Sustainability of concrete construction in Indian context

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Versatility of concrete as a construction material is highlighted followed by issues related to sustainability of concrete in Indian context. The author believes that large-scale mechanisation for production of engineered concrete with mineral and chemical admixtures, with right quality control scheme, can lead to better sustainability of concrete in India.

Sustainability in a broad sense is the ability to preserve a certain process or state over a long period in future.[1] In the ecological context, the process is sustainable when it is able to maintain ecological processes, biodiversity and productivity into the future. The process of production and use of sustainable materials up to disposal or reuse/recycling, therefore would create no ecological imbalances, preserve the environment, would have no impact on human health and the process can continue in this manner for a long-time into the future without compromising with the productivity. Materials that are readily available in nature would not require production, therefore, there use only need to be considered for sustainability. Manufactured materials on the other hand are produced with great expense of energy and therefore their sustainability needs careful analysis and evaluation for both production and use. The green materials are sustainable and have low embodied energy. While locally available natural material may add to green practice, buildings and structures where functional concerns are dominant and loads are high, engineered construction materials such as concrete cannot be avoided. Besides, site constraints, land availability, durability requirements and construction speed make it impossible to avoid using conventional engineered construction material in structures. At present developed countries are more concerned about maintenance of existing structure and infrastructures. On the other hand in India, need for new constructions both for housing and for infrastructure sectors, necessitates large-scale use of engineered construction material. Hence, it is not surprising that India is second largest producer (consumer) of cement after China and this production is likely to increase significantly, as the per-capita consumption of cement in India is lower compared to world average per-capita consumption. Concrete is the most popular construction material because of its versatility and relatively low cost, and this is another reason for likely large-scale increase in its use in Indian construction in near future. Concrete is a man made construction material, therefore there is need to look into its sustainability. In the recent past, several articles have been reported on sustainability of concrete in the global context.[2-7] As concrete construction practice is significantly different in India vis-à-vis developed countries, this article attempts to explore concrete construction practices and related sustainability issues in the Indian context.

Concrete a versatile construction material

Concrete, the most commonly used construction material, has come a long way since its first use. The popularity of the concrete as a construction material is due to many advantages. The main advantages are: a) it's relative low cost as a finished product, b) it's mouldability to any desired shape, c) high range of mould-ability from zero slump roller compacted concrete to Self Compacting Concrete with slump flow, d) the robustness it can give to a structure when required for example robustness needed against sliding or overturning in retaining wall or in gravity dam, e) versatile in terms strength with strength ranging from 5-10 MPa in mass concrete to 800 MPa in Reactive Powder Concrete (RPC) and; f) with proper reinforcement, (or pre-stressing) it can be designed for the required resistance against mechanical loading and desired ductility (e.g fibre reinforcement for pseudo-ductility).[8,9] In brief, concrete with appropriate reinforcement (RCC) or with proper pre-stressing (PSC) as other composites, can be designed for desired property. The advantage of relatively low cost is an essential requirement for a construction material, especially when it is meant for large-scale consumptions. However, low cost of normal strength concrete is also responsible for its non-judicious use in the sense that a large volume of concrete construction is not properly engineered resulting in poor execution of construction. This is true for India, where bulk volume of our construction is executed by non-engineered or by semi-engineered means. It must be realised that, however cheap a material may appear, the natural resources of any country is limited and most optimal utilisation of resources is essential for long-term sustenance. Concrete as a material is well understood, although much empiricism remains to be taken care of. However, this understanding of the behaviour of the material seems to be sparingly translated into construction and execution practices in many projects. Poor quality construction results in large maintenance and repair cost during the service period of the structure, rendering the construction relatively uneconomic and affecting its sustainability.

As for the structural design is concerned it has become advanced in recent years, loads are now estimated more realistically than ever before and analysis and design have become more precise. In India, concrete construction on the other hand has lagged behind and has not advanced with the same pace as the design. Thus, the benefit of refinement in structural design is not fully realised. To realise this benefit quality of construction practice must be at par. The durability aspect of concrete needs more attention with adequate rigour. A low initial cost may not be always economical. Low initial cost with high maintenance and repair cost may result in lower overall economy. So, minimising life cycle cost may be accepted as the objective of structural design rather than minimising initial cost alone.[10] The quality of concrete construction also plays an important role for life cycle cost. One of the definite ways of improving the quality of construction is adopting mechanisation in construction, besides applying statistical quality control measures using the knowledge of concrete technology.

Table 1. Embodied production energy for some construction materials

Type of material	Thermal Energy (MJ/g)
Ordinary Portland Cement (OPC)	5.85
Lime	5.63
Lime- pozzolana	2.33
Steel	42.00
Aluminium	236.80
Glass	25.8

Concrete sustainability: Global warming and resource limitations

Climate change and global warming are current and major concerns for humanity. The global warming is attributed to greenhouse effect because of gases termed as green house gases for example, water vapor, methane and carbon dioxide (CO_2). The world's energy production is largely dependent on fossil fuel burning that produces CO_2. Thus major contributor to anthropogenic CO_2 emission that is, CO_2 produced and emitted because of human activity, is energy production. Hence, higher the energy used in making of a material, the more its contribution to anthropogenic CO_2. Embodied energy is defined as the available energy that was used in the work of making a product.[11] Higher embodied energy thus contributes to global warming and hence acts against preservation of environment and ecological balance. A sustainable material therefore shall have low embodied energy. Embodied energy is the sum of energy consumed in the production and transport. Basic energy used in producing some materials are given in Table 1 and embodied energy for transport of some materials is given in Table 2.[12,13]

Cement has small-embodied energy and concrete has still smaller embodied energy. Volumetric thermal capacity and thermal diffusivity of concrete is relatively

Table 2. Embodied production and transportation energy for some construction materials.

Material	Energy (MJ/kg)		
	Production	Transportation	
		50 Km	100 Km
Sand	0.0	87.5	175
Crushed aggregate	20.5	87.5	175
Burnt clay bricks	2550	100	200
Ordinary Portland Cement	5850	50	100
Steel	42000	50	100

Table 3. Analysis of Cement used through RMC in NCR region

For national capital region only	Concrete, million m^3 p.a.	Equivalent Cement, M.M.T. p.a.
Commercial RMC	1.080	@ 300 kg/ m^3 = 0.3240
RMC for Projects (DMRC)	1.800	@ 420 kg/ m^3 = 0.7560
Total RMC	2.880	1.0800
Only Delhi Cement Sale	-	3.387
Other NCR Cement Sale	-	2.4
Total Cement Sale	-	5.787
% of total Cement routed through RMC	-	18.66 %

low, hence concrete is relatively more environment friendly than steel or aluminium in the context of energy transmission. However, concrete is the most popular material on earth and commonly uses ordinary Portland cement (OPC). In the year 2004, 2.0 billion tones of OPC were produced globally with India contributing 116.1 million tons (production capacity 146.4 million tons). Concrete produced amounted to 1 m^3 per person.[13,14] Thus, even though concrete has low embodied energy per unit mass, yet it contributes to maximum embodied energy. In most buildings, concrete is the maximum contributor of embodied energy followed by steel. Besides, cement production additionally contributes to CO_2 emission because of calcinations of limestone during production of cement. $CaCO_3$ is calcined to CaO and CO_2 is released. Both embodied energy and direct emission contribute to total CO_2 emissions. Total amount CO_2 emitted per ton of cement production reported by various researchers vary from one another, and ranges from 0.74 ton to 1.24 ton. Generally, it is accepted that one ton of cement produces about an equal amount of CO_2 through consumption of fuel in burning and decomposition of $CaCO_3$.[14] Cement consumption in the world has increased exponentially since 1926 and is continuing to increase. Because of its scale of consumption and manufacture, Cement is only next to fossil fuel burning contributing to anthropogenic CO_2 emissions (5-10%). Thus, control of this greenhouse gas emission is a major issue for sustainable concrete. Judicious use of cement in optimal fashion thus is a prerequisite for sustainability of concrete. Use of supplementary cementitious material, especially other industrial byproduct such as blast furnace slag and fly ash in concrete to reduce OPC clinker consumption is currently being considered as a major step towards achieving sustainability of concrete.

The world and national limestone resources are limited. Hence, again optimal use of cement is desirable. Similarly, natural resources for aggregate production are also limited. Later issue can be tackled by the adoption of recycled aggregate that can be obtained from demolition, construction or some other solid wastes. Receding aggregate resource and use of recycled aggregate may not be an immediate concern in Indian context, but inefficient production and wasteful use of aggregate is likely to hasten the process of decline of available aggregate resource. Mechanised engineered production of aggregate or manufactured aggregate on the other hand, not only ensures optimal use of parent (rock) resources for aggregate production but also reduces the variability of concrete due to poor aggregate quality. The mining/quarrying of sand from pit or collection from riverbed is now prohibited by court orders in many parts of the country. Pond ash and/or bottom ash as well as crusher dust can be suitably used as fine aggregate instead of sand in concrete.[15] Thus to make concrete sustainable in the Indian context a multiprong strategy should be adopted some of the possible ways are discussed below.

Concrete Construction practice in India and Cement Consumption

Unlike most of the developed countries, majority of the concrete in India is produced through non-engineered or at best, semi-engineered construction practices. This is obvious from a survey conducted in 2004 that only about 10-11% of cement in India is routed through Ready-Mixed Concrete (RMC) process.[16] Cities such as Delhi, which had on going Metro Rail (DMRC) project in 2004, percentage of cement used through RMC is estimated to be roughly 18.66 percent as illustrated in Table 3.[16] All the structural concrete used in DMRC project is through RMC. If figures related to DMRC are taken out of the calculations, approximately 6.44 percent of cement consumed in Delhi is through RMC route. Total production of RMC in India then was 3.5 million cubic meters. In 2004, 2.0 billion tons of cement was produced globally with India contributing 116.1 million tons. If on an average one assumes that 300 kg of cement is used per cubic meter of RMC, total cement consumed through RMC equals 11.67 million metric tons (MMT) per annum which amounts to 10.32 percent of total cement consumption then. For the sake of comparison, USA uses 75 percentage of their total cement through RMC, for Japan this percentage is 70 percent and that in developing countries like Malaysia, is 16 percent. Although cement production has increased in absolute terms, the percentage consumption of cement through RMC would not have changed much in last 6 years.

Mechanised construction has been the hallmark of large infrastructure projects. But the same seems to have little impact on traditional building sector.[17-20] By end use, building sector is the largest consumer of cement in the country, accounting for about 60 percent of the total consumption. Infrastructure sector, which includes roads, bridges and dams accounts for another 25 percent of the total demand. Repair etc., accounts for the balance 15 percent of cement consumption. Non-engineered and semi-engineered construction practice leads to wastage of cement besides resulting in poor quality concrete.

Thus large-scale mechanisation and production of concrete by engineered means can result in efficient cement utilisation and hence would lead to sustainability. Grade of concrete is defined by 95 percentile characteristic strength. Mean strength is given by $f_m=f_{ck}+1.65\sigma$; where, f stands for cube compressive strength and subscript

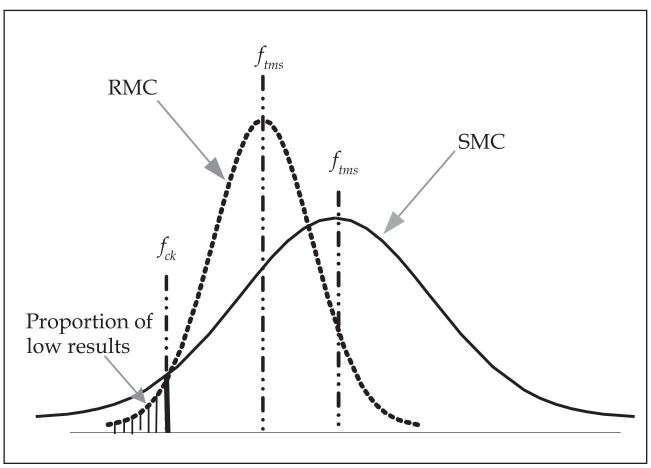

Figure 1. Role of quality control on mean strength

'm' and 'ck' denote mean and characteristic strengths respectively. σ is the standard deviation that indicates the overall degree of quality control during production. Mixes are designed on the basis of f_m and for higher value of σ, f_m would be higher even though the grade of concrete i.e., f_{ck} is same as illustrated in Figure 1 for site mixed concrete (SMC) and RMC with proper quality control. Variability of concrete properties from sample to sample depends on variation of materials, variations because of batching, mixing, sampling and that due to testing etc. Thus standard deviation would be lower when above variations are controlled. This is possible by adopting strict forward control, that is testing of ingredients, maintenance and regular calibration check of batching plant, maintenance of mixer and appropriate quality monitoring and correction that is strict retrospective control.[21] Such quality control scheme can only be adopted in a plant where automated batching and testing facilities are available. Widespread popularisation of engineered ready-mixed concrete production through proper quality control can make it possible. This can be understood easily through following illustration. Variation of strength, ± Δf, would be directly related to W/C± Δ(W/C); Δ(W/C) is given by following equation

$$\Delta\left(\frac{W}{C}\right)=\frac{\Delta W}{C}-\frac{W\Delta C}{C^2} \qquad \text{....[1]}$$

Thus +Δ(W/C) or, -Δ(W/C) depend on ΔW and ΔC, and larger the value of ±ΔW and ±ΔC, ±Δf would be higher, hence higher standard deviations. Manual and volumetric batching done by untrained persons always would result in higher ±ΔW and ±ΔC, thus higher σ and inefficient use of cement. Fifty percent of the cement consumed in building sector i.e., 30% of overall cement is used for structural concrete.[22] Infrastructure sector uses 25 percent of the total cement. Non-structural works in infrastructure projects are very less. And hence not more than 10 percent of cement, used in infrastructure works (i.e., 2.5% of overall) would be required for non-concreting works. Also one can assume that half of remaining 15 % of total cement (i.e., 7.5% of overall) used for miscellaneous and repair works, is used as structural concrete. On this basis, the percentage of total cement used for concreting is estimated as 60 percent. It was shown earlier that RMC in India uses not more than 10 percent of total cement. Thus cement used for SMC works out to be 50 percent. National consumption of cement for the year 2004-05 was 116.13 MMT. Taking national consumption of Cement as 116 MMT, quantity of cement that goes into SMC equals 58 MMT.

To estimate the saving through better quality control, one can consider M20 and M25 grade of concrete. The standard deviation (SD) for both grades is 4.0 MPa for good control etc as par IS456:2000. For poorer control SD is 1MPa more i.e.5 MPa according to the same code. Thus, SD for RMC with good quality control and semi-engineered SMC can be assumed as 4.0 MPa and 5.0 MPa respectively. W/C ratios for M20 and M25 concretes may be realistically assumed as 0.50 and 0.45 respectively for their corresponding target mean strength for RMC. For 1 MPa increase in SD the target mean strength would increase by 1.65MPa. By using British DOE strength versus W/C curves, the increase in W/C for increase in strength of 1.65 MPa can be estimated. These +Δ(W/C) works out to be 0.018 and 0.15 respectively for M20 and M25 concrete. Accordingly, the saving in cement due to better quality control is estimated and the average saving is 3.5 percent. If p percent of total cement is used in RMC, total cement saved equals [(3.5/100)*(p-10)/100*CP] MMT p.a. where, CP is the annual cement production in MMT. For p equals to 70 %, saving in cement is 2 % of total annual production. Plasticising chemical admixtures or Water reducing agent or high range water reducing agent (WRA/HRWRA) can be effectively used in mechanised production of fresh concrete and with 10-30% reduction in water demand, the cement consumption can be reduced by an equal amount in concrete. As water requirement of concrete could be reduced for same plasticity and wetness, hence, cement content also can be reduced proportionally for same strength, by maintaining constant water to cement ratio. Modern day second or higher generation plasticiser can reduce the water content by 25-30%. Thus, 12-15% additional saving in total cement consumption can be expected when these materials are used in concrete production in a large scale.

Fly ash is a waste generated from thermal power plant and readily available only for transportation cost. Safe disposal of fly ash is a cause of concern for power industry and use of the same in construction material is a boon. Extensive use fly ash, ground granulated blast furnace slag(ggbfs) either through direct use in RMC or through use of Portland Pozzolana (PPC) and Portland Slag Cements can reduce OPC clinker consumption to a significant extent. This has multi fold benefits, namely reduction in OPC consumption resulting in reduction in environmental hazard and also, reduction in production of green house gas CO_2, besides ensuring better durability for concrete.[23,24] For same strength i.e. grade of concrete and for similar workability adding fly ash results in an increase in overall cementitious (OPC+Fly ash) material by about 10% to 15%. Assuming on an average 30% [F/(C+F)] fly ash in total cementitious materials, it can be shown that, these results in a saving of at least 20% clinker. At present data on quantum of fly ash or GGBFS used exclusively in concrete production is not readily available. It may be noted that at places, OPC is not available for retail sale to individuals for use in housing and on the other hand, fly ash is not used in many government and infrastructure projects. Thus making use of fly ash where it is technically possible would enable a significant reduction in OPC consumption and enhance sustainability. Thus, use of plasticisers together with fly ash in mechanised production of concrete can make it more sustainable in Indian context. Blended and composite cements containing one or more supplementary cementitious material can be used wherever appropriate. High volume fly ash concrete, concrete with activated blast furnace slag, geo-polymer concretes are the other developments in recent times that can lead to better sustainability of concrete.

Sustainability and durability of concrete

Sustainable concrete must be durable. Service life allows for quantification of durability. A structure, if maintained regularly, may exhibit a very long physical life far beyond intended design life. Physical life may be curtailed to shorter economic life by human intervention when maintenance cost becomes too high and economical maintenance becomes unviable. Sometimes function of the structure may change at the end of functional life because of business reasons or for functional obsolescence. At the end, for sustainability, materials in the structure shall be recycled and reused without any waste left for disposal. Now steel in reinforced concrete can be reused and concrete demolition wastes can be used for landfill or processed further for use as aggregate. Service life in the context of concrete is associated with plain cement concrete, reinforced cement concrete or pre-stressed concrete component/element of a structure e.g., a beam, column, girder, deck slab etc. Like all other man made materials produced at the expense of energy, concrete also has a tendency to change chemically to a more stable state under a facilitating environment. This chemical change, often results in deterioration of material, leading to functional degradation of structural element. Acceptable limit of the degradation is defined in terms of suitable service-ability limits.[10,25] Service life of the element is the time when such a limit state is attained by the element due to any deterioration mechanism under exposure to service condition. A more durable element would exhibit higher service life. At the end of the service life an element would demand repair and rehabilitation or replacement. Repairs or replacement implies additional effort, energy and disruption of primary activity for which the structure was constructed. Inspection is also a part of maintenance and repair. Recommended inspection schedule are available in literature.[25] Sustainable concrete structure shall exhibit longer service life and longer repair cycle. Exposure environment and nature of loading say, static or fatigue, both play role in degradation process. Fatigue loading is more severe than static ones. Considering the overall severity of exposure the specification in terms of grade of concrete and cover depth etc may be chosen even to be better than those recommended in codes as, current practice of adhering to prescriptive recommendations of code in terms of minimum cement content, maximum w/c ratio, minimum grade etc, may be inadequate at places. Some of them are also questionable, e.g. recent findings of various research workers demonstrate that minimum cement content (OPC) prescribed in many codes is questionable[26-28]. However, durability design of concrete structure, based on service life, is still in its infancy because of lack of adequate understanding of the degradation phenomena. Thus currently, there is no option other than using available prescriptive recommendations. Other issue related to durability is the quality of concrete. Quality control is the means of meeting the specifications and a better quality control ensures the product meets the specifications with sufficient closeness. The short repair cycle is often due to poor quality control during construction. An analysis of several cases of buildings demonstrates that for most of the cases the causes of short repair cycle are linked to poor quality construction.[29] Mechanisation and adoption of stringent quality adherence scheme can increase the service life of elements and ensure better sustainability. Use of fly ash and ggbfs again enhances the service life largely by making the concrete impervious and by increasing the electrical resistivity of concrete[23,24], especially when produced under adequate control. Thus for improving the sustainability by enhancing the service life it is necessary to adopt large-scale mechanisation in concrete production and make use of eco-friendly fly ash etc., with chemical admixtures.

Conclusion

The discussions presented above leads to the conclusion that there is a need for being concerned about sustainability of concrete in India and minimising the CO_2 emission. There is also a need to minimise wastage of precious natural resources by making their efficient and judicious use. This is possible by large-scale mechanisation of concrete construction in the country through extensive use of batching plant, RMC practices and prefabrication wherever possible. Further use of six components namely, coarse aggregate, fine aggregate, water, OPC cement with mineral admixture/blended cement and plasticiser for production of engineered concrete, instead of non-engineered/semi-engineered concrete production with four components, can make concrete sustainable in India.

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