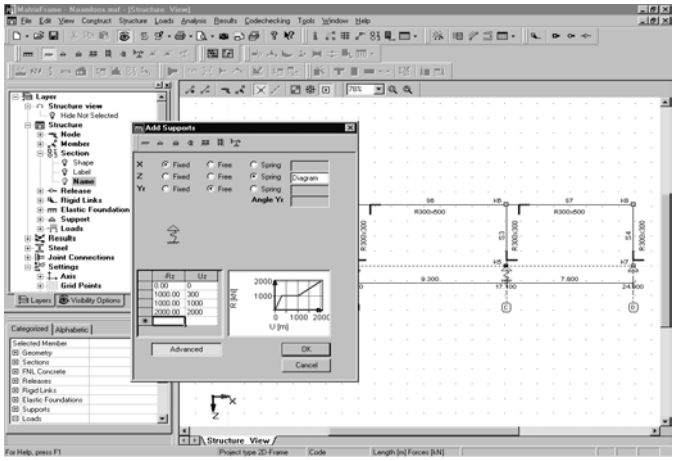

Figure 1. MatrixFrame® *Professional*-template

The MatrixFrame "easy to learn, easy to use" *Start/Student*-template is distinguished by skipping advanced options and not necessary toolbars, showing on-line alpha-numerical data in Table windows and last but not least a strictly workflow:

- Select from left to right a chapter by pressing a button in the chapter toolbar
- Select from top to bottom a subject, by pressing a button in the –chapter related- subject toolbar
- Define the parameters of the object, optional by using a pre-setting, in the Definition window

Apply this defined object to the structure in the Structure view window by adding to a member or node, or apply to a selection.

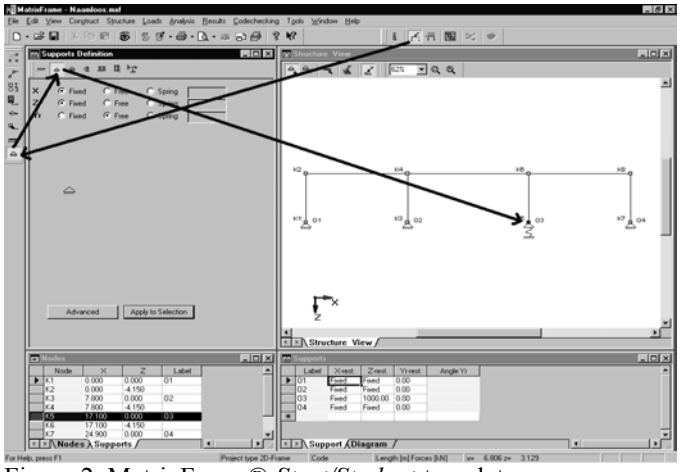

Figure 2. MatrixFrame® *Start/Student*-template

The second part of the exercise, the material specific part, is designed as a wizard. To be sure that students can manage the exercise themselves, without intervention of teachers, a wizard structure is extremely suitable for this purpose, because the step-by-step procedure guarantees that students don't forget issues, and on behalf of the Previous-Next structure they never get lost. Also the final target is well defined by the Finish button.

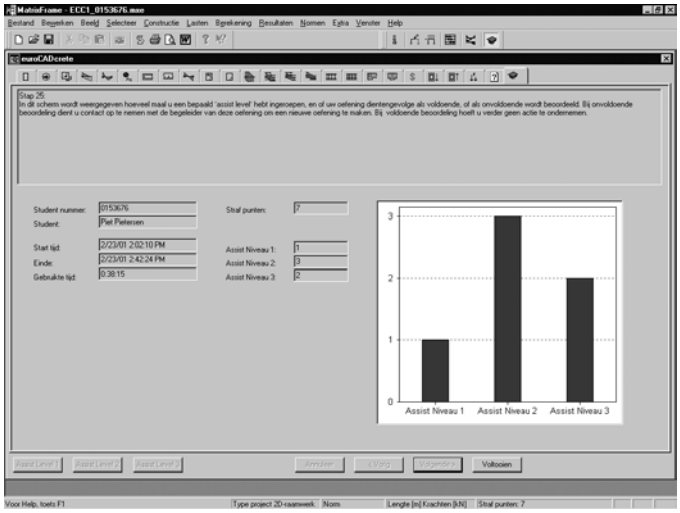

Figure 3. euroCADcrete-wizard Step 25: *Finish*

euroCADcrete is based on the standard concrete module from MatrixFrame. A very high level of designing- and generative procedures characterizes this concrete module, so in that way this module is not really suitable for educational purposes. To manage the educational principles, the "Concept of Hierarchical levels" (Weener 2000) is used. In brief, the concept is based on the assumption that processes, computer programs in particular, do have a ground level zero, where results of calculations are very well pure defined by input parameters. These primary functions can be developed to a higher level, by adding special functions which calculates the primary input data as well. This is called the next level (level 1) in the hierarchy. This procedure can be repeated several times, increasing

the level in the hierarchy, but at the same time also decreasing the quantity of possibilities in usage and quality of the result.

In euroCADcrete the student has to enter primary data step by step on a very low level. The entered data is proved by euroCADcrete immediately by using the higher level (= generative) mechanism, as a standard internal procedure, in the engineering version of MatrixFrame. For example, in MatrixFrame the covering is generated automatically after entering the exposure class. In euroCADcrete the student has to enter this covering too after entering the exposure class. The covering is lower level information, because it can be generated in the same way like in MatrixFrame. That's the way the check mechanism is working. Of course the example of the covering is quite simple, but the same mechanism is implemented for more complex steps.

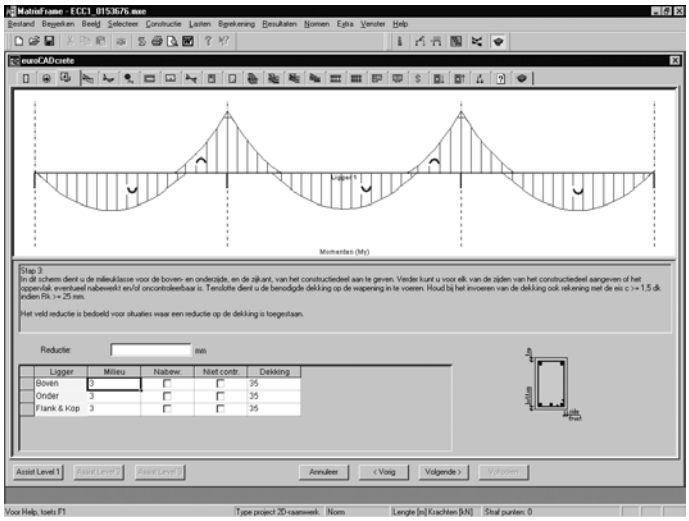

Figure 4. euroCADcrete, wizard Step 3: *Covering*

Much more complex is the check on possible bar combinations. Here the algorithm calculates all possible bar combinations that meets the requirements concerning capacity, minimum bar distance, maximum bar distance, bar diameter, cracking, etc. In MatrixFrame the user can select the proper bar combination from a drop list (this drop list contains all possible bar combinations). In euroCADcrete the entered value is colored red in case of the wrong answer. To be sure that the student will deliver a proper engineering masterpiece, he can't continue with the next step, until all values are correct in this step.

Every screen will show some explanatory text, and most screens also show a graph with information specific for that screen. When the student doesn't have any idea how to get a proper result, the program offers him an assist function. According to educational considerations, this assist will give the student additional information in 3 steps. On the bottom these three assist buttons can be seen for help on three different levels. It is not possible to get help on level 2 without asking for help on level 1, and on level 3 without help on level 2. The <Next> button becomes available when everything on the screen is proved to be allright. The value of help in points will be adjusted by experience. The first help level or Assist 1 is free and shows some common information related to the active cell. The second help level or Assist 2 has a penalty of one point, and shows more specific information for the active cell. The third help level with a penalty of two points gives the correct answer for the active cell and the student can continue with the next step in de euroCADcrete wizard. In this way the student is able to navigate through the exercise without intervention of a teacher. Of course using the assist will result in penalties, and too many penalties.....

4 EUROCADCRETE, STEP BY STEP

Since euroCADcrete is an examination program, the automated exercise is the "grande finale" of the concrete lectures of the third academic year. To prepare students for this exercise, two introduction lectures, including a lecture note, are part of the exercise.

The student is supposed to enter the geometry of his structure, the loads and the loading-combinations in MatrixFrame. Eventually this part of the exercise could be done at his own home-PC using the limited student version of MatrixFrame. For this part the student needs to estimate the sizes of the structural components used in his frame by rules of thumb.

The student can obtain information regarding his exercise from a manual (the lecture note), which comprises of the necessary data to construct his own personalized exercise, and some basic information for the calculation and distribution of the reinforcement in the beam.

With MatrixFrame the student can calculate all governing moments and shearforces in the ultimate- and servicability limitstate. Based on these results he can make all the necessary calculations for the input in euroCADcrete, and take these results to the computers where euroCADcrete is installed.

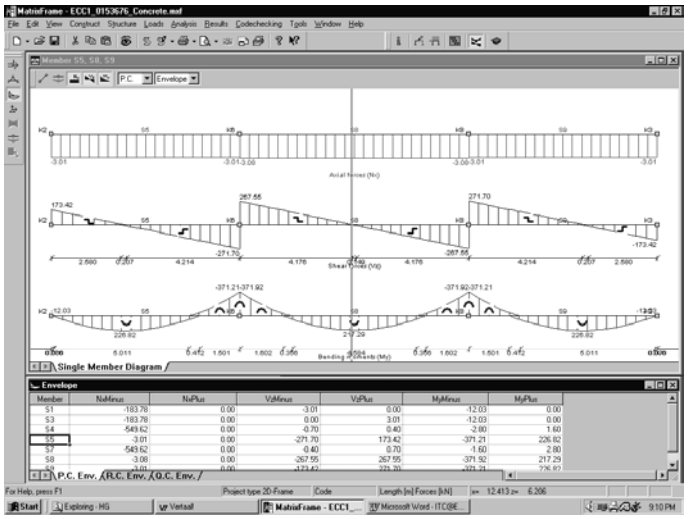

Figure 5. MatrixFrame® studentversion for ULS & SLS

Now he can either input his data for the geometry, loads and loading-combinations in the computer step-by-step on site, or let MatrixFrame read the diskette with his own data developed at home. Then he can start euroCADcrete by clicking the appropriate button. First euroCADcrete starts with a check of the geometry, concrete strength class, loads and loading-combinations. An error message will be given if the data is not in accordance with the student's personal number.

If ok, than euroCADcrete really starts with Step 1, and the student is first asked for some general information, like structural member and structure type (beam, slab spanning in one direction, strip), steel name, way of fabrication, nominal aggregate size and the size of the vibrator used.

In the next step, see figure 6, the student has to determine the correct sequence of the design steps. The background of this step is typical for the influence of the educational technologist during the design of the program. Since we decided to use the wizard-technology, the sequence of calculating a concrete structure is pre-defined. In educational point of view this is not preferable, because one of the basic issues in education on university level is that students should be able to structure their problemetic issues. We solved this by introducing step 2, to be sure that students make up their mind about the structure of their calculations before starting the concrete design. To make it easier, the process has already been divided into four blocks, of which the first and last block are given. Above this the other steps have already been grouped in two blocks, one for the cross-section-related steps and the other for the global reinforcement bar positioning steps. For every block the students can choose steps from a list, which only shows steps not used in previous steps.

Figure 6 also reveals the layout of the screens. On top of the window all the tabs, corresponding with the steps of the exercise, can be seen. These tabs become visible when step 2 is successfully finished.

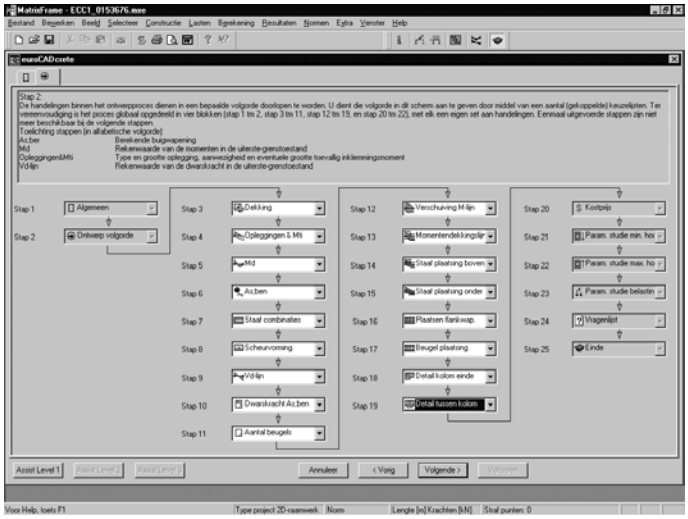

Figure 6. euroCADcrete Step 2: *Sequence of design steps*

In this stage of the development the program is divided in 4 blocks with 25 steps:

I. Block 1, General:
   1. General information
   2. Sequence of design steps

II. Block 2, Cross section:
   3. Exposure class and covering
   4. Type and size of supports, implied moments
   5. Governing sections and moments
   6. As,req. cross section of bending reinf. for ULS
   7. Bar combinations, split in basic- and add. bars
   8. Check for crack width
   9. Governing sections for shear force
   10. Required cross section of shear reinforcement
   11. As,prov for Stirrups, basket and add. stirrups

III. Block 3, Bar positioning:
   12. Shift of moment diagram
   13. Reinforcement cover diagram
   14. Bar position bottom
   15. Bar position top
   16. Positioning surface reinforcement
   17. Stirrups positioning, basic basket and add.
   18. Detailing end column connection
   19. Detailing intermediate column

IV. Block 4: Economics and evaluation:
   20. Calculation of cost price
   21. Parameter study: Min. height
   22. Parameter study: Max. height
   23. Parameter study: Lower loads
   24. Questionnaire, opinion about the program
   25. Student results, total of penalties, etc

5 BIG BROTHER IS WATCHING YOU

The second part of the exercise, the concrete part, should be performed with the euroCADcrete-wizard on the computer network environment of the University. All computer entries of the student are logged in a central database. Thanks to this central database we can control the following points:

After closing the program students can continue the next time with the same step

- Counting penalties for each student. In this way a list of marks for all students can be generated.
- Get detailed information about students activities
- Guard against manipulations of results!

Because all data is stored in one central database, it is easy to generate statistics and other information (Galjaard, Vos & Weener 2000), for example:

- The average of using the assist for each level for each wizard step (see Figure 7)
- The average and maximum of attempts of data entry for each cell in a wizard step.
- Results of the students questionare from step 24
- Student opinions related to the exercise and program from the memo field in step 24.
- Average and maximum duration of the exercise
- Snapshot about the progress of the exercise.

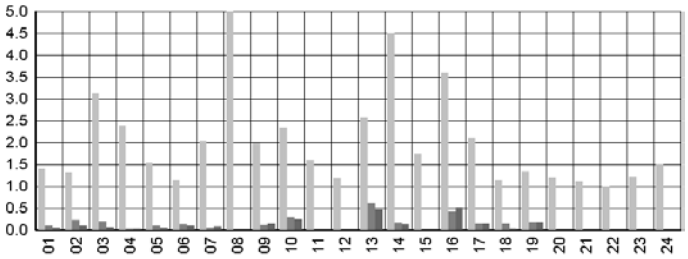

Figure 7. euroCADcrete logfile: *Average of Log Assist*

6 FUTURE DEVELOPMENTS

Although the euroCADcrete exercise is utilized very well on the Delft University during the last three years, a lot of ideas have come forward to improve the program.

The first group of improvements is created by analysis of the logfile. Target is to improve the quality of the exercise and to reduce the human assistence during the exercise:

- Reduce trial and error; some students did enter a value more than 200 times to find the proper value.
- Try to reduce consultancy of Assist level 3, because a student should find the result himselve
- Upgrading "Assist level 1" to lectures note level
- Replace the flat explanation text from "Assist level 2" by a kind of expert system.
- Replace the flat result from "Assist level 3" by a kind of toolkit for detailed calculations and intermediate results.

The second group of improvements is focused on dissemination of euroCADcrete to other countries, because it's really a pity that one single institute uses such a unique (and expensive) program:

- After implementation of the EC2 (instead of the current Dutch NEN6720) the dissemination will start (Spring 2003). Info: www.eurocadcrete.com
- Make it suitable for different kind of (practical) structures instead of the standard building structure defined by the Delft University.
- Flexible wizard steps. Switch on/off wizard steps, add or change multiple-choice windows, define parametric studies.
- At this moment euroCADcrete is an examination program, after modifications it also will be suitable as an open-distance learning program

euroCADcrete is not a simple CAL program, using multiple choice or static data. It distinguishes itself by difficult on-line calculations and generative procedures. A small change in input data in the beginning can result in a completely different calculation at the end: the butterfly effect from the chaos-theory in ultimate forma.

To create a good financial and educational base, in combination with a strong relationship with the engineering practice, a consortium is established to continue developing of the euroCADcrete exercise. As a part of the Leonardo da Vinci programme the Universities of Delft, Glasgow, Munich, Rome, Turino, Vilnius and the ECSN with the Concrete Societies of England, Finland, Germany, The Netherlands and Matrix Software participate in this consortium. Start date of this three year LdV-programme will be January 2003 after approval (we hope) from the European Commission.

7 IMPACT AND CONCLUSIONS

Primary goal of the euroCADcrete program was to reduce the educational staff resources and to manage a practical concrete exercise with a large amount of students. Unforeseen was the positive influence of secondary effects:

- Teachers are exempt from the boring look over activities, and focus more on the lectures (this was considered as one of the most important reasons for the polytechnics to make a start with euroCADcrete)
- Impact on the skills of students, because isolated subjects are combined and integrated to one begin-to-end practical overall exercise.

This is the really preparation on the engineering practice.

- To give a clear insight in the mechanism of designing structures, by introducing parameter studies in euroCADcrete.
- Impact on the curriculum, by introducing new (practical) issues, like detailing of reinforcement and the economics of the design.
- Impact on the curriculum, by analyzing results of the log-file. For example, the steps 13-17 are consulted more than average, so the teachers decided to pay more attention to these subjects during the lectures.

Very soon the EuroCodes will replace the current national standards. There will be an enormous need for retraining practisising civil engineers. Research from the ECSN learned that education about the new EuroCodes is missing all over Europe.

The euroCADcrete exercise can contribute to a common understanding of what every student or civil engineer should know about reinforced concrete, in order to the exchange of students in special master courses as well as the transparancy of the skills of civil engineers throughout the EU.

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