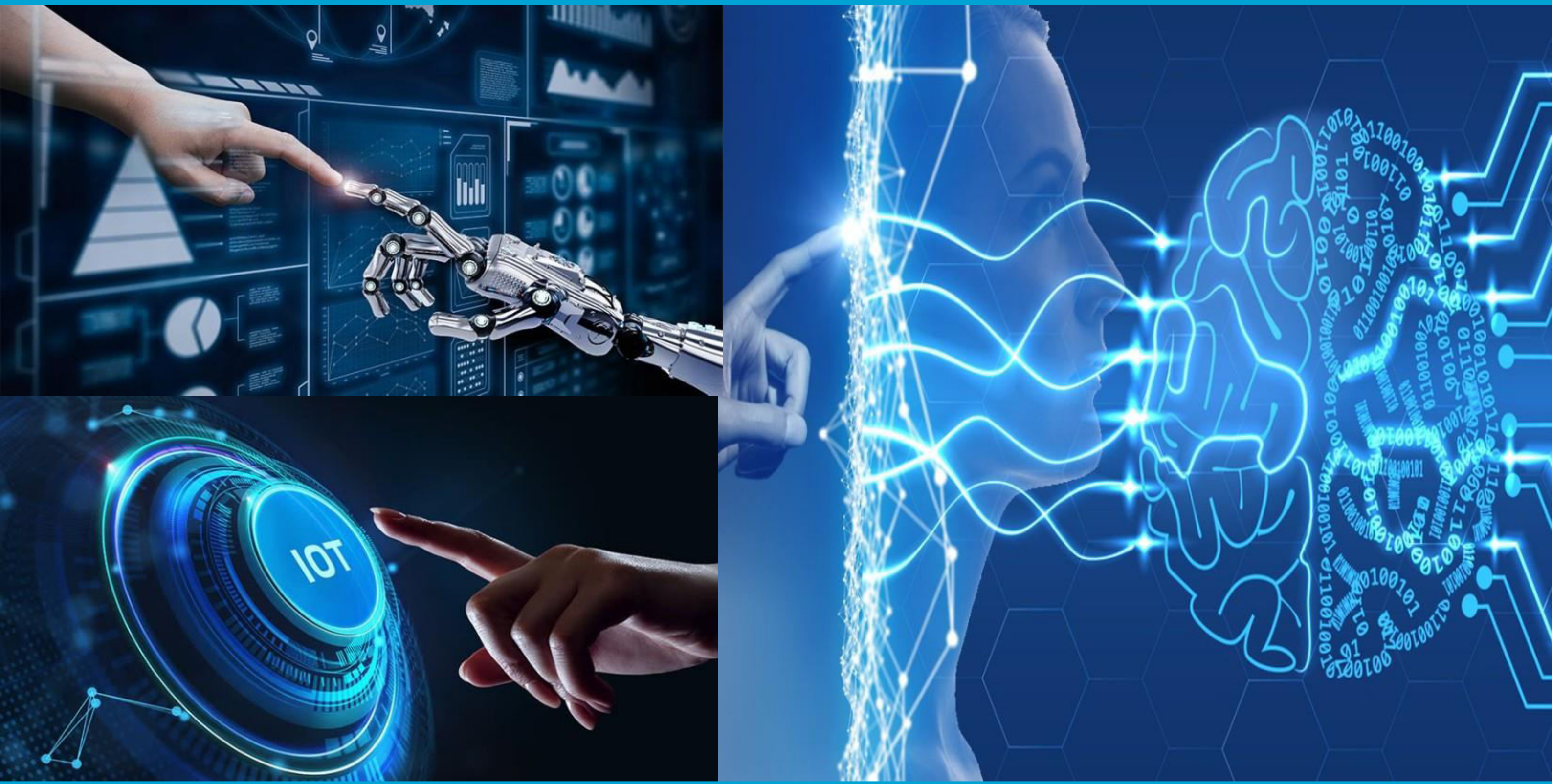
IJMRSETM

e-ISSN: 2395 - 7639



INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH

IN SCIENCE, ENGINEERING, TECHNOLOGY AND MANAGEMENT

Volume 8, Issue 1, January 2021

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

Impact Factor: 7.580

+91 99405 72462 +9163819 07438 ijmrsetm@gmail.com www.ijmrsetm.com

International Journal of Multidisciplinary Research in Science, Engineering, Technology & Management (IJMRSETM)

| ISSN: 2395-7639 | www.ijmrsetm.com | Impact Factor: 7.580| A Monthly Double-Blind Peer Reviewed Journal |

| Volume 8, Issue 1, January 2021 |

DOI:10.15680/IJMRSETM.2021.0801010|

Development of Methodology of Prestressed Concrete Pavement

[1]Umesh Tiwari, [2]Dr. Vandana Tare

[1]Research Scholar, Dept. of Civil Engineering, SGSITS College, Indore, Madhya Pradesh, India

[2]Research Guide and Professor, Dept. of Civil Engineering, SGSITS College, Indore, Madhya Pradesh, India

ABSTRACT: Prestressed concrete is a form of concrete used in construction. It is substantially "prestressed" (compressed) during production, in a manner that strengthens it against tensile forces which will exist when in service.[1][2]:3–5[3]

This compression is produced by the tensioning of high-strength "tendons" located within or adjacent to the concrete and is done to improve the performance of the concrete in service.[4] Tendons may consist of single wires, multi-wire strands or threaded bars that are most commonly made from high-tensile steels, carbon fiber or aramid fiber.[1]:52–59 The essence of prestressed concrete is that once the initial compression has been applied, the resulting material has the characteristics of high-strength concrete when subject to any subsequent compression forces and of ductile high-strength steel when subject to tension forces. This can result in improved structural capacity and/or serviceability compared with conventionally reinforced concrete in many situations.[5][2]:6 In a prestressed concrete member, the internal stresses are introduced in a planned manner so that the stresses resulting from the imposed loads are counteracted to the desired degree.

KEYWORDS: prestressed, concrete, pavement, compression, tension, degree

I.INTRODUCTION

Prestressed concrete is used in a wide range of building and civil structures where its improved performance can allow for longer spans, reduced structural thicknesses, and material savings compared with simple reinforced concrete. Typical applications include high-rise buildings, residential slabs, foundation systems, bridge and dam structures, silos and tanks, industrial pavements and nuclear containment structures.[6]

First used in the late-nineteenth century,[1] prestressed concrete has developed beyond pre-tensioning to include post-tensioning, which occurs after the concrete is cast. Tensioning systems may be classed as either monostrand, where each tendon's strand or wire is stressed individually, or multi-strand, where all strands or wires in a tendon are stressed simultaneously.[5] Tendons may be located either within the concrete volume (internal prestressing) or wholly outside of it (external prestressing). While pre-tensioned concrete uses tendons directly bonded to the concrete, post-tensioned concrete can use either bonded or unbonded tendons.

Pre-tensioned concrete

Pre-tensioned concrete is a variant of prestressed concrete where the tendons are tensioned prior to the concrete being cast.[1]:25 The concrete bonds to the tendons as it cures, following which the end-anchoring of the tendons is released, and the tendon tension forces are transferred to the concrete as compression by static friction.[5]:7

Pre-tensioned bridge girder in precasting bed, with single-strand tendons exiting through the formwork

Pre-tensioning is a common prefabrication technique, where the resulting concrete element is manufactured off-site from the final structure location and transported to site once cured. It requires strong, stable end-anchorage points between which the tendons are stretched. These anchorages form the ends of a "casting bed" which may be many times the length of the concrete element being fabricated. This allows multiple elements to be constructed end-to-end in the one pre-tensioning operation, allowing significant productivity benefits and economies of scale to be realized.[5][7]

| ISSN: 2395-7639 | www.ijmrsetm.com | Impact Factor: 7.580| A Monthly Double-Blind Peer Reviewed Journal |

| Volume 8, Issue 1, January 2021 |

DOI:10.15680/IJMRSETM.2021.0801010|

The amount of bond (or adhesion) achievable between the freshly set concrete and the surface of the tendons is critical to the pre-tensioning process, as it determines when the tendon anchorages can be safely released. Higher bond strength in early-age concrete will speed production and allow more economical fabrication. To promote this, pre-tensioned tendons are usually composed of isolated single wires or strands, which provides a greater surface area for bonding than bundled-strand tendons.[5]

Unlike those of post-tensioned concrete the tendons of pre-tensioned concrete elements generally form straight lines between end-anchorages. Where "profiled" or "harped" tendons[8] are required, one or more intermediate deviators are located between the ends of the tendon to hold the tendon to the desired non-linear alignment during tensioning.[1]:68–73[5]:11 Such deviators usually act against substantial forces, and hence require a robust casting-bed foundation system. Straight tendons are typically used in "linear" precast elements, such as shallow beams, hollow-core planks and slabs; whereas profiled tendons are more commonly found in deeper precast bridge beams and girders.

Pre-tensioned concrete is most commonly used for the fabrication of structural beams, floor slabs, hollow-core planks, balconies, lintels, driven piles, water tanks and concrete pipes.

Post-tensioned concrete

Post-tensioned concrete is a variant of prestressed concrete where the tendons are tensioned after the surrounding concrete structure has been cast.[1]:25

The tendons are not placed in direct contact with the concrete, but are encapsulated within a protective sleeve or duct which is either cast into the concrete structure or placed adjacent to it. At each end of a tendon is an anchorage assembly firmly fixed to the surrounding concrete. Once the concrete has been cast and set, the tendons are tensioned ("stressed") by pulling the tendon ends through the anchorages while pressing against the concrete. The large forces required to tension the tendons result in a significant permanent compression being applied to the concrete once the tendon is "locked-off" at the anchorage.[1]:25[5]:7 The method of locking the tendon-ends to the anchorage is dependent upon the tendon composition, with the most common systems being "button-head" anchoring (for wire tendons), split-wedge anchoring (for strand tendons), and threaded anchoring (for bar tendons).[1]:79–84

Tendon encapsulation systems are constructed from plastic or galvanised steel materials, and are classified into two main types: those where the tendon element is subsequently bonded to the surrounding concrete by internal grouting of the duct after stressing (bonded post-tensioning); and those where the tendon element is permanently debonded from the surrounding concrete, usually by means of a greased sheath over the tendon strands (unbonded post-tensioning).[1]:26[5]:10

Casting the tendon ducts/sleeves into the concrete before any tensioning occurs allows them to be readily "profiled" to any desired shape including incorporating vertical and/or horizontal curvature. When the tendons are tensioned, this profiling results in reaction forces being imparted onto the hardened concrete, and these can be beneficially used to counter any loadings subsequently applied to the structure.[2]:5–6[5]:48 :9–10

Bonded post-tensioning

In bonded post-tensioning, tendons are permanently bonded to the surrounding concrete by the in situ grouting of their encapsulating ducting (after tendon tensioning). This grouting is undertaken for three main purposes: to protect the tendons against corrosion; to permanently "lock-in" the tendon pre-tension, thereby removing the long-term reliance upon the end-anchorage systems; and to improve certain structural behaviors of the final concrete structure.[9]

Bonded post-tensioning characteristically uses tendons each comprising bundles of elements (e.g., strands or wires) placed inside a single tendon duct, with the exception of bars which are mostly used unbundled. This bundling makes for more efficient tendon installation and grouting processes, since each complete tendon requires only one set of end-anchorages and one grouting operation. Ducting is fabricated from a durable and corrosion-resistant material such as plastic (e.g., polyethylene) or galvanised steel, and can be either round or rectangular/oval in cross-section.[2]:7 The tendon sizes used are highly dependent upon the application, ranging from building works typically using between 2 and 6 strands per tendon, to specialized dam works using up to 91 strands per tendon.

| ISSN: 2395-7639 | www.ijmrsetm.com | Impact Factor: 7.580| A Monthly Double-Blind Peer Reviewed Journal |

| Volume 8, Issue 1, January 2021 |

DOI:10.15680/IJMRSETM.2021.0801010|

Fabrication of bonded tendons is generally undertaken on-site, commencing with the fitting of end-anchorages to formwork, placing the tendon ducting to the required curvature profiles, and reeving (or threading) the strands or wires through the ducting. Following concreting and tensioning, the ducts are pressure-grouted and the tendon stressing-ends sealed against corrosion.[5]:2

Unbonded post-tensioning

Unbonded post-tensioning differs from bonded post-tensioning by allowing the tendons permanent freedom of longitudinal movement relative to the concrete. This is most commonly achieved by encasing each individual tendon element within a plastic sheathing filled with a corrosion-inhibiting grease, usually lithium based. Anchorages at each end of the tendon transfer the tensioning force to the concrete, and are required to reliably perform this role for the life of the structure.[9]:1

Unbonded post-tensioning can take the form of:

- Individual strand tendons placed directly into the concreted structure (e.g., buildings, ground slabs)
- Bundled strands, individually greased-and-sheathed, forming a single tendon within an encapsulating duct that is placed either within or adjacent to the concrete (e.g., restressable anchors, external post-tensioning)

For individual strand tendons, no additional tendon ducting is used and no post-stressing grouting operation is required, unlike for bonded post-tensioning. Permanent corrosion protection of the strands is provided by the combined layers of grease, plastic sheathing, and surrounding concrete. Where strands are bundled to form a single unbonded tendon, an enveloping duct of plastic or galvanised steel is used and its interior free-spaces grouted after stressing. In this way, additional corrosion protection is provided via the grease, plastic sheathing, grout, external sheathing, and surrounding concrete layers.[9]:1

Individually greased-and-sheathed tendons are usually fabricated off-site by an extrusion process. The bare steel strand is fed into a greasing chamber and then passed to an extrusion unit where molten plastic forms a continuous outer coating. Finished strands can be cut-to-length and fitted with "dead-end" anchor assemblies as required for the project.

Comparison between bonded and unbonded post-tensioning

Both bonded and unbonded post-tensioning technologies are widely used around the world, and the choice of system is often dictated by regional preferences, contractor experience, or the availability of alternative systems. Either one is capable of delivering code-compliant, durable structures meeting the structural strength and serviceability requirements of the designer.[9]:2

The benefits that bonded post-tensioning can offer over unbonded systems are:

- Reduced reliance on end-anchorage integrity
  Following tensioning and grouting, bonded tendons are connected to the surrounding concrete along their full length by high-strength grout. Once cured, this grout can transfer the full tendon tension force to the concrete within a very short distance (approximately 1 metre). As a result, any inadvertent severing of the tendon or failure of an end anchorage has only a verylocalised impact on tendon performance, and almost never results in tendon ejection from the anchorage.[2]:18[9]:7
- Increased ultimate strength in flexure
  With bonded post-tensioning, any flexure of the structure is directly resisted by tendon strains at that same location (i.e. no strain re-distribution occurs). This results in significantly higher tensile strains in the tendons than if they were unbonded, allowing their full yield strength to be realised, and producing a higher ultimate load capacity.[2]:16–17[5]:10
- Improved crack-control
  In the presence of concrete cracking, bonded tendons respond similarly to conventional reinforcement (rebar). With the tendons fixed to the concrete at each side of the crack, greater resistance to crack expansion is offered than with unbonded tendons, allowing many design codes to specify reduced reinforcement requirements for bonded post-tensioning.[9]:4[10]:1

International Journal of Multidisciplinary Research in Science, Engineering, Technology & Management (IJMRSETM)

| ISSN: 2395-7639 | www.ijmrsetm.com | Impact Factor: 7.580| A Monthly Double-Blind Peer Reviewed Journal |

| Volume 8, Issue 1, January 2021 |

DOI:10.15680/IJMRSETM.2021.0801010|

- Improved fire performance
  The absence of strain redistribution in bonded tendons may limit the impact that any localised overheating has on the overall structure. As a result, bonded structures may display a higher capacity to resist fire conditions than unbonded ones.[11]

The benefits that unbonded post-tensioning can offer over bonded systems are:

- Ability to be prefabricated
  Unbonded tendons can be readily prefabricated off-site complete with end-anchorages, facilitating faster installation during construction. Additional lead time may need to be allowed for this fabrication process.
- Improved site productivity
  The elimination of the post-stressing grouting process required in bonded structures improves the site-labour productivity of unbonded post-tensioning.[9]:5
- Improved installation flexibility
  Unbonded single-strand tendons have greater handling flexibility than bonded ducting during installation, allowing them a greater ability to be deviated around service penetrations or obstructions.[9]:5
- Reduced concrete cover
  Unbonded tendons may allow some reduction in concrete element thickness, as their smaller size and increased corrosion protection may allow them to be placed closer to the concrete surface.[2]:8
- Simpler replacement and/or adjustment
  Being permanently isolated from the concrete, unbonded tendons are able to be readily de-stressed, re-stressed and/or replaced should they become damaged or need their force levels to be modified in-service.[9]:6
- Superior overload performance
  Although having a lower ultimate strength than bonded tendons, unbonded tendons' ability to redistribute strains over their full length can give them superior pre-collapse ductility. In extremes, unbonded tendons can resort to a catenary-type action instead of pure flexure, allowing significantly greater deformation before structural failure.[12]

Tendon durability and corrosion protection

Long-term durability is an essential requirement for prestressed concrete given its widespread use. Research on the durability performance of in-service prestressed structures has been undertaken since the 1960s,[13] and anti-corrosion technologies for tendon protection have been continually improved since the earliest systems were developed.[14]

The durability of prestressed concrete is principally determined by the level of corrosion protection provided to any high-strength steel elements within the prestressing tendons. Also critical is the protection afforded to the end-anchorage assemblies of unbonded tendons or cable-stay systems, as the anchorages of both of these are required to retain the prestressing forces. Failure of any of these components can result in the release of prestressing forces, or the physical rupture of stressing tendons.

Modern prestressing systems deliver long-term durability by addressing the following areas:

- Tendon grouting (bonded tendons)
  Bonded tendons consist of bundled strands placed inside ducts located within the surrounding concrete. To ensure full protection to the bundled strands, the ducts must be pressure-filled with a corrosion-inhibiting grout, without leaving any voids, following strand-tensioning.
- Tendon coating (unbonded tendons)
  Unbonded tendons comprise individual strands coated in an anti-corrosion grease or wax, and fitted with a durable plastic-based full-length sleeve or sheath. The sleeving is required to be undamaged over the tendon length, and it must extend fully into the anchorage fittings at each end of the tendon.
- Double-layer encapsulation
  Prestressing tendons requiring permanent monitoring and/or force adjustment, such as stay-cables and re-stressable dam anchors, will typically employ double-layer corrosion protection. Such tendons are composed of individual

| ISSN: 2395-7639 | www.ijmrsetm.com | Impact Factor: 7.580| A Monthly Double-Blind Peer Reviewed Journal |

| Volume 8, Issue 1, January 2021 |

DOI:10.15680/IJMRSETM.2021.0801010|

strands, grease-coated and sleeved, collected into a strand-bundle and placed inside encapsulating polyethylene outer ducting. The remaining void space within the duct is pressure-grouted, providing a multi-layer polythene-grout-plastic-grease protection barrier system for each strand.

- Anchorage protection
  In all post-tensioned installations, protection of the end-anchorages against corrosion is essential, and critically so for unbonded systems.

Several durability-related events are listed below:

- Ynys-y-Gwasbridge, West Glamorgan, Wales, 1985
  A single-span, precast-segmental structure constructed in 1953 with longitudinal and transverse post-tensioning. Corrosion attacked the under-protected tendons where they crossed the in-situ joints between the segments, leading to sudden collapse.[14]:40
- Scheldt River bridge, Melle, Belgium, 1991
  A three-span prestressed cantilever structure constructed in the 1950s. Inadequate concrete cover in the side abutments resulted in tie-down cable corrosion, leading to a progressive failure of the main bridge span and the death of one person.[15]
- UK Highways Agency, 1992
  Following discovery of tendon corrosion in several bridges in England, the Highways Agency issued a moratorium on the construction of new internally grouted post-tensioned bridges and embarked on a 5-year programme of inspections on its existing post-tensioned bridge stock. The moratorium was lifted in 1996.[16][17]
- Pedestrian bridge, Charlotte Motor Speedway, North Carolina, US, 2000
  A multi-span steel and concrete structure constructed in 1995. An unauthorised chemical was added to the tendon grout to speed construction, leading to corrosion of the prestressing strands and the sudden collapse of one span, injuring many spectators.[18]
- Hammersmith Flyover London, England, 2011
  Sixteen-span prestressed structure constructed in 1961. Corrosion from road de-icing salts was detected in some of the prestressing tendons, necessitating initial closure of the road while additional investigations were done. Subsequent repairs and strengthening using external post-tensioning was carried out and completed in 2015.[19][20]
- Petrulla Viaduct ("ViadottoPetrulla"), Sicily, Italy, 2014
  One span of a 12-span viaduct collapsed on 7 July 2014, causing 4 injuries,[21] due to corrosion of the post-tensioning tendons.
- Genoa bridge collapse, 2018. The Ponte Morandi was a cable-stayed bridge characterised by a prestressed concrete structure for the piers, pylons and deck, very few stays, as few as two per span, and a hybrid system for the stays constructed from steel cables with prestressed concrete shells poured on. The concrete was only prestressed to 10 MPa, resulting in it being prone to cracks and water intrusion, which caused corrosion of the embedded steel.
- Churchill Way flyovers, Liverpool, England
  The flyovers were closed in September 2018 after inspections revealed poor quality concrete, tendon corrosion and signs of structural distress. They were demolished in 2019.[22]

Applications

Prestressed concrete is a highly versatile construction material as a result of it being an almost ideal combination of its two main constituents: high-strength steel, pre-stretched to allow its full strength to be easily realised; and modern concrete, pre-compressed to minimise cracking under tensile forces.[1]:12 Its wide range of application is reflected in its incorporation into the major design codes covering most areas of structural and civil engineering, including buildings, bridges, dams, foundations, pavements, piles, stadiums, silos, and tanks.[6]

Building structures

Building structures are typically required to satisfy a broad range of structural, aesthetic and economic requirements. Significant among these include: a minimum number of (intrusive) supporting walls or columns; low structural thickness

International Journal of Multidisciplinary Research in Science, Engineering, Technology & Management (IJMRSETM)

| ISSN: 2395-7639 | www.ijmrsetm.com | Impact Factor: 7.580| A Monthly Double-Blind Peer Reviewed Journal |

| Volume 8, Issue 1, January 2021 |

DOI:10.15680/IJMRSETM.2021.0801010|

(depth), allowing space for services, or for additional floors in high-rise construction; fast construction cycles, especially for multi-storey buildings; and a low cost-per-unit-area, to maximise the building owner's return on investment.

The prestressing of concrete allows "load-balancing" forces to be introduced into the structure to counter in-service loadings. This provides many benefits to building structures:

- Longer spans for the same structural depth
  Load balancing results in lower in-service deflections, which allows spans to be increased (and the number of supports reduced) without adding to structural depth.
- Reduced structural thickness
  For a given span, lower in-service deflections allows thinner structural sections to be used, in turn resulting in lower floor-to-floor heights, or more room for building services.
- Faster stripping time
  Typically, prestressed concrete building elements are fully stressed and self-supporting within five days. At this point they can have their formwork stripped and re-deployed to the next section of the building, accelerating construction "cycle-times".
- Reduced material costs
  The combination of reduced structural thickness, reduced conventional reinforcement quantities, and fast construction often results in prestressed concrete showing significant cost benefits in building structures compared to alternative structural materials.

II.DISCUSSION

Civil structures

Bridges

Concrete is the most popular structural material for bridges, and prestressed concrete is frequently adopted.[35][36] When investigated in the 1940s for use on heavy-duty bridges, the advantages of this type of bridge over more traditional designs was that it is quicker to install, more economical and longer-lasting with the bridge being less lively.[37][38] One of the first bridges built in this way is the Adam Viaduct, a railway bridge constructed 1946 in the UK.[39] By the 1960s, prestressed concrete largely superseded reinforced concrete bridges in the UK, with box girders being the dominant form.[40]

In short-span bridges of around 10 to 40 metres (30 to 130 ft), prestressing is commonly employed in the form of precast pre-tensioned girders or planks.[41] Medium-length structures of around 40 to 200 metres (150 to 650 ft), typically use precast-segmental, in-situ balanced-cantilever and incrementally-launched designs.[42] For the longest bridges, prestressed concrete deck structures often form an integral part of cable-stayed designs.[43]

Dams

Concrete dams have used prestressing to counter uplift and increase their overall stability since the mid-1930s.[44][45] Prestressing is also frequently retro-fitted as part of dam remediation works, such as for structural strengthening, or when raising crest or spillway heights.[46][47]

Most commonly, dam prestressing takes the form of post-tensioned anchors drilled into the dam's concrete structure and/or the underlying rock strata. Such anchors typically comprise tendons of high-tensile bundled steel strands or individual threaded bars. Tendons are grouted to the concrete or rock at their far (internal) end, and have a significant "de-bonded" free-length at their external end which allows the tendon to stretch during tensioning. Tendons may be full-length bonded to the surrounding concrete or rock once tensioned, or (more commonly) have strands permanently encapsulated in corrosion-inhibiting grease over the free-length to permit long-term load monitoring and re-stressability.[48]

International Journal of Multidisciplinary Research in Science, Engineering, Technology & Management (IJMRSETM)

| ISSN: 2395-7639 | www.ijmrsetm.com | Impact Factor: 7.580| A Monthly Double-Blind Peer Reviewed Journal |

| Volume 8, Issue 1, January 2021 |

DOI:10.15680/IJMRSETM.2021.0801010|

Silos and tanks

Circular storage structures such as silos and tanks can use prestressing forces to directly resist the outward pressures generated by stored liquids or bulk-solids. Horizontally curved tendons are installed within the concrete wall to form a series of hoops, spaced vertically up the structure. When tensioned, these tendons exert both axial (compressive) and radial (inward) forces onto the structure, which can directly oppose the subsequent storage loadings. If the magnitude of the prestress is designed to always exceed the tensile stresses produced by the loadings, a permanent residual compression will exist in the wall concrete, assisting in maintaining a watertight crack-free structure.[49][50][51]:61

Nuclear and blast

Prestressed concrete has been established as a reliable construction material for high-pressure containment structures such as nuclear reactor vessels and containment buildings, and petrochemical tank blast-containment walls. Using pre-stressing to place such structures into an initial state of bi-axial or tri-axial compression increases their resistance to concrete cracking and leakage, while providing a proof-loaded, redundant and monitorable pressure-containment system.[52][53][54]:585–594

Nuclear reactor and containment vessels will commonly employ separate sets of post-tensioned tendons curved horizontally or vertically to completely envelop the reactor core. Blast containment walls, such as for liquid natural gas (LNG) tanks, will normally utilize layers of horizontally-curved hoop tendons for containment in combination with vertically looped tendons for axial wall pre-stressing.

Hardstands and pavements

Heavily loaded concrete ground-slabs and pavements can be sensitive to cracking and subsequent traffic-driven deterioration. As a result, prestressed concrete is regularly used in such structures as its pre-compression provides the concrete with the ability to resist the crack-inducing tensile stresses generated by in-service loading. This crack-resistance also allows individual slab sections to be constructed in larger pours than for conventionally reinforced concrete, resulting in wider joint spacings, reduced jointing costs and less long-term joint maintenance issues.[54]:594–598[55] Initial works have also been successfully conducted on the use of precast prestressed concrete for road pavements, where the speed and quality of the construction has been noted as being beneficial for this technique.[56]

Design agencies and regulations

Worldwide, many professional organizations exist to promote best practices in the design and construction of prestressed concrete structures. In the United States, such organizations include the Post-Tensioning Institute (PTI) and the Precast/Prestressed Concrete Institute (PCI).[61] Similar bodies include the Canadian Precast/Prestressed Concrete Institute (CPCI),[62] the UK's Post-Tensioning Association,[63] the Post Tensioning Institute of Australia[64] and the South African Post Tensioning Association.[65] Europe has similar country-based associations and institutions.

It is important to note that these organizations are not the authorities of building codes or standards, but rather exist to promote the understanding and development of prestressed concrete design, codes and best practices.

Rules and requirements for the detailing of reinforcement and prestressing tendons are specified by individual national codes and standards such as:

- European Standard EN 1992-2:2005 – Eurocode 2: Design of Concrete Structures;
- US Standard ACI318: Building Code Requirements for Reinforced Concrete; and
- Australian Standard AS 3600-2009: Concrete Structures.

III.RESULTS

In structural engineering, a prestressed structure is a load-bearing structure whose overall integrity, stability and security depend, primarily, on prestressing: the intentional creation of permanent stresses in the structure for the purpose of improving its performance under various service conditions.[1]

International Journal of Multidisciplinary Research in Science, Engineering, Technology & Management (IJMRSETM)

| ISSN: 2395-7639 | www.ijmrsetm.com | Impact Factor: 7.580| A Monthly Double-Blind Peer Reviewed Journal |

| Volume 8, Issue 1, January 2021 |

DOI:10.15680/IJMRSETM.2021.0801010|

The basic types of prestressing are:

- Precompression with mostly the structure's own weight
- Pre-tensioning with high-strength embedded tendons
- Post-tensioning with high-strength bonded or unbonded tendons

Today, the concept of a prestressed structure is widely employed in the design of buildings, underground structures, TV towers, power stations, floating storage and offshore facilities, nuclear reactor vessels, and numerous bridge systems.[2] It is especially prominent in construction using concrete (see pre-stressed concrete).

The idea of precompression was apparently familiar to ancient Roman architects. The tall attic wall of the Colosseum works as a stabilizing device for the wall piers beneath it.

Concrete has relatively high compressive strength (resists breaking, when squeezed), but significantly lower tensile strength (vulnerable to breaking, when pulled apart). The compressive strength is typically controlled with the ratio of water to cement when forming the concrete, and tensile strength is increased by additives, typically steel, to create reinforced concrete. In other words we can say concrete is made up of sand (which is a fine aggregate), ballast (which is a coarse aggregate), cement (can be referred to as a binder) and water (which is an additive).

Reinforced concrete

Concrete has relatively high compressive strength, but significantly lower tensile strength. As a result, without compensating, concrete would almost always fail from tensile stresses even when loaded in compression. The practical implication of this is that concrete elements subjected to tensile stresses must be reinforced with materials that are strong in tension (often steel). The elasticity of concrete is relatively constant at low stress levels but starts decreasing at higher stress levels as matrix cracking develops. Concrete has a very low coefficient of thermal expansion, and as it matures concrete shrinks. All concrete structures will crack to some extent, due to shrinkage and tension. Concrete which is subjected to long-duration forces is prone to creep. The density of concrete varies, but is around 2,400 kilograms per cubic metre (150 lb/cu ft).[1]

Reinforced concrete is the most common form of concrete. The reinforcement is often steel rebar (mesh, spiral, bars and other forms). Structural fibers of various materials are available. Concrete can also be prestressed (reducing tensile stress) using internal steel cables (tendons), allowing for beams or slabs with a longer span than is practical with reinforced concrete alone. Inspection of existing concrete structures can be non-destructive if carried out with equipment such as a Schmidt hammer, which is sometimes used to estimate relative concrete strengths in the field.

Mix design

The ultimate strength of concrete is influenced by the water-cementitious ratio (w/cm), the design constituents, and the mixing, placement and curing methods employed. All things being equal, concrete with a lower water-cement (cementitious) ratio makes a stronger concrete than that with a higher ratio.[2] The total quantity of cementitious materials (portland cement, slag cement, pozzolans) can affect strength, water demand, shrinkage, abrasion resistance and density. All concrete will crack independent of whether or not it has sufficient compressive strength. In fact, high Portland cement content mixtures can actually crack more readily due to increased hydration rate. As concrete transforms from its plastic state, hydrating to a solid, the material undergoes shrinkage. Plastic shrinkage cracks can occur soon after placement but if the evaporation rate is high they often can actually occur during finishing operations, for example in hot weather or a breezy day.

In very high-strength concrete mixtures (greater than 70 MPa) the crushing strength of the aggregate can be a limiting factor to the ultimate compressive strength. In lean concretes (with a high water-cement ratio) the crushing strength of the aggregates is not so significant. The internal forces in common shapes of structure, such as arches, vaults, columns and walls are predominantly compressive forces, with floors and pavements subjected to tensile forces. Compressive strength is widely used for specification requirement and quality control of concrete. Engineers know their target tensile (flexural) requirements and will express these in terms of compressive strength.

| ISSN: 2395-7639 | www.ijmrsetm.com | Impact Factor: 7.580| A Monthly Double-Blind Peer Reviewed Journal |

| Volume 8, Issue 1, January 2021 |

DOI:10.15680/IJMRSETM.2021.0801010|

Wired.com reported on April 13, 2007 that a team from the University of Tehran, competing in a contest sponsored by the American Concrete Institute, demonstrated several blocks of concretes with abnormally high compressive strengths between 340 and 410 MPa (49,000 and 59,000 psi) at 28 days.[3] The blocks appeared to use an aggregate of steel fibres and quartz – a mineral with a compressive strength of 1100 MPa, much higher than typical high-strength aggregates such as granite (100–140 MPa or 15,000–20,000 psi). Reactive powder concrete, also known as ultra-high-performance concrete, can be even stronger, with strengths of up to 800 MPa (116,000 PSI).[4] These are made by eliminating large aggregate completely, carefully controlling the size of the fine aggregates to ensure the best possible packing, and incorporating steel fibers (sometimes produced by grinding steel wool) into the matrix. Reactive powder concretes may also make use of silica fume as a fine aggregate. Commercial reactive powder concretes are available in the 17–21 MPa (2,500–3,000 psi) strength range.

Elasticity

The modulus of elasticity of concrete is a function of the modulus of elasticity of the aggregates and the cement matrix and their relative proportions. The modulus of elasticity of concrete is relatively constant at low stress levels but starts decreasing at higher stress levels as matrix cracking develops. The elastic modulus of the hardened paste may be in the order of 10-30 GPa and aggregates about 45 to 85 GPa. The concrete composite is then in the range of 30 to 50 GPa.

Thermal properties

Expansion and shrinkage

Concrete has a very low coefficient of thermal expansion. However, if no provision is made for expansion, very large forces can be created, causing cracks in parts of the structure not capable of withstanding the force or the repeated cycles of expansion and contraction. The coefficient of thermal expansion of Portland cement concrete is 0.000009 to 0.000012 (per degree Celsius) (8 to 12 microstrains/°C)(8-12 1/MK).[6]

Thermal Conductivity

Concrete has moderate thermal conductivity, much lower than metals, but significantly higher than other building materials such as wood, and is a poor insulator.

A layer of concrete is frequently used for 'fireproofing' of steel structures. However, the term fireproof is inappropriate, for high temperature fires can be hot enough to induce chemical changes in concrete, which in the extreme can cause considerable structural damage to the concrete.

Cracking

As concrete matures it continues to shrink, due to the ongoing reaction taking place in the material, although the rate of shrinkage falls relatively quickly and keeps reducing over time (for all practical purposes concrete is usually considered to not shrink due to hydration any further after 30 years). The relative shrinkage and expansion of concrete and brickwork require careful accommodation when the two forms of construction interface.

All concrete structures will crack to some extent. One of the early designers of reinforced concrete, Robert Maillart, employed reinforced concrete in a number of arched bridges. His first bridge was simple, using a large volume of concrete. He then realized that much of the concrete was very cracked, and could not be a part of the structure under compressive loads, yet the structure clearly worked. His later designs simply removed the cracked areas, leaving slender, beautiful concrete arches. The Salginatobel Bridge is an example of this.

Concrete cracks due to tensile stress induced by shrinkage or stresses occurring during setting or use. Various means are used to overcome this. Fiber reinforced concrete uses fine fibers distributed throughout the mix or larger metal or other reinforcement elements to limit the size and extent of cracks. In many large structures, joints or concealed saw-cuts are placed in the concrete as it sets to make the inevitable cracks occur where they can be managed and out of sight. Water tanks and highways are examples of structures requiring crack control.

Shrinkage cracking

International Journal of Multidisciplinary Research in Science, Engineering, Technology & Management (IJMRSETM)

| ISSN: 2395-7639 | www.ijmrsetm.com | Impact Factor: 7.580| A Monthly Double-Blind Peer Reviewed Journal |

| Volume 8, Issue 1, January 2021 |

DOI:10.15680/IJMRSETM.2021.0801010|

Shrinkage cracks occur when concrete members undergo restrained volumetric changes (shrinkage) as a result of either drying, autogenous shrinkage, or thermal effects. Restraint is provided either externally (i.e. supports, walls, and other boundary conditions) or internally (differential drying shrinkage, reinforcement). Once the tensile strength of the concrete is exceeded, a crack will develop. The number and width of shrinkage cracks that develop are influenced by the amount of shrinkage that occurs, the amount of restraint present, and the amount and spacing of reinforcement provided. These are minor indications and have no real structural impact on the concrete member.

Plastic-shrinkage cracks are immediately apparent, visible within 0 to 2 days of placement, while drying-shrinkage cracks develop over time. Autogenous shrinkage also occurs when the concrete is quite young and results from the volume reduction resulting from the chemical reaction of the Portland cement.

Tension cracking

Concrete members may be put into tension by applied loads. This is most common in concrete beams where a transversely applied load will put one surface into compression and the opposite surface into tension due to induced bending. The portion of the beam that is in tension may crack. The size and length of cracks is dependent on the magnitude of the bending moment and the design of the reinforcing in the beam at the point under consideration. Reinforced concrete beams are designed to crack in tension rather than in compression. This is achieved by providing reinforcing steel which yields before failure of the concrete in compression occurs and allowing remediation, repair, or if necessary, evacuation of an unsafe area.

Creep

Creep is the permanent movement or deformation of a material in order to relieve stresses within the material. Concrete that is subjected to long-duration forces is prone to creep. Short-duration forces (such as wind or earthquakes) do not cause creep. Creep can sometimes reduce the amount of cracking that occurs in a concrete structure or element, but it also must be controlled. The amount of primary and secondary reinforcing in concrete structures contributes to a reduction in the amount of shrinkage, creep and cracking.[7]

Water retention

Portland cement concrete holds water.[8] However, some types of concrete (like Pervious concrete) allow water to pass, hereby being perfect alternatives to Macadam roads, as they do not need to be fitted with storm drains.[9]

Concrete testing

Engineers usually specify the required compressive strength of concrete, which is normally given as the 28-day compressive strength in megapascals (MPa) or pounds per square inch (psi). Twenty eight days is a long wait to determine if desired strengths are going to be obtained, so three-day and seven-day strengths can be useful to predict the ultimate 28-day compressive strength of the concrete. A 25% strength gain between 7 and 28 days is often observed with 100% OPC (ordinary Portland cement) mixtures, and between 25% and 40% strength gain can be realized with the inclusion of pozzolans such as flyash, and supplementary cementitious materials (SCMs) such as slag cement. Strength gain depends on the type of mixture, its constituents, the use of standard curing, proper testing by certified technicians, and care of cylinders in transport. For practical immediate considerations, it is incumbent to accurately test the fundamental properties of concrete in its fresh, plastic state.

Concrete is typically sampled while being placed, with testing protocols requiring that test samples be cured under laboratory conditions (standard cured). Additional samples may be field cured (non-standard) for the purpose of early 'stripping' strengths, that is, form removal, evaluation of curing, etc. but the standard cured cylinders comprise acceptance criteria. Concrete tests can measure the "plastic" (unhydrated) properties of concrete prior to, and during placement. As these properties affect the hardened compressive strength and durability of concrete (resistance to freeze-thaw), the properties of workability (slump/flow), temperature, density and age are monitored to ensure the production and placement of 'quality' concrete. Depending on project location, tests are performed per ASTM International, European Committee for Standardization or Canadian Standards Association. As measurement of quality must represent the potential of concrete material delivered and placed, it is imperative that concrete technicians performing concrete tests are certified to do so according to these standards. Structural design, concrete material design and properties are often specified in accordance with national/regional design codes such as American Concrete Institute.

| ISSN: 2395-7639 | www.ijmrsetm.com | Impact Factor: 7.580| A Monthly Double-Blind Peer Reviewed Journal |

| Volume 8, Issue 1, January 2021 |

DOI:10.15680/IJMRSETM.2021.0801010|

Compressive strength tests are conducted by certified technicians using an instrumented, hydraulic ram which has been annually calibrated with instruments traceable to the Cement and Concrete Reference Laboratory (CCRL) of the National Institute of Standards and Technology (NIST) in the U.S., or regional equivalents internationally. Standardized form factors are 6" by 12" or 4" by 8" cylindrical samples, with some laboratories opting to utilize cubic samples. These samples are compressed to failure. Tensile strength tests are conducted either by three-point bending of a prismatic beam specimen or by compression along the sides of a standard cylindrical specimen. These destructive tests are not to be equated with nondestructive testing using a rebound hammer or probe systems which are hand-held indicators, for relative strength of the top few millimeters, of comparative concretes in the field.[10]

Mechanical properties at elevated temperature

Temperatures elevated above 300 °C (572 °F) degrade the mechanical properties of concrete, including compressive strength, fracture strength, tensile strength, and elastic modulus, with respect to deleterious effect on its structural changes.[11]

Chemical changes

With elevated temperature, concrete will lose its hydration product because of water evaporation. Therefore its resistance of moisture flow of concrete decreases and the number of unhydrated cement grains grows with the loss of chemically bonded water, resulting in lower compressive strength.[12] Also, the decomposition of calcium hydroxide in concrete forms lime and water. When temperature decreases, lime will reacts with water and expands to cause a reduction of strength.[13]

IV.CONCLUSION

Physical changes

At elevated temperatures, small cracks form and propagate inside the concrete with increased temperature, possibly caused by differential thermal coefficients of expansion within the cement matrix. Likewise, when water evaporates from concrete, the loss of water impedes the expansion of cement matrix by shrinking. Moreover, when the temperatures reach 573 °C (1,063 °F), siliceous aggregates transform from α-phase, hexagonal crystal system, to β-phase, bcc structure, causing expansion of concrete and decreasing the strength of the material.[14]

Spalling

Spalling at elevated temperature is pronounced, driven by vapor pressure and thermal stresses.[15] When the concrete surface is subjected to a sufficiently high temperature, the water close to the surface starts to move out from the concrete into atmosphere. However, with a high temperature gradient between the surface and the interior, vapor can also move inwards where it may condense with lower temperatures. A water-saturated interior resists the further movement of vapor into the mass of the concrete. If the condensation rate of vapor is much faster than the escaping speed of vapor out of concrete due to sufficiently high heating rate or adequately dense pore structure, a large pore pressure can cause spalling. At the same time, thermal expansion on the surface will generate a perpendicular compressive stress opposing the tensile stress within the concrete. Spalling occurs when the compressive stress exceeds the tensile stress.[16]

REFERENCES

1. Lin, T.Y.; Burns, Ned H. (1981). Design of Prestressed Concrete Structures (Third ed.). New York, US: John Wiley & Sons. ISBN 0-471-01898-8. Archived from the original on 8 February 2017. Retrieved 24 August 2016.
2. ^ a b c d e f g Federation Internationale du Beton (February 2005). fib Bulletin 31: Post-tensioning in Buildings (PDF). FIB. ISBN 978-2-88394-071-0. Archived from the original (PDF) on 8 February 2017. Retrieved 26 August 2016.
3. ^ American Concrete Institute. "CT-13: ACI Concrete Terminology". American Concrete Institute. Farmington Hills, Michigan US: ACI. Archived from the original on 11 December 2016. Retrieved 25 August 2016. Post-tensioned concreted is "structural concrete in which internal stresses have been introduced to reduce potential tensile stresses in the concrete resulting from loads."

| ISSN: 2395-7639 | www.ijmrsetm.com | Impact Factor: 7.580| A Monthly Double-Blind Peer Reviewed Journal |

| Volume 8, Issue 1, January 2021 |

DOI:10.15680/IJMRSETM.2021.0801010|

4. ^ Warner, R. F.; Rangan, B. V.; Hall, A. S.; Faulkes, K. A. (1988). Concrete Structures. South Melbourne, Australia: Addison Welsley Longman. pp. 8–19. ISBN 0-582-80247-4.
5. ^ a b c d e f g h i j k Warner, R. F.; Faulkes, K. A. (1988). Prestressed Concrete (2nd ed.). Melbourne, Australia: Longman Cheshire. pp. 1–13. ISBN 0-582-71225-4.
6. ^ a b Post-Tensioning Institute (2006). Post-Tensioning Manual (6th ed.). Phoenix, AZ US: PTI. pp. 5–54. ISBN 0-9778752-0-2.
7. ^ Tokyo Rope Mfg Co Ltd. "CFCC Pre-tensioning Manual" (PDF). MaineDOT. Archived (PDF) from the original on 8 February 2017. Retrieved 19 August 2016.
8. ^ "Tendons having one or more deviations from a straight line, either vertically or horizontally, between the ends of the structure"
9. ^ a b c d e f g h i Aalami, Bijan O. (5 September 1994). "Unbonded and bonded post-tensioning systems in building construction" (PDF). PTI Technical Notes. Phoenix, Arizona US: Post-Tensioning Institute (5). Archived (PDF) from the original on 23 November 2016. Retrieved 23 August 2016.
10. ^ Aalami, Bijan O. (February 2001). "Nonprestresed Bonded Reinforcement in Post-Tensioned Building Design" (PDF). ADAPT Technical Publication (P2-01). Archived (PDF) from the original on 8 February 2017. Retrieved 25 August 2016.
11. ^ Bailey, Colin G.; Ellobody, Ehab (2009). "Comparison of unbonded and bonded post-tensioned concrete slabs under fire conditions". The Structural Engineer. 87 (19). Archived from the original on 17 September 2016. Retrieved 22 August 2016.
12. ^ Bondy, Kenneth B. (December 2012). "Two way post-tensioned slabs with bonded tendons" (PDF). PTI Journal. US: Post-Tensioning Institute. 8 (2): 44. Archived (PDF) from the original on 28 August 2016. Retrieved 25 August 2016.
13. ^ Szilard, Rudolph (October 1969). "Survey on the Durability of Prestressed Concrete Structures" (PDF). PCI Journal: 62–73. Archived (PDF) from the original on 16 September 2016. Retrieved 7 September 2016.
14. ^ a b Podolny, Walter (September 1992). "Corrosion of Prestressing Steels and its Mitigation" (PDF). PCI Journal. 37 (5): 34–55. doi:10.15554/pcij.09011992.34.55. S2CID 109223938. Archived (PDF) from the original on 16 September 2016. Retrieved 7 September 2016.
15. ^ De Schutter, Geert (10 May 2012). Damage to Concrete Structures. CRC Press. pp. 31–33. ISBN 978-0-415-60388-1. Archived from the original on 17 April 2020. Retrieved 7 September 2016.
16. ^ Ryall, M. J.; Woodward, R.; Milne, D. (2000). Bridge Management 4: Inspection, Maintenance, Assessment and Repair. London: Thomas Telford. pp. 170–173. ISBN 978-0-7277-2854-8. Archived from the original on 17 April 2020. Retrieved 7 September 2016.
17. ^ CARES. "Post-Tensioning Systems". www.ukcares.com. CARES. Archived from the original on 11 June 2016. Retrieved 7 September 2016.
18. ^ NACE. "Corrosdion Failures: Lowe's Motor Speedway Bridge Collapse". www.nace.org. NACE. Archived from the original on 24 September 2016. Retrieved 7 September 2016.
19. ^ Ed Davey and Rebecca Cafe (3 December 2012). "TfL report warned of Hammersmith Flyover collapse risk". BBC News, London. Archived from the original on 3 December 2012. Retrieved 3 December 2012.
20. ^ Freyssinet. "Extending the Life of Hammersmith Flyover". www.freyssinet.com. Freyssinet. Archived from the original on 15 September 2016. Retrieved 7 September 2016.
21. ^ "GiùilviadottoPetrulla, panicosullaStatale 626". 8 July 2014.
22. ^ "Churchill Way Flyovers Deconstruction Scheme". Archived from the original on 9 April 2020. Retrieved 8 April 2020.
23. ^ Australian Society for History of Engineering and Technology. "An Engineering Walk around the Sydney Opera House" (PDF). ashet.org.au. ASHET. Archived (PDF) from the original on 8 February 2017. Retrieved 1 September 2016.
24. ^ Martin, Owen; Lal, Nalean. "Structural Design of the 84 Storey World Tower in Sydney" (PDF). ctbuh.org. Council on Tall Buildings and Urban Habitat. Archived (PDF) from the original on 14 April 2016. Retrieved 1 September 2016.
25. ^ "The Tower, One St. George Wharf, London, UK". cclint.com. CCL. Archived from the original on 30 April 2020. Retrieved 1 September 2016.

| ISSN: 2395-7639 | www.ijmrsetm.com | Impact Factor: 7.580| A Monthly Double-Blind Peer Reviewed Journal |

| Volume 8, Issue 1, January 2021 |

DOI:10.15680/IJMRSETM.2021.0801010|

26. ^ Knoll, Franz; Prosser, M. John; Otter, John (May–June 1976). "Prestressing the CN Tower" (PDF). PCI Journal. 21 (3): 84–111. doi:10.15554/pcij.05011976.84.111. Archived (PDF) from the original on 15 September 2016. Retrieved 2 September 2016.
27. ^ VSL. "Kai Tak Cruise Terminal Building - Hong Kong" (PDF). vslvietnam.com. VSL. Archived (PDF) from the original on 14 September 2016. Retrieved 1 September 2016.
28. ^ ARUP. "International Commerce Centre (ICC)". www.arup.com. ARUP. Archived from the original on 4 September 2016. Retrieved 2 September 2016.
29. ^ CM Engineering Consultants. "Ocean Heights 2, Dubai UAE". www.cmecs.co. CMECS. Archived from the original on 24 September 2016. Retrieved 1 September 2016.
30. ^ Design Build Network. "Eureka Tower, Melbourne Victoria Australia". www.designbuild-network.com. Design Build Network. Archived from the original on 13 February 2012. Retrieved 1 September 2016.
31. ^ Martinez, Julio; Gomez, Miguel (July 2008). "Torre Espacio. Building Structure". Hormigon y Acero. Madrid, Spain. 59 (249): 19–43. ISSN 0439-5689. Archived from the original on 8 February 2017. Retrieved 1 September 2016.
32. ^ BBR Network (2016). "Reaching for the Skies" (PDF). Connaect. 10: 51. Archived (PDF) from the original on 22 September 2016. Retrieved 2 September 2016.
33. ^ BBR Network (2016). "Gateway to South Eastern Europe" (PDF). Connaect. 10: 37–41. Archived (PDF) from the original on 22 September 2016. Retrieved 2 September 2016.
34. ^ Schofield, Jeff (2012). "Case Study: Capital Gate, Abu Dhabi" (PDF). CTBUH Journal (11). Archived (PDF) from the original on 30 July 2016. Retrieved 2 September 2016.
35. ^ Tang, Man-Chung (2007). "Evolution of Bridge Technology" (PDF). IABSE Symposium Proceedings: 7. Archived (PDF) from the original on 17 September 2016. Retrieved 5 September 2016.
36. ^ Hewson, Nigel R. (2012). Prestressed Concrete bridges: design and Construction. ICE. ISBN 978-0-7277-4113-4. Archived from the original on 17 April 2020. Retrieved 2 September 2016.
37. ^ R. L. M'ilmoyle (20 September 1947). "Prestressed Concrete Bridge Beams Being Tested in England". Railway Age. Vol. 123. Simmons-Boardman Publishing Company. pp. 54–58. Archived from the original on 17 April 2020. Retrieved 25 August 2018.
38. ^ "History of Prestressed Concrete in UK". Cambridge University. 2004. Archived from the original on 25 August 2018. Retrieved 25 August 2018.
39. ^ Historic England. "Adam Viaduct (1061327)". National Heritage List for England. Retrieved 25 August 2018.
40. ^ "History of Concrete Bridges". Concrete Bridge Development group. Archived from the original on 14 December 2013. Retrieved 25 August 2018.
41. ^ Main Roads Western Australia. "Structures Engineering Design Manual" (PDF). www.mainroads.wa.gov.au. MRWA. pp. 17–23. Archived (PDF) from the original on 16 September 2016. Retrieved 2 September 2016.
42. ^ LaViolette, Mike (December 2007). Bridge Construction Practices Using Incremental Launching (PDF). AASHTO. p. Appendix A. Archived (PDF) from the original on 30 November 2016. Retrieved 7 September 2016.
43. ^ Leonhardt, Fritz (September 1987). "Cable Stayed Bridges with Prestressed Concrete". PCI Journal. 32 (5): 52–80. doi:10.15554/pcij.09011987.52.80. Archived from the original on 16 September 2016. Retrieved 7 September 2016.
44. ^ Roemermann, A. C. (February 1965). "Prestressed Concrete Dams: 1936–1964" (PDF). PCI Journal. 10: 76–88. doi:10.15554/pcij.02011965.76.88. Archived (PDF) from the original on 16 September 2016. Retrieved 2 September 2016.
45. ^ Brown, E. T. (February 2015). "Rock-engineering design of post-tensioned anchors for dams - A review". Journal of Rock Mechnanics and Geological Engineering. 7 (1): 1–13. doi:10.1016/j.jrmge.2014.08.001.
46. ^ Institution of Engineers Australia. "Catagunya Dam Tasmania" (PDF). www.engineersaustralia.org.au. IEAust. Archived (PDF) from the original on 14 September 2016. Retrieved 2 September 2016.
47. ^ Xu, Haixue; Benmokrane, Brahim (1996). "Strengthening of existing concrete dams using post-tensioned anchors: A state-of-the-art review". Canadian Journal of Civil Engineering. 23 (6): 1151–1171. doi:10.1139/l96-925. Archived from the original on 29 June 2020. Retrieved 2 September 2016.
48. ^ Cavill, Brian (20 March 1997). "Very High capacity Ground Anchors Used in Strengthening Concrete Gravity Dams". Conference Proceedings. London UK: Institution of Civil Engineers: 262.

| ISSN: 2395-7639 | www.ijmrsetm.com | Impact Factor: 7.580| A Monthly Double-Blind Peer Reviewed Journal |

| Volume 8, Issue 1, January 2021 |

DOI:10.15680/IJMRSETM.2021.0801010|

49. ^ Priestley, M. J. N. (July 1985). "Analysis and Design of Prestressed Circular Concrete Storage Tanks" (PDF). PCI Journal: 64–85. doi:10.15554/pcij.07011985.64.85. Archived (PDF) from the original on 16 September 2016. Retrieved 5 September 2016.
50. ^ Ghali, Amin (12 May 2014). Circular Storage Tasnks and Silos (Third ed.). CRC Press. pp. 149–165. ISBN 978-1-4665-7104-4. Archived from the original on 17 April 2020. Retrieved 5 September 2016.
51. ^ Gilbert, R. I.; Mickleborough, N. C.; Ranzi, G. (17 February 2016). Design of Prestressed Concrete to AS3600-2009 (Second ed.). CRC Press. ISBN 978-1-4665-7277-5. Archived from the original on 17 April 2020. Retrieved 5 September 2016.
52. ^ a b Bangash, M. Y. H. (2011). Structures for Nuclear Facilities – Analysis, Design and Construction. London: Springer. pp. 36–37. ISBN 978-3-642-12560-7. Archived from the original on 17 April 2020. Retrieved 5 September 2016.
53. ^ Gerwick, Ben C. (13 February 1997). Construction of Prestressed Concrete Structures (Second ed.). New York: John Wiley & Sons. pp. 472–494. ISBN 0-471-53915-5. Archived from the original on 17 April 2020. Retrieved 5 September 2016.
54. ^ a b Raju, Krishna (1 December 2006). Prestressed Concrete (PDF) (Fourth ed.). New Delhi: Tata McGraw Hill. ISBN 0-07-063444-0. Archived (PDF) from the original on 11 September 2016. Retrieved 5 September 2016.
55. ^ "Building Post-Tensioned Slabs on Grade". www.concreteconstruction.net. Concrete Construction. Archived from the original on 18 September 2016. Retrieved 5 September 2016.
56. ^ Merritt, David; Rogers, Richard; Rasmussen, Robert (March 2008). Construction of a Precast Prestressed Concrete Pavement Demonstration Project on Interstate 57 near Sikeston, Missouri (PDF). US DOT Federal Highway Administration. Archived (PDF) from the original on 15 September 2016. Retrieved 5 September 2016.
57. ^ Connall, John; Wheeler, Paul; Pau, Andrew; Mihov, Miho. "Design of the Main Spans, Second Gateway Bridge, Brisbane" (PDF). www.cmnzl.co.nz. Archived (PDF) from the original on 17 September 2016. Retrieved 2 September 2016.
58. ^ DYWIDAG. "Incheon Bridge, Seoul, South Korea". www.dywidag-systems.a. DYWIDAG. Archived from the original on 10 August 2016. Retrieved 2 September 2016.
59. ^ "SRG Remote Projects" (PDF). www.srglimited.com.au. SRG Limited. p. 10. Archived (PDF) from the original on 26 February 2017. Retrieved 6 September 2016.
60. ^ Eberhardt, A.; Veltrop, J. A. (August 1965). "1300-Ton-Capacity Prestressed Anchors Stabilize Dam" (PDF). PCI Journal. 10 (4): 18–43. doi:10.15554/pcij.08011965.18.36. Archived (PDF) from the original on 16 September 2016. Retrieved 6 September 2016.
61. ^ Precast/Prestressed Concrete Institute
62. ^ "Canadian Precast/Prestressed Concrete Institute". Archived from the original on 5 May 2020. Retrieved 12 September 2016.
63. ^ "Post-Tensioning Association". Archived from the original on 19 September 2016. Retrieved 12 September 2016.
64. ^ "Post Tensioning Institute of Australia". Archived from the original on 25 September 2016. Retrieved 12 September 2016.
65. ^ "South African Post Tensioning Association". Archived from the original on 25 May 2016. Retrieved 12 September 2016.

INTERNATIONAL JOURNAL

OF MULTIDISCIPLINARY RESEARCH

IN SCIENCE, ENGINEERING, TECHNOLOGY AND MANAGEMENT