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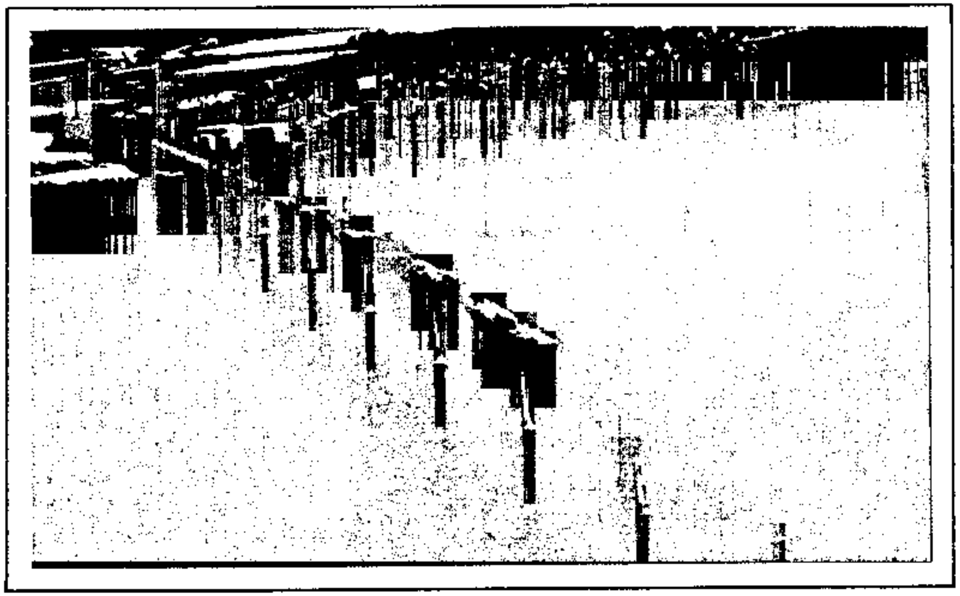

P.K. Mehta
Editor

"Structural Design and Concrete Technology: Divorce or Symbiosis?"

by T.P. Tassios

Summary: Traditionally, a designer of concrete structures and a concrete technologist do not have much in common, despite the fact that they both serve the same material.
Several cases are described in this paper to show the deplorable consequences of this situation.
The need for an integrated approach across several disciplines is stressed. Happily enough, modern requirements for broader performances of concrete structures (such as durability, aesthetics and others) make such a unification indispensable.

Keywords: Design, analysis, concrete technology, stresses, cracking, tensile strength, creep, durability, integration.

Theodossios P. Tassios, FACI, is a professor at the National Technical University of Athens. He is honorary president of CEB and a co-author of the European Code No. 8 on Aseismic Design. His research interests include concrete under seismic conditions.

INTRODUCTION

The history of structural engineering has followed a well known path: A master builder (up to the 18th century) used to be the unique engineer; just one person handling conceptual design, selection and manufacturing of materials, building techniques, trials and redesign.

Nowadays, an explosion of specialities has generated several interfaces between programmer, designer, materials' producer, contractor etc.; thus potential leakage of responsibility and lack of optimization is considerably increased. It is therefore recognized that any effort towards a certain **re-integration** of fragmented sub-fields is highly desirable. And there is already a tendency of good designers to be deeply involved in construction techniques and materials' technology, instead of the monopoly of sophisticated mathematical tools alone.

In this respect, a more specific splitting of specialities such as the dichotomy between designers of concrete structures and concrete technologists, will be the subject of this paper. In fact, it is sometimes surprising to observe that designers tend to have a rather hazy idea of the basic material they are supposed to design; they merely recognize "classes" of concrete according to its compressive strength, as measured from some artificially made and artificially cured specimens. Design codes seemed to encourage this apparently narrow-minded attitude, by "translating" every performance of concrete into its compressive strength. This practice occasionally produced some deficient designs or even gross errors. This was for instance the case, some decades ago, of the fanatic reduction of w/c ratio to such an extent as to produce strong but permeable concrete; their high compressive strength was accompanied by remarkably low tensile strength and low water tightness, with detrimental consequences to serviceability.

The same dichotomy between "analysis" and "technology" is portrayed in the pseudo-scientific question we frequently put: "Are these cracks due to stresses or they are just due to inadequate curing?". It is however clear to

everyone that stresses are **always** the cause of cracking or discontinuities produced in materials. Stresses are induced by several **actions**, such as:

- loads
- differential settlements
- restraint strains, due to thermal or drying shrinkage
- local swellings, (e.g. iron oxides due to steel corrosion, etringite formation, etc.).

In **all** these cases, the basic mechanism for cracking is the exceeding of extensibility of concrete when it is subjected to a field of tensile stress.

Here again, the need for a unification of approach becomes apparent. Situations are presented where a broader understanding of concrete technology is needed by a designer in order to better serve his purpose.

PARTIAL SAFETY FACTORS

In the semi-probabilistic format actually adopted by several Reinforced Concrete Codes, a certain "given" level of **Quality Assurance** (Q.A.) is supposed (the lowest possible), independently of the "actual" Q.A. conditions of the specific work. In real life, however, there are several possible Q.A. scenario related to the design, the construction and the use of the structure in consideration. Table I describes well known QA-levels where different partial safety factors could be used, if such level were formally ensured by means of appropriate normative mechanisms.

Table I: Possible Quality Assurance levels

Production stage	"C"	"B"	"A"
DESIGN	Unchecked	Checked by third party	- Checked by third party - Internal QA certification for design
CONSTRU-CTION	Elementary supervision	Formal supervision and testing	- Formal supervision and testing - Internal QA certification for construction
USE	Uninspected and unmain-tained	Periodically inspected and maintained	-Periodically inspected and maintained -Monitoring installed

Most of the prerequisites for a QA upgrading are not of analytical nature (such as, for instance, the use of a better finite elements' topology); they are more connected with organisational and technological measures having to do with materials , testing and construction.

A possible new design format could eventually provide for
- lower model-uncertainty factors γ_{Sd} (incorporated in the usual load-factors)
- lower strength conversion components and geometrical deviations, incorporated in the strength reducing factor γ_c.
- less demanding minimal measures [see (1)].

Nevertheless, for such a rational development to be feasible, structural engineers need to bridge the gap in their knowledge of concrete technology.

IN-SITU VERSUS IN-LAB STRENGTHS

In spite of the diverging opinions published on this issue [see i.a. (2)], there is a considerable agreement on the following.

a) In- situ to in-lab **strength** ratio (on geometrically identical specimens and with possible influences of testing methods appropriately considered) may be considerably lower than unity, (0.7 to 1.0), especially in the case of slabs, depending on the curing method.

b) In-situ strength variability (subtracting the additional variability possibly induced by some non-destructive methods) may be considerably larger than in-lab strength variability; depending on construction techniques and control levels, values ranging from 0% to 300% are reported.

The combination of these two facts may substantially undermine the significance of the actually used concept of the characteristic compressive strength "f_{ck}"; especially so in small job-sites which may be disproportionately influenced by the operational curves selected in shaping the compliance criteria.

It is beyond the scope of the present paper to discuss the possible alternatives of the concrete strength control system actually used. But it may be maintained that part of the problem is due to the dichotomy between "analysts" and concrete "technologists".

THE FUNDAMENTAL IMPORTANCE OF TENSILE STRENGTH

When nearly all concrete properties are "expressed" in terms of its compressive strength, structural engineers are encouraged to disregard the complex reality of the basic material. And it is well known that, more specifically, the "translation" of tensile into compressive strength is rather problematic (if not arbitrary), especially for the actually available multipurpose performance-oriented concretes. In this respect, it is first interesting to recall briefly the design situations directly governed by tensile rather than compressive strengths:

a) The so called shear (and torsion) resistance of RC elements is shaped by the compressive strength of inclined concrete struts, their final direction going aslant to previous cracks. By way of consequence, the compressive strength of these struts is in fact a complex property depending on actual transverse tensile stresses (induced by reinforcements crossing the cracks), as well as of the shear stresses transferred along the interfaces of these cracks. Eventually, the aforementioned resistance depends on the tensile strength of concrete and its extensibility.

b) Bond strength between steel bars and concrete is a direct function of tensile strength of concrete and, to a certain extent, of the concrete cover. A lot of "unexpected" bond failures of short columns under horizontal loading or of "strange" flexural cracking in badly cured regions are due to a locally deficient tensile strength.

In this respect, the detrimental effects of incidental electrical connection of galvanized to bare bars should be mentioned: Bond resistance is drastically reduced.

In all these cases, a good designer should be aware of the conditions which would ensure adequate tensile strength. In this connection, the importance of at least two "technological" facts should be mentioned, on top of a good mix design: The first is the need for avoidance or adequate treatment of cold joints; despite modern available means, we still do observe such (honey combed) joints even in important technical works.

Second, it would suffice to remind the underestimated importance of the quality of skincrete: Inefficient curing and non-absorptive forms may lead to a drastic decrease of tensile strength available within the cover (3).

A final point related to tensile strength should be made here, referring to plain concrete structures. In fact, the most critical property of **plain concrete** structures is their tensile strength, whether it is direct flexural stress or transversal tensile stress developing across deviating compressive stress-paths. We learned now that, after some decades, residual tensile strength of concrete may be as low as half of the initial tensile strength value, [see i.a. (4)], even in the internal parts of the structure which were free of environmental influences. This alarming message should be heard by both the concrete designer and the concrete technologist; urgent and interdisciplinary research is needed in this field.

SOME OTHER ANALYTICAL DEFICIENCIES RELATED TO CONCRETE TECHNOLOGY

Creep of concrete is rarely measured; yet it is used in everyday calculations of prestressed concrete, as well as in checking the creep effects on buckling resistance. Designers should however be reminded that occasionally, real creep values may be surprisingly higher than those given in codes. Some additives (including those of extra-fine materials) together with insufficient curing, may result in such increase creep and shrinkage. Designers should learn to cope with such situations by coupling their calculations with provisions related to mix designs and other technical measures.

Another example of numerical calculations based on formal "literature data", has to do with thermal analysis; such basic data, non-representative of the specific materials eventually used on the site, may lead to completely wrong decisions: Adiabatic temperature of cement may drop up to 10% with a substantial pozzolan replacement, coefficient of thermal expansion of concrete may dramatically be reduced (~50%) if limestone aggregates are used instead of quartzite, whereas thermal diffusivity in the same case may drop by 15%. Here again, designers are simply invited to be acquainted with actual mix design details.

DESIGN FOR DURABILITY

Although rational modeling for quantitative durability design is not always feasible, actual design of reinforced concrete structures is frequently governed by detailed durability provisions of codes. Chapter 8 of the CEB-FIP Model Code 90 is good example of recent developments along this line.

Modern designers are now obliged to specialize themselves in concrete technology. Otherwise, a formalistic application of durability provisions (without a deeper knowledge of diffusion, permeability, pathological

mechanisms and scientifically based remedies), may lead to gross-errors and threaten the future of concrete structures.

CONCLUSION

It seems that, nowadays, designers of concrete structures are invited to tailor their concrete, optimizing its design within a 3-dimensional design-space encompassing three categories of actions, i.e. (i) loads, (ii) imposed deformations and (iii) physical-chemical influences (not to mention the fourth one, which is "appearance of concrete surfaces"). In doing so, a modern designer has to bridge the old gap between "structural analysts" and concrete "technologists", and move towards an integrated approach in engineering kind – of a worthy heir of the ancient master builders.

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