Some Aspects of Sustainability

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The concept of sustainability began to loom large following the Report of the 1987 World Commission on Environment and Development, specifically the so-called "Brundtland Report." The crucial words from that report are: "Humanity has the ability to make development sustainable—to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs."

I have not yet published any papers on sustainability, but the topic has become the flavor of the decade, and society tells us that we must all be supporters of sustainability. I am unable to add to the rhetoric, if not clamor, but instead I would like to redress the balance with a few cool comments that may be useful.

Parenthetically, I could add that our grip of fear regarding the running out of primary materials is not new. Soon after World War II, the so-called Club of Rome presented arguments about the dangers of running out of primary materials, such as coal, oil, iron ore, and some other metal ores. In most cases, the argument was based on known reserves, existing methods of extraction, and a continuing increase in population with the same consumption rate per capita. None of these proved to be a safe assumption. For example, not only have new reserves of metal ores been discovered, but also the methods of extraction have been improved so that old mine tailings are now being reworked to extract the metal. Moreover, in many applications, such as motorcars, steel has been

replaced by plastics and fibers. So the old fears were largely unfounded, and the Club of Rome died a quiet death.

Only the population growth continues, especially in Asia, but this is too sensitive a topic in religious and moral terms for me to broach. I shall limit myself to saying that these megations will demand, and rightly so, provisions of modern life not only for a larger number of people but also at the standard currently demanded by wealthy countries.

Against this backdrop, our local application of sustainability will prove puny, but this does not mean that we need not do our best here at home.

To start with generalities, of course, we want the world to be run in a sustainable manner, by which I mean not being wasteful of materials or energy and not degrading the environment. As Broers[1] put it, "The sustainable development concept requires of all of us—as engineers and citizens—to consider much more widely than before the impact of our own lives and of the infrastructure and products we produce..." He then continues, "Engineers need to integrate consideration of whole-life environmental and social impacts—positive as well as negative—with the mainstream and commercial aspects of their work. Wise use of natural resources, minimum adverse impact and maximum positive impact on people and the environment are the targets."

SUSTAINABILITY OF CONCRETE CONSTRUCTION

This editorial is about concrete, and I should therefore limit myself to sustainability of concrete and concrete construction. Strictly speaking, the term construction subsumes concrete as a material because our interest in the material *per se* is limited. It follows that, wherever possible, we should improve the production methods of concrete and of cementitious materials. We should also design concrete structures so that their operation is conducive to minimizing energy consumption and that they are adequately durable. In my opinion, there is no such thing as inherently durable concrete. There is durable concrete for a purpose, that which performs its intended function during its intended life, but not necessarily any longer.

To promote sustainability, the approach has to be such that all aspects of concrete structures are taken into account. Taking energy as an example, we should consider not only the energy efficiency of the operation of a building but also the energy demands required to produce the materials used and during the process of construction. Alas, those who want to show themselves to be on the side of the angels of sustainability often do so by a partial and selective approach and even by slinging the proverbial mud at competing types of construction. Such an approach does not enhance the image of concrete and indeed tarnishes it in the eyes of intelligent and informed readers.

Let me give an example of what I consider crude overselling coupled with casting of wholesale aspersions on steel structures. Before I report some details of the statements in what I consider to be the offending article, I have to say that it was not published in a commercial journal but in a highly reputable periodical, *Science in Parliament*. This periodical is the journal of the Parliamentary and Scientific Committee, whose objectives are, "(a) to inform the scientific and industrial communities of activities within Parliament of a scientific nature and of the progress of relevant legislation; (b) to keep Members of Parliament abreast of scientific affairs." The journal probably does not have a wide circulation, but it is highly influential, being the forum for views of scientists and engineers for consumption by parliamentarians. As a member of the Parliamentary and Scientific Committee, I am aware of the situation and I deplore even more profoundly the crude approach of "character assassination" of steel while allegedly promoting concrete.

BEHAVIOR OF CONCRETE IN FIRE

I shall refer to only a few aspects of the behavior of concrete in fire, good fire resistance being essential for a given concrete structure to satisfy the desiderata of safety. This editorial is not an exposé on the behavior of concrete in fire.

The article that I intend to criticize was written by a chemist who is the Head of Residential Buildings at the Concrete Centre in England. Structural engineers know that what is crucial is not just the fire resistance of steel as a material as compared with the fire resistance of concrete. It is known that steel has to be fireproofed, but it should not be forgotten that the comparable structural material is not just concrete, but reinforced concrete. The reinforcement is obviously steel, and once sufficiently high temperatures have been reached, the concrete cover to reinforcement may spall, and the exposed steel then becomes vulnerable to fire because it is...steel. Concrete with an extremely low water-cement ratio, that is, very high-strength concrete, is particularly vulnerable in this respect.

The description of the consequences of fire on the Windsor Tower in Madrid[2] to the effect that "failure was limited to the perimeter steel frame whereas the internal concrete frame survived complete burn-out with no collapse" may well be true, but it is not an appropriate comparison of steel and concrete with respect to fire endurance.

We ought to rejoice that concrete as a material behaves well in fire because it is incombustible, does not emit toxic gases, and offers reasonable insulation against transmission of heat. But in structural design—and structures are the most important end use of concrete—we are concerned with fire endurance rating, which is the survival time of specific structural assemblies or components. Fire endurance rating is strongly affected by the properties of coarse aggregate used, by the thickness of cover to any embedded steel, and, very importantly, by the structural system and design details, including restraint during heating in a fire.

But this is not all. Large structures, such as the World Trade Center in New York City and the Windsor Tower in Madrid, have to be robust and to contain numerous redundancies to prevent progressive collapse, such as occurred at Ronan Point in England in 1968. Assessment of fire resistance of a structure, as against a single structural element, is a task for a structural engineer and requires a careful and impartial approach. As someone who has spent the best part of half a century studying concrete and establishing its properties, and

thus promoting it, I find it a pity that all of this is endangered by an undocumented accusation of the inadequacies of steel, and thereby of superiority of concrete.

CONCRETE VERSUS STEEL

With respect to fire resistance, concrete and steel are not simply interchangeable so as to optimize the fire resistance of a structure. Nor do they have the same mass for a given applied loading, so that the size of the foundations is likely to be affected by the choice of the material for the frame. Larger or more massive foundations mean more labor, more concrete, and therefore more energy used in the construction and possibly more carbon dioxide emissions in the production of the cement.

Parenthetically, I would add that, in recent years, we have found it increasingly easier to make very high-strength concrete, even 140 MPa or so. Alas, the design methods, and certainly design codes, have not kept up with the progress in concrete technology so that we often do not derive full benefit from producing very high-strength concrete.

Generally, design of concrete structures is more laborious and time consuming than steel design. As they say, time is money, so that time represents cost, and this should not be ignored in any comparison of different types of structures. Nowadays, we should also say: Energy is money. While we want to economize on energy and therefore on emissions of noxious gases, we cannot disregard the direct expenditure on personnel, computer time, office operation, etc.

RECYCLING AND CONCRETE

Because sustainability has become everybody's goal, it is a lively topic. However, the approach is fragmented. Basically, we seek to economize energy in the production of new construction materials. Nowadays, energy used to manufacture portland cement includes a wide range of combustible materials, including car and truck tires, but this does not significantly conserve fossil fuels, such as coal or natural gas, and does not greatly reduce the emission of carbon dioxide. But, of course, it is a move in the right direction.

So is recycling of aggregate and concrete. However, we have to blend recycled material with virgin aggregate to have a workable mixture. Recycling requires crushing and, therefore, transportation to the crusher and back from it. Ignoring the energy involved in transportation as well as the more general cost of stockpiling, removal of steel, grading, and quality control of the recycled material does not present a true picture of the situation. Moreover, the shape and texture of crushed concrete are such that there may be a considerable influence on workability and, hence, appropriate measures have to be taken.

PRECAST CONCRETE

The topic of recycling easily leads to consideration of precast concrete with respect to sustainability. In a precasting plant, there is less concrete waste, and what waste there is can be easily recycled.

There is also economy in the *actual* amount of cement used per cubic meter of concrete. This is because the difference between the design (minimum) strength and the actual mean strength is smaller due to the lower variability of concrete produced in a fixed plant, as compared with site mixing. The energy saving is considerable because the main energy consumed in producing concrete is in the manufacture of cement; the energy required to manufacture the cement is about three-quarters of the total energy used in making the given concrete.

Another benefit of precasting lies in closer control of the concrete cover to reinforcement so that excessive cover (to be on the safe side) is not necessary.

It may also be useful to extend the above argument by restating the fact that the outermost part of a concrete member is critical in resisting external chemical attack and therefore the quality of the finish is important with respect to durability. Precast concrete gives, in general, a superior finish because workmanship in a precasting plant is usually better than on a "movable" site. In consequence, precast concrete generally has an enhanced durability.

FLY ASH

Returning to the binders in concrete, the days of using pure, unadulterated portland cement are gone. Most mixtures used today contain fly ash or ground granulated blast-furnace slag, or both. (This is in addition to 5% of inert filler in so-called "pure" portland cement.) These are waste materials from other processes but, with careful control or beneficiation, they are useful by-products. But "careful control" does not come free and without knock-on effects. For example, to produce high-quality fly ash at the point of exit from combustion imposes restraints on the burning process.

Among the desiderata for high-quality fly ash, there is the need for a large proportion of vitreous spherical particles and also of particles smaller than 10 μm. These features are achieved by the use of very high burning temperatures in the power-generating stations that burn coal powder. The need to reduce the emission NO_x gases, however, requires the use of lower peak burning temperatures with the consequence that minerals with a high melting point do not always fuse completely. With luck and ingenuity, a technology satisfying both the environmental requirement of limited NO_x emissions and the concrete user's need for small and spherical fly ash particles will be developed.

A further complication arises from the fact that an increasing number of power stations are mixing coal with biomass, wood in various forms, paper pulp, and vegetable fiber; European standards limit the mass of ash from these materials to 10% of the total ash. These changes will affect the use of fly ash in the concrete binder.

The biggest problem, however, is the relatively low percentage of fly ash use in the world. In many countries, including the United States, some power-generating stations simply do not bother to produce fly ash suitable for use in concrete because of the strict burning controls, including the use of coal from a single source. Progress is being made, but there is a long way to go before fly ash is not just a waste product.

Sustainability is a multifaceted problem, and we are as yet nowhere near an approach that takes all its aspects into account.

USE OF TIRES IN A CEMENT KILN

Tires can be fed into a kiln as fuel in shredded form as a continuous process or intermittently through a special opening at the level of the burner, one or two tires being inserted per revolution of the kiln. While the calorific value of tires burnt in the kiln is high (if anything, higher than coal on a mass basis), there are costs associated with the process. In some Canadian cities, Quebec for example, there is a subsidy paid by the government (I believe $50 per tonne of tires) so that, from the standpoint of the cement manufacturer, the tire fuel represents a negative cost. Also, compared with coal, there is the benefit of reduced carbon dioxide emission. The residual matter from tire combustion, which enters clinker, consists of sulfur, limestone filler, and iron; these are, by and large, beneficial.

Thus, the use of tires in the manufacture of cement is beneficial from the point of view of preserving natural resources (fossil fuel) and reducing carbon dioxide emissions. But in broad terms, this is just the proverbial drop in the ocean because cement kilns and tire depots may be far apart. Traditionally, cement plants are located in the vicinity of exploitable raw materials for the manufacture of cement, and such a location may or may not be near the source of waste tires. This, of course, is inevitable, but I am mentioning it because some enthusiasts claim very large benefits in terms of sustainability of concrete due to using tires as kiln fuel. Even more outlandish claims are sometimes made.

For example, it is not correct to say: "Within kilns, the steel content of tyres (*sic*) provides an essential source of iron, avoiding the need for shales and clays."[3] Now, shales and clays are fed into the kiln to provide alumina and silica, which together represent typically 20% to 33% of the mass of portland cement. If the entire fuel consisted of tires in a modern cement plant, only about 100 kg would be required to burn the raw materials for 1 tonne of cement. So shale or clay are still necessary.

This may be an appropriate place to mention that the production of 1 tonne of portland cement requires about $1^1/_2$ tonnes of limestone and clay.[4] Another "admission" that should be made is that the production of 1 tonne of portland cement generates about 1 tonne of carbon dioxide. A further admission is to say that, worldwide, the manufacture of portland cement is reported to be about 8% to 10% of all human-generated carbon dioxide.

GENERAL

In my opinion, care is required in making sweeping statements, such as "thermal mass of concrete offers the opportunity to reduce the energy requirements of buildings."[2] The same applies, of course, to brickwork and is the underlying principle of night-storage heaters. But what happens in practice depends on the periods of radiation reaching the concrete and of radiation *by* the concrete in relation to the indoor temperature required. I accept that advantage should be taken of the thermal properties of concrete, but architects are often lax in exploiting this.

Enthusiasm exceeding technical knowledge is also unhelpful. At a recent conference on sustainability at the Royal Academy of Engineering, a speaker urged us to design new buildings with a provision for a change of use so that, for example, a factory could be, at a later date, refitted to become a block of flats. Although refitting is often advantageous, provision during the initial construction is unrealistic because of the social requirements for accommodation: headroom, sanitation, fenestration, staircases, etc. Moreover, the capital cost of providing for a possible *future* use is generally unacceptable to the first owner. Indeed, the distinction between initial cost and later costs (including maintenance) is an important factor in design.

Sustainability is a multifaceted problem, and we are as yet nowhere near an approach that takes all its aspects into account. They say charity begins at home. The American Concrete Institute has so far not produced a single guide on taking sustainability into account in concrete construction, but in 2005 it decided to "encourage the development of sustainable structures..." I think that the United Kingdom is more advanced in this respect, and the Royal Academy of Engineering is conducting several in-depth studies, but no definitive views on sustainable concrete construction are available. We still have to await a cool, wide-ranging appraisal. At present, Holland[4] has written the best overview available, in 2002, which points out that in the United States "there is no national activity geared toward specifying or certifying structures for their impact on the environment."

REFERENCES

1. Broers, Lord (Alec), "Foreword," *Engineering for Sustainable Development: Guiding Principles*, The Royal Academy of Engineering, September 2005, p. 3.

2. Scothern, A., "Concrete is the Best Bet for Sustainable Development," *Science in Parliament*, Summer 2004, pp. 16–17.

3. Hird, A. B., Griffiths, P. J., and Smith, R. A., "Tyre Waste and Resource Management: A Mass Balance Approach," *Viridis Report VR2*, TRL Ltd, 2002, www.trl.co.uk, 72 pp.

4. Holland, T. C., "Sustainability of the Concrete Industry: What Should Be ACI's Role?" *Concrete International*, Vol. 24, No. 7, 2002, pp. 35–40.

The views posed in this editorial are not necessarily those of PCI. Reader comment is invited.