NEED BASED ADVANCEMENTS IN MAKING CONCRETE PAVEMENTS

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Abstract

Presently, innovations in concrete pavements are completely changing its design and construction. New-age concrete of compressive strengths more than 200 MPa also has very high tensile strength with or without the inclusion of steel/ synthetic structural fibers. Similar types of concrete mix proportions are referred in IRC: SP: 83-2008 under “Early Opening to Traffic” (EOT) concrete pavements, for maintenance of rigid pavement.

Among other special concrete, Self-Consolidating Concrete (SCC) eliminates the need of mechanical consolidation and electrical energy at site and yields a required surface finish without segregation and undulation. Recently, it has been recommended in IRC:SP-62-2014 for construction of low volume concrete pavements in villages where skilled labour and mechanical/ electrical energy may not be easily available. Other similar technologies which are cost effective and environment friendly are given as under:

i) Recycled concrete pavements,
ii) Roller compacted concrete pavements (IRC:68-2005),
iii) Ultra high performance concrete pavements(IRC:SP:76-2015),
iv) High volume processed fly ash concrete pavements (IRC:SP:68-2005),
v) Fibre reinforced concrete pavements (IRC:SP:46-2013),
vi) Continuously reinforced concrete pavements- IRC:118-2015,
vii) No joint sealant concrete pavements as per ACPA
viii) Two lift concrete pavement/bonded concrete pavement (IRC:58-2015)
ix) Sound reduction technologies
x) Evaluation of Rigid pavement using falling weight deflectometer (IRC:117-2015)

The paper thus describes new, cost effective, ecofriendly and practically need based advancements for making good quality concrete pavements and their evaluation for saving time and energy which are essential requirements for more infra-structure development with the creation of more jobs to the semi-skilled younger generation.

Introduction

In the early years of human history, beginning with the earliest humans about two million years ago, every place in the world was in the Stone Age, and all the people in the world got their food by hunting and gathering. For a long time, (50 000 BC) there were probably only about 2000 people in the whole world.

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Coming to the history of concrete materials in 2500 BC, Roman used earth and mud (which has very low modulus of elasticity) in structures and made thick structures. Roman first used Pozzolana in 128 AD, Ordinary Portland Cement (OPC) was developed by Joseph Aspdin in 1824.

History of Concrete

Considering history of concrete making and catastrophes, very useful things can be made from concrete and individual designs that can take advantage of the shape and cast ability of concrete. Concrete is the "liquid stone" mankind has been searching for, throughout history. Concrete allows the human mind to design a shape and form the shape with common building materials and then pour the concrete into the form and shape a structural reality. The concrete form and cast system is much more economical and efficient than conventional like in case of stone slab in time and money.

RCC was first patented by W.B. Wilkinson in 1854;pre-stressed concrete developed in 1888 by P.H. Jackson; in1900 steel construction works started; in 1907shotcrete developed by Carl Akeley; and in 1930 first Roller compacted concrete pavement (RCCP) started in Sweden.

Continuing with the history of concrete, liquid and mineral admixtures came on the concrete scene in the 1930s. These items are generally called lignin of lye and a powder product called fly ash/calcined clay. These two products, when in combination or separately, added to concrete, reduced the amount of cement/water.

In 1970 first work on HPC- High Performance Concrete pavement started in Norwegian and in 1988 work on SCCwas initiated in 2002 using HPC/Ultra High Performance Concrete.In 2008 onward geo-polymer materials, low strength material, micro-crete, precast concrete productsand advance equipment came into existence.

Current Practice for Construction and Maintenance

It is good practice to use minimum cement content of 450 kg/cum and maximum W/C ratio 0.38 for quality concrete pavement and during construction sprinkling water or curing compound just after initial setting of concrete (that is after about 4 hours in summeri.e. when ambient temperature is more than 25^{o}C and after 10 hours in winter when ambient temperature is less than 25^{o}C) with the aim to bring rate of evaporation of water from top fresh concrete surface by less than 1kg/m^{2}/hour as per IRC: 15. By adopting this technique, plastic shrinkage cracks (which are parabolic parallel cracks perpendicular to wind direction of width less than 0.3 mm and depth less than about 100 mm) may be avoided. Subsequently, further after about 3 hours, joint cutting is started to make contraction (Transverse) and longitudinal joint (when width of PQC slab is more than 4.5m). The time of initial joint cutting is very crucial to avoid transverse random cracking. The joint cutting justcommenceswhen there is no marking sign of the wheels of joint cutting machine placed on the freshly laid concrete surface or when compressive strength of concrete reaches about 7 MPa as per IRC: 15.

Initial cut with diamond blade cutter is about 3 mm wide and up to 1/3rd depth of Pavement Quality Concrete (PQC) and grade of concrete shall preferably be minimum M40. The transverse joint spacing is about 15 times the thickness of PQC slab. All joint cutting shall preferably be completed within 48 hours to avoid random transverse cracking. Continuous water curing/ curing compound is spread uniformly after final setting or during joint cutting onwards but at least up to 14 days for OPC concrete and 16 days for concrete made with blended cement. Acute angle in concrete joints is avoided. If there is any acute angle or where length: breadth ratio of the concrete slab is more than 1.5, the slab is reinforced with nominal reinforcement 8-10mm steel deformed bars @ 150 mm c/c.

Excessive water in the concrete, improper quality and quantity of chemical admixture, and non-compatibility of chemical admixture with the used cement cause shrinkage cracks which are of Y Shape or crow foot type cracks of depth and width similar to plastic shrinkage cracks.

The remedy for both plastic and drying shrinkage cracks is to fill the crack within 2-3days of casting with slurry of cement/silica fume/fine fly ash on well moist and surface dry surface and thereafter covering with wet hessian cloth. Low viscosity epoxy may be applied in the cracks in case the concrete has been hardened and dry. Aggregates (as filler of sizes 2.36 mm less than the crack width) may also be used in case of wider cracks before filling required binder inside the crack to avoid shrinkage of epoxy resins and make repair cost effective also.

In case of bonded concrete overlay over existing concrete surface or repair with conventional concrete, the best technique before preparatory repair work is to wet the existing concrete surface at least for 48 hours to achieve sustainable performance and without any shrinkage cracks in the repaired/strengthened surface. The reason is: both the new and old concrete surface shrinks simultaneously and any chemical bonding reaction will take place when there is liquid for achieving good bond between two surfaces.

For bigger concrete patch (bomb damaged area) similar to stitch segment; nominal steel bars may be inserted into the existing concrete surface with epoxy resins, at specified location, applying cement slurry along all the boundaries of the patch before placing conventional high strength concrete for repair or strengthening. Proper compaction of concrete/ patch material will not only increases its strength but bond strength with adjoining surface is also improved. After repair also, cement slurry again shall be applied along all the boundaries to make the patch water proof and tight from all the sides.

More void due to poor compaction in the concrete reduces compressive strength and the general relation is 1% air void reduces 6% compressive strength. Any sign of corner crack (i.e. at a distance of generally 2.5 times the thickness) means either rigid pavement is under design,over loading, or movement of construction vehicle over pre-matured concrete slab. Main reason of longitudinal cracking may be poor compaction of sub-grade/embankment/sub base/ improper drainage/shoulder drop-off/improper widening, late joint cutting of longitudinal joint. Remedies may be to construct toe wall along high embankment and repair shoulder drop off with cross stitching of cracked PQC as per IRC: SP:83 besides compaction of lower layers.

Specifications. In the last 75 years there have been changes in the makeup of different types of concrete. Some of the changes have been for the good. Concrete now includes mineral admixtures (fly ash, silica fume, powdered granulated blast furnace slag, rice husk ash etc.) as per IS:456/IRC:114-2013 and chemical admixtures (plasticizers, super plasticizers, retarders, air entraining agent, poly carboxylic ether based admixtures etc. as per IS:9103) and polymeric/steel fibers (IRCSP:46-2013)/reactive steel metal fibre (obtained by chilling hot metal by rapid cooling). Many of these affect the amount of water required to produce a sustainable concrete and thereby improving strength and durability. There is about 50-70 % increase in strength due to the addition of silica fume in the concrete. The known reason is very small size (nano) of silica fume. Weight of one particle of cement is approximately equal to the weight of 100 particle of silica fume. That is why bulk density of silica fume is very low (about 200 kg/cum as compared to 1440 kg/cum of cement and 1660 kg/cum of natural aggregates). List of the current relevant Codes in concrete pavement is given in Table 1.

Table 1: Relevant National and International Codes

Sl. No	Code No	Title
1.	IRC:SP: 46-2013	Guidelines for Design and Construction of Fibre Reinforce Concrete Pavement
2.	IRC:SP:62-2014	Guidelines for Design and Construction of Cement Concrete Pavements for Low Volume Roads
3.	IRC:SP76-2015	Tentative Guidelines for Conventional, Thin and Ultra-Thin White toping
4.	IRC: 85 -2014	Recommended Practice for Accelerated Strength Testing and Evaluation of Concrete for Road and Airfield Pavements
5.	IRC:SP-86-2010	Guidelines for Selection, Operation and Maintenance of Paver Finishers
6.	IRC:SP-96-2012	Guidelines for Selection, Operation & Maintenance of Concrete Batching and Mixing Plants
7.	IRC:114-2013	Guidelines for Use of Silica Fume in Rigid Pavement
8.	IRC:117-2015	Guidelines for Structural Evaluation and Strengthening of Rigid Road Pavements Using Falling Weigh Deflectometer (FWD) Technique
9.	IS: 3812 (part 1) :2013	Pulverized fuel ash - Specification part 1 for use as Pozzolana in Cement, Cement Mortar and Concrete
10.	IS: 8112-2013	43 Grade Ordinary Portland Cement Specification
11.	IS: 12269-2013	Cement Concrete Mix Design
12.	MORTH -2013	SPECIFICATIONS FOR ROAD AND BRIDGE WORKS *(Fifth Revision)Published by* Indian Roads Congress, NEW DELHI

Basic Need of New Technologies

Portland cement production consumes more energy and pollutes world more than any other industries, the main issue is how to control greenhouse emissions (GHG)? Since Portland cement production is so GHG-intensive, that the challenge is to produce concrete structures with the same quality and strength using less Portland cement, but more supplementary cementing materials to form the same quality, but greener and cheaper product.

As production of cement is one of the largest industrial sources of CO_2 emissions. Globally, there is very rare availability of good quality aggregates; the speed and buildability, adequate pre-planning, pre-casting of elements and the use of appropriate technology in design and construction can make concrete inexpensive and fastest material for constructing durable, quality concrete pavements. Perpetual pavement with new techniques is one of the example.

According to the findings of the SHRP, in its benefits-versus-costs analysis, the Texas Transportation Institute (TTI) predicted that highway agencies can reap substantial savings by adopting a few new test methods and guidelines SHRP developed for Portland cement concrete pavement. These methods and guidelines can allow highway agencies to:

- Design concrete mixes that will be more resistant to spalling, cracking, and other common problems in concrete roads.
- Quickly assess the condition of existing concrete structures.
- Mitigate the effects of alkali-silica reactivity (ASR) and D-cracking in pavements.

Innovations

SHRP research on concrete, focused on the following products:

- Maturity Meter
- Hydraulic Fracture Test Chamber
- Modified Freeze-Thaw Test for Concrete
- Guidelines for Mitigating D-Cracking
- Surface Air Flow Permeability Meter
- Guidelines for Mitigating ASR in Existing Concrete

Besides above, a brief of the new technologies and construction equipment is given as under:

Device for Rapid Chloride Penetrability Test for Continuously Reinforced Concrete Pavement (CRCP). It is a laboratory test device for the measurement of the electrical resistance of concrete against the penetration of chloride (RCPT) according to the standard methods such as ASTM C1202, AASHTO T277 and ASTM C1760.

Device for measurement of surface electrical resistivity of concrete. This device is used for rapid, easy and accurate measurement of surface electrical resistivity of concrete to determine the chloride permeability of concrete in accordance with AASHTO TP95. (Fig. 1)

Figure 1: Device for Measurement of Surface Electrical Resistivity

New Products Made with Industrial by-products and fibres. High performance concrete usually contains cement, aggregates, water, chemical admixtures and mineral admixtures (mostly byproducts) and thereby reduces the need to dispose of these materials which conceal too much potential energy. Some of these materials include fly ash (waste by-product from coal burning), ground granulated blast furnace slag (waste by-product of steel industry), very reactive processed fly ash/ granulated slag, silica fume (a waste by-product of ferro-silicon alloy industry) and silica gel (a highly viscous material usually used in making dampers for cable stayed bridges). But perhaps the biggest benefit of using these is the reduction in the need to use Portland cement which have beneficial effects on reduction in the creation of carbon dioxide emissions and a reduction in energy consumption, both of these reductions will improve the global warming situation.

It is estimated that the production of cement worldwide contributes five to eight percent of global carbon dioxide emissions. To reduce the consumption of Ordinary Portland Cement, partial use of fly ash as a substitute to OPC as per Central Public Works Department (CPWD) circular 2004, one can replace only 15% cement with 25% dry fly ash in Ordinary Portland Cement (based on different specific gravities of each materials). Similarly, potentially reactive powdered granulated blast furnace slag (upto50% by weight of Portland cement) in concrete pavement are cost effective as compared to virgin cement and they have properties that improve the quality of the final concrete pavement particularly in harsh chemical environment.

Today's new types of concrete have live spans measured in the hundreds of years rather than decades. The use of by-products will save hundreds of thousands of acres of land that would have been used for disposal purposes. Many countries including India are exporting fly ash to oil producing countries where soil and aggregates contains harmful salts and number of coal based power plant are very limited or rare.

Microcrete. Hydrated cement paste (HCP) is a nanomaterial (Figure 2). The nano particles size structure of calcium silicate hydrate is much like clay, with thin layers of solids separated by gel pores filled with interlayer and adsorbed water. Micro-concrete is a dry ready mix of cementitious based composition formulated for use in repairs of areas where the concrete is damaged and the area is restricted in movement making the placement of conventional concrete difficult. It is supplied as a ready to use dry powder which requires only addition of clean water at site to produce a free flowing non shrink repair micro concrete. This imparts controlled expansion characteristics in the plastic state with reduced water demand.

Advancements in Concrete Equipment. Manufacturers are now incorporating technical modifications in the products line wherein some of the changes are stated to be quite refined in nature. The new advancements being carried out by the concrete equipment manufacturing industry are quite significant, keeping the major innovations in view done in the past; and whenever there was a need of higher job volumes, the mobile crushers, (Figure 3-6)andmobile batching plants are being manufactured now.

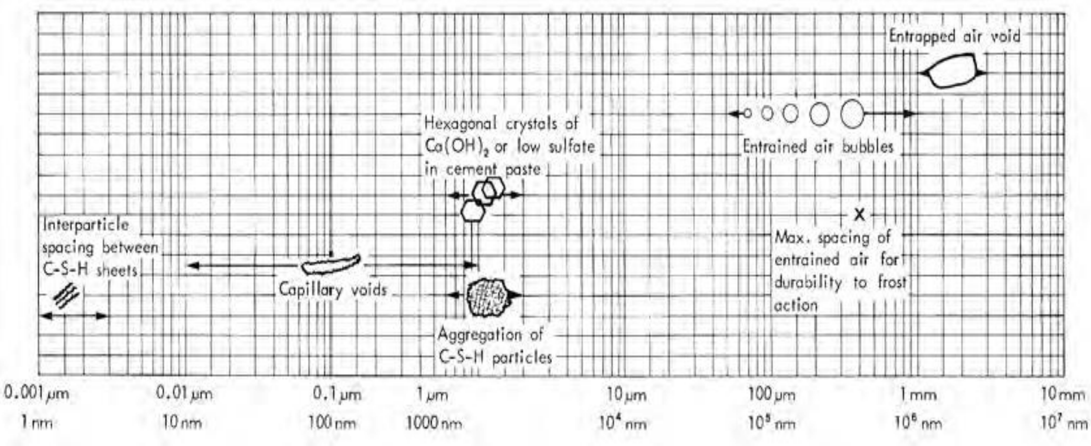

Figure 2: Dimensional Range of Solids and Pores in a Hydrated Cement Paste


Figure 3: Mobile Impact Crusher Figure 4: Mobile Cone Crusher


Figures 5: Mobile Jaw Crusher Figure 6: Mobile VSI Crusher

Considering placing of concrete at high altitude for making concrete pavement, an important operating feature of one of the innovative boom pump is that it can be operated through radio remote control from very distant locations which is the need of today like for making concrete roads in hills. The existing and emerging potential in concrete placing is trailer mounted concrete pumps and concrete boom placers of 1736 meters (NBMC March 2014).

Portable scanning device use the pulse radar technology to detect multiple layers of rebar, tandem, metal conduits, plastic conduits, post tensioned cables, glass fiber cables, voids at depths up to 300 mm(Figure 7). Ground penetration radar (GPR) and falling weight deflectometer are also in use for determining of voids between layers and their behavior.

In the field testing of concrete, there is new pullout test (ASTM –C 900) of determining in-situ strength of field concrete. Windsor HP Probe (Bullet test) - ASTM C-803 is another new electronic measuring system for measurement of compressive strength of 110 MPa. Maturity meter determines the developing strength of concrete which helps in improvement of safety, ensures quality and reduces costs, monitors the strength for rehabilitation as concrete ages.

Figure7 (a): Auto Scanner **Figure7 (b): Scanner used to locate Rebars**

Innovative Technologies for Remote/Border areas. People are facing hardship in remote areas because of inadequate and/or lack of basic infrastructural facilities. Also, due to adverse climatic conditions, the working season remains very short in the state, resulting in low levels of development.

Therefore, it is necessary to bring out urgently the new materials and techniques to meet special needs of the people of the region for infra-structure development considering prevailing environmental and natural conditions. Most of the border areas are inaccessible, have high rain fall and are at an altitude of about 4 km above sea level, difficult terrain, very high wind speed, harsh climate and lack of infrastructural facilities. The winter temperature in the area may be as low as -45°C. Somewhere, total cultivable area may be only about 22 per cent. Prolonged and severe winters restrict the growth of crops.

More and more construction of precast concrete roads or precast concrete paver block over stabilized layer, precast box culvert etc with new materials and technique may save time, money and the environment of border area. Rapid setting materials (magnesium phosphate cement) for repair of bomb damaged areas, high strength concrete which need less time for curing (due to high heat of hydration which helps in hydration faster in severe cold climate), self-compacted concrete, and natural cementitious soil stabilizers i.e. RBI Grade 81 (already used in airfield pavement), Fibre Reinforced Plate (FRP) plates for repair, and as well as for bullet proof product may be practicable technologies.

Thin White Topping (TWT). It is usually suitable where existing flexible pavement is frequently distressed due to frequent stop and start of the vehicles and inadequate drainage. The basic purpose of it is to improve the riding quality, load carrying capacity besides protecting the sub-grade/ sub base quality, and to maintain the level difference between the Finished Road Level (FRL) and adjoined property/building flooring level from drainage point of view. Salient features of White Topping are:

i) Minimum thickness of existing bituminous layer shall be 75 mm
ii) The grade of concrete shall be minimum M-40 and thickness of PQC is less (100 to 200mm)
iii) Modulus of subgrade reaction of the existing lower layers shall not be too high
iv) Fibres and closer joint spacing helpswhite topping in behaving like flexible pavement and because of closer joint spacing and bonding of whitetopping with the bituminous layer or stabilized layer reduces the thickness of top layer.
v) The reduction in stresses is 35-45 % due to bonding and lesser warping of slabs.
vi) In considering fatigue analysis, allowable repletion of existing bituminous layer is reduced by 25% as the life of bitumen is about six years and life of white topping is about more than 20 years.

Noise reduction technologies. Artificial turf drag, burlap drag, and longitudinal tinning appeared to offer the best for sound reduction technologies. Diamond grinding can provide smoothness, acoustic durability, and skid resistance for years.

In this field, innovative concrete pavement solutions are: exposed aggregate concrete pavements and pervious concrete pavements, which have been identified as potential candidates for fast-track advancement. However, these technologies require further study and detailed cost-effectiveness evaluation.Sound of 60-80dBA generated in concrete payment due to the movement of the vehicleis considered likely be close to the quietest concrete pavements textured.

Double-layer pervious concrete has also been demonstrated to avoid regular cleaning of pervious pavement as a possible solution, where a top lift with smaller aggregates is placed over a larger stone mix. The resulting system may help to minimize infiltration of debris that causes clogging

Common New Techniques

Following techniques are currently being used:

(i) Shotcrete (IS:9012) and self-consolidating concrete (IRCSP:62/IRC: 112, IRC:SP:70 draft),
(ii) Vacuum process(dewatering) for concrete pavement,
(iii) Recycled concrete pavement (IS:383 draft),
(iv) Delayed concrete with continuous agitation to reduce W/C ratio,
(v) Roller compacted concrete pavement or zero slump concrete pavement (IRC:SP:68),
(vi) High performance concrete (IRC: 113),
(vii) Ultra high performance concrete (IRC:SP:76-2015), (IRC:113-2014)
(viii) High volume fly ash concrete pavement (IRC:SP:68),
(ix) Fibre reinforced concrete pavement (IRCSP:46),
(x) Early opening to traffic concrete pavement (IRC:SP:83),
(xi) Joint-less rigid pavement (IRC:118-2015) ,
(xii) Use of construction and demolition (C&D) waste (IS:383 draft),
(xiii) Two-lift project,

In case of two lift projects, dense, wear-resistant aggregates for the top lift concrete (40-75 mm thick) is used but locally available, more porous limestone/marginal aggregates for the bottom lift (280-320 mm) is used. This technology significantly lowers the cost of purchasing and transporting materials and saves natural aggregates.

When water freezes, there is an expansion of about 9%, however, some of the water may migrate through the boundary, decreasing the hydraulic pressure which depends on permeability of the material. Under such situation, concrete shall be preserved at least for 7 days at temperature more than 2^0C and continuous curing with water is generally avoided in freezing regions. Under abnormal environmental conditions, soil stabilization with cementitious material or precast technologies are being preferred.

Conclusions

New types of concrete have better corrosion resistance, equal or higher compressive and tensile strengths, higher fire and seismic resistance, and rapid curing and strength gain. In addition, the production and life cycle of these new concretes reduces greenhouse gas emissions. Technologies such as corrosion-inhibitors need to be looked seriously particularly when used in high volume slag or fly ash concrete for reinforced concrete pavements.

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