A new future-oriented Model Code for concrete structures

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ABSTRACT: Codes have always played an important role in the design of structures. In the past, CEB and FIP devoted considerable attention to the actualisation of codes, especially by writing the Model Codes for Concrete Structures. Those codes were intensively used as a basis for updating national codes and as a source for providing a new European code – the Eurocode, which is nowadays accepted as hEN. However, code writing is still at the centre of interest. It is felt that new developments ask for new ideas about the basis and the content of codes in the future. In this paper some general reflections are given to the renovation of codes and progress in drafting the new *fib* Model Code for concrete structures.

1 PAST AND FUTURE OF THE MODEL CODE

1.1 The history of the Model Code

In 1953 the Euro-International Concrete Committee (CEB – Comité Euro-International du Béton) was founded. The founders Balency-Béarn, Nennig, Base, Rüsch, Torroja and Wästlund, had the vision that post-war Europe needed a common approach in concrete design and construction. The greatest concern was the enormous disparity between codes in Europe and their very limited scientific basis. Therefore, the main goal of CEB has been from the start the development of a European code, based on a more scientific approach. The idea of a harmonized Model Code was born. During writing the first Model Code, contact was sought with another large international organization, the International Federation for Prestressing (FIP – Fédération Internationale de la Précontrainte). FIP which was founded in 1952 by the pioneers of pre-stressing: Freyssinet, Torroja and Magnel, aimed at the promotion of the prestressing philosophy, design and techniques on a world wide scale. Experts from CEB and FIP started working together on preparing international recommendations. The most important milestones which have been achieved are the following:

- 1964: 1st CEB International Recommendations (covering reinforced concrete structures),
- 1970: 2nd CEB/FIP International Recommendations (covering structures in plain, reinforced and prestressed concrete)
- 1978: 1st CEB/FIP Model Code
- 1990: 2nd CEB/FIP Model Code

The 2nd CEB/FIP International Recommendations were an important step forward since it was the first time that a common basis was created for new national codes, which were up to then extremely different. The most important break-through was the introduction of a new safety philosophy based on limit states and on partial safety factors. Next, in the seventies, safety concepts were developed with semi-probabilistic approaches, and later-on real probabilistic analyses were made as a basis for a better evaluation of structural safety and for a more scientifically based definition of the partial safety factors.

In the Model Codes 1978 and 1990 improved models were developed for a more accurate representation of the structural behaviour of reinforced and prestressed concrete structures and new chapters were introduced to cover new fields. In 1990 an important chapter was introduced on the concrete material properties, inspired by the new option to analyse the behaviour of structures by non-linear finite element methods. The Model Codes became the basic reference documents for the development of Eurocode 2 by the Commission of the European Communities, and to a large extent influenced the up-dating of design codes in many countries.

1.2 Towards a new Model Code for concrete structures

In 1998 CEB and FIP have merged into the new organization, the International Federation for Structural Concrete (*fib* – fédération internationale du béton).
One of the major aims of fib organization is to produce an international recommendations for the design of concrete structures, reflecting the newest insights and design philosophy. In the following years numerous documents accompanying the Model Code 1990 were elaborated and published by fib such as application manuals, trial calculations, etc. In particular, the background of the Model Code 1990 was extensively treated in the so-called Model Code Text Book, published in the first three volumes of the new fib Bulletin.

Shortly after the merge, within fib preparations have started for a new Model Code. It was felt that new developments ask for new ideas about the basis and the content of a future-oriented code. It was recognized that “just giving formula’s” for specific cases is not sufficient. Hence, a general approach, based on common principles and harmonised design philosophy was needed. In 2004 the Special Activity Group of fib, the SAG5 began its work of up-dating and enhancing the 1990 CEB-FIP Model Code. At this moment a team of about 25 experts from various countries work for the first concept of the new code. Completion of the work on the new fib Model Code is currently targeted for 2008.

2 BASIC REQUIREMENTS FOR A CODE

Discussions on basic requirements for a code have been held at various occasions in the references, see for instance Virlogeux (1999) and Walraven (2004). There is agreement on a number of principles that should at least be regarded.

2.1 Well-founded

Codes should be based on clear and scientifically well founded theories, consistent and coherent, corresponding to a good representation of the structural behaviour and of the material physics. On the other hand, they shall reflect best engineering practice build up on the good experience from the past.

2.2 Flexible

A code should be open-minded, which means that it cannot be based on one certain theory excluding others. Hence, a code may have different levels of sophistication and models, with different degrees of complexity may be offered. For instance, simple, practical rules can be given, leading to conservative and robust designs. However, in a number of cases, as an alternative, more detailed design rules may be offered, which require more calculation time, but result in a more economic solutions. For instance, in some large scale projects there may be a need for very thorough analyses because of the high safety requirements. In such a case high level analyses, should not be restricted by too rigorous definitions or limitations. As an example (Virlogeux, 1999) the pre-definition of a behaviour-coefficient loses any significance when a non-linear time history of the dynamic response can be produced, like in the case of the Rion Antirion Bridge (Fig. 1).

2.3 Transparent

Codes should be transparent. That means among others that the code is not prepared for those who made it, but for those who will use it. Therefore the set-up of the Model Codes was chosen, where the recommendations are given at the right-hand side and explanations at the left-hand side of the pages.

2.4 State-of-the-art

New developments should be recognized as much as possible, but not at the cost of complex theoretical formulations.

2.5 As simple as possible, but not simpler

A code should be simple enough to be handled by practitioners without considerable problems. On the other hand simplicity should not lead to lack of accuracy. On the other hand, it shall be acknowledged that very “accurate” formulations, derived by scientists, not necessarily lead to very accurate results, because often the input values can not be estimated very accurately. An example is the calculation of the long term deformation by creep, which is influenced by the ambient temperature and the humidity, the variation of loads and the construction sequence. Here the famous sentence of Einstein applies, who once said that “A theory should be as simple as possible, but not simpler”.

Figure 1. The Rion Antirion Bridge during construction: design based on a non-linear time history of the dynamic response.
3 NEW TRENDS AND ASPECTS TO BE REGARDED

The new Model Code should be more than a document which presents updated knowledge in the various fields treated in the Model Code 1990. It should also introduce new trends and cope with upcoming needs that may have been less urgent or not existing in the past. Such a need is for instance the creation of a good basis for the diagnosis, repair and redesign of old structures. In direct relation to this the design for service life has been moved to the centre of interest, as a consequence of the increasing cost for upgrading or even removing and rebuilding existing structures. In the following a number of such aspects will be defined and discussed.

3.1 Integral approach

In designing a structure it should be realized that there is more to be regarded than structural safety and serviceability during a service stage, which were the highlights of traditional codes. The new fib Model Code incorporates integrated life cycle perspective. Accordingly, structures should not only be designed ensuring sufficient safety and serviceability, but there should as well be a due consideration of their construction, future use and final dismantlement. Hence, the influence of time is introduced in its widest sense. Experience has learned that cost optimization of a structure should be done including the maintenance costs. The Sitter (1984) introduced the rule of fives, saying “If maintenance is not performed, then repairs equalling five times the maintenance costs are required. In turn, if those repairs are not affected, then renewal expenses can reach five times the repair costs. Therefore, postponing the maintenance compounds the amount of deferred maintenance”. It should be noted, however, that the initial design can reduce the future maintenance cost very much.

Accordingly, the new fib Model Code recommends that already in the design stage of the structure a defined service life for the structure shall be considered, an appropriate inspection and maintenance plan shall be developed and the aspect of dismantling of the structure shall be regarded. In this way, the design of structures according to the new fib Model Code becomes a truly holistic approach.

3.2 Performance-based design

In the new Model Code performance-based approach to the design of structures is followed. In particular, the new Model Code recommends that in order to perform design of a structure, the performance requirements have to be defined and described in terms of the three criteria:

- a definition of the relevant limit state
- a duration of the reference period
- a level of reliability for not passing the limit state during this period

The performance requirements have to be agreed with the owner of the structure, keeping in mind possible minimum levels given in national legislation and standards. The new fib Model Code is not only written for new structures, but as well for existing structures which have to be upgraded, strengthened or adapted. For the assessment of existing structures, the various aspects are integrated to a consistent system based on defined performance requirements were the residual service life is considered as one of the verification criteria.

Here it should noted, that service life as well as residual service life can be required for to various reasons. A distinction shall be made between the technical service life, the functional service life and the economic service life. The technical service life ends when the structure, due to deterioration, cannot fulfill its attributed function with sufficient safety or serviceability any more (Fig. 2).

The functional service life ends, when the structure is not able anymore to fulfill its originally attributed functions due changed service conditions, e.g. by an increase of the traffic loads or the traffic intensity. A building, for instance, will mostly not reach the end of its service life due to physical deterioration, but due to changes in ideas concerning the accommodation or the facilities. This could for instance be anticipated by designing adaptable structures (Fig. 3).

Finally, the economic service life ends, when the costs of upgrading or adapting the structure are larger than the costs of demolition and rebuilding. Considerations as sketched before illustrate the need of considering the life cycle of structures in design, including all the costs arising after handing over the structure. An optimum design requires the consideration of all performance requirements that may even vary during the lifetime of a structure.
3.3 Probability-based verification

For the verification of performance of a structure with respect to particular requirements the new Model Code recommends to follow to the limit state design principles. Verification of the limit states with regard to safety, serviceability and durability shall be realised by a probability-based method. In the new Model Code the designer is given four options to verify that his design fulfils the performance requirements:

– full probabilistic safety format
– partial factor safety format
– global factor safety format
– deemed-to-satisfy approach
– avoidance of reaction approach

Full probabilistic design will be seldom possible for the design of new structures, due to lack of statistical data. On the contrary, this option is well suited for assessment of existing structures, where relevant data might be derived from the structure. All other safety formats are calibrated against either the full probabilistic method or on the basis of long-term field experience of building tradition. Partial factor durability design can be well used for new structures to verify safety and serviceability. The global safety format is very well suited for verifying using numerical methods, which are very powerful in verifying safety and serviceability of existing structures. The deemed-to-satisfy method and avoidance of reaction design gives are often used in the Service Life Design, which is discussed further in the following section.

3.4 Integrated service life design

In 2006 the fib Task Group 5.6 chaired by Prof. Schießl completed the Model Code for Service Life Design, which was published in the fib bulletin number 34. The basics of this guide are integrated in the new Model Code, where clear demands are formulated with regard to durability of structures.

In the modern regulations for reinforced concrete such as the new Model Code, the design for durability has the same significance as design for safety and for serviceability. Consequently, the Service Life Design tends to be moved to the centre of interest. One other upcoming need is the creation of a reliable systematic for dealing with the existing structures. The increasing cost for upgrading, removing and rebuilding existing structures ask for a good basis for the diagnosis, repair and redesign of old structures including the rational verification of durability requirements.

The new Model Code covers some major deterioration mechanisms such as for chloride ingress, carbonation and freeze-thaw. Just as in case of the design for safety and serviceability, the designer is given four safety formats to verify that his design fulfils the performance criteria. The traditional methods are the deemed-to-satisfy approach and the avoidance of reaction approach. The deem-to-satisfy approach typically comprises a set of rules for dimensioning, material and product selection, and execution procedures that ensures the fulfilment of the performance criteria. These are usually the predefined demands with regard to water-cement ratios, cover to the reinforcement, limitations of crack width, etc. Avoidance of reaction, which implies that the design excludes the detrimental reaction, gives the most robust design for durability. This can be achieved for instance by applying membranes or coatings to avoid excessive moisture for frost-exposed structures, applying cathodic protection, using stainless steel or non-reactive aggregate etc. New in the Model Code is a model-probabilistic approach, which is well suited for design of special structures (for instance for very long service life of 100 years) or for assessment of deteriorated existing structures.

3.5 Sustainability

Another important innovation in the new Model Code is the introduction of sustainability requirements. Verification of sustainability concerns specific through-life issues related to the impact of a structure the environmental and society. Although the international research community has not settled on one single model for the verification of sustainability, the new Model Code gives some general guidelines representing international efforts in regulating this area of design.

3.6 New types of concrete

In the last decade a new generation of high performance concrete’s has been developed. In the newest version of Eurocode 2, the design recommendations are already extended to a maximum concrete strength class C90/105. Meanwhile, however designs are made with concrete’s which have a compressive strength of even twice these values. It is clear that the mechanical
properties of such a concrete are not simply related to the cylinder- or cube-compressive strength, like in conventional concrete. Therefore other testing methods should be defined. It is expected that in future concrete will more and more be composed for defined properties rather than only for strength (defined performance concrete's). For example, self-compacting concretes, special fibre reinforced concrete's, low-binder concrete's, concrete's with various types and volumes of demolished materials as aggregate, and concrete with improved fire resistance will become more popular. This means that well-defined acceptance procedures will be necessary in order to facilitate the reliable use of such “defined performance concrete's”.

The new Model Code will therefore deal with:
- properties of “conventional concrete” with compressive strengths up to C120.
- properties of special concrete's in the strength classes up to C120 (self-compacting concrete, lightweight concrete, fiber reinforced concrete, textile concrete, low binder concrete)
- properties of special concretes in the strength classes C120-C200
- properties of concrete’s with recycled components
- properties of retrofitting concrete

Concrete according to the new Model Code is characterized by its properties in the fresh state, and in the hardening and, in particular, by its resistance to deterioration, ability to protect the reinforcement against corrosion and other properties related to the environment. For the formulations of the properties various levels of sophistication are considered:
- classical formulations on the basis of the concrete compressive strength
- more advanced formulations, including influences like cement type, cement content and w/c ratio
- properties which are based on tests (in this respect a number of qualification tests will be described).

3.7 Re-design and assessment

Until now, codes have almost exclusively been written for the design of new structures. Currently, upgrading of existing structures is on its way to become a significant part of the engineer’s daily work. Many older structures suffer from various degrees of deterioration and traffic loads are becoming higher and more intensive. The new Model Code will offer methods for performance verification of existing structures. This can vary from taking samples of the structure, to testing the structure as a whole. Fig. 5 shows the determination of the remaining bearing capacity of a part of a slab viaduct, attacked by the alkali silica reaction. The test was carried out at TU Delft.

Moreover, adequate attention will be given to the reliability of repairing and strengthening techniques, for instance aiming at providing sufficient interface shear between new and old concrete, strengthening techniques for structures using various types of externally glued reinforcement and repair of cracks and missing areas.

3.8 New design criteria for ULS and SLS

In the past the design was carried out regarding predominantly two major stages of the structure’s performance: the Ultimate Limit State (ULS) and the Serviceability Limit State (SLS). Basically the ULS was checked for static loading. For the control of the SLS two aspects were controlled: deflection and crack width. Experiences with damage have learned that there has not been sufficient attention for a number of design criteria. Such criteria are:
- Fatigue: Until now the weight of concrete structures was normally high enough to render fatigue to a criterion with very limited practical relevance. Now, however, concrete’s with high and very high strengths have been developed. Structures designed with those materials are so light, that the increased
Figure 6. Lack of tightness in an underground parking garage.

Figure 7. Progressive collapse of a series of balconies, Maastricht, Netherlands, 2003.

traffic load, in combination with large frequency, will require control in fatigue. Measurements of the traffic in The Netherlands have shown, that a number of $10^8$ load variations is more realistic than the actual number, used in design, of $10^6$.

- **Tightness**: Leakage of structures has become a very frequent source of concern in structures below ground water (Fig. 6). It seems therefore logic to give recommendations to reduce the danger of leakage through structures, which can lead to very substantial financial consequences.

- **Fire**: A number of recent catastrophes have demonstrated again the significance of designing against fire. Up to now the design against fire has concentrated mostly on the bearing resistance of members in stead of total structures. fib Task Group 4.3 has concentrated on design considerations for fire, combining material science and structural application. It will publish a recommendation (as a fib Bulletin) in 2005. The results will be integrated in the new Model Code.

- **Earthquake**: It is the idea of the writers of the New Model Code that design against earthquake should not be treated on a singular basis in a separate code. In the New Model Code therefore a chapter on earthquake will be included.

- **Robustness**: By developing improved design methods the bonus robustness enjoyed by older structures is disappearing: therefore modern structures are likely to be more sensitive and require more detailed consideration than older structures, which often possess ample redundancy. The sensitivity of structures for progressive collapse should receive renewed attention (Fig. 8).

3.9 **Controlling the influence of the quality of construction**

It has often been stated that design of a concrete structure for service life is an imaginary option, since the quality of construction overrules everything. Indeed, the quality of construction is a very dominant factor. Influencing aspects in the construction stage are: casting, compaction, curing, storage, moulding and demoulding, placing the reinforcement, the choice of the mixture, the working conditions and quality assurance. Therefore the strategy for producing a low maintenance structure, in spite of all dangers
encountered in the construction stage, is important. One of the elements of this strategy is choosing an optimal conservation plan, which shall be sought with an objective of minimizing the life cycle costs. Fig 7 shows the general flow of through-life conservation process. Although the new Model Code foresees the possibility of applying a reactive conservation for structures or components thereof for which apparent deterioration causes no appreciable failure of satisfying required performances, a pro-active approach to conservation is encouraged. A pro-active approach to conservation of concrete structures is desirable as it should enable early identification of problems and possible risk issues affecting condition of the structure, potentially enabling early preventative action to be taken to minimise the overall cost of ownership.

In general, a through-life conservation process starts with defining the conservation strategy, including determination of regime for condition control. After finalizing construction, at handing over, an initial inspection is held, checking if the agreed quality of the structure has been achieved. The initial condition of the structure is documented in Birth Certificate Document (As-Build Documentation). This report contains the details of the structure and the data about its initial condition. On the basis of the report the conservation strategy may be revised and final inspection regime for condition control may be redefined. If the contractor has not achieved the quality as agreed in the contract, this might have consequences for him. Measures could be the duty of upgrading the structure, or paying the capitalized costs for more expensive maintenance in future. Depending on the conservation approach, more or less regular condition surveys are carried out, followed by condition assessment, evaluation and decision-making which might lead to small or large interventions. Results of inspections or monitoring and essential results of condition assessment, evaluation and decision-making are recorded in Service Life File. After execution of any intervention an inspection is carried out and the results are recorded again.

The conservation activities shall seek to ensure that the performance of the structure is above the required performance level. In the holistic approach incorporated in the new Model Code, information obtained through conservation provides feedback to the design employed (in particular to the verification of limit states associated to durability), facilitating assessment of compliance with the original performance requirements or revised performance requirements, if appropriate.

4 STRUCTURE OF THE NEW MODEL CODE

The table of contents for the New Model Code is shown Table 1. The idea of life cycle design is clearly recognized in the structure of the code.

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(Continued)
5 CONCLUSIONS

- The new Model Code is a future oriented document. Therefore the content is directed to Life Cycle Design.

- Performance-based design of structures, and especially materials, is an important new design philosophy. Therefore methods are described with regard to the experimental determination of special material properties.
- Limit state design will not only be used for safety and serviceability, but as well for durability, in appropriate cases.
- The new Model Code will not only address new structures but as well existing structures which have to be upgraded.
- Building processes are a part of future design philosophy.

REFERENCES
