SUSTAINABLE CONCRETE FOR APPLICATIONS

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Abstract

An attempt has been made to study the qualities of concrete, in a limited manner, to satisfy the requirements of sustainability and green building design and as a building material. Considering the seminar to be on tall structures, comments are made briefly on the issues related to tall buildings covering column sizes, spacing of columns, soft storey condition, floating columns etc. in the layout for structural design. Concrete has been used as an efficient, versatile and durable material for high-rise buildings and for other applications for a long time. Sustainability has been discussed broadly, in this presentation, to cover different aspects and associated items. Main emphasis, however, is placed to comment on the influence of concrete on green building design, effect on environment, emission of green-house gasses, use of carbon negative aggregates and contribution for carbon capturing capacity of concrete. Further, discussion on the emission of green-house gases and some control on CO2 emission has been done briefly. Exploring the use of OPC, blended cement or geo-polymer as binder for concreting has been included. Discussion on the choice of selection of a suitable and sustainable building material from concrete and steel has been included. The comments on the performance of concrete against fire and blast are added. For assessment and confirmation on appropriate design approach both LEED & GRIHA requirements have been mentioned highlighting the basis of ratings and points against different categories. Main credit areas for assessment have also been referred. It is concluded that concrete is an efficient and sustainable material for design and construction and will cause less environmental damage than structural steel. The same may be used along with other associated materials to meet design requirements, in different projects, with confidence and certification for high rating can be aimed for.

Key Words : *RCC, Tall buildings, Sustainability, environment, greenhouse gases by concrete, Fire & blast, Assessment (LEED, GRIHA), Environmental impact.*

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1. INTRODUCTION

The material that is selected carefully for design and construction should satisfy the requirements of functional suitability, availability, cost for economy, acceptable environmentally, CO_2 emission and emission of other greenhouse gases covering all associated activities. Furthermore, it should be possible to re-cycle the material, repairable if required, have good performance against fire, aesthetically acceptable after construction, easy to accommodate any building form. Other items will include durability and good long term performance, will not need specialised skilled labour to handle the material, finishes can be provided easily and sustainability of the material can be ensured. Presence of CO_2 and other green-house gases, in the atmosphere, beyond certain limit will be harmful to human beings. It is, therefore, necessary to examine CO_2 emission starting from manufacture including the constituents materials from production, transportation, placement/construction etc. when selecting a suitable building material. However, the question of sustainability and CO_2 emission including other greenhouse gases will be examined more in detail covering some of the basic issues which are important for deciding the right construction material.

Considering concrete's durability, strength and relatively low cost, it has been possible to make significant impact for the development activities including infrastructural works world-wide. Concrete has been used for projects like housing, schools, hospitals, air-ports, bridges and highways etc. successfully. For the development of urban areas, exposure to extreme climates, a sustainable material will be essential at an economical price. The use of concrete will be more appropriate as a solution for such applications. Furthermore, attempts are being made, in recent years, through detailed research and studies to reduce green house gas emissions of most important gradient i.e. cement from its production. Checks are to be made on the assessment of environmental impact and cost during the entire service life of the structure related to infrastructure or building projects. A brief discussion will be made covering some of the above issues for design consideration.

2. TALL BUILDINGS

General comments are made covering a few selected items on the design of high-rise buildings as summarised below:
In recent years we are experiencing a lot of high-rise construction specially in commercial and housing sectors and in busy urban areas. Shortage of space and high cost of land, in cities, have almost dictated the use of high-rise buildings in the restricted areas of metropolis. The design of the high-rise buildings covering aesthetics and utility is not simple and associated with various complications starting from foundation work to overall safety aspects under wind and seismic loading. The performance of the structure has to be good during service life and ultimate load conditions particularly when buildings are constructed in high seismic zones. Both steel and concrete have been used successfully

and efficiently for the design of tall buildings. In this connection various guidance are available in Indian and International codes for the engineers. Here, some comments have been made related to design issues for structures made of concrete and proper planning at the layout stage of tall buildings as given below :

- Concrete will be more suitable and a common construction material for tall structures. The emphasis should be given for green building design and sustainability.
- The properties of concrete material and its mass also help to create lateral stiffness for horizontal loads. Hence, the occupants will experience less building motions(1) in high-rise buildings with concrete as compared to similar tall buildings with other constructional materials. With concrete as a building material, it will be possible to offer comfort and security with low energy bills and low maintenance cost.
- 3D analyses are often carried out using STAAD Pro, ETABS etc. for the structural arrangement. Shear walls/shear cores in the layout should preferably be located symmetrically to both the axes of the building. It is quite difficult to have this type of ideal symmetrical arrangement in actual practice for all tall building projects. Keeping this in mind a better and efficient arrangement should always be attempted during the planning stage to achieve this question of symmetry and to ensure assured and balanced behaviour of the structure. It will be easier for the structural engineer to handle the design with symmetrical arrangement of load bearing column elements. M-70/M-80 strength to concrete is quite common for the design of high-rise buildings. Lateral displacement at the top as mentioned will be less with concrete material.
- Concrete is normally taken from ready mix plants with different types of admixtures for high strength and self compacted as per the requirements of the project and is placed by pumping the same into the position.
- Column sizes should be finalised as per the layout and column loads. Often without considering the column loads, the column sizes are decided to satisfy some other requirements. Otherwise this may create problems for the structural behaviour specially to satisfy displacement issues. Suggest, the structural engineer should be involved right from the very beginning of the project when the layout of floor plans are being finalised. Column sizes can not be made same, in the plan, on all floors when the spacing of columns, in the layout, and loads are different on the elements. Proper interaction with the structural engineers from the beginning will help the architect to understand and organise column layout and sizes efficiently along with the interior design and associated work accordingly.
- It will be important to avoid soft storey condition and floating columns in the layout for tall buildings especially under high seismic zones. Apart from dead and live loads, winds, seismic, blast loads and other secondary and temporary loads as applicable are generally considered in the design.
- The object is to design the structure carefully so that the same is strong against all applicable loads including lateral loads without excessive deformation/deflection. Care must be taken to provide proper and adequate detailing/anchoring of reinforcing bars at the critical joints to provide proper ductile behaviour of the structure under seismic load conditions and to avoid/control cracking.
- Reinforcement - Good analyses and design must take into account adequate reinforcement and proper ductile detailing so that it matches with the design assumptions and analyses modelled by the engineer. Reinforcing bars are required basically to resist internal tensile forces as found out from the analyses. Sufficient reinforcement in the concrete elements, will be required to provide ductility, reduce long term deflection and to ensure adequate flexural capacity of the sections under worst load combinations. Furthermore, adequate reinforcement will control excessive cracking resulting from shrinkage or temperature change in the restrained structural elements.
- Defective construction materials, poor workmanship during execution, wrong assessment of environmental conditions at the design stage etc. will increase the risk of damage to the structure.
- Proper monitoring with pro-active maintenance work will be required from time to time to extend the service life of the structure and to reduce overall maintenance cost.
- Provision in the design shall be kept for structural health monitoring and monitoring of concrete repairs with proper records if applicable. This will need proper importance.

3. SUSTAINABLITY

In this article, discussion will be carried out on selected items which will be relevant for sustainability of concrete material related to green building design.

The word sustainability will tend to include quite a few areas(2) such as

- The Philosophical Basis - It often means a balance amongst environmental, social and financial issues. This must cover the wider impact of human activities for the benefit of future generations.
- Environmental Sustainability - This may include items such as earth's resources which has to be used efficiently. The related items are population growth, deterioration in land and soil, pollution of water, changing atmosphere, reduction in bio-diversity and sea level and temperature change.
- Sustainability - Political motivation - The development must meet the needs of the present without

compromising the ability of future generations to meet their own needs.

- Social Sustainability - The need to reduce environmental threats to health due to poor sanitary conditions, overcrowding, inadequate water provision, hazardous air and water pollution and accumulations of solid waste.
- Corporate Sustainability - This is good for business and sometimes referred as three Ps as people, planet and profit.
- Economic Sustainability - This is connected with the control on the emission of gases and studies the environmental degradation on the economy and commitment of lowering GHGs below the current levels.
- Sustainability of Construction - It has a large impact on sustainability throughout the life cycle and its contribution towards sustainability is related to manufactured capital, human capital, natural and social environment and technological progress.
- Sustainability for Engineers - Engineers are to accept changes required for sustainability. This is associated with sustainable urban drainage system and sustainable energy generation. Furthermore, it should accommodate change of use, scope for refurbishment, design for safe construction and use, reuse and recycle the materials, using materials of low environmental impact. Efficient use of materials, design for long life, integrated design with architect and environmental engineer and design for deconstruction are to be included.

4. INFLUENCE OF CONCRETE ON ENVIRONMENT

Concrete is an environment friendly and sustainable building material[3] as mentioned. In this context some related items are –

- Resource Efficiency - Lime stone is used for the production of cement and the same is available in sufficient quantities in many countries. Waste products from different industries such as fly ash, ggbs, silica fume etc. are also used with cement efficiently to produce the right type of concrete for different applications.
- Durability - With proper designing and construction, the concrete structures will be durable as already stated and will last for a long time. Concrete is a sustainable material and its performance against fire is better than other common building materials.
- Thermal Mass - Concrete as a material has the ability to absorb and retain heat and is energy efficient[3]. Hence, expenditure for heating or cooling the building as per the requirements will be significantly reduced.
- Reflectability - Light coloured concrete will absorb less heat and reflect more solar radiation than dark coloured materials. The demand for air conditioning is expected to be reduced in summer.
- Applicable to retaining storm water - Pervious concrete can help to retain storm water to some extent when used for drive-ways, parking areas, side walls and parking and later replenish local water supplies.
- Minimum waste - Concrete can be produced as per the requirements of the project with minimum waste. After prolonged use concrete can be crushed and recycled as aggregates for the production of new concrete or as road base material or back fill item. Other Important Information on Sustainability Further assessment based on UK Construction Industry[4] on a few items will be broadly discussed below. Hopefully similar activities for improvement can be expected in the future. These will provide useful information and guidance to all concerned persons involved with a project.
- Bio-diversity - It is reported that concrete industry is putting special effort towards contribution to bio-diversity, nature of conservation through proper management and restoration of sites of mineral extraction. Action plan is developed for site restoration, bio-diversity or geo-diversity. The value in 2014 is 99% as per the report and targeting 100% in 2020.
- CO_2 Emission - CO_2 emissions per tonne of concrete using DEFRA factors may be obtained using constituent materials and cement. Data are updated considering the demand for different types of concrete. As per the report for a standardised mix carbon intensity is 76.2 kg of CO_2 per tonne of concrete in 2014 which is lower than the value in 2008. CO_2 emission through transport was 8.8 kg. of CO_2 per tonne in 2014. Reference may be made to the reduction of coal use in U.K. in 2015 and hence fall of emission of CO_2 is about 4% due to less use of coal as per the government energy statistics published in March, 2016[5]. Additional comments will be made on green-house gases and CO_2 emission later.
- Emissions excluding CO_2 - The emissions excluding CO_2 is reportedly zero convictions in 2014 as per the report and expected to continue like this in the future.
- Energy efficiency - The reduction of CO_2 emission associated with the production of concrete and its constituent materials may be achieved by improving energy efficiency methods and reducing power consumption. The indicator is KWh/tonne. The figure for the rolling mix is 133.9 KWh/tonne[4] of concrete in 2014.
- Environmental management - This will be associated with controlling and managing the environmental impacts on the procurement of constituent materials and manufacturing concrete products for sustainable development.
- Health & safety - Reportable injury frequency rate is 326[3] injuries per 100,000 direct employees in 2014. This figure is reduced drastically as compared to that of 2008. Lost time injuries are also reduced in recent years and it is 3.4 direct employees per one million hours worked. This is lower than the value in 2010. As per the recent information, 59% reduction[5] in re-portable injuries is mentioned since 2008 in U.K.

- Waste minimisation - This reflects on waste disposal for land filling per tonne of concrete production. Significant improvement has been made to reduce the waste and it is 1.0 kg.[3] of waste for land fill per tonne of concrete produced in 2014. Attempts are being made to reduce further and to make the figure zero for land fill. As per recent report 28% use[5] of recycled or secondary aggregates is done in 2015.
- Water - Water will be required for the hydration of cement and it is an important resource for concrete production and the in-gradient materials. It seems that water usage is gradually reducing although it may vary seasonally. As per report the water consumption was 80.2[3] lit.[.] per tonne of concrete in 2014.
- Local Community - It is common that concrete supply production sites have large impacts on local community starting from vehicular movement, noise, dust etc. and have close links with local community through employment of local people and use of local materials. Regular liaison activities including council meetings will need to be carried out with local community.
- Quality & Performance - It is important for sustainability that the produced materials are not rejected or wasted which will otherwise be costly both economically and environmentally. In 2014, 91.2%[3] of total concrete was acceptable. The target for 2020 is 95%[3].

5. ASSESSMENT FOR SUSTAINABILITY(6)

For assessment and to estimate impact on the environment of a construction material related to sustainability, the following stages are to be examined :

- Production of Materials - This is associated with the combination of all raw materials with the consumption of energy and the production of waste. Whether wastes will have any impact on the environment.
- Construction - Will require some expenditure on energy and will produce waste. How much of each manufactured material will be used. Other alternative materials may be used with less environmental impact, if available, should be considered.
- Life Cycle - During the service life, the building will consume a lot of energy. It is also related to durability of the construction material used and its contribution to their insulation property and hence use of energy. Flexibility in design for repair and renovation work is to be considered. The repair and maintenance work will be required and whether the same will have any environmental impact. Energy requirement during the service life with environmental impact has to be assessed.
- Demolition - How much of the structure can be reused. How much of the materials can be recycled. The impact on the environment from the waste produced from demolition has to be computed.

6. GREEN HOUSE GASES[7, 8, 9 & 10]

A brief discussion on the emission of green-house gases is presented.
With the development of industrial revolution[7] emission of CO_2 has increased significantly. CO_2 emissions being an important item of green house gases largely come from natural process[7] like respiration and combustion of carbon based fuels i.e. coal, oil, and natural gas along with de-forestation and soil erosion.

Each greenhouse gas that is emitted has different Global Warming Potential (GWP) and stay for different length of time in the atmosphere.

Sun's radiations on the earth surface provide visible light, Ultra-violate (UV)[8], infrared (IR) and other types of radiations which are not visible to human eyes. Green house gases absorb the radiations and heat and are capable of holding the heat in the atmosphere. With more green house gases, in the atmosphere, the same will absorb more heat or cause temperature rise leading to global warming[8]. The exchange of incoming and outgoing radiations will warm the earth surface and is referred as "Green-House Effect". CO_2 in the atmosphere plays a big role towards global warming. Hence, the presence of green house gases in the atmosphere within the specific limit will provide a balance and cooler earth surface.

The primary green-house gases in earth's atmosphere are water vapour, CO_2, Methane,[7] Nitrous Oxide, Ozone (O_3) and chlorofloro carbons (CFCs). With the present rate of green-house gas emission, earth surface temperature will be high which will have potentially harmful effects on eco-system, bio-diversity and the livelihood of people worldwide. Rising temperature, in-turn, will produce[9] change in weather, sea levels and land use pattern commonly known as climate change.

Three main greenhouse gases that are important to be mentioned with their 100 year global warming potential (GWP) and compared to carbon dioxide[10] are

1 x – Carbon dioxide (CO_2)

25 x – Methane (CH_4)	[i.e. releasing 1Kg. of methane (CH_4) in atmosphere is equivalent to releasing about 25 Kg of CO_2]
298 x – Nitrous Oxide (N_2O)	[i.e. releasing 1Kg. of N_2O into atmosphere is equivalent to releasing about 298 Kg. of CO_2]

Other greenhouse gases having far greater global warming potential (GWP) but are less prevalent in our present discussion. Some of these are –

- Sulphur Hexafluoride (SF_6)
- Hydrofluoro Carbons (HFC_s)
- Perfluoro Carbons (PFC_s)

Three factors[8] will affect the degree to which any green house gas will influence global warming.

Its abundance in atmosphere

- How long it stays in atmosphere
- Its global warming potential

Carbon dioxide has a significant impact on global warming mainly due to its abundance in the atmosphere.

Anthropogenic (Human Induced Green-house Gas) warming[7]

Anthropogenic warming will elevate green-house gas levels and may have a lot of detrimental influence on many physical and biological systems. Future warming may have different impact such as sea level rise, increased frequencies and severities of some extreme weather events, loss of bio-diversity and regional changes in agricultural productivity. Emissions of mercury (Hg) from coal combustion[11] is higher than that of the emission from oil combustion. A lot of emissions come from gold production using Hg technology.

Other indirect green-house gas - Carbon monoxide (CO) is only a very weak direct green-house gas[12] and has importance in direct effect on global warming. Carbon monoxide reacts with hydroxyl (OH) radicals in the atmosphere and reduces their adequate presence. As OH radicals help to reduce strong green-house gases like methane, hence, carbon monoxide indirectly increases the global warming potential of these gases. It is estimated that more than half (½) of carbon monoxide emission are manmade and tend to occur close to areas of high human population. Additional natural source, will include emission from vegetation and world's oceans. Carbon monoxide in the atmosphere can also help to form tropospheric green-house gas 'ozone'.

Alternative fuel, if considered, will include natural gas, bio-mass and waste-derived fuels such as tires, sewage sludge and municipal solid waste. These are less carbon intensive fuels and can reduce overall emission of CO_2 by 18-24%[13]by 2050 from the present level.

Bio-Mass Fuel - Bio-mass is a source of fuel which is developed from organic materials may be considered as a substitute power. Bio-mass power is referred as carbon neutral[14] electricity which is generated from renewable organic waste. These are scrap lumber, forest debris, certain crops, manure and some types of waste residues.

Summary

The main sources of green-house gases due to human activities[7] are –

a) Burning of fossil fuels and de-forestation leading to higher CO_2 concentration in the air. Change of land use.
b) Livestock enteric fermentation and manure management, paddy rice farming, pipe-lines losses, land use and wet land changes.
c) Use of cholorofluoro carbons (CFCs) in refrigeration system and use of CFCs and Halons in fire suppression system and manufacturing process.
d) Agricultural activities including use of fertilizers which can lead to higher nitrous oxide (N_2O) concentration.

In India also strict emission control standards[15] are being introduced for coal based thermal power plants. In this connection the emphasis is given for CO_2 emission and water consumption in the revised standard. The revised standard is expected to be implemented in phases. There will be more restrictions for the thermal power plants which will be commissioned in the future.

The new emission standard will have restriction for particulate matter (PM), sulphur dioxide (SO_2), nitrogen dioxide (NOx) and mercury. By controlling the proposed limit for sulphur dioxide and NOx the same will also help to control the emission of mercury.

7. GREEN HOUSE GAS EMISSION DUE TO(16)

CONCRETE MANUFACTURE

If we use concrete in projects, we have to study the contribution of concrete including its in-gradients in producing CO_2 and other green house gases which will be very important to assess the suitability of the material to be selected for design and construction.

Concrete is the most consumed substance on earth after water. On the average three tons of concrete are used each year by every person[13] on the planet.

The clients are interested to have environmentally sustainable design (ESD) for the projects[16]. The emission of CO_2 is considered to be the basis for rating technique to compare environmental impact for other different construction materials in ESD.

CO_2 emission from cement production will be both directly and indirectly.
Direct - 50% (i.e. heating lime stone)
Indirect - 40% (burning of fossil fuel to heat the kiln directly)

Additional emissions from other plant machinery and transportation - 5-10%.

CO_2 emission by concrete will include all activities related to manufacture and till placement of concrete material. The results are indicated from a case study below in terms of equivalent CO_2 emission[16].

			Emission of CO_2	
•	Portland Cement	-	74 - 81%	Of total CO_2

				emission
•	Coarse Aggregate [(a) Blasting, Excavation, hauling and transportation - < 25% (b) Explosives - < 0.25%]	-	13 – 20% (From Electricity about 80%)	”
•	Fine aggregates Fine aggregate will generate less equivalent CO_2, since aggregates are only graded and not crushed	-	30 – 40% of coarse aggregate per tonne	
•	Diesel / Electricity	-	Similar to fine aggregate	”
•	Admixture	-	Negligible	
•	Concrete batching, transport and placement of material Note	-	Small amount	
•	CO_2 emission from normal strength concrete using Portland cement binder	-	0.29 to 0.32 t CO_2-e/m^3	
•	GGBS can reduce the emission of the concrete mix	-	By 22%	
•	Fly ash can reduce the emission of the concrete mix	-	By 13 – 15%	

The above data are from Australia(16) as per their manufacturing practice and placement methods. CO_2 emission per ton of cementitious binder as per South Africa(17) = 765 Kg.

8. USE OF CARBON NEGATIVE AGGREGATES(18)

The secondary aggregates, in this case, are carbonated during the manufacturing process when CO_2 is permanently captured by the aggregates and hence produce carbon negative aggregates. The aggregate is manufactured from air pollution control residues (APCr) that are generated from the treatment of the flue-gas from energy-from-waste (EfW) plants.

There is a need for recycling option of APCr waste. In the new technology of recycling, accelerated carbonation is done to produce pellets that can be used in the form of blocks or in lean concrete mix. CO_2 emission can be captured through carbon capture and storage(13) (CCS) technique. As a mitigation, accelerated carbonation can be achieved by exposing freshly mixed concrete to flue gases with high CO_2 concentration.

9. CARBON CAPTURE BY CONCRETE(19)

Carbon capture is a process when concrete and some other materials react with carbon dioxide in the air and reduce its concentration in the atmosphere. Further information will be required for attempting to increase effect of sequestration and to modify the concrete design mix accordingly.

The total potential of sequestration will be around 19%(19) of cement (if fully carbonated) present in concrete. Hence, with 350 kg./cum. of cement, in a concrete mix, the total potential of sequestration of CO_2 will be about 65 kg./cum. of concrete. The current value will be about 3% during the initial life of the structure i.e. 10 kg./cum. as per U.K. figure. Considering an industrial floor with 750 cum. of concrete and assuming 50% already carbonated which would sequester about 20 tonnes of CO_2.

In a reinforced concrete element sequestration will be primarily limited to outer layer i.e. the depth of concrete cover. Sequestration will be more effective when the concrete is crushed for reusing the material as aggregates in foundation material or road work exposing much more internal surfaces with the result of more rapid sequestration. For increased sequestration, water may be added to crushed material as for carbonation water will be required.

Concrete is not the only material that sequesters CO_2. Blast furnace slags containing calcium oxide and some other hot process may also produce materials that have high level of sequestration capacity. It will be a good opportunity to know more and gather further information for carbon capture capacity of concrete and other construction materials with their storage conditions and the basis of measurement.

10. ADDITIONAL INFORMATION ON CONCRETE FOR GREEN BUILDINGS(20, 21)

Ordinary Portland Cement (OPC) has been used largely as binder for the production of concrete. However, OPC has high embodied energy with the result of emission of carbon dioxide equivalent (CO_2-e) and various green-house gases to atmosphere having global warming potential as already mentioned. The emission rate may vary(21) from 0.66 to 0.82 kg. of CO_2 for every kilogram of cement manufactured. Similar values have already been indicated before.

The important reasons for high emission of CO_2 during manufacturing of cement are –

- Calcination of lime stone
- High energy consumption during manufacturing process with high temperature greater than 1400^0C required for the raw materials in the rotating kiln.

Blended cement with OPC and partly replacing the cement quantity by supplementary cementitous materials as common binders like fly ash (a waste product) and slag (a waste residue) has been tried efficiently to reduce the emission of CO_2. It is observed that blended cement can reduce CO_2 emission by 13-22%.

Geo-polymer is an alternative cementitous [20] binder that has been attempted as a substitute for OPC which is comprised of an alkali-activated fly ash. Geo-polymers are in organic materials rich in silicon (Si) and aluminium (Al) that will react with alkaline activators to become cementitous. The alkaline activators used for geo-polymers may be a combination of hydroxyl usually sodium hydroxide (NaOH) or potassium hydroxide (KOH) with silicate like sodium silicate or potassium silicate. Considering cost and availability, NaOH and sodium silicate are commonly used for geo-polymer concrete which can reduce the emission of CO_2-e to a large extent[20]. However, high temperature curing will be required for geo-polymer concrete which will consume power and emission of CO_2.

The following are very relevant for the design of green buildings[21] with concrete :

- Concrete creates sustainable sites
- Concrete assemblies can enhance energy performance
- Concrete contains recycled materials
- Concrete is manufactured locally
- Construction with concrete will be durable.

11. CHOICE ON THE SELECTION OF A SUSTAINABLE BUILDING[22]

MATERIAL FROM CONCRETE AND STEEL

The common materials that are often used for infra-structural and development work including tall structures are concrete and steel. These two materials have been used successfully for different projects. The selection of a suitable material for design and construction should be examined covering the following items :

•	SAFETY	Concrete	-	Safer, very suitable and versatile material and will resist high temperature for a long time.
		Steel	-	Properties will be affected at high temperature, hence, will need protection against fire.
•	COST	Concrete & Steel	-	Prices are going up for both the materials. Concrete structure will be little cheaper.
•	MATERIAL AVAILABILITY	Concrete & Steel	-	Both concrete and steel will be available for applications.
•	CONSTRUCTION SCHEDULE	Concrete & Steel	-	Both the materials will be comparable to meet construction schedule using modern technique; with proper planning steel structures will take a little less time.
•	DESIGN POSSIBILITIES	Concrete & Steel	-	Any type of construction can be done with both the materials. For special and complicated building form, concrete will be preferable.
•	ENVIRONMENTAL CONSIDERATION	Concrete & Steel	-	Concrete will be preferable than steel.
•	ENERGY REQUIREMENT	Concrete & Steel	-	Less energy will be required for concrete as compared to steel.

It may be mentioned that concrete will be a suitable and sustainable material for different applications.

12. FURTHER ADVANTAGES OF USING CONCRETE

- Fire Engineering & Performance of Concrete under Fire[23, 24, 25 & 26]

Following recent fires in various parts of the world, the performance of structures during fire has become a very important design issue to engineers. The real structure, however, will behave differently from a simple beam commonly tested in a furnace for obtaining data for fire design. The actual structures will have in-built secondary load paths which are often mobilized during fire when structural deflections are larger. Concrete has performed very well during fire over the years and the same has been observed during tests carried out.

Fire engineering is multi-disciplinary activity in nature having substantial relationship(23) with building services involving mechanical, electrical and structural engineering and it embraces the understanding of human behaviour. Therefore, structural engineers have a very important role to play in fire engineering particularly with the involvement for fire protection system, laws, regulations and standards to fire risk management.

It is important to note that the stability of the members and overall structural performance will depend upon(24) (a) maximum temperature and temperature distribution (including penetration) (b) material properties (c) the applied loads (d) the level of composite action with slab (e) the restraints provided by surrounding structure (f) the continuity interaction with other cold/heated members and (g) engineering factors.

The change of properties of concrete due to high temperature will depend upon type of concrete aggregates used. The aggregates of concrete may be carbonate (i.e. lime stone, dolomite), siliceous (i.e. granite and sand stone) and light weight aggregates (i.e. manufactured by heating shale, slate or clay). The systems that are often considered for fire engineering design are -

- Prescriptive Code of Practice
- Performance based approach

It may be noted the mechanical properties of concrete, structural steel and reinforcing steel bars will decrease as the temperature rises. All these materials are found to retain only half of their basic strengths when the temperature reaches 450^0C to 600^0C.

The structural components must be able to withstand dead and live loads without collapse even when the rise in temperature causes a decrease in the strength and modulus of elasticity of concrete and steel. Furthermore, fire will cause expansion of structural components and the resulting stresses and strains must be resisted.

Considering the reduction of strength of concrete and steel, and with the rise of temperature the moment capacity for the applied loads of the structural elements will decrease and finally the flexural collapse will take place. The safety during the duration of fire depends on the protection to the reinforcing bars provided by concrete cover to reach its critical strength. A proper performance based approach apart from high temperature must consider ventilation conditions, compartment temperatures at various times and active protective systems eg. Sprinklers or fire brigades on the growth of fire.

For an analytical model and the analysis to tackle fire conditions, in structural components, the following will be important(25) apart from external service loads.

- Internal forces due to restraints that prevent free expansion.
- Internal forces due to change of pore pressure
- Re-distribution of internal forces due to change of mechanical properties of concrete and steel
- Secondary effects on the internal forces due to interaction of external loads and deformation due to above effects

Guidance are available in different codes regarding member sizes, cover etc. for the prescriptive approach based on fire tests on concrete components of structures. For a more accurate approach and specially when handling unusual structures, however, alternative methods based on performance based approach must be attempted for the safe fire design of the structure.

Spalling of concrete under fire condition is a major concern for using high strength concrete in the design. It has been reported that strength higher(26) than 55 MP are more susceptible to spalling and may show lower fire resistance. Carbonate aggregates (predominantly lime stone) will be preferable in concrete mix for enhancing fire performance. In order to reduce spalling, in high strength concrete under fire, fibres may be used in the mix or protecting the concrete surfaces at salient places with thermal barriers.

- Design for Blasts

Considering the present situation, in almost all countries forces developing from explosive blasts are to be considered in the design for the structures. Blast will result in producing high-amplitude impulse (27) loading which will last for a very short time period and producing high pressure loads. The forces that will be experienced by the structural elements will depend on size, geometry and proximity of the explosion. Explosion may cause damage to structural elements with the result of additional and progressive collapse of the structure.

Concrete has performed well against blast loads. As mentioned, blast load durations are for a very short period of time as compared to many other extreme loads and often shorter than the natural time period of many structural elements. Presence of continuous reinforcement with good detailing will provide reserve capacity to develop alternate load path and resistance mechanism under extreme conditions. Potential of developing fires from explosion is quite high. Fire may take place as a consequence from the damage caused by explosion. The inherent fire resistance of concrete has been found to be good which will be helpful in critical conditions.

13. ASSESSMENT, CONFIRMATION & CERTIFICATION

Assessment of project can be done with the certification by LEED and GRIHA. The main emphasis is on CO_2 emission and sustainability. Concrete will play an important role for assessment and in scoring for high rating along with other items required for the project in design and following strict construction norms with efficient project management. The above two types of certification will be briefly described below :

01. Leadership in Energy and Environmental Design (LEED)[21, 28] - This is point based rating system developed by the U.S. Green Building Council (USGBC) to evaluate the environmental performance of a building and encourage market transformation towards sustainable design. The approach will be an effort to develop "consensus-based, market[21] driven rating system to accelerate the development and implementation of green building practices."

The LEED Green Building rating system as described, for new construction will promote environmentally sustainable buildings for improvement.

(a) Review of the work

The document may be submitted in two parts – Design credits and construction credits and the review will cover –

- Preliminary Design Review
- Final Design Review (Optional)
- Preliminary Construction Review
- Final Construction Review (Optional)

Certification is the final step in the LEED review process.

LEED is based on point rating system as already mentioned to evaluate mainly the environmental performance of a building. In order to obtain LEED Certification, the green building design approach will consider issues such as use of environmentally sustainable building materials for improvement of indoor and outdoor building quality, conservation of resources, reduction of emission of CO_2 during service life and reduction of waste during construction and the period later on. Concrete will be appropriate as a suitable building material for LEED Certification.

Based on the number of points achieved a project can earn one of the four LEED rating levels as mentioned below : [28]

o	Certified	-	40-49 points
o	Silver	-	50-59 points
o	Gold	-	60-79 points
o	Platinum	-	80 + points

Main Credit Areas for Rating[21]

- Integrative process
- Location and transportation
- Sustainable sites
- Water efficiency
- Energy and atmosphere
- Materials and resources
- Indoor environmental quality

Each category is divided into credits. Additional points can be earned for inclusion of a LEED accredited professional in the project team.

02. Green Rating for Integrated Habitat Assessment (GRIHA)[29] - This is India's national system for Green Building design. Griha rating system will be assessed on 34 criteria categorised under various sections such as site selection and site planning, conservation and efficient utilisation of resources, building operation and maintenance and innovation points. Concrete will be very suitable as a building material along with other materials as per the design requirements for the project and following strict construction norms with efficient project management for assessment in obtaining high Griha rating. Eight of 34 criteria are mandatory, four from the balance are partly mandatory while the rest are optional.

Different levels of certification are awarded based on number of points earned as mentioned below. Reviews will be done by GRIHA council team.

GRIHA RATING
POINTS REQUIRED

- 1 Star
  50 - 60
- 2 Star
  61 - 70
- 3 Star
  71 - 80
- 4 Star
  81 – 90
- 5 Star
  91 – 100

The minimum points required for certification is 50.

14.HOW SUSTAINABLE IS CONCRETE & ASSESSMENT ON ENVIRONMENTAL IMPACT[6]

In order to compare the performance of two common and popular building materials for environmental impact assessment, the work carried out at University of Illinois, USA[6] is referred. Concrete and structural steel materials have been considered for this study. For assessment two beam samples had been made for the same moment capacity, one with concrete and the other using structural steel. Energy used in the production of portland cement and then the concrete have been estimated. The total energy in the production of steel was also computed. It was concluded from the study that the production of concrete beam required less energy and would have lower environmental impact than the steel beam.

CONCLUSIONS

A brief review has been made on the suitability of concrete as a building material for all types of applications. It is important that the building material shall be durable, cost effective, and easily available, will not damage the environment during production and applications and should be able to accommodate the building form easily for which the material shall be selected. It is stated that concrete will be very suitable considering its large impact we have experienced already on development work through-out the world over a long period. CO_2 emission related to concrete production along with its ingredients have been studied with the emission of other green-house gases. Comments are made on alternative fuel with less CO_2 emission such as bio-mass fuel, human induced green-house gas and indirect effect of other green-house gases. Discussion includes the choice of selection of a suitable and sustainable building material from concrete and steel. For proper assessment and high certification, concrete will be very much suitable along with other materials to meet design requirements with good construction practice and efficient project management and to achieve high rating as per LEED and GRIHA norms. It is concluded that concrete will be sustainable and will require less energy and will have lower environmental impact when used, than alternative structural steel material.

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REFERENCES

[1]. PCA, America's Cement Manufactures, Home - Buildings and Structures.
[2]. What is sustainability? IStructE Sustainable Construction Panel, The Structural Engineer, May 2008, Volumn-86, No.-9.
[3]. BALOGH, A. What makes concrete a Sustainable Building material? Concrete Network.Com, by.
[4]. Sustainable Concrete, the leading material in Sustainable Construction, U.K. Construction Industry.
[5]. Concrete Society News Alert, March 2016.
[6]. STRUBLE, L., GODFREY, J., How sustainable is concrete, University of Illinois at Urbana – Champaign, USA.
[7]. Green House Gas, Wikipedia, the free encyclopedia.
[8]. LALLANILLA, MARC, Greenhouse Gas Emission : Causes & Sources, SCIENCE, February 10, 2015.
[9]. EIA Brochure Green-house Gases, Climate Change, and energy.
[10]. CLIMATE CHANGE, Connecting Manitobans to climate change facts and solution.
[11]. PACYNA, E., G., PACYNA., J., M., STEENHUISEN, F., WILSON, S., Global Anthropogenic mercury emission inventory for 2000, Science Direct.
[12]. Other green-house gases, Source Sinks, Science.
[13]. RUBENSTEIN, M., State of the Planet, Earth Institute, Columbia University, May 2012.
[14]. Renewable Energy Holdings, What is Bio-Mass?
[15]. Stringent Emission Standards for Coal based thermal power plants, NCB News 2016.
[16]. FLOWER, D. J. M., SANJAYAN, J., G., Springer Link, Greenhouse gas emissions due to concrete manufacture.
[17]. GRIEVE, G., GOUWS, S. CSIR Research Space, Structural Concrete and Sustainability.
[18]. CAREY, P., Carbon-negative aggregates, Concrete February 2013.
[19]. CLAISSE, P., Carbon Capture Concrete. Concrete, July/August 2013.
[20]. TURNER, L.K., Collings F.G., Carbon dioxide equivalent (CO_2-e) emissions. A comparison between geo-polymer and OPC Cement Concrete. Department of Civil Engineering, Australia.
[21]. Sustainability – Green Buildings & Storm Water Management, Buildings & Structures, Sustainability, PCA America's Cement Manufacturers.
[22]. BUILDINGS, Smarter facility Management Concrete vs. Steel, 06.01.2005, which is the better building material?
[23]. GANGULY, K.K., Some Design Issues and Alternative Building Materials – A Brief Review, National Convention of Architectural Engineers. The Institution of Engineer, 31st January, 2014.
[24]. INGHAM, J., TARADA, F., Turning up the heat – full service fire safety engineering for Concrete Structures, Concrete, October 2007.
[25]. BILOW, D.N., KAMARA, M.E & SHOKIE, OR., Portland Cement Association 5420, Structures 2008 : Crossing Border.
[26]. KODUR, V.K.R., Fire Performance of High-Strength Concrete Structural Members, Construction Technology update No. 3, NRC – CNRC.
[27]. Design of Security with Concrete, PCA America's Cement Manufacturers, Building & Structures.
[28]. USGBC, Choose which rating system best suits your project LEED Certification US Green Building Council.
[29]. Green Rating for Integrated Habitat Assessment, GRIHA, Content & View Article.

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