Sustainable Infrastructure Development Strategies through Technological Innovation of Smart Materials

Khandaker M.A. Hossain
Associate Professor, Dept. of Civil Engineering, Ryerson University, Toronto, Canada.

Abstract
Over the last decades there has been a tremendous growth of built environment to meet higher standards of living with growing industrialization and urbanization. The replacement and rehabilitation of aging and deteriorating existing infrastructures are the challenges of the 21st century. Development of new environmentally friendly building materials can lead to lower greenhouse gas emission, consumption of wastes, durable construction, sustainability in construction industry and minimize worldwide infrastructure problems. The paper addresses critical infrastructure needs and focuses on the strategies for the development of sustainable infrastructure based on technological innovation of smart materials and rehabilitation technologies. In the strategy of smart infrastructure materials, emphasis is placed on the deterioration (degradation) process of traditional construction materials and on the development of new generation of advanced materials. The strategy area of rehabilitation techniques focusses on renewing, modifying, and upgrading constructed facilities, through integrating smart materials and new design approaches. This paper also presents the development of new generation of advanced materials and their contributions to infrastructure sustainability based on structural capacity enhancement, service life and economy through illustrating case studies.

Keywords: sustainable infrastructure, smart materials, technological innovation, rehabilitation, greenhouse gas emission

INTRODUCTION
The definition of sustainability emphasizes the importance of ensuring the satisfaction of present need without compromising the ability of future generations to meet their own requirements. Sustainable development achieves social, economic and environmental objectives in parallel (Howard 2000). For the construction industry, sustainability means: progress that meets the needs of the society, economic development, preservation of environment and efficient use of resources. A simplistic illustration (Fig. 1) of sustainability in construction is the cradle to the grave material flow (Somervile 1990).

A total plan for sustainability requires: reduction of emission of greenhouse gases (GHG), efficient use of resources, constructive reuse of waste, reduction of harmful effects from construction activities and building occupation, reduced environmental impact, and improved levels of energy use throughout the life of the built product. Development of new materials/construction technologies and their implementation to sustainable infrastructure development is vital to protect the environment.
Significant opportunity exists to reduce GHG emissions through the development of energy conscious construction materials.

Author remains a promoter of sustainable infrastructure development through the strategy of technological innovation of smart materials and structural systems. Author’s major achievements in recent years include the development of novel “ecological” construction materials using waste products and natural pozzolans. Over the last twelve years, author’s research team at Ryerson University has developed sustainable green high performance concrete (HPC) materials (including self-consolidating concrete ‘SCC’, fiber reinforced SCC, engineered cementitious composite ‘ECC’, ultra-high performance/strength concrete ‘UHPC/UHSC’) and innovative structural systems/construction technologies (Hossain, 2003, 2004, 2014; Hossain and Lachemi, 2004a,b; Hossain et al. 2012; Issani and Hossain 2013, Lachemi et al. 2003, Sahmaran et al. 2009; Ozbay et al. 2012; Rafiei et al. 2013; Issani et al. 2013). This paper presents critical infrastructure needs, the development of new generation of sustainable materials/technologies and their contributions (illustrated by case studies and cost benefit analyses) to foster sustainable infrastructure development/rehabilitation as strategies.

SUSTAINABLE INFRASTRUCTURE AND PERFORMANCE BASED DESIGN
In the context of durability and design life, a more relevant sustainability diagram is shown in Fig. 2, which plots ‘sustainability’ against ‘quality’, where quality is representative of a desired achievement in design compared with required performance in service (Somervile 1999). This suggests to move from curve 1 towards curve 2, thus creating a zone of sustainable construction with a definite plateau. If on one hand, too little quality is put into the structure, and it fails to meet the owner’s in-service performance requirements, then this constitutes ‘failure’, in sustainability terms. On the other hand, it is equally bad to over-design or over-specify, since this wastes scarce resources. The only solution to this dilemma is to get as close as we can in design, to an exact fit with clearly defined performance requirements. Fig. 2 gives the element of strategy, towards a performance based design approach, consistent with greater sustainability. Essential to this is the establishment of limiting performance criteria and this has to be at two levels: (i) a requirement which deals with the in-service time factor-possibly a target, expressed in terms of ‘life’ and (ii) a requirement which directly relates to a minimum acceptable technical performance, over that life.

Most cities have buildings dating from the last century. Few will be found to be exactly the same due to changes in use, upgrading and replacements in whole or in part. Obsolescence, and changes in use, is therefore an issue. The situation is similar, for civil engineering structures, especially for highway structures. In 2012, one in nine of the USA bridges were classified as structurally deficient. Over two hundred million trips are taken daily across deficient bridges. The average age of 607,380 bridges is currently 42 years. Federal Highway Administration (FHWA) estimates that to eliminate the nation’s bridge deficient backlog by 2028, $20.5 billion annually is to be invested (FHWA 2012). Every year, in Canada alone, hundreds of millions of dollars are spent in bridge rehabilitation.

Owners of modern infrastructure are now more conscious of the need for regular inspection and good maintenance. Further, if structural changes have to be made, they wish the disruption to the operation of the structure to be kept to a minimum. This needs the development of a systematic and economical plan which involves whole life costing methods with the objective of minimizing total cost and maximizing the operational use of the structure. The sustainability argument implicit in Fig. 2 makes it clear that the performance based criteria should be used in design. To appreciate this, it is necessary to resort to feedback from in-service performance of structures. Fig. 3 shows deterioration mechanisms for bridges, buildings, car parks and marine structures (BCA 1997). Easily the most dominant mechanism is corrosion, from various causes. Table 1 shows an analysis of factors contributing to the deterioration and failure of infrastructures (BCA 1997).

‘Environment’ (natural or man-made) is the biggest single factor. However, low cover, poor concrete quality, poor design detailing and poor workmanship are added together then, collectively, they are of the same magnitude as for Environment. This feedback strongly suggests that, if durability design for sustainability is to be significantly improved, two essential elements must be dealt with: (i) identification and quantification of critical aggressive actions and (ii) improving, or otherwise dealing with, quality of construction.

This reflects the importance of the development of durable infrastructure materials and rehabilitation technologies to address critical infrastructure needs for sustainable development. A British Standard ‘BSI HB 1041’ exists, which simultaneously encourages the development of materials and components on a targeted service life basis. Current research and numerous researches in the past focus on the development of durable and environmentally friendly building materials to ensure sustainability in the construction industry and infrastructures worldwide.
The production of cement has increased within the last century from less than 2 Mt in 1880 to more than 4.0 billion in 2013 worldwide. The production of Portland cement (PC) accounts for 7% of CO₂ emissions. Since the late 1950’s new types of binders, produced by chemical or mechano-chemical activation of natural siliceous materials or industrial siliceous wastes were developed in several European countries. Chemical activation with caustic alkalis and with salts of alkaline metals produced so called ‘soilcement’. Sodium metasilicates or water glass was used to obtain new hydraulic cements. The hardening/strength gaining processes in these binders can be enhanced and accelerated by a heat treatment, with the best results reported in the range of between 900°C and 1000°C (Samarin 1995). As this process requires no calcinations and low processing temperature, compared to the Portland clinker formation, which is of the order of 1400°C, it results in more than 50% reduction in CO₂ emission compared to modern PC plants.

Sustainable Smart Materials and Construction/Rehabilitation Technology Development Strategies

New materials and construction technologies should be developed and used as a part of the holistic approach to reduce the harmful effects of the construction industry on our environment and to promote sustainable development. In this section, focus will be provided on the development of construction materials and technologies related to promoting infrastructure sustainability.

Development of Energy Conscious Cement

The production of cement has increased within the last century from less than 2 Mt in 1880 to more than 4.0 billion in 2013 worldwide. The production of Portland cement (PC) accounts for 7% of CO₂ produced around the world. Reduction of the CO₂ burden can be achieved by modifying the cement or the concrete (Hossain 2003).

Use of supplementary cementing materials (SCM) in blended cement: The use SCM such as fly ash (FA), slag, silica fume (SF), rice husks, volcanic ash (VA), finely ground pumice, metakaolin, limestone filler and other industrial or natural by-products in PC is thoroughly researched. Wide spread use of these materials have been almost universal for several decades. For every tonne of PC produced, cement plants generate approximately one tonne of CO₂. As a result, one cubic meter of concrete, made with 320 kg/m³ PC only, will generate 0.41 tonnes of CO₂, emitted to the atmosphere. If 30% of PC is replaced with SCM, this figure is reduced to 0.29 tonnes of CO₂ that is approximately 30% reduction of GHG emissions. The energy content of PC is 4.2 GJ/tonne, for Portland fly ash cement it is 3.6 GJ/ton, and for blast-furnace cement it is 2.5 GJ/ton. Very reactive, highly pozzolanic and ultra fine SCM will allow much higher PC replacement without reduction of concrete strength. By optimizing the composition of blended cements and proper curing methods, it can be possible to reduce CO₂ emissions to less than 0.1 tonne/m³ of concrete.

Use of waste derived fuels in the cement manufacture: Use of waste-derived fuels in place of fossil fuels will also reduce energy consumption in PC manufacturing. Instead of natural gas, coke oven, pyrolysis and land fill gases are being used. Mineral, hydraulic, industrial oils, distillation residues and halogen-free spend solvents are also viable alternative liquid fuels. Pulverized coal can be supplemented and in some cases possibly replaced with tar, petroleum coke, saw dust, dried sewage sludge, some selected plastics, agricultural residue, and car tyres. Steel-belted tyres in some cases may assist in the iron deficiency or a raw feed (Samarin 1995).

Use of industrial wastes in the manufacturing of cements: Industrial wastes can be used as a raw feed in manufacturing new types of energy conscious cements, resulting in the reduction of energy required for clinker formation, and thus in the lower CO₂ emissions. Since the late 1950’s new types of binders, produced by chemical or mechano-chemical activation of natural siliceous materials or industrial siliceous wastes were developed in several European countries. Chemical activation with caustic alkalis and with salts of alkaline metals produced so called ‘soilcement’. Sodium metasilicates or water glass was used to obtain new hydraulic cements. The hardening/strength gaining processes in these binders can be enhanced and accelerated by a heat treatment, with the best results reported in the range of between 900°C and 1000°C (Samarin 1995). As this process requires no calcinations and low processing temperature, compared to the Portland clinker formation, which is of the order of 1400°C, it results in more than 50% reduction in CO₂ emission compared to modern PC plants.

Slag-alkaline cements are widely used in European countries (Krivenko 1996; Dravidovits 1994). Another family of inorganic binders is geopolymers produced by blending three ingredients - calcined alumino-silicates, alkali-disilicates and granulated blast furnace slag or FA. Geopolymeric concretes were reported to reach compressive strengths of 20 MPa in 4 hours, and up to 100 MPa in one month. As geopolymers do not use CaCO₃ as a raw feed component, and also because chemical reaction of formation of alumino-silicates takes place at
temperatures of approximately 750°C, it results in between 0.1 tonne and 0.2 tonnes of CO₂ emitted for every tonne of this mineral binder (Dravidovits 1994). Another alternative to PC are the new types of binders produced by mechano-chemical activation of inert siliceous materials, such as FA or silica sand know as “silica-water-suspension-binders”. This process requires no calcinations of clinker, and also no high temperatures for binder formation, and thus produces no CO₂ from either the combustion of fuel, or from the conversion of CaCO₃. The best results were obtained when concrete based on silica-water-suspension-binders were cured at temperatures of between 40 and 120°C. Up to 90% reduction of CO₂ emissions, as compared with PC production, can be achieved with these binders (Samarin 1995).

Development of Sustainable Concrete
Concrete is definitely the most commonly used construction material. Concrete product manufacture requires little energy and produces little harmful substances. Concrete wastes that place a load on the environment are formwork moulds, formwork oil, insulation and packings. The moulds and packing can be reused and can be made with recycled materials. Formwork removal agents contain additives, harmful to the environment and are responsible for 15% of the hydrocarbon emissions (Hendriks and Jensen 1999). The development of decomposable synthetic products and the replacement of environmentally damaging solvents by oil-in-water emulsions in recent years reduced harmful effects on environment. Vegetable oil-based formwork removal agents are also commercially available.

Use of wastes as continuous fibre reinforcement and additives for concrete: Bamboo is the most common and one of the oldest organic reinforcing materials used in concrete. Bamboo waste and specially harvested plants have been used as concrete reinforcement in many developing countries. It is recommended, that bamboo main reinforcement in PC concrete should be in the range of between 3.5 and 4.5%. To enhance long term durability, bamboo is often pre-treated (Fang and Fay 1978). Many organic fibres, including wastes, broadly classified as natural (either of vegetable or animal origin) or synthetic are used as concrete reinforcement. Most natural or even synthetic fibres of organic origin have relatively low modulus of elasticity and the most common use for these fibres is to restrain plastic shrinkage cracking of fresh concrete. In the hardened concrete, the strain in these fibres is usually too big to effectively control drying shrinkage, thermal and creep induced cracking. There are still, some natural fibres of reasonably high elastic modulus, such as coir (4 to 6 GPa), jute (17 to 18 GPa), and sisal (35 to 60 GPa). However, in many developing countries, bagasse fibre, coconut husk fibre and other natural organic fibres have been successfully used (Sarja 1996). Industrial wastes such as short steel wire offcuts (free of harmful impurities) can be used in structural concrete, in place of steel fibre.

Wastes as additives and binders in concrete: Wood lignins were successfully used as extenders of bitumen, and lignins as well as waste oils as binders for the wearing courses in the low cost and temporary pavements. The blend containing lignin (30% by weight of bitumen) showed higher resistance to the fatigue failure, with the resistance to moisture and freeze-thaw damage virtually unchanged (Samarin 1999). A blend of epoxy resins, coal tar and phenol was also used as a binder for special application concrete. In Canada and several other countries, period of considerable over supply of sulphur leads to the development and widespread use of sulphur concrete (Malhotra 1980).

Wastes as aggregate in concrete: A wide range of unprocessed waste, with variable degrees of success has been used as aggregate in concrete. Most widely researched is the use of blast furnace slag aggregate. Less widely used is steel slag, although several steel slag aggregates performed well in PC concrete. Assessment of ferro-chromium and silica-manganese slags in concrete was also carried out. The use of crushed brick or a mixture of crushed brick and concrete rubble as an aggregate in structural concrete was reported to be promising. Crushed glass, can be used as fine aggregate in concrete. It is important to have sufficient content of either ultra fine glass particles, or of fly ash or other good quality pozzolans, to prevent alkali-aggregate expansion in large glass particles.

Lightweight concretes can be produced with unprocessed wastes, such as expanded polystyrene granules. There are several patented lightweight construction systems incorporating expanded polystyrene concrete panels. A classical example is “Strake Ges.m.b.h system” in Viena. This system made with lightweight concrete with polyester aggregate of between 300 and 350 kg/m³ is used as a permanent formwork in buildings, providing excellent thermal and acoustic properties (Samarin 1999). Cork granules are used in place of expanded polystyrene chips. Saw dust is used as aggregate for concrete. Typical saw dust concrete has a strength of 15 MPa and a density of approx. 1000 kg/m³. Use of shredded rubber as an aggregate was not very successful due to considerable concrete strength reduction. However, use of rubber aggregate in semi-rigid concrete can be quite promising. Unprocessed wastes such as cane bagasse, wood ash, china clay waste, paper waste, etc. have potential to be used as aggregate in concrete, particularly for either temporary or low cost housing (Bijen 1996). ‘Lytag’, a sintered lightweight aggregate is used to manufacture concrete with an air dry density of about
1800 kg/m$^3$ and with a compressive strength of up to 70 MPa. Attempts have been made to convert household and industrial garbage into concrete aggregate. Australian company, “Neutralysis” spent 12 million Dollars over a period of six years developing technology of manufacturing concrete aggregate from a blend of household and industrial waste. A process, which converts the residue from incinerated toxic waste into pellets, was developed by a Singapore company “Miltox’. Miltox, a Singaporean, Malaysian and Australian joint venture built a pilot plant with an output of approx. 400 kg/hour in 1994. However, long term durability and environmental effects of such products are to be studied before they can be safely used in building and construction materials.

**Recycled construction and demolition (C&D) wastes in concrete:** Significant opportunity exists to reduce GHG emissions through the development of energy conscious construction materials by maximizing the use of C&D wastes, now merely used as landfill. The advantages of using C&D wastes are two folds: reduction of the use of virgin natural resources and creation of a safe, effective and environmentally friendly means of disposal of wastes. About 200 Mt of C&D wastes are produced in European countries every year and significant portions are land filled. Only Netherlands, Belgium and Denmark recycle more than 80% of C&D wastes (Hossain and Lachemi 2004a). In the US, building demolition accounted for 48% of the national C&D wastes, while renovations accounted for 44% and new construction for 8%. C&D waste comprises approximately 25% of national landfill content. Construction, renovation, and demolition industries produce between 25% and 33% of the waste stream in Canada. An impressive volume of research is conducted worldwide on the use of recycled materials especially on aggregates (Pacheco-Torgal et al. 2013).

**Development of High Performance Concrete for Sustainable Development**

Very high strength cement matrices with a 28 day compressive strength of 276 MPa were developed in 1930. In 1980, a new material called DSP (Densified with Small Particles) with a compressive strength of up to 250 MPa was developed (Hjorth 1983). Another material of strength around 400 MPa was MDF (Macro-Defect Free Paste) where rheology of fresh mix was modified by the addition of water soluble polymer. The general application of superplasticizers created a new kind of concrete called HSC (High Strength Concrete) in the late 1980’s. Using better quality of aggregates, careful selection of aggregate gradation and low water/cement ratio resulted in a HSC exceeding a 28 day compressive strength of 60 MPa. With addition of SF, HSC of over 100 MPa is produced. Next a different concept was introduced to develop HPC characterized by excellent fresh workability, high density, high early strength and higher long term strength and durability (Zhou et al. 1995). New types of HPC have been developed by replacing a high percentage of cement by SCM derived from recyclable industrial by-products or natural pozzolans (Neville and Aitcin 1998; Lachemi et al. 2003). The use of SCM can ensure high fluidity and good cohesiveness of the mix and enhance durability of HPC. Roller compacted concrete (RCC) is special technology which provide considerable economics in time and cost together with high strength and long term durability (Richard and Cheyrezy 1995). Researches are conducted to develop HPCs and blended cements with volcanic materials (Hossain 2003, 2004).

Two other concrete technologies have been developed in the last decades are self-cured concrete and SCC. Self-cured concrete where special compounds with polymers and oils are included into fresh mix. SCC is one of the newest forms of HPC that can spread readily into place and self-consolidate under its own weight without exhibiting any significant separation of constituents (Khayat el al. 1997, Yurugi 1998). SCC technology incorporating natural and industrial wastes offers limitless advantages from the standpoint of energy and materials conservation, durability, cost efficiency, job site productivity, and overall sustainable construction. Research leads to the development of SCCs incorporating volcanic materials and industrial wastes (Hossain and Lachemi 2004b, Lachemi et al. 2003).

During the last decades, tremendous progress has been made on the HPC and the modern day concrete frontiers can be defined by “high strength and high tensile ductility” characteristics. Such HPC technology involves the family of highly durable fibre reinforced ECC and UHSC/UHPC. UHSC/UHPC is characterized by high strength with moderate ductility while ECC materials have high ductility, tight crack width and low to high strength (Ranade et al. 2013; Li 2003). ECC strain hardens after first cracking, like a ductile metal, and demonstrates a strain capacity 300 to 500 times greater than conventional concrete. Even at large deformation, crack widths of ECC remain less than 60 µm. With intrinsically tight crack width associated with self-healing potential and high tensile ductility, ECC is the material of future which offers significant potential to resolve durability problems of RC structures. Over the last twelve years, research at Ryerson University has developed sustainable HPCs and innovative structural systems/construction technologies. Ryerson research team has developed “Ryerson UHPC” through evaluation of mechanical/durability properties and structural...
The preventive measures, methods of diagnosis and modeling of deterioration process of concrete infrastructures are the object of intensive research in many countries (Swamy 1994). Outstanding progress has been made in repair methods with the development of new HPC materials and technologies. Application of composite materials: fibre reinforced concrete (FRC), slurry infiltrated concretes, polymer concretes and ECC allows to overcome most factors that endangers durability. Recent developments concern steel micro-fibres, polypropylene/poly vinyl alcohol fibres, carbon fibres and new techniques in improvement of durability of alkali-resistant (AR) glass fibres in cement paste. The use of such fibres increases the toughness and controls opening and propagation of micro-cracks. Carbon fibres are excellent reinforcement of thin elements and are resistant to all types of chemical attack and to high temperature (Van Gamert 1996). Numerous methods have evolved to increase the durability of concrete including: mineral and chemical admixtures, epoxy-coated and/or stainless-steel reinforcement, fiber reinforced polymer (FRP) bar, protective surface sealers, and cathodic protection. Extensive research has been conducted on the strengthening and rehabilitation of structures (Van Gamert 1996; Hollaway and Leeming 1999; Belarbi 2013). Retrofitting techniques have been developed for adhesive bonded steel or fibre reinforced polymer (FRP) plates to strengthen concrete infrastructures. These techniques are also applied to retrofit steel, timber and masonry structures.

Sustainable Infrastructures - Case Studies And Cost Benefit-Energy Consumption Analyses

The construction phase for the California Franchise Tax Board's State Offices at Butterfield Way, Sacramento, CA, realized tremendous financial benefits from recycling C & D debris. 69% of C & D wastes (over 15,000 tons) was recycled, and reutilized on-site saving $104,000 (Table 2). This saving was resulted from eliminated tipping fees, and reduction in road-base/landscape materials the project would have needed to purchase.

Table 2: Details of recycling efforts and savings

<table>
<thead>
<tr>
<th>Description</th>
<th>Wood/Green waste</th>
<th>Concrete</th>
<th>Asphalt concrete</th>
<th>Misc.</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>C&amp;D waste, cubic yards</td>
<td>1,200</td>
<td>2,500</td>
<td>8,200</td>
<td>364</td>
<td>12,264</td>
</tr>
<tr>
<td>Recycled on-site, %</td>
<td>100</td>
<td>20</td>
<td>84</td>
<td>0</td>
<td>69.2</td>
</tr>
<tr>
<td>Recycled off-site, %</td>
<td>0</td>
<td>80</td>
<td>16</td>
<td>0</td>
<td>30.4</td>
</tr>
<tr>
<td>Total recycling (savings), US$</td>
<td>8,800</td>
<td>20,411</td>
<td>75,252</td>
<td>0</td>
<td>104,543</td>
</tr>
</tbody>
</table>

(a) Danish strait bridge  (b) Akashi-Kaikyo bridge
(c) Trade tower  (d) Adelaide bridge

Fig. 4: Typical structures (Case study)

Table 5 also compares the total price and the CED per meter length for four different column options. UHSC/UHPC-160 column option is found to be more economical compared to composite column (44% lower) and steel column (52% lower). On the other hand, the energy consumption is also significantly lower (58% and 64% lower compared to composite and steel column, respectively). HSC-100 and UHSC column options are quite close based on both cost and CED. The benefits of UHSC/UHPC columns in sustainable infrastructure development is illustrated based on lower costs and energy demand besides enhanced durability and service life.
Table 5: Cost benefit-energy consumption Analyses of UHSC/UHPC columns

<table>
<thead>
<tr>
<th>Steel materials</th>
<th>Concrete type</th>
<th>Price US$/t</th>
<th>CED MJ/t</th>
<th>Price US$/m³</th>
<th>CED MJ/m³</th>
<th>Column type</th>
<th>Costs US$/m</th>
<th>CED MJ/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel reinforcement</td>
<td>HSC-100</td>
<td>1500</td>
<td>13700</td>
<td>563</td>
<td>2600</td>
<td>C100</td>
<td>1375</td>
<td>9600</td>
</tr>
<tr>
<td>Steel sections/tube</td>
<td>NC-45</td>
<td>1750</td>
<td>13700</td>
<td>163</td>
<td>1200</td>
<td>UHPC/UHSC</td>
<td>1463</td>
<td>8500</td>
</tr>
<tr>
<td>Formwork</td>
<td>UHPC/UHSC-160</td>
<td>100</td>
<td>50</td>
<td>1500</td>
<td>6000</td>
<td>Composite</td>
<td>2588</td>
<td>20500</td>
</tr>
</tbody>
</table>

CONCLUSIONS
This paper describes strategies for the development of sustainable infrastructures in the next millennium. As part of the strategy, a comprehensive description on the development of energy conscious smart construction materials and technologies is provided with their contributions to the reduction of greenhouse gas emission and sustainable infrastructure development. Case studies and relevant cost-benefit and energy consumption analyses demonstrate that significant contribution can be made to attain infrastructure sustainability through strategies based on the development of high performance energy conscious smart concrete materials and novel construction technologies. Every country should include these strategies in the overall national capacity building strategy to promote sustainable development and hence poverty alleviation in the long run through smart use of resources.

REFERENCES


Federal Highway Administration (FHWA) (2012), National bridge inventory, Washington D.C., USA.


Lachemi M., Hossain K. M. A., Lambros V. and Bouzoubaâ N. (2003), Development of cost-effective SCC incorporating fly ash, slag or viscosity modifying admixtures, ACI Mat. J. 100 (5).


