New Concrete Materials in Civil Engineering

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ABSTRACT

The evolution of new concrete materials stands as a transformative force within the realm of civil engineering, offering a spectrum of innovative solutions that address longstanding challenges and elevate the standards of construction practice. These materials, ranging from advanced composites to eco-friendly formulations, represent a convergence of cutting-edge research, technological advancement, and sustainability imperatives, poised to redefine the landscape of infrastructure development.At the forefront of this paradigm shift is the emergence of high-performance concrete, engineered to surpass traditional counterparts in terms of strength, durability, and resilience. By harnessing advanced admixtures and reinforcement techniques, high-performance concrete enables the construction of structures capable of withstanding extreme loads, environmental stresses, and seismic events, thereby enhancing safety, longevity, and structural integrity.

The advent of self-healing concrete introduces a groundbreaking approach to maintenance and durability management. Through the incorporation of microorganisms, encapsulated healing agents, or intrinsic chemical reactions, self-healing concrete possesses the capacity to autonomously repair cracks and fissures, mitigating the need for costly interventions and extending the lifespan of infrastructure assets. The integration of environmentally-friendly concrete materials underscores a concerted effort towards sustainable construction practices. From recycled aggregates to supplementary cementitious materials, these eco-conscious alternatives offer not only reduced environmental impact but also enhanced performance characteristics, contributing to a holistic approach to infrastructure development that prioritizes both durability and environmental stewardship.

Keyword: - *Concrete, Civil Engineering, New Materials, Applications, Sustainability*

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1. Introduction

In recent decades, the landscape of civil engineering has undergone a profound transformation, fueled by relentless innovation and technological advancement within the cement and concrete industry. This evolution has given rise to a plethora of new concrete materials, each offering unique properties and capabilities that challenge the conventions of traditional construction practices. In this dynamic milieu, the integration of these novel materials has emerged as a cornerstone of modern civil engineering, driving unprecedented advancements in durability, strength, and sustainability.The cement industry's relentless pursuit of progress has yielded a rich tapestry of concrete materials that extend far beyond the confines of conventional mixes. These new formulations encompass a spectrum of innovations, from high-performance concretes fortified with cutting-edge admixtures to eco-friendly variants engineered to minimize environmental impact. Such diversity reflects not only the industry's commitment to pushing the boundaries of material science but also its recognition of the multifaceted demands placed upon modern infrastructure. The significance of these new concrete materials lies not merely in their novelty, but in their ability to address longstanding challenges inherent to civil engineering. Unlike their predecessors, which often struggled to withstand the rigors of time and environmental exposure, these advanced materials boast superior durability and longevity. They are engineered to withstand a myriad of stressors, from corrosive chemicals to seismic activity, ensuring the longevity and reliability of critical infrastructure assets. The advent of new concrete materials heralds a paradigm shift in sustainability within the construction industry. As environmental concerns loom large on the global stage, the imperative for eco-friendly construction practices has never been more pronounced. In response, researchers and engineers have developed a range of environmentally-conscious concrete materials, leveraging recycled aggregates, supplementary cementitious materials, and novel production techniques to reduce carbon emissions and minimize waste. At the heart of this transformative journey lies the recognition that materials are not merely inert components of construction but fundamental drivers of performance, resilience, and longevity. The integration of new concrete materials into civil engineering projects represents a departure from convention, a bold step towards a future where infrastructure is not only functional but sustainable, resilient, and adaptable to the evolving needs of society.

2. The present classification of concrete

In light of recent advancements in concrete ingredients and production technology, a classification of cement-based concrete has been devised, reflecting varying levels of strength and performance. This classification delineates conventional concrete (CC) up to grade 60 MPa, high-strength concrete (HSC) ranging from grades 60 to 90 MPa, very high-strength concrete (VHSC) spanning grades 90 to 130 MPa, reactive powder concrete (RPC) with grades from 200 to 800 MPa, and high-performance lightweight concrete (HPLC) surpassing 55 MPa.This classification primarily hinges on concrete's compressive strength, yet the concept of high-performance concrete (HPC) has been introduced to address additional criteria essential in specific civil engineering applications. These criteria include absorbability, carbonization resistance, freeze resistance, and grindability, collectively enhancing concrete's resilience in aggressive environments. Notably, HPC often aligns with HSC or VHSC grades, making it a preferred choice for bridges, industrial and municipal buildings, and prestressed concrete structures across various degrees of prestress.

A critical consideration in achieving desired concrete properties lies in the formulation of mixture proportions. These mixtures typically leverage natural resources available within a region, resulting in compositional differences even when similar performance characteristics are attained Table 1. The influence of the technological process employed in concrete production cannot be overstated, as it significantly impacts the final composition and properties of the concrete. The author's research is intricately linked with the production of prestressed concrete pipes, highlighting the practical application and relevance of these advancements in concrete technology within specific civil engineering domains.

Table 1Concrete mixtures and materials properties

Mixtureno.	1(B85)	2(B105)	3(B100)[a]
CementPZ45F(kg/m^3)Cement PZ 55 (kg/m^3)Cement CP 45 (kg/m^3) Aggregate(kg/m^3)	450	450	450
0/2mm	815	820	457
2/4mm	339	342	970
4/8mm	543	547	406
Silicafume(kg/m^3)	45	45	45
Water(l/m^3)	164	149	130
w/cratio	0.364	0.331	0.29
Superplasticiser(1/m^3)	10	17.5	10.8
Retarder(1/m^3)	1.8	1.8	
$f_{cube,28d}$(MPa)	96.1	111.4	108
E_o(MPa)	369000	43200	42300
[a] Theauthor'sresearch.			

3. Characteristic properties of HSC:

In Fig. 1, notable disparities in the compressive strength evolution over time between high-strength concrete (HSC) and conventional concrete are clearly delineated, providing valuable insights into their respective performance trajectories. The distinguishing features of HSC facilitate expedited construction processes, allowing for prestressed structures to be initiated as early as 48 hours post-concrete placement. Figure 2 illustrates the fundamental σ–צ relationship for HSC concrete, revealing distinct characteristics compared to conventional concrete. Notably, HSC exhibits a reduced sensitivity to load velocity in influencing its strength (fc), alongside a marginally higher Poisson's ratio (vc) and a significantly greater ultimate strain. Intriguingly, experimental observations under controlled longitudinal deformation reveal a snap-back phenomenon in the σ–צ relationship following the attainment of the maximum stress (σ). In contrast to conventional concrete, where specimens typically fail catastrophically, HSC specimens demonstrate a divergent failure behavior, indicative of greater fracture energy inherent to HSC.These findings underscore the nuanced mechanical properties and behavior of HSC, presenting both challenges and opportunities in engineering design and construction practices. By elucidating these distinctions, researchers and practitioners can leverage the unique attributes of HSC to optimize structural performance and resilience in diverse applications.

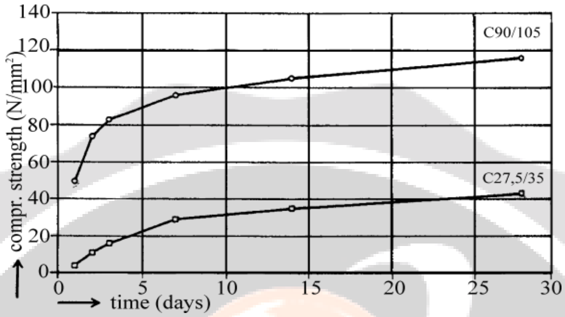

Fig. 1.Development of cube strength C90/105 and C27.5/35 with time.

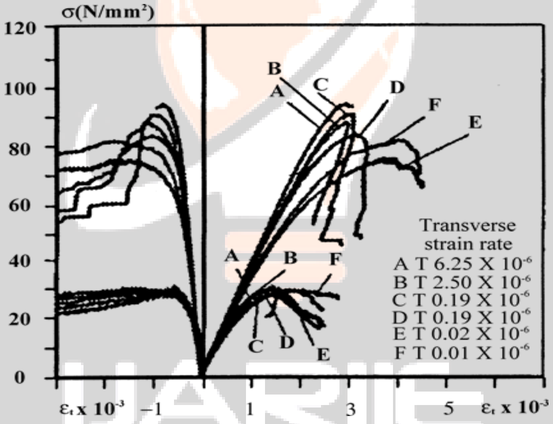

Fig. 2. Stress–strain relationship for HSC subjected to various loading rates.

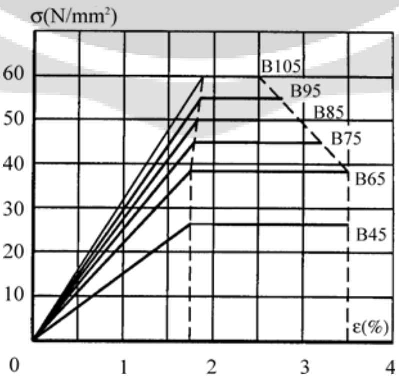

Fig. 3. Design stress–strain relationships for concrete in compression (Dutch recommendation for HSC)

In terms of design considerations, selecting the suitable characteristic strength (fck) level is paramount for various concrete grades. The Dutch provisions, as depicted in Fig. 3, offer guidelines in this regard, closely resembling the German standards.

A notable advancement in concrete technology is Reactive Powder Concrete (RPC), predominantly employed in fiber-concrete composites. Presently, RPC is available in two grades: RPC-200 and RPC-800, with essential parameters for both grades outlined in Table 2. RPC-800 exclusively exists as a fiber-concrete composite.

Table 2 Characteristic of RPC

	RPC-200	RPC-800
Presettingpressurisation	None	50MPa
Heat-treating	20–90°C	250–400°C
Compressivestrength	170–230MPa	490–810MPa
Flexuralstrength	30–60MPa	45–141MPa
Fractureenergy	20000–40000J/m^2	1200–20000J/m^2
Young'smodulus	50–60GPa	65–75GPa

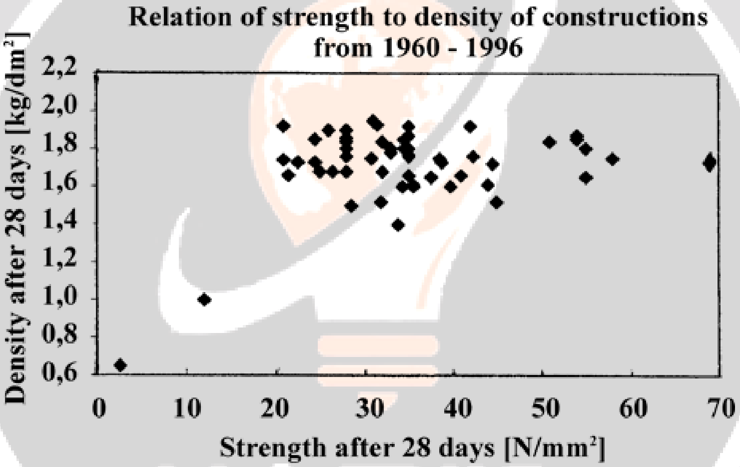

Fig. 4.The relation between strength and weight by volume in light- weight concrete.

This represents a significant advancement in cement concrete technology, characterized by its novel properties. Notably, this concrete exhibits remarkably high gas permeability, water absorbability, resistance to carbonization and freezing, as well as grindability. Anticipated applications for this material encompass building columns, prestressed members, industrial floors, thin slabs, bridge decks, overlays, bearings, joints, seismic joint locations, guardrails, abrasion-resistant products, blast or impact-resistant structures, security doors and vaults, waste containment systems, transportation vessels, storage tanks, prestressing anchorage, and molds.

In lightweight concrete, the relationship between strength and volume weight assumes particular importance. Noteworthy progress in this area is illustrated in Fig. 4, as per the provided data.

4. Application of HSC and HPC:

High-strength concrete holds particular utility in prestressed concrete structures, finding application across various branches of civil engineering. However, present-day resistance to its adoption persists, stemming from entrenched practices within certain specialist groups and specialized production facilities. For instance, research by PCI [9] indicates a sluggish uptake of High Performance Concrete (HPC) in plants manufacturing precast concrete elements. The field of precasting in civil engineering appears conservative, with limited enthusiasm among engineers for embracing advanced control technology or additional training. Another factor, highlighted in PCI's investigation, is the preference for High Strength Concrete (HSC) due to streamlined mass production organization and consistent order provision. The inquiry further reveals that HSC is most commonly employed in precast columns (45%), prestressed bridge girders (40%), parking structures and garages (20%), piles (10%), and architectural details (10%). While this trend may evolve in the future, it underscores the current dynamics shaping the adoption of high-strength concrete in civil engineering practices.

On the base of literature reviewed, a few examples of high strength and HPC application in engineering practice arepresented. Adverted examples of this concrete application arebuildings in Holland. In the office building in Breda the whole structure is made from concrete grade C95, the span length of floors in this structure, without extra supports, with a conventional height of floor, being 12.60 m. This allows for efficient space organization, with facade elements of the walls spanning 43.0 meters without requiring expansion joints. Remarkably, the construction cycle for both walls and floors was completed within a single day.Thanks to the implementation of High Performance Concrete (HPC), a significant reduction in section size, amounting to 68%, was achieved. Notably, this marks the pioneering use of HPC in structural construction in Holland. In Poland, an intriguing application of HPC in municipal engineering involves the fabrication of two-directionally prestressed pipes for water lines and sewerage systems. Utilizing HPC, as detailed in the author's composition (Table 1), has enabled their deployment in transportation and industrial settings subjected to substantial dynamic loads. Strength tests conducted on these pipes are depicted in Fig. 5.Another notable instance of HPC application is seen in the construction of an ecological protection barrier at the offshore platform Ekofisk in the North Sea near Norway. These prestressed barriers were fashioned using V75/80 concrete, tailored to meet specialized requirements. The Troll platform stands out as one of the largest concrete platforms, boasting a total height of 472 meters, inclusive of the flare boom.The concrete gravity structure contains 245 000 m3of HSC. The photograph (Fig. 6) shows the platform and compare the structure to London's Tower Bridge.

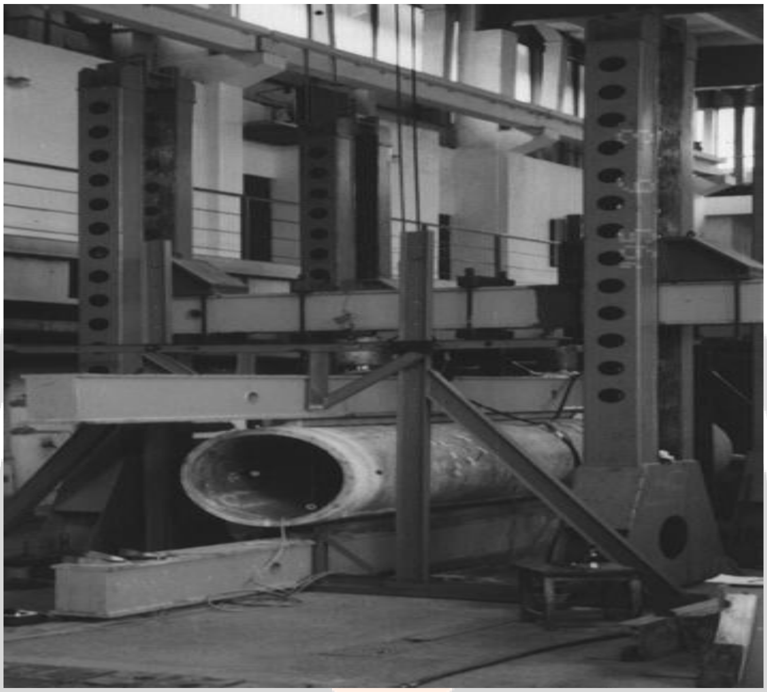

Fig. 5.A pipe on the test stand.

Fig. 6.The Troll platform.

An intriguing application of High Performance Concrete (HPC) in prestressed concrete structures is exemplified by piles featuring a unique concrete thread that can be screwed into the soil without the need for vibration or noise. These piles, with an optimal diameter ranging from 0.50 to 0.60 meters, leverage the exceptional properties of high-strength concrete, enabling their use even in contaminated soil. The pioneering use of such piles dates back to their deployment in the construction of a railway viaduct in Utrecht in 1992.

Undoubtedly, this type of concrete holds promise for the potential construction of the planned bridge over Gibraltar. Two variants of pylons are envisaged: the first standing at a height of 1075 meters (625 meters above the deck), while the second soaring to a height of 1350 meters (900 meters above the deck).In Hertogenbosh, within the "Office of the Future" building, a precast column of variable section (depicted in Fig. 7) was erected. The top and bottom sections of the column were crafted from concrete C60, while the middle segment was composed of C120 concrete. During the construction of the Normandie Bridge, the application of HPC facilitated a 30% reduction in the thickness of the box section walls within the pylons (as illustrated in Fig. 8), decreasing from 0.60 to 0.40 meters. This yielded significant economic benefits in one of Europe's largest bridge structures.

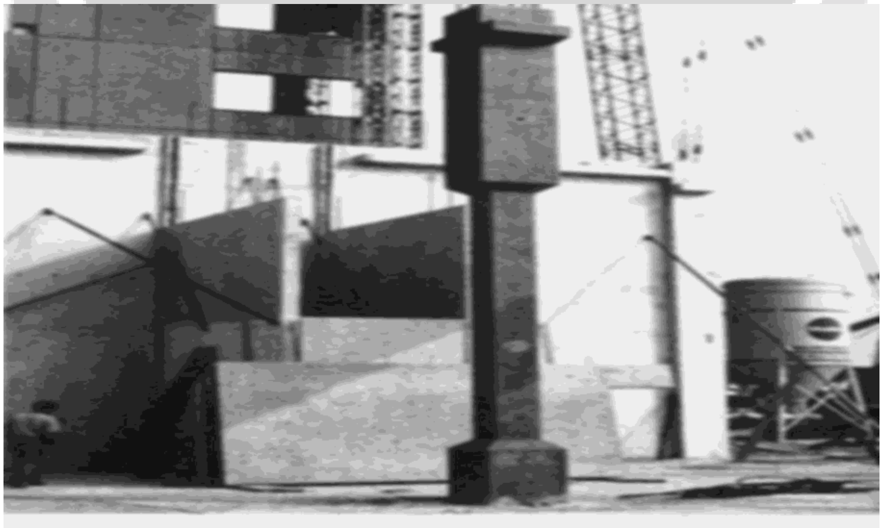

Fig. 7.Demonstration column of HSC in the Office of the Future.

The economic impact of High Strength Concrete (HSC) application in Louisiana in 1988 was substantiated through concrete results. By employing HSC, the costs associated with bridge construction were slashed by a notable 25%. This reduction was primarily attributed to a decrease in the number of

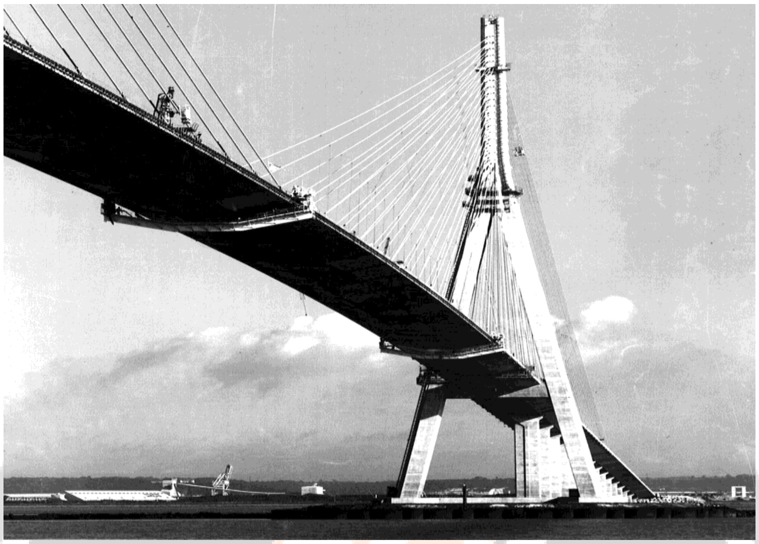

Fig. 8.Normandie Bridge pylon.

Fig. 9. Design concept of the bridge across the Vistula.

A significant reduction in transport and installation efforts was achieved by decreasing the number of major girders from 9 to 4, coupled with a slight increase in slab thickness by 2.5 cm.High Performance Concrete (HPC) was also employed in Poland for the construction of a bridge near Cracow (Chabo´wka). Additionally, there are plans to incorporate HPC in one of the design concepts for the bridge near Płock, spanning the Vistula river (refer to Fig. 9).

An intriguing proposal regarding the use of Reactive Powder Concrete (RPC) is outlined in. This involves the application of prestressed concrete structures made from high-grade fiber-concrete without passive reinforcement.

Experiments conducted on a 10.0-meter-long beam, as illustrated in Fig. 10, demonstrated the excellent performance of such structures fabricated from RPC-200 concrete (see Fig. 10). Notably, despite the of the lack of transverse reinforcement, the cracking did not take place in the support zone and the limit capacity was achieved by breaking of the prestressing tendons without the destruction of the concrete compressive zone.One could argue that High Strength Concrete (HSC) is typically employed in tall structures such as chimneys, TV towers, and tall public buildings. Notably, an intriguing analysis regarding the use of HSC in the latter category of structures is presented in.It's worth noting the resurgence of the old concept of reinforcement using high-strength prestressed concrete. Experiments conducted with the reinforcement depicted in Fig. 11 highlight the advantages of such solutions (refer to Fig. 12).

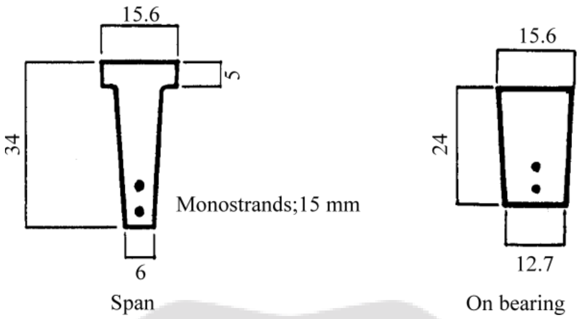

Fig. 10. Transverse cross-section (dimensions: m).

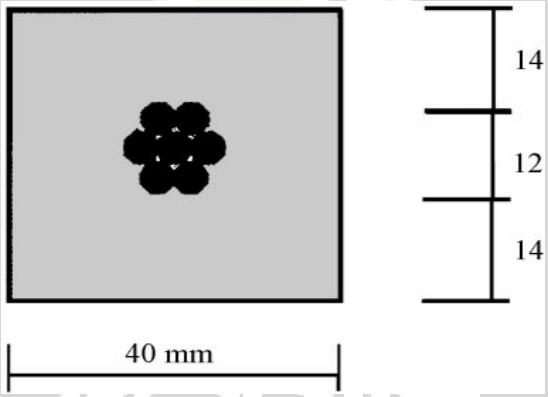

Fig. 11.Cross-section of the prestressed bar.

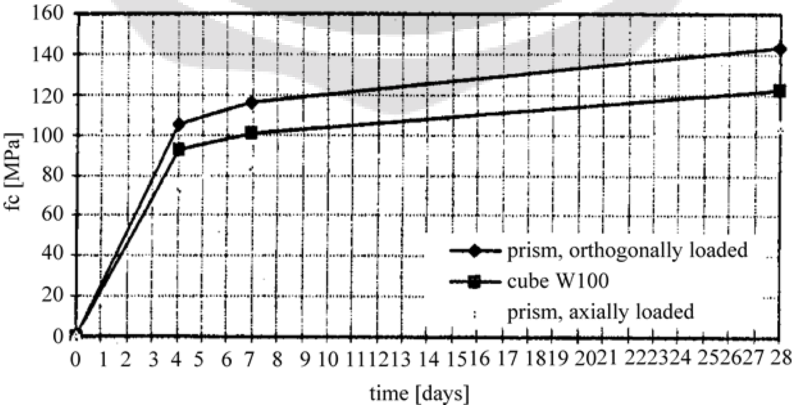

Fig. 12.Development of high strength mortar (used for prestressed bars) with time.

Table 3The tallest concrete structures in the world

Building	Location	Height(m)	Yearofcompletion
TwinTowers	KualaLumpur	450	1996
CentralPlaza	Hongkong	374	1992
311SouthWacherDrive	Chicago	292	1989
WaterTowerPlace	Chicago	262	1976
Messeturn	Frankfurt	253	1990
Cityspire	NewYork	248	1988
RialtoCentre	Melbourne	243	1987
Proposedmillenniumtowerandskyscrapers LondonMillenniumCentre	London	376	
ShanghaiFinancialCentre	Shanghai	460	
NewYorkSockExchangeTower	NewYork	546	
Bombay TVTower	Bombay	560	
TokyoMillenniumTower	Tokyo	840	
GibraltarCrossing—pylon	Spain—Morocco	1350	

Table 3 provides a compilation of tall concrete structures and proposals for the construction of millennium skyscrapers for the year 2000, showcasing potential applications of High Strength Concrete (HSC).

5. Conclusions

In conclusion, the exploration of new concrete materials in civil engineering represents an ongoing journey characterized by continuous innovation and evolution. Despite significant advancements made thus far, the present state of technological research in this domain remains open-ended. Anticipated are further improvements and the emergence of entirely new concepts in concrete technology. This is underscored by the recognition of the need for formal regulation and standardization within the realm of new types of cement-based concrete. A pertinent example of this imperative is the Fifth International Symposium on Utilization of High Strength/High Performance Concrete held in Norway in 1999. Furthermore, the pressing need for standardization, particularly on a European scale through initiatives like Eurocode and national standards, highlights the challenges inherent in the design and implementation of new generation concrete. These challenges extend to methodologies for laboratory and in situ testing of materials and construction techniques.

As we navigate these complexities, it becomes evident that collaboration, research, and a commitment to innovation will be essential in realizing the full potential of new concrete materials in shaping the future of civil engineering. With concerted efforts and a focus on standardization, the stage is set for continued advancements that will enhance the resilience, efficiency, and sustainability of infrastructure projects worldwide.

6. References

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