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Box Pushing Technology: A Comprehensive Review.

Sulfath. H*, Nifa Thaslim. M*, Beena Kumari IP*

**B. Tech Student, Department of Civil Engineering, Ahalia School of Engineering and Technology, Palakkad, 678557*

**B. Tech Student, Department of Civil Engineering, Ahalia School of Engineering and Technology, Palakkad, 678557*

***Assistant Professor, Department of Civil Engineering, Ahalia School of Engineering and Technology, Palakkad, 678557*

A B S T R A C T

The fast-paced growth of transportation and urban infrastructure has come to emphasize the demands for surface-minimal, cost-effective, and environmentally friendly construction methods. Traditional open-cut excavation tends to generate issues of traffic disruption, noise pollution, relocation of utilities, and safety hazards, especially in urban settings. Box Pushing Technology presents an effective trenchless solution, allowing precast reinforced concrete box structures to be installed under existing utilities, railways, and roads with minimal disturbance. This review paper synthesizes the existing body of knowledge on Box Pushing Technology in terms of methodology, design aspects, and construction techniques. Major issues like soil stability, ground settlement, large thrust forces, and water level variations are addressed, along with innovations and countermeasures to counter them. Both pros—e.g., lower environmental impact, quicker project delivery, and enhanced safety—and cons, such as high upfront cost and specialized equipment, are analyzed. Specific attention is drawn to the Indian urban environment, where the method has been used with increasing frequency in metro rail construction, highway underpasses, and sewerage networks. Case studies emphasize successful uses and site-specific customizations. The study concludes by setting research gaps and suggesting future developments, such as optimization of pushing loads, implementation of intelligent monitoring systems, and the use of automation to improve efficiency and wider utilization.

Keywords: Box Pushing Technology, trenchless construction, precast concrete box structures, urban infrastructure, environmental impact, highway underpass, intelligent monitoring

1. Introduction

The high rate of urbanization and the ongoing growth of transport infrastructure have necessitated an urgent need for construction techniques that not only provide efficiency but also cause minimal disturbance to the urban landscape. In highly populated cities, the preservation of unbroken traffic flow and minimizing environmental degradation during infrastructure construction is a vital issue for engineers and urban planners to address. Conventional open-cut excavation methods, although extensively employed to build underpasses, culverts, and utility corridors, tend to cause serious maladies like mass traffic congestion, utility diversion, enhanced noise and dust pollution, escalated accident possibilities, and longer project timelines. These problems underscore the necessity for different methods that can balance infrastructure building and sustainable urban dwelling. Trenchless construction technologies have come to the forefront as a sound alternative to overcoming the drawbacks of conventional open-cut practices. Among these, Box Pushing Technology (BPT) has drawn major interest as a special technique for the precast reinforced concrete box structure installation under existing road and railway tracks with minimal surface excavation. It entails driving precast box sections into the ground using hydraulic jacks while excavating soil off the front edge at the same time. The process allows the building of underpasses, subways, and utility tunnels with minimal disruption to surface operations, thus mitigating one of the biggest challenges of construction in modern urban areas: maintaining continuity of surface traffic and services when building underground. The relevance of Box Pushing Technology is more than being convenient, as it resonates with the tenets of sustainable construction and resilient infrastructure development. By lessening surface disturbances, the process keeps environmental degradation to a minimum, avoids widespread displacement of utilities, and improves safety for workers and the general public. In addition, its flexibility in limited urban environments makes it a preferred choice for city planners wanting to increase infrastructure capacity without causing significant disruption to the existing systems.

But amidst all its many benefits, the technology also has its own set of limitations and drawbacks that limit it from being widely adopted. Some of the issues with soil compatibility, high capital equipment cost, need for expert skill, and some structural restraints need to be analyzed critically to know the actual capabilities of this technology. Thus, there is a need for a systematic review and appraisal of Box Pushing Technology to determine its extent of applicability to varied geotechnical and urban settings. This review paper seeks to offer an in-depth understanding of Box Pushing Technology through an investigation of its basic principles, construction method, practical use, and primary advantages over traditional methods. Besides, the research also addresses its limitations, challenges, as well as the future scope with emphasis on its ability to influence sustainable, efficient, and resilient city infrastructure. In so doing, the paper aims to contribute to the expanding pool of information regarding trenchless construction technology and emphasize the revolutionary potential of Box Pushing Technology in contemporary civil engineering practices.

2. Historical Background and Evolution

Box Pushing Technology, alternatively referred to as the "Box Jacking Method," is a major innovation in trenchless construction technologies. The technology has its roots in the initial uses of tunneling and mining techniques, where the digging of underground tunnels facilitated the recovery of mineral deposits without surface disruption. These early mining practices were the precursors to applying pushing or jacking methods to civil engineering projects.In the mid-20th century, the expanding need for underground infrastructure in cities—underpasses, culverts, and utility tunnels—paralleledled the limitations of open-cut excavation. Open-cut construction disrupted roadways, utilities, and urban life on a large scale, and therefore was not appropriate for intensifying urbanizing environments. Engineers looked for other options that would reduce surface disturbance while providing structural integrity and safety. It was against this background that box pushing technology first started to develop as a niche application of conventional jacking methods.

The technology picked up speed with developments in hydraulic systems, which could deliver the required force necessary to push large precast reinforced concrete (RCC) box sections incrementally through the ground. Mechanical jacks were initially used, but their limited capacity limited applications to small projects. The advent of hydraulic jacks with high capacities in the second half of the 20th century was a turning point, enabling the installation of large-size RCC boxes for transportation and drainage works under densely populated urban corridors.Along with hydraulic advances, the evolution of reinforced concrete design standards helped develop this technology. Preplaced RCC elements with enhanced strength, durability, and load capacity enabled longer service life as well as enhanced resistance to soil pressure and traffic loading. These advances made box pushing a more dependable choice for projects with high population density, where long-term performance and low maintenance were critical.

In the late 20th and early 21st centuries, box pushing technology continued to advance with the inclusion of real-time monitoring and geotechnical instrumentation. Monitoring systems that could detect soil movement, settlement, and jack pressure during installation helped improve safety and accuracy. Such advancement lowered hazards for ground subsidence and damage to nearby structures, previously restricting trenchless construction in sensitive urban areas.Today, box pushing is used extensively in highway crossings, railway underpasses, stormwater drains, and utility conduits. Its development is part of a larger tendency in civil engineering—moving towards sustainable and non-intrusive construction techniques that address the needs of contemporary urbanization. The technique continues to advance with continuous research in soil-structure interaction, newer lubricants for minimizing friction during pushing, and computer software such as Building Information Modeling (BIM) for project planning.

In short, Box Pushing Technology has progressed from its early origins in mining to be a state-of-the-art trenchless construction technique. Motivated by advances in hydraulics, concrete technology, and monitoring systems, it is currently a world-known solution for the construction of underground infrastructure with little disturbance to surface operations.

3. Methodology

The box pushing methodology is a building method applied to underground facilities such as underpasses, culverts, or subways, wherein a Reinforced Cement Concrete (RCC) box is driven into place under existing facilities—e.g., roads or railways—with no open-cut excavation. This trenchless technique* aims to reduce surface activities interference and guarantee the structural integrity of both the new and existing facility.

Below is an elaborate description of each phase:

3.1. Preparation of the Ground

This stage makes sure the site environment is adequately comprehended and prepared prior to initiating box pushing. Activities involved:

3.1.1 Geotechnical surveys:

Borehole and sampling of the soil to investigate the soil strata, density, cohesion, angle of internal friction, and bearing capacity.Assists in determining the optimal method for box pushing as well as the design of the thrust bed and shield.

3.1.2 Soil testing:

Moisture content testing, compaction, permeability, and soil classification testing. Detection of possible issues such as soft ground, boulders, or composite ground conditions.

3.1.3 Groundwater investigation:

Indication of water table elevation and likelihood of water infiltration during excavation and pushing.Can need dewatering systems or waterproof measures.

3.1.4 Site clearance:

Clearance of vegetation, rubbish, or pre-existing utilities.Providing access for machinery such as cranes, hydraulic jacks, and service vehicles.

3.2. Thrust Bed Construction

The thrust bed is the launching platform from which the RCC box is pushed ahead by jacking. It is essential to the operation's success. Features:

3.2.1 Reinforced concrete foundation:

Designed to resist and dissipate the large hydraulic forces involved in pushing.Generally encompasses braced pads or beams to withstand horizontal and vertical loads.

3.2.2 Accurate alignment:

Makes the RCC box travel in the specified direction without deflection. Deviation can cause structural failure or running failure.

3.2.3 Smooth surface and steering rails:

In many cases, comes with rails or grooves to assist in guiding the box members while jacking.

3.3. Shield Fabrication

Steel shields are deployed at the front (and occasionally the rear) during pushing to safeguard workers and minimize soil resistance.Shield roles:

3.3.1 Stabilize the working face:

Ensures that soil at the face will not collapse as it is excavated ahead of the box. Most critical in loose or permeable soils.

3.3.2 Guide the RCC box:

Maintains direction of movement and assists in soil cutting.

3.3.3 Minimize friction and soil resistance:

Serves as cutting edge and minimizes lateral earth pressure against RCC box walls.May be provided with soil-cutting blades or face support mechanisms.

3.4. Casting and Placement of RCC Box Segments

RCC boxes may be precast off-site and shipped or cast on-site close to the launch pit. Main steps:

3.4.1 Precasting:

Provides quality control and accelerates construction. Segments incorporate reinforcement to resist thrust, earth pressure, and loads from top.

3.4.2 Curing and handling:

Curing is assured to provide specified strength and longevity. Lifting, handling, and shipping should avoid cracking or deformation.

3.4.3 Box placement:

Positioned in the launch pit, positioned against the shield, and joined with earlier segments through rubber gaskets, steel dowels, or sealing compounds. Joints have to be watertight and structurally continuous.

3.5. Hydraulic Jacking and Pushing

This is the critical phase of the process.How it functions:

Hydraulic jacks (typically double-acting) press on the back of the RCC box from the thrust bed.

3.5.1 Sequential pushing:

Boxes are shoved sequentially one behind another, with continuous excavation in front of the front shield.While one segment is shoved ahead, the next is attached and jacked in sequence.

3.5.2 Lubrication systems:

Bentonite or polymer slurry is pumped around the box in order to minimize skin friction between box walls and soil. It reduces jacking forces and prevents structural stress.

3.6. Monitoring and Alignment Control

There must be continuous monitoring to verify the box is traveling properly and to observe any variation. Instruments and tools:

3.6.1 Total stations:

To monitor horizontal and vertical movement of the box at the millimeter level.

3.6.2 Inclinometers:

Monitor the tilt angle in the box or shield to avoid rotation or settlement.

3.6.3 Laser levels:

Mounted within the box to act as a visual alignment reference line for pushing.

3.6.4 Settlement markers and surface monitoring:

Track any movement on the surface (particularly important beneath roads or railways) to ensure safety and avoid damage.

3.6.5 Real-time data logging:

Assists engineers in adjusting jacking pressure, excavation rate, or lubrication if issues occur.

4. Problems and Remedial Measures

The box pushing technique, though efficient and less intrusive compared to conventional open-cut methods, is not free from engineering difficulties. These include mainly ground conditions, operational misalignments, and subsurface uncertainties. The following section discusses the principal issues faced in box pushing operations and recommends good remedial practices based on field experience and engineering best practices.

4.1 Tilting of Box

Tilting is a condition where the box segment is not in the planned vertical position, causing angular displacement. This can be due to unequal resistance from the soil, uneven jack pressures, or ground condition variability across the box cross-section.

Implications:

- Unnecessary structural stress and damage to box joints.
- Unnecessary jacking force due to misalignment.
- Possible surface deformation or subsidence.

Remedial Measures:

1. Differential jacking:

Hydraulic pressure adjustment on a single jack to realign.

Provides equal thrust along the base of the box.

2. Adjustments in rear-end metal sheet:

Insertion of shim plates or steel sheets at the back of the tilted box to align the axis.

Serves as a guide wedge to rectify tilt in the next push.

3. Ongoing monitoring:

Regular level checks with laser levels and inclinometers to identify initial signs of tilting.

4.2. Longitudinal Misalignment

Longitudinal misalignment is the displacement of the box from the planned course in a horizontal direction, usually due to compounded errors in jacking alignment, faulty surveying, or uneven soil conditions along the alignment.

Implications:

- Delicate structural connection of segments.
- Potential for harm to nearby utilities or infrastructure.
- Failure to advance the push along the specified corridor.

Remedial Measures:

1. Accurate surveying:

Creation of a clearly defined baseline with total stations and GPS to monitor alignment.

2. Reference pegs:

Pegs fixed at intervals as reference points for monitoring alignment.

Checked prior to and after every push cycle.

3. Corrective jacking:

Varying pressure across jacks to steer the box back toward the centerline.

4. Front shield guidance:

Ensuring the cutting shield has directional control features to adjust horizontal deviation.

4.3. Hard Rock Encounters

Unanticipated encounters with hard rock strata or boulders can stall progress and cause excessive wear on the shield and box edges. This challenge is more common in variable geological settings.

Implications:

- Construction schedule delays.
- Extensive wear and damage to shield edges and jacking system.
- Higher energy consumption and jacking force.

Remedial Measures:

1. Pavement breakers or hydraulic splitters:

Mechanical breaking of the rock mass ahead of the shield in localized areas.

2. Controlled blasting (if allowed):

Controlled environments can use small charge explosives for fragmenting rock ahead of the shield.

3. Diamond-tipped cutting tools:

For more difficult materials, custom cutting tools might be mounted on the shield.

4. Advance geological probing:

Drilling ahead of the alignment to find and trace out rock positions prior to starting pushing.

4.4. Groundwater Intrusion

Groundwater entry into the face of the excavation or along the face of the RCC box can create soil instability, higher friction, and even flooding of the workplace.

Implications:

- Threat to laborer safety and equipment destruction.
- Soil lubrication with resulting settlement or washouts.
- Metal components corrosion risk.

Remedial Measures:

1. Dewatering systems:

Well point or deep well installation surrounding the site to decrease the water table level.

2. Seepage control with grouting:

Chemical or cement grouting to close seepage channels around the box or launch pit.

3. Waterproofing membranes and gaskets:

External application of sealing layers and internal rubber gaskets to joints for preventing water ingress.

4. Utilization of sump pumps:

Fitted at the working face's base in order to drain infiltrated water on a continuous basis.

4.5. Soil Settlement

Settlement of soil can be caused by over-excavation, soil loss at crown or box sides, or by loss of effective stress due to groundwater depression. It may cause surface deformation and structural instability over the path of pushing.

Implications:

- Road, railway, or utility surface subsidence.
- Structural integrity issues for the box and nearby infrastructure.
- Public safety risks in urban areas.

Remedial Measures:

1. Lubrication system usage:

Bentonite or polymer slurry injection decreases skin friction and eliminates ground adhesion to the box.

2. Sheet drag arrangements:

Sheets placed on top of the box reduce friction and distribute loads more evenly.

3. Backfilling and grouting:

Grouting of annular gaps behind the box immediately after pushing to stabilize the soil.

4. Jacking speed control:

Slow, gradual pushing prevents instantaneous soil movement.

5. Monitoring settlement in real time:

Drilling of surface settlement markers and inclinometers close to the box to ascertain incipient movement of the ground.

5. Advantages vs Limitations

Box pushing technology has several obvious benefits, especially for city and high-traffic areas. Its greatest advantage is that uninterrupted traffic flow during construction is ensured without closing the road or railway. This leads to less social inconvenience and increased safety both for the public and workers. Besides, as the process does not involve surface excavation at large scale, it leaves a lesser environmental footprint than conventional open-cut procedures—reducing dust, noise, and disruption to the surrounding ecosystem. The technique also facilitates accelerated project implementation, particularly in urban locations, as a significant portion of the work could be premanufactured or staged in parallel. The structural integrity of RCC box segments provides durable long-term performance under high loads, qualifying it for permanent infrastructure such as culverts and underpasses. In highly populated corridors, the approach is *cost-effective because it optimizes land acquisition, surface rehabilitation, and utility rearrangement.

Still, with all these benefits, the technology has some limitations that should be taken into account during design and planning. A main disadvantage is the heavy upfront investment in specialty equipment, including hydraulic jacking systems and specially fabricated thrust beds. The technique is also less adaptable to long-distance tunneling, since alignment control diminishes over longer pushes. In narrow urban corridors, space restrictions during operation may curtail equipment mobility and staging areas. Rocky formations or hard strata are challenging, commonly involving tedious breaking or blasting, which decreases the process efficiency. Second, errors of alignment, if not discovered early, are hard to rectify and may invalidate the eventual installation. Lastly, the danger of accidental damage to underground utilities is ever present, particularly in aging or inadequately documented urban infrastructure. Thus, while box pushing is a forceful method when used in appropriate circumstances, rigorous site evaluation and engineering design are essential to overcome its built-in limitations.

6. Comparative analysis with other trenchless methods

Within the overall scope of trenchless construction, box pushing is one of the established technologies along with micro-tunneling, horizontal directional drilling (HDD), and pipe jacking. All these techniques have specific uses, advantages, and disadvantages based on the size, application, and geological setting of the project.

6.1 Box Pushing and Micro-Tunneling

Micro-tunneling is remotely controlled pipe jacking that is commonly applied in the installation of small to mid-diameter water, sewer, and gas utilities pipelines. While micro-tunneling is most precise and well adapted to long-distance applications in unsteady soil conditions, it is usually not practical for building large cross-sectional structures, like pedestrian or vehicle underpasses. Box pushing, on the other hand, is most adapted to large-section applications, where occupancy by humans or vehicles is required in the end use. Yet micro-tunneling provides better distance ability and automation, making it more desirable for long-term utility corridors.

6.2 Box Pushing vs Horizontal Directional Drilling (HDD)

Horizontal Directional Drilling (HDD) is a guided technique for the installation of pipelines and cables below obstructions such as roads or rivers without trenching. It is much favored for its minimal surface impact and quick installation, especially where there is soft ground. Nevertheless, just as with micro-tunneling, HDD is confined to small-diameter installations and is inappropriate for load-carrying structures. Box pushing, however, makes possible the construction of accessible underground tunnels directly, like subways and car underpasses, which HDD cannot do. However, HDD is also usually more cost-efficient for long-distance, small-diameter projects.

6.3 Box Pushing vs Pipe Jacking

Pipe jacking is similar to box pushing but normally involves driving round pipes, usually of smaller diameter. Both methods involve the use of hydraulic jacks, although pipe jacking is better for pressurized pipes or drainage networks, particularly where installation has to follow a complex or curved path. Box pushing is better when there is a need for a rectangular cross-section, e.g., road or railway underpasses. Nonetheless, pipe jacking is more adaptable in terms of length and alignment and is more suitable for non-rectilinear alignments, while box pushing tends to be relatively straight and less limited in curvature.

In short, box pushing technology completes a niche in trenchless construction that allows the development of habitable or load-carrying underground structures. While other trenchless technologies have strengths in utility installations and applications at greater reach, box pushing is particularly suitable for urban areas where large, durable, and accessible structures are needed under existing infrastructure. Selection of method must thus be driven by a careful consideration of project requirements, ground conditions, and long-term functionality.

7. Prospects and Research Horizon

Box pushing technology has been found to be a worthy trenchless construction technique, especially for the construction of underpasses, culverts, and subway tunnels in densely populated urban areas. As the demands for urban infrastructure continue to increase, and environmental and social pressures increasingly put focus on non-interfering construction practices, the future of box pushing is towards the development of its technical capabilities, widening its application base, and enhancing its economic viability. Emerging technologies and focused research can address present limitations and advance the efficiency, safety, and sustainability of this process.

7.1. Development in Automation and Smart Systems

One of the most promising developments is the automation of box push operations. The existing process is very much dependent upon manual monitoring and operator judgment, especially in alignment control and jacking pressure modulation. The future systems can include AI-based alignment tracking and automated feedback mechanisms based on data from total stations, laser levels, inclinometers, and load sensors to provide real-time corrections. Such smart systems would not only minimize the possibility of misalignment but also increase operating speed and minimize human error. Machine learning algorithms can be trained using historical project data to forecast soil behavior and optimize pushing sequences, resulting in more adaptive and robust operations.

7.2. Advancements in Lubrication and Reduction of Friction

Friction between the RCC box and ambient soil is still one of the most significant challenges in box pushing, often resulting in higher jacking forces, increased energy consumption, and early equipment wear. Existing lubrication practices, like bentonite or polymer slurry injection, are efficient but may be further optimized. Studies on smart lubrication systems, which modulate slurry composition and rate of flow according to real-time measurements of soil resistance, can improve pushing efficiency. Further, the creation of biodegradable, environment-friendly lubricants will be helpful for environmental stewardship, particularly in environmentally sensitive areas or groundwater recharge zones.

7.3. Improved Hydraulic Jacking Systems

Hydraulic jacking is at the heart of box pushing, and future systems are likely to provide higher precision, modularity, and force control. The creation of digitally controlled hydraulic units that can adjust pressure autonomously in reaction to localized resistance would enable improved correction of tilt and alignment errors. Additionally, lightweight, energy-efficient hydraulic systems would minimize the overall operation footprint and expense. The use of IoT (Internet of Things) technologies in hydraulic controls might also provide remote diagnostic and predictive maintenance capabilities, enhancing reliability even further.

7.4. Materials and Modular Construction Improvements

Conventional RCC box segments are strong but heavy and time-consuming to manufacture. The use of high-performance concrete (HPC), fiber-reinforced concrete (FRC), or geopolymer concrete can lead to lighter, stronger, and more sustainable segments. Modular construction techniques, such as interlocking box segments, preassembled utility corridors, or composite material integration, could streamline on-site installation and reduce construction time. Research into 3D printing of concrete components may also open new possibilities for on-demand fabrication with custom geometries.

7.5. Expanding Applicability in Challenging Geological Conditions

Currently, box pushing is most appropriate for soft to medium soil conditions. Its performance in rocky, mixed-face, or high groundwater environments is poor. Research in the future has to concentrate on designing flexible shield designs, integrating soil conditioning technologies, and optimizing excavation tools to be capable in adverse strata. New methods involving the integration of box pushing with micro-tunneling or auger boring could also be developed to address complex geological profiles.

7.6. Cost Reduction and Lifecycle Analysis

One of the major hindrances to broader implementation of box pushing is the initially high cost of equipment and installation. Economies of scale, component standardization, and advances in modular equipment can decrease capital outlay. Further, performing lifetime cost analyses—beyond construction, including maintenance, longevity, and social costs—can better illuminate long-term value. Including Building Information Modeling (BIM) and Digital Twin technology can enhance planning precision and enable simulation-based cost control.

7.7. Environmental and Sustainability Research

Along with international trends towards sustainable building, emerging box pushing developments should also take into account environmental performance. Studies on carbon footprint minimization, noise and vibration mitigation, and restoration site practice can guarantee the process meets green building criteria. Incorporation of recycled materials, non-toxic grease, and renewable energy-powered machines could further add to this technique's environmental merit.

8. Conclusion

Box Pushing Technology is a contemporary, real-world, and increasingly eco-friendly trenchless construction technique, particularly applicable to urban infrastructure development projects with huge cross-sectional structures like underpasses, subways, and culverts. Its greatest benefit rests in the capacity to carry out underground construction without interfering with surface-level operations, a consideration especially significant in heavy-density, traffic-conscious environments. By eliminating the need for extensive surface excavation, the method significantly reduces traffic congestion, environmental degradation, and social inconvenience, all while enhancing safety for both workers and the public.

The technology's focus on precast RCC segments, hydraulic jacking, and accurate monitoring not only ensures quicker project implementation but also helps ensure the long-term durability and structural performance of the finished facility. These features have rendered box pushing a viable option over conventional open-cut approaches, particularly in nations such as India, where urbanization stresses and infrastructural shortages compel minimally invasive yet expandable construction methods.

Nonetheless, as with all construction technology, box pushing has its drawbacks. High front-end costs, poor ability to adapt for long-distance or highly varied geologic conditions, and difficulty in controlling alignment are concrete limitations. These economic and technical limits could delay its implementation in some scenarios, especially where ground conditions are unfavorable or where there are budgetary restrictions on the utilization of sophisticated equipment. Regardless of these problems, successful deployment in some Indian cities, sometimes in complicated urban settings, has shown that with meticulous planning, competent execution, and site-specific modification, the technique can be both dependable and affordable.

On the horizon, the future of box pushing is bright. Developments in automation, AI monitoring, intelligent lubrication systems, and modular construction methods can overcome present shortcomings and expand the technique's uses. As trends in global construction remain focused on sustainability, pace, and minimized disruption, box pushing presents itself as a workable mainstream alternative to urban infrastructure construction across the globe.

In summary, box pushing is not only a different construction technique but a paradigm for urban underground construction delivery efficently, safely, and sustainably. With ongoing funding for research and technology, it has the promise of becoming a standard practice in world civil engineering for the next several decades

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