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Civil and Structural Engineering

Developing Kruger Shalati

Ionic Interactions for Durability

Highlights

Diaphragm Wall Concretes

Fundamentals of Electro Kinetics

Discovering Thoughts, Inventing Future

VOLUME 23 ISSUE 4 VERSION 1.0

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Developing Kruger Shalati: The Train on the Bridge

By Gert Noordzy, Richard Whitfield, Li-Chun Lin & Tshepo Makhudu
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Abstract- This is a case study on the development of the *Kruger Shalati: The Train on the Bridge*, a themed, luxury boutique hotel in Kruger National Park (KNP), South Africa. Two key drivers of this project were authenticity and a strong ethos for Environmental, Social and Governance (ESG). Considering the target market the hotel serves and the local situation, this case study explains why modular construction was better to build parts of the property, instead of using traditional in situ construction methods. It further explains how the hotel was built, and the challenges that had to be addressed to complete the project. Finally, it examines how the use of modular construction methods and the uniqueness of the project impacted the normal hotel pre-opening activities and ongoing hotel operations. This case study has been prepared after reviewing published materials about the project and extensively interviewing five senior members of the project team.

Keywords: new hotel development; project management; case study; modular construction; ecotourism; experiential hospitality; kruger national park; wagon-lit, railway bridge; railfans; ESG, authenticity.

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DEVELOPINGKRUGERSHALATITHETRAINONTHEBRIDGE

Strictly as per the compliance and regulations of:

Developing Kruger Shalati: The Train on the Bridge

A Unique Modular Hotel Construction Case Study in Kruger National Park

Gert Noordzy [α], Richard Whitfield [σ], Li-Chun Lin [ρ] & Tshepo Makhudu [Ѡ]

Abstract- This is a case study on the development of the *Kruger Shalati: The Train on the Bridge*, a themed, luxury boutique hotel in Kruger National Park (KNP), South Africa. Two key drivers of this project were authenticity and a strong ethos for Environmental, Social and Governance (ESG). Considering the target market the hotel serves and the local situation, this case study explains why modular construction was better to build parts of the property, instead of using traditional in situ construction methods. It further explains how the hotel was built, and the challenges that had to be addressed to complete the project. Finally, it examines how the use of modular construction methods and the uniqueness of the project impacted the normal hotel pre-opening activities and ongoing hotel operations. This case study has been prepared after reviewing published materials about the project and extensively interviewing five senior members of the project team.

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Source: Keith Stannard

Exhibit 1: Kruger Shalati: the Train on the Bridge

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I. Executive Summary

This case study [1] is on the development of the *Kruger Shalati: The Train on the Bridge*, [2] a themed, luxury boutique hotel in South Africa. It is uniquely formed from authentic train carriages, permanently stationed [3] on the historically-rich Shalati Bridge above the Sabie River within the Kruger National Park. The carriages were recovered from a train graveyard and then refurbished, using prefabricated prefinished volumetric construction (PPVC) methods with a twist. This case study illustrates the processes of developing a unique new hotel concept and operationalizing the vision. It also illustrates the motivations for using this alternative construction method for hotels in remote locations with high levels of difficulty and complexity, as well as the practical benefits and challenges of adopting it.


Source: Kevan Zunckel, Zunckel Ecological + Environmental Services

Exhibits 2 and 3: Views from the bridge: eastward *(left)* in winter and westward *(right)* in summer, river swollen from rainfall

In modular construction, a building is made in sections in a factory while the foundations are prepared at the site where the building is to be located. [4] The building sections are then transported to the site and assembled onto the foundations using cranes. The building sections may be a flat wall, floor, and/or ceiling panels that are assembled like a house of cards. Alternatively, they may be volumetric boxes that are arranged and stacked like shipping containers. A building may be composed of a mixture of panels and volumes as needed.

By contrast, hotels are mostly built using traditional construction methods whereby manpower, machinery, and materials are assembled at the building site and the workforce uses the machinery and materials to construct the facilities in situ. On completion of the construction project, the waste materials and machinery are removed from the site and the workforce is disbanded.

To begin, and to provide a context, the authors describe KNP and its local market situation, then consider why modular construction was adopted for the project. The authors then assess how the Kruger Shalati project was conceptualized and delivered, following the project life cycle for new hotels [5] (Noordzy & Whitfield, 2021a):

1. *Hotel Conceptualization Stage:* First, the authors assess the concept development and tender process, to evaluate the environmental, financial, and economic viability of the proposed project.
2. *Hotel Delivery Stage:* Second, the authors explain how Kruger Shalati was designed, prototyped, built, and opened. In particular, the authors review the refurbishment, transportation, and positioning of the train carriages.
3. *Hotel Operations Stage:* Third, the authors review the main differences in operations and maintenance when compared to more conventional hotel development projects.

Finally, the authors discuss the achievements and lessons learned of this novel hotel development project.

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[1] Yin, R. K. (2002). *Case Study Research, Design and Methods* (3rd ed.). Newbury Park, Sage Publications.
[2] Kruger Shalati (PTY) Ltd. (2021, September 7). *Kruger Shalati the Train on the Bridge*. www.krugershalati.com/
[3] Balt, M. (2019, July 1). *Project manager answers KNP train questions*. Lowvelder. https://lowvelder.co.za/490727/project-manager-answers-knp-train-questions/
[4] Noordzy, G., & Whitfield, R. (2021b). Modular Construction, An Important Alternative Approach for New Hotel Development Projects. *The Journal of Modern Project Management*, 9(2), 217–235. https://doi.org/10.19255/JMPM02715
[5] Noordzy, G., & Whitfield, R. (2021a). The New Hotel Development Project Life Cycle. *The Journal of Modern Project Management*, 8(3), 89–99. https://doi.org/10.19255/JMPM02508

II. Context and Motivation for Modular Construction

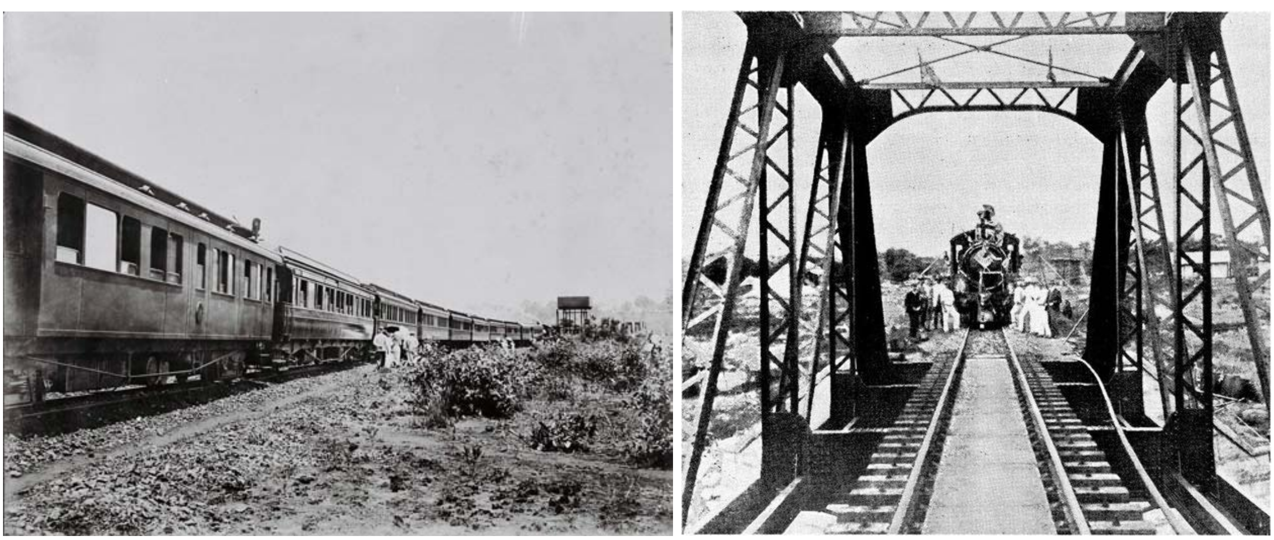
a) Kruger National Park, South Africa

The Kruger National Park [6] is a world-famous 19,485km^2 protected area in the north-eastern part of South Africa, near the border with Mozambique. It was established in 1898 and is one of the largest parks in Africa, most famous for the Big Five: lion, leopard, rhinoceros, elephant, and Cape buffalo. It hosts hundreds of other mammal species and a diverse range of fauna and flora. It is part of the "Kruger to Canyons Biosphere", officially designated by the United Nations Educational, Scientific and Cultural Organization (UNESCO), [7] as well as part of the Great Limpopo Transfrontier Conservation Area with Mozambique and Zimbabwe. [8] Geographically it is sub-tropical and includes mountains as well as bush plains and tropical forests.

Each year, the park welcomes approximately 1 million visitors, mostly South African nationals. The park is managed by South African National Parks [9] on behalf of its traditional landowners and the people of South Africa. It has good infrastructure, including roads, and contains a variety of lodges and camps, where most international and national visitors, who make up a large portion of the total number who visit the park annually, stay. SANParks manages a number of these camps, which include chalets, shops, restaurants, etc. In addition, SANParks have provided concessions for third-party private developers and operators to develop and operate safari lodges and camps for definite periods within concession areas, within which the concessionaire has sole access. These concessions, along with others, and entrance fees are the major sources of park income. These are used to pay for its operations and maintenance, and to support the traditional owners.

Because of the dangers to human life, access to the park is quite restricted, and visitors can only stay overnight housed in approved accommodation. To preserve its ecology, there are also restrictions on materials, flora and fauna that can be brought into the park. For example, the use of industrial pesticides are strictly controlled. The KNP has a serious problem with alien invasive plants and therefore needs to use herbicides, but the concessionaires are not responsible for natural resource management and therefore this remains a KNP responsibility, unless otherwise stated in their PPP agreement. In addition, relatively severe penalties apply for poaching, damaging, or defacing the landscape and historic structures within the park.

From the early 1900s, visitors were able to undertake multi-day train tours of the park, sleeping overnight in the carriages and traveling between points of cultural and natural interest during the days (Kruger Park, 2021). [10]In 1923, South African Railways (SAR) curated a tour to the Lowveld and the border of Maputo. The trains would travel from Komatipoort to Sabie Bridge during the day, a game ranger would accompany the tourists and would stay with them at Sabie Bridge. At the time, there were no overnight facilities, therefore the tourists slept on the train. [11]



Source: SANParks, Republic of South Africa

Exhibits 4 and 5: A train in Kruger National Park in the 1920s

[6] Kruger National Park. www.sanparks.org/parks/kruger

[7] UNESCO. (2001). *Kruger to Canyon Biosphere Reserve, South Africa*. https://en.unesco.org/biosphere/africa/kruger-to-canyon

[8] Great Limpopo Transfrontier Park. (2021. *A Major Dynamic Conservation Initiative.* www.greatlimpopo.org

[9] South African National Parks. (2021.) *Kruger National Park.* www.sanparks.org/

[10] Kruger Park. (2021). *Modern History of Kruger National Park*. www.krugerpark.co.za/Krugerpark_History-travel/kruger-national-park-modern-history.html

[11] Big on Wild. (2018, July 27). *History of the Kruger National Park - Part One.* http://bigonwild.co.za/history-of-kruger-national-park-part-one/

By the 1970s, increasing freight train traffic on the railway line through the park was killing many animals after they wandered onto the tracks and so the train line was relocated outside the park boundary. At that time much of the track in the park was removed, but the stations, bridges, and other structures were left as historical relics.

Source: Kelly Ermis

Exhibit 6: The Shalati Bridge over the Sabie River

In the 2010s, park management looked to increase its income by refurbishing abandoned structures for accommodation and other purposes. [12] Among other proposals, it issued a tender for a 25-year concession based on repurposing and refurbishing the Shalati Bridge and nearby Kruger Station. In particular, park management hoped that an accommodation experience could be created that paid homage to the earlier train tours of the park. The site consisted of the station building and bridge connected by approximately 500m of track in a sweeping curve. The bridge is a historic monument and could not be altered or damaged. Kruger Station was built after the railway closed to house a locomotive with carriage and information displays about the old railway and had to be kept. At the midpoint of the track, there was also "Waterkant", a historic, SANParks managed, thatched structure, that was not originally included in the site and was not historically protected.

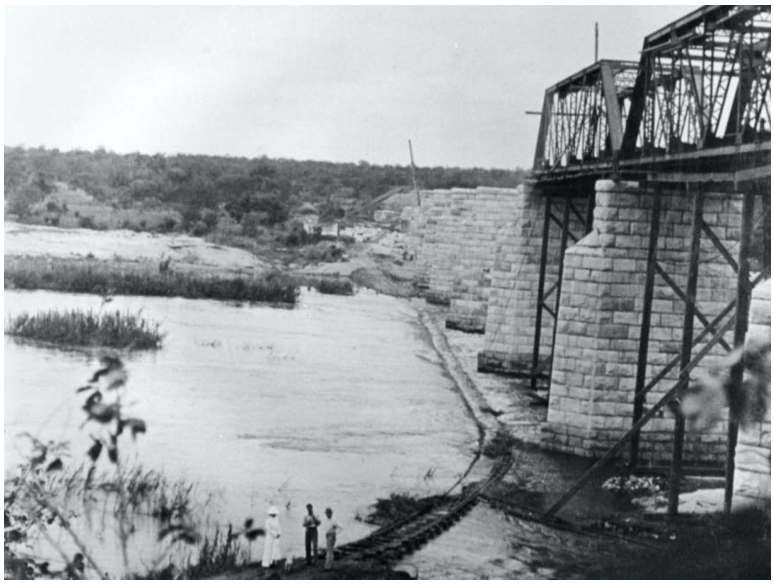
Source: SANParks, Republic of South Africa

Exhibit 7: Waterkant

[12] Balt, M. (2029, July 13). *This train will go nowhere but reminds of the past.* Lowvelder. https://lowvelder.co.za/554756/this-train-will-go-nowhere-but-reminds-of-the-past/

Opposite the station, there was a redundant Distribution Center (from when KNP did its own procurement). These structures are located within Skukuza Camp, which is the administrative headquarters of KNP, and home to approximately 1,000 residents. The Shalati Bridge itself is located just outside of the camp.

The 400-meter-long single line bridge dates from 1910, and consists of repeating steel-arched sections that span between 9 sandstone piers. It is a very early example of modular construction, wherein the steel sections were made in the United Kingdom and transported by sea and overland to the site before being craned into position on the locally built piers. The bridge has sweeping views and stands approximately 15 meters above the Sabie River, which is known for its crocodiles, hippos, buffaloes, and elephants. In addition, the area boasts abundant bird life.



Source: SANParks, Republic of South Africa

Exhibit 8: The Shalati Railway Bridge under construction

Interestingly, the park management came up with the original idea for a train-based hotel that would move out onto the bridge every night and then be drawn back to the station during the day. During the bidding process it was agreed that the train would be static and remain on the bridge permanently. The reason being the impracticality of installing the infrastructure that would be required to facilitate this daily movement.

The Thebe Tourism Group (Thebe), now known as the Motsamayi Tourism Group, with Londolozi Private Game Reserve as its operating partner, won the tender with a proposal for a luxury boutique hotel, using the station as an information center, a new building to house the hotel reception and dining area, and refurbished train carriages, repurposed as guest rooms, permanently parked on the bridge, with a newly added pedestrian pathway for guest room access. [13] The company was founded by Nelson Mandela with a vision to create iconic tourism products and has a strong culture of community involvement and community upliftment.

The current visitor market of KNP is largely Caucasian (mainly Afrikaans-speaking) and aging, requiring park management to consider new products to attract a new generation of visitors with different demographics. The proposed target market for Kruger Shalati was middle class and up South African and international train enthusiasts, looking for a truly unique park experience. In addition, Thebe's proposal maximized park income and benefited the traditional landowners by making them shareholders and providing employment and business opportunities. Thebe did not have direct hotel experience but formed alliances with well-respected hotel and tour operators, and engineering firms for the project. By contrast, it did have a strong track record in successfully fostering partnerships to develop new ventures in a variety of industries.

b) The Shalati Bridge and Kruger Station

Kruger Shalati: The Train on the Bridge, fully opened in February 2021, comprising 13 carriages on the bridge, with 4 carriages to the south and 8 carriages to the north of the lounge car. Each carriage is divided into 2 luxury rooms. The lounge car is positioned opposite a non-historic water tower, which has been repurposed as the hotel's suspended swimming pool, and is connected to the lounge car with a deck. The KNP has several information centers and Kruger Station serves to provide history on the railway line, the trains, and the bridge. Kruger Station has

[13] Wiley, M. (2020, December 16). *Look inside a luxury hotel made of vintage train cars that sits atop a bridge in South Africa's largest national park*. Insider. www.insider.com/kruger-shalati-hotel-on-bridge-south-africa-kruger-national-park-2020

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been repurposed as the park information center, including a 360° video information wall, public dining facility, and souvenir outlets. "Waterkant", the non-historic lodge accommodation, has been rebuilt as the Bridge House, using a "shed style" to align with the "railway/steel" architectural style. It houses the hotel's reception, indoor/outdoor dining facility with kitchen and double swimming pool. It also incorporates several hotel rooms in separate buildings, that opened in 2022. Finally, a spur and switch were added to the railway to connect it to the Distribution Center, which SANParks allowed the hotel to take over and repurpose as an operation center (for its back-of-house areas), with photovoltaic panelsadded to its roof. As discussed later, the result differs somewhat from the initial tender proposal. Please refer to *Appendix A* for a map of Skukuza Rest Camp, Kruger Station, and the Shalati Bridge.

Initially planned as a 3-year development, completion of the entire project took over 6 years. Obtaining the Environmental Approval, without which the project could not commence, took much longer than predicted due to the general sensitivities of the site. Construction from the first car arriving at the factory in Johannesburg to full and final occupation by paying guests in Skukuza took 3 years.

The reasons are explained and discussed below. While the Covid-19 pandemic has delayed project work *(this turned out to be a blessing, allowing for design enhancements)*, and is expected to reduce hotel occupancy in the short term, Kruger Shalati has a promising future, if industry and social media "buzz" is a good indicator.

III. Hotel Conceptualization Stage

KNP is an important global asset with tremendous biodiversity and cultural heritage. It is an important source of economic activity and national pride for the Republic of South Africa. SANParks' tender process required the candidate concessionaire to elaborate in detail the dynamics of the product and service offering, socio-economic impact (i.e., how the project will support local economies), operating policies and procedures, transformation and business plans, and environmental impact. To manage this process, Thebe appointed a project manager, and formed partnerships with a hotel operator, tour operator, railway and civil engineering consultants, and an interior design firm. In addition, it engaged specialty consultants to prepare the project cost analysis and return-on-investment model, and conduct the environmental impact assessment. Because the proposed hotel project was in a national park, the Department of Environmental Affairs (DEA), (now called the Department of Forestry, Fisheries and the Environment (DFFE)) required detailed plans in advance before Environmental Clearance could be issued and any work could start. These requirements formed part of the Environmental Impact Assessment (EIA) and the subsequent application for Environmental Authorization, which was accompanied by the Final Basic Assessment Report and Environmental Management Plan Report. [14] This provided the project team with the advantage of a compulsory pre-planning process.

To plan scope, time and cost, instead of refurbishing old carriages, the project team did consider the options of a.) buying new train carriages and b.) building modular "replicas" of railway carriages. Both options were deemed not viable:

- *Option a:* It was felt that partnering with a train carriage manufacturer outside of South Africa had no special advantages. It would make design coordination and quality monitoring more complex and would introduce the added difficulties of transporting the railway carriages much longer distances by ship as well as road.
- *Option b:* Given the extensive structural modifications envisaged for the carriages and the known and unknown additional difficulty of renovation works when compared to new build construction, some consideration was given to the idea of building new "replicas" of railway carriages. However, all the stakeholders agreed that authenticity was crucial to create the unique guest experience and establish the "high-end" market positioning of the proposed hotel.

a) Tender Process

Preparing the tender document took considerable efforts to develop and design the entire hotel concept, and to evaluate its environmental, financial, and economic viability. It also required extensive discussions with park management and public consultation with the traditional landowners; most stakeholders are conservative in their outlook.

Stringent site restrictions to minimize the dangers to human life, ecological degradation, and damage to the historic monuments, along with the novel nature of the hotel rooms, required an alternative approach to in-situ construction. The project team estimated that the best approach was to renovate and refurbish authentic railway carriages as guest rooms off-site in Johannesburg and then move them into position on the bridge. This decision required the project team to manage the following constraints:

[14] Zunckel, K. (2018). *Kruger Shalati, Environmental Assessment Report and Environmental Management Programme Report.* Zunckel Ecological + Environmental. https://zunckelecological.wordpress.com/resources/

1. *Production:* Identify steel and carpentry works near Johannesburg, chosen for its industrial base (incl. mining), large population (± 5m), intervening road infrastructure and relative proximity to KNP (± 400km).
2. *Transportation:* Acquire a specialized large container transport vehicle with adequate lifting cranes to transport a single railway carriage, measuring ±25 meters in length, over 4 meters in width and weighing 30 tons.
3. *Roads:* Investigate possible routes and limitations (e.g., size, access times, escort, etc.) outside and inside KNP.
4. *Tracks:* Add a straight spur and switch to the existing track between the bridge and station, as a railway carriage can only be mounted onto a straight length of the track. *(The space on the spur also allowed carriages to stack-up on arrival, for remedial works and fit-out, before moving them onto the bridge.)*

Source: Andrea Kleinloog

Exhibits 9 and 10: Adding the straight spur and switch

b) *Environmental Impact Assessment (EIA)*

Thebe appointed an independent environmental impact assessment practitioner and an independent heritage resources consultant to conduct the EIA and to ensure that every relevant aspect was reviewed:

1. *Impact Assessment:* To assess the impact of the proposed hotel on the biodiversity and ecosystem within the park, traffic flows, light pollution, waste disposal, and the capacities of local utilities and sewerage, and other infrastructure, and to determine if potential impacts could be avoided, mitigated or off-set.
2. *Historic Structure (Impact) Assessment (HSA):* To ensure the preservation of historic structures, emphasis was put on the heritage value. The final product had to mirror what the carriages looked like in the 1930s and 1950s.
3. *Structural Assessment:* To demonstrate that the bridge could easily handle the static loads of a train permanently parked on it.
4. *Hydrological Assessment:* To confirm that the bridge deck and buildings are well above the 100-year flood level, and that there were no significant hydrological features that would be impacted on by the development and its operations. Included in this assessment was an assessment of flood risk, which is implied in the application of the 1:100-year flood line.
5. *Visual Impact Assessment (VIA):* Part of the EIA, the visual and heritage aspects played a key role in the finish of the carriages, so that they resembled the look of those used at the time the railway line was in use. This required interesting research to ensure this requirement was met.
6. *Traffic Impact Assessment (TIA):* Part of the EIA to assess potential impacts of traffic generated by the proposed project on the KNP infrastructure and environment.

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The DFFE granted Environmental Authorization, but imposed specific conditions to be complied with, to make sure that identified negative impacts were fully avoided or mitigated, including:

- *Traffic Burden:* The TIA found that a large part of the hotels guests would arrive by airplane to the nearby Skukuza Airport (SZK), i.e., the hotel would not add substantially to the traffic volumes in the south the KNP.
- *Light Pollution:* To reduce nighttime light pollution only minimal external lighting may be used; these are not allowed to be visible from the Skukuza Camp.
- *Fire Safety:* Park authorities judged it was too dangerous to permit gas storage or cooking facilities within the carriages, especially on a permanently parked train.
- *Compliance:* Once Environmental Authorization had been received, the developer must appoint an independent environmental compliance officer (ECO) to monitor implementation throughout out the development cycle of the project.

Key advantages were that the railway line and bridge infrastructure, and infrastructure for running the development and managing the daily operations were already in place. The EIA demonstrated that the project would require next to no clearing of undisturbed vegetation and would not impact the natural flora and fauna.

Initially, it was estimated that the assessment process would take 9 months, but eventually it took 18 months before any construction on site could start. One of the main reasons for the extended time was because the authorities wanted to make sure that any risk of appeal against a positive recordof decision were minimized as far as possible. Given that the KNP has an active and well-informed watchdog group, it was possible that an appeal could have been lodged. Nonetheless, in many ways, the impact assessment was simpler than it would be for a comparable greenfield hotel site within the park, because it largely repurposed and reused pre-existing buildings and other structures. In addition, the area is zoned as “high-intensity leisure” by SANParks and does not fall in a wilderness zone.

c) Concession

By the time the Environmental Clearance was received and the 25-year Concession Contract was signed, the project team had spent 18 months planning and brainstorming. It was only possible to successfully navigate this process because Thebe had the foresight to bring together innovative and adaptable partners with the full spectrum of required expertise from the onset.

In the words of its C.E.O., Thebe won the bid by “sheer madness”, with a project team, including railway fanatics with a deep understanding of railways and engineering, that was able to start from scratch, a design team with carte blanche that “really went to town” and a management team that “was hungry for it”.

The winning concept of the final tender entailed:

1. Sourcing old railway carriages in South Africa and refurbishing these in two close-by Johannesburg factories; then transporting them by road to mount them on railway tracks and move them into permanent positions on the bridge.
2. Manufacturing an external walkway on the bridge, an on-bridge deck and suspended swimming pool, as well as a service channel and pier-top sewerage holding tanks in a third factory; then move and install these onto the bridge.
3. Adding a short rail spur line and switch to the Distribution Center.
4. Taking over the Distribution Center from SANParks and repurposing it as an operations center with back-of-house areas, including adding photovoltaic panels to the roof.
5. Demolish “Waterkant” and build new accommodation elsewhere for SANParks to offset the loss of room inventory.
6. Creating a new Bridge House between the station and bridge as the hotel’s front-of-house area, with reception, indoor/outdoor dining area, kitchen, double swimming pool, as well as several additional luxury guest rooms.
7. Renovating and expanding the 1,000m^2 Kruger Station building to extend the park information center, food & beverage, edutainment, and souvenir outlets that are all open to the public.

IV. Hotel Delivery Stage

a) Architecture

Once the *architectural* work commenced, the project team recognized that mixing publicly accessible areas (e.g., the park information center, restaurants, and souvenir outlets) with luxury boutique hotel front-of-house areas (e.g., concierge, reception and dining) in the same building was neither desirable, nor workable. An agreement was reached to demolish “Waterkant”, the non-historic basic lodge accommodation and rebuild it as the hotel reception and related areas, using a similar building footprint. This allowed for additional space to add six non-carriage hotel rooms and a honeymoon suite within this new Bridge House area, making the hotel concept accessible for prospective guests with acrophobia as well. Please refer to *Appendix D* for the TOB interior design drawing of a typical non-carriage hotel room.

To take better advantage of the dramatic views from the bridge and to increase the hotel's "Wow! factor", the project team decided to re-purpose the old steam train re-watering tower as a suspended swimming pool with a deck instead of demolishing it. The tower was 1/3 the way down the bridge and was not a historic landmark. Therefore, it could be altered and a deck could be added to link it to the bridge, on the condition that the deck could be removed at the end of the concession to restore the bridge to its original state.

Source: Andrea Kleinloog

Exhibits 11 and 12: Suspended swimming pool under construction

On the technical side, the lack of space in the carriages disallowed back-of-house facilities. Moreover, during the tender consultation process, misgivings were expressed concerning fire risks and the lack of escape routes if there would be gas-fired cooking services in the carriages. Therefore, it was decided to locate all back-of-house facilities, including all kitchens, in the Kruger Station, the Bridge House, and the Distribution Center.

b) Interior Design

The team had to work with structural challenges, and a combination of size constraints and compactness. Once the *interior* design work [15] commenced, the project team quickly realized it was facing a number of challenges:

1. The client brief stipulated a *"luxury feeling"*. To meet *luxury standards* for hotel guest rooms, the carriages could only be divided into 2 suites each, instead of the 4 compartments on the old trains. In addition, the client brief specified that no plastic was to be used.
2. To satisfy *comfort levels*, the room size needed to be expanded. To this end, the carriage corridors were deleted and incorporated into the guest rooms. In addition, *blisters* were added to the sides of the carriages to expand the room space. This involved pushing wall sections out from the sides of the carriage to fit larger beds and allow for larger bathrooms. The depth of the *blisters* was restricted, to miss the bridge girders.
3. To take advantage of the *dramatic bridge top views*, installation of large, full-height windows was required.
4. To provide *guest room access*, it was necessary to add a generous external walkway along the tracks on the upstream side of the carriages. This required complex engineering because in adding the walkway the bridge structure could not be damaged. At the same time, it had to be possible to remove it and restore the bridge to its original state at the end of the concession.

[15] SA Decor and Design. (2019, August 25). *Afrocentricity At The Centre of Kruger Shalati Train On The Bridge*. SA Decor & Design. www.sadecor.co.za/interior-design-blog/featured/afrocentricity-at-the-centre-of-kruger-shalati-train-on-the-bridge/


Source: Keith Stannard

Exhibits 13 and 14: Welding panels and *blisters* to increase interior floorspace

Source: Andrea Kleinloog

Exhibit 15: Blisters with windows added to the side of the carriage

Adding the external walkway along the bridge provided two additional benefits:

1. The Shalati Bridge is the emergency evacuation route for the Skukuza Camp residents in case of a flood or other disaster, but it had some known safety issues. Permanently positioning carriages on the bridge makes this escape route much less viable, but the new walkway resolves both the escape and pre-existing safety issues.

2. A site survey showed that electricity, water, and sewerage services could be run within an existing service channel between the tracks along the bridge and underneath the external walkway. Sewerage was especially difficult to deal with and required making and installing removable, sealed holding tanks and pumping equipment on the bridge piers.

Source: Andrea Kleinloog

Exhibit 16: The original emergency evacuation route

Source: Keith Stannard

Exhibits 17 and 18: The service channels during installation on the western side of the train *c) Rehabilitating the Carriages*

This section describes the sequence and the process from sourcing abandoned rail carriages at a shunting yard to winching the refurbished carriages into their permanent positions on the bridge. Originally, the plan was to refurbish 4 carriages at a time and to deliver these to the site on a 4-week cycle. Because of constraints (space, manpower and others), design changes, and extra customizations on a carriage-by-carriage basis, this proved not possible. Each individual carriage took approximately 10 weeks to complete on average. In reality, because of the staggered approach adopted, it took 15 months for the overall process from start to finish to complete all 13 carriages.

a. *Partner Selection*

A Special Purpose Vehicle (SPV) company was assembled as a Joint Venture (JV) to undertake this project under a lumpsum contract. The 2 individual principals makingup this JV were former government officials working in the railway environment, with a keen interest in rail-related developments. As such, they kept track of rolling stock in shunting yards around South Africa and had become aware of such a yard in the town of Ladysmith in Kwazulu Natal Province, just 400km southeast of Johannesburg. This yard held approximately 30 carriages in various states of repair.

Chance had it that these 2 individuals had been working on another project to reactivate a redundant railway line for tourism in Eastern Cape Province. For this purpose, they had acquired the stock at the Ladysmith shunting yard. Since that project was experiencing delays (due to regulatory hurdles), the JV came to the Kruger Shalati project with this stock in hand, thereby short-circuiting the procurement process.

In another fortunate opportunity and good fit, the JV was able to partner with an industry colleague that owned and operated a specialist company that builds specialist road trailers. This specialist company owned a:

- *Steel workshop* with gantry hoists and other specialist equipment on the outskirts of Johannesburg, and a
- *Wood workshop*, a 3,000m^2 facility with a 15m. high roof and gantries used to store trailers just 5km. from the steel factory. Half of this space was prepared with a concrete floor, allowing for 9 carriages to be lined up inside in rows and allowing the side-lifting trailer to maneuver into the space.

Source: Keith Stannard

Exhibit 19: Steel workshop

Source: Keith Stannard

Exhibit 20: Wood workshop

b. *Logistics*

The JV purchased a multi-axle hydraulic low bed trailer with side-lifting, extendable arms from New Zealand to transport the carriages from the shunting yard to the steel workshop, then to the wood workshop and finally to the Shalati Bridge. To lift the carriage on and off the low bed trailer, the train couplings were removed and their center mounting points were adapted to be the lifting points for the cranes.

The project team engaged a specialist to arrange special transport permits and facilitate:

- *Registration:* The trailer is not a conventional low bed trailer but fits onto an intermediate wheelset that then connects to the truck tractor. It becomes a complicated rig, involving 3 vehicles, that must be registered with the Department of Transportation (DOT), Road Transport as a unit.
- *Restrictions:* The project team had to manage weight issues for the completed carriages, as well as weight restrictions per axle, height, and width restrictions on specialist trailers.
- *Regulations:* No special transports are allowed on weekends, public holidays, when it is raining, and on certain roads and routes. The truck must be escorted by vehicles in the front and back.

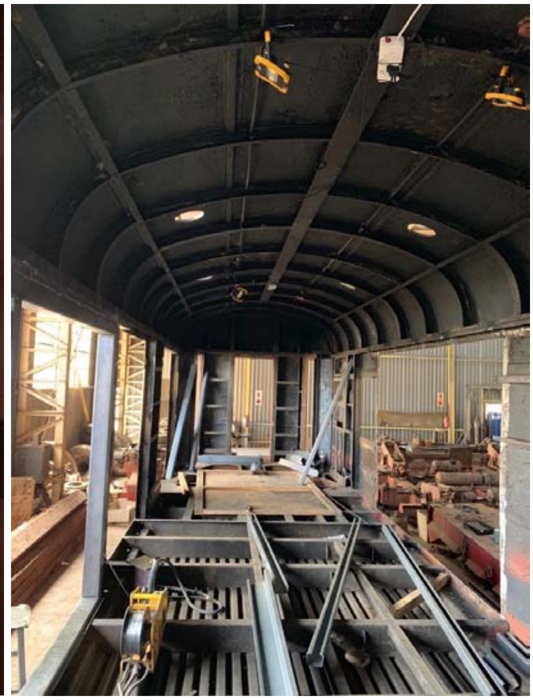
Transportation of the "prototype" carriage was proof of concept and took 3 days. It exposed height and weighbridge issues, cut corners and damaged bridges. Delivery of the last carriage only took 1 day and 4 hours.

Source: Keith Stannard

Exhibit 21: The multi-axle hydraulic low bed trailer with side-lifting, extendable arms

c. *Shunting Yard*

A contractor in Ladysmith gutted and stripped down the selected carriages to their bare metal shells, and disposed of the internal compartments, gangways and scraps. Then, the wheel bogies were separated from the carriages, further reducing the weight, as well as the height for transportation to the steel workshop.



Source: Keith Stannard

Exhibits 22 and 23: Carriage, gutted and ready for internal restructuring

d. *Wheel Bogies*

Each carriage was separated from its double-axle wheel bogies so that they could be reconditioned (i.e., checking the bearings, cleaning, painting and refurbishing). Each set of wheels was specific to a carriage and they were not interchangeable. Therefore, all sets of wheels were numbered and transported separately, to be laid out on the tracks, ready to receive the completed carriages in the right sequence.

Source: Keith Stannard

Exhibit 24: Carriage bogies, stripped and reconditioned

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Source: Keith Stannard

Exhibits 25 and 26: Carriage bogies delivered separately to site and laid in sequence on the track

e. *Prototype*

Since the entire project concept centred around using authentic train carriages as luxury hotel guest rooms, one of the critical success factors of the project was the decision to develop a prototype, as "there are too many unknowns in this kind of project...". Therefore, it was decided to first build one prototype carriage and get it into position on the bridge to test the entire production, transportation, and installation process. Running a prototype added seven months to the overall program, but was critical to unearthing "unknown unknowns" and understanding the challenges and constraints these posed. Following are seven examples.

i. *Access Constraint*

The width of the train door is 65cm. only, making it a challenge getting equipment and materials in and out of the carriage for set-up, maintenance, and renovations. As a result, the *default line* in development thinking became "quality and durability of finishes". This included anything that was finite and could not easily be redone: structural shape and integrity of each carriage, including windows, doors, plumbing and light positions.

ii. *Bathroom Orientation*

The interior design drawings would indicate the position of the bathtub, the drain and waste trap with a plug. Upon positioning the tub in the carriage in accordance with the drawings, it turned out that there was a beam at 1.5m and a major steel structural member right beneath the hole. These were integral to holding the carriage together and so the bathroom orientation had to be changed.

iii. *Main Bedroom Window*

After positioning and stabilizing the first carriage on pedestals in the wood workshop, the team went in to measure the carpentry and get prepared to start paneling. The team then realized that the main feature picture window in front of the double bed was too low; while on a bridge, one tends to look more down than up. The decision was made to increase the size of the window. This involved making structural modifications by introducing steel elements to reinforce the structural frame, as the team was cutting almost into the roof structure.

iv. *Environmental Control*

From the beginning, it was understood that the carriages would have to be extensively water sealed, insulated (150mm.), and fitted with air-conditioners because of the high summer temperatures at the site. Moreover, they needed to be fitted with insect- proof mesh and baboon-proof screens to ensure the safety and comfort of guests. These were not issues in the much earlier train tours of the park but were significant concerns for the proposed target guests for the new hotel. Retrofitting such materials into the carriages was identified as being especially problematic.

v. *Original Design Intent*

Train carriages are designed to *bend and flex* as they move along railway tracks. In addition, they *varied in size* by up to 50mm., making planning difficult. These physical limitations were resolved by designing tolerances as follows:

- *Bending and Flexing:* Tight-fitting hard surface finishes, (e.g., large floor tiles, permanent wall-to-wall mirrors, and cupboards) could not be used, because these would be damaged during transportation to the bridge. Instead, mosaic bathroom tiles, rugs, adjustable wooden wall panels, etc. were used for maximum flexibility.

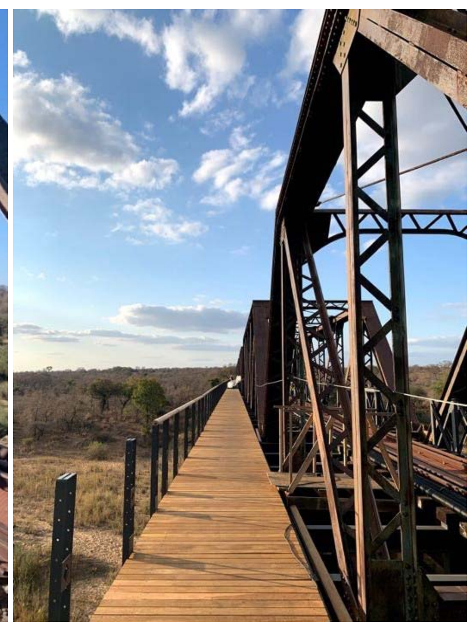
- *Varying Sizes:* Fixed fittings had to be size adjusted from carriage to carriage, significantly increasing the refurbishment work. This was remedied by using timber. Interior designs incorporated various smaller, easily removable items to simplify the on-site final fit-out work. This has the added benefit that future room renovations should be relatively straightforward, especially as structural changes are not possible.

vi. *Bridge Span Movement:* Daily changes in temperature cause thermal expansion and contraction of the bridge by up to 40mm. This figure is the potential extent to which each of thebridge spans moves and therefore the tracks underneath each car. To remain securely connected to the services, these needed to be accommodated via sliding or flexible couplings to all service ways. The interesting challenge was that each car was slightly different in size from the next and had to be measured individually. This is interesting in that "modular" implies that fitments joinery could be premanufactured in numbers for install. This proved notstrictly the case, with tolerances having to be addressed and provided for or specifically cut tomeasure per car.

vii. *Maintenance:* To allow easy dismantling for maintenance and renovation, floor coverings, wall coverings, décor and furnishings had to be removable. Everything was designed to be “steel supported and boltable”. Click-in-place fixtures, furniture, and equipment was used. Bedside tables were electrically wired, so that the sockets and lamps moved with the tables.

To avoid unnecessary delays, the project coordinator insisted that the contractor not wait untilthe prototype was completed before commencing construction of the remaining 12 carriages. As a result, by the time the project team signed off on the prototype, carriage no. 5 was already in production. This meant that some re-work was required. This slowed the production of carriages 2, 3 and 4, but ensured that the production line remained in process to optimise production time.

In parallel with the prototype, the rail spur line and the first sections of the external walkway were installed. At the same time, the holding tanks and service channel were manufactured and installed. Next, the first carriage was transported to the site and mounted onto its bogies on the rail spur line. Winches were used to drag the carriage into its final position, and it was permanently locked into place using wheel chocks clamped to the tracks. Lastly, utilities and other services were connected and the steps to the guest room entry doors were fitted.

Source: Andrea Kleinloog

Exhibits 27 and 28: Installation of the external walkway

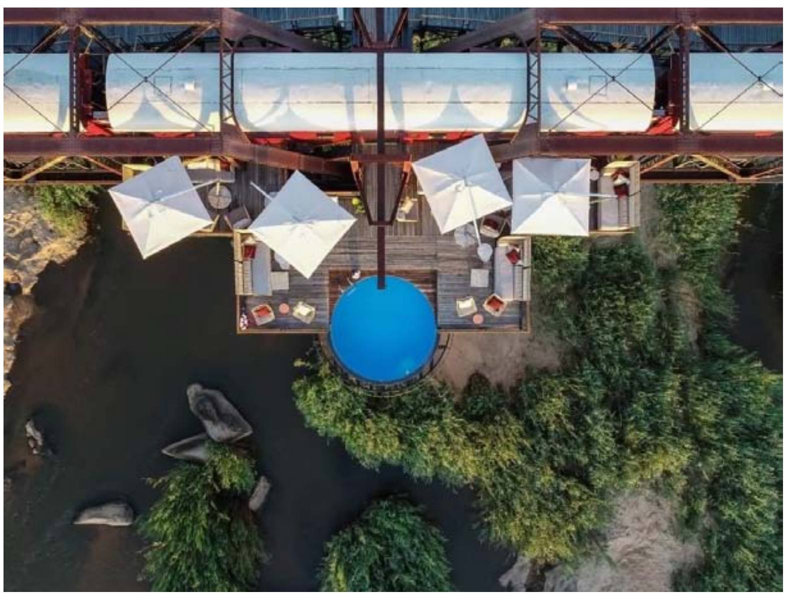
A specific challenge (and potential bottleneck) the project team had to manage and coordinate was between the bridge and carriage teams, in that bridge access was from the South end, but carriage placement had to start from the North end. Key to this was the walkway attached to the Western sideof the bridge. Until its installation, the only access down the line was via a narrow tread plate betweenthe tracks in the centre of the bridge. As a result, all services were thus fixed onto the bridge from South to North, comprising of potable water, fire water, and the waste water return from the 9 sewer tanks on each of the bridge support piers. These all had to be in place and pressure tested before the carriages were in place, as access would otherwise not be possible. Electrical, data and fire sensor cables were installed sequentially under the guest access walkway with access hatches, as work progressed

Southwards. The cars were then connected progressively *(main power supply and data last)*. Because each carriage was fully reticulated to a single connector, temporary power was always available to support testing and commissioning (e.g., FF&E, hot water cylinders, AC, lighting, etc.), whether on the spur or on the bridge.

While in the factories in Johannesburg, the project team identified a number of design deficiencies in the prototype, including:

- The windows had to be further enlarged to fully appreciate the dramatic views.
- The bathroom floors needed dropping to increase headroom.
- Some furniture arrangements required adjusting.

Once these and other significant prototype deficiencies had been identified and all the design challenges had been addressed, the design drawings were updated accordingly and communicated to the steel and wood workshops. Please refer to *Appendix B* for the TOB interior design drawing of a typical carriage guest room. The remaining carriages, including one with a Universal Accessibility (UA) guest room, accessible with a remote-controlled wheelchair lift from its end, rather than from its side, were then refurbished and delivered to the site sequentially in the order that they were to be positioned in on the bridge. As part of that sequence, the lounge carriage was prepared, which had to be perfectly aligned with the suspended pool, and therefore became the starting point for plotting the position of all other carriages. The mandatory dependency (datum) for positioning the first and furthest-most carriage was to ensure that when the lounge carriage was positioned, it was centred with the pool; it would have been virtually impossible to have to relocate 8 carriages down the line at that point. Please refer to *Appendix C* for the TOB interior design drawing of lounge carriage.



Source: Kruger Shalati Pty Ltd.

Exhibit 29: The lounge carriage and suspended pool

f. *Steel Workshop*

Here, the team cut window openings, made structural reinforcements, fixed panels and spray painted the carriages, then moved the carriage to the wood workshop. One of the constraints of this facility was the maximum capacity of 5 carriages, which were rotated in and out on a 4 to 5 week cycle. The project encountered a serious challenge when it ran out of steel, during Covid-19, and a significant price increase once steel became available again.

Source: Keith Stannard

Exhibits 30 and 31: The first car in the steel workshop with bogies separated

Source: Keith Stannard

Exhibits 32 and 33: Setting out for the cut

Source: Keith Stannard

Exhibits 34 and 35: Picture window openings cut and framed

g. *Wood Workshop*

Upon arrival, the carriages were manoeuvred into position and placed on pedestals, and measured for carpentry, panelling and fit-out by three specialist teams:

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i. *Structural Team (Lumpsum Contract):* Installation of wall studs and panels, framing, insulation, flooring, and the structure for the vaulted ceilings.

ii. *Woodwork Team (Lumpsum Contract):* Finetuning of the actual wall panels and architraves, fitting aluminum windows into openings, hanging doors (custom-made for each carriage by an artisan) into doorframes, and fitting baths.

iii. *Interior Fit-out Team (Client Resource):* Tiling, wallpapering, fitting-out of sanitary ware and amenity trays. The interior design for the carriage guest rooms incorporated all Furniture, Fixtures and Equipment (FF&E), and part of the Hotel Operating Equipment (HOE). The original plan was to entirely fit out each guest room before being transported to the site. However, this proved impractical and after transportation of the "prototype", most of the loose furnishings were transported to the hotel separately and fitted into the carriages there. This was done partly because of fears of damage during transportation, but also to improve the storage security for the loose fittings.

Source: Keith Stannard

Exhibit 36: Exterior finishing

Source: Keith Stannard

Exhibits 37 and 38: Internal structure before closure and panelling ready for wood finishing

Source: Keith Stannard and Andrea Kleinloog

Exhibits 39 and 40: Installation of Furniture, Fixtures & Equipment

The key challenge included managing the overlap coordination of the various trades, some of which had critical interdependencies.

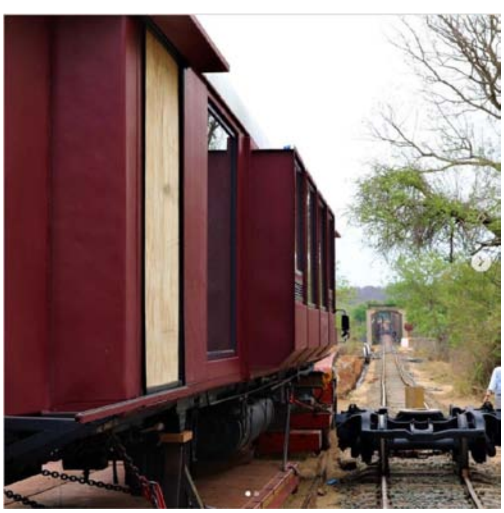
d) Testing and Commissioning

Each carriage was regularly inspected by the architectural team [16] during its refurbishment. Upon completion of the refurbishment, the electrical, plumbing, and waste services were tested before each carriage was released for site delivery. In addition, cursory testing of the water sealing of the carriages was carried out.

Climate control created complications beyond normal projects because Johannesburg is located at 1,760 meters above sea level, a relatively high altitude with very dry air. By contrast, the hotel site is in a lowland area below 300 meters above sea level, with relatively high humidity and summer temperatures rising up to 46^{o} Celsius. This made it difficult to factory test the effectiveness of the carriage air-conditioning systems for climatic endurance. The air conditioning was installed on the spur line prior to placement on the bridge, to enable the use of a local vendor and service provider,rather than requiring technicians to travel from Johannesburg. During transportation, the project team did experience some cracking and breaking due to the carriages expanding as the temperature rose.

e) Transportation and Installation

As explained, the carriages were completed in the order that they were to be positioned on the bridge. Upon completion, each carriage was transported by road to KNP. Because of the size of the rig, SANParks only approved one access point into KNP, and imposed a special escort. Once the trailer was aligned with the spur, the carriage was hoisted back onto its original wheel bogies on the rail spur line and winched into final position on the bridge.



Source: Keith Stannard

Exhibits 41 and 42: The first carriage being hoisted back onto its original wheel bogies on the rail spur line

[16] Hesse Kleinloog. (2019). *Kruger Shalati*. www.hkstudio.co.za/kruger-shalati

One anecdote of a particular project issue is that the special transport vehicle blew a tire in the middle of a bridge over a crocodile-infested low-level river in the middle of the park, with repairs only possible from the river. The crew was advised to remain inside the cab, while it took several hours for the repairmen to reach the site and fix the vehicle in dangerous conditions with lions about.

Source: Keith Stannard

Exhibit 43: The first carriage being winched into position on the bridge

Once each carriage was in position, it was connected to the utilities and the sewerage system.

- *Power:* KNP has an electricity grid, but the hotel just uses it for backup. The 400kW of photovoltaic panels the hotel installed on the roofs of the Distribution Center and car park, fully provide for its electrical needs, making the hotel self-sustaining, and increasing its environmental credentials while simultaneously reducing the additional load on the park's infrastructure.
- *Green, Grey, and Black Water:* The hotel also taps into the park's main water supply, sewerage, and waste treatment infrastructure. The carriage guest rooms incorporate water and waste pumping technologies based on the facilities in caravans and modern long-distance trains. Efforts were made to ensure that all piping remains hidden but can be easily removed from the bridge at the end of the concession. In addition, the nearby Skukuza Airport had to be provided with fresh water via an existing pipe over the bridge which the project was required to upgrade.

Similarly, the room entrance from the walkway was finalized, and all the carriage equipment was tested. It should be noted that the repeating structural "wavelength" of the bridge arches is different from the somewhat variable carriage lengths. Thus, each carriage accessway and services channel section was different and unique, as was the balcony of each carriage.

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Source: Kyle Lewin

Exhibits 44 and 45: Finished interior

f) In-situ Construction and Renovations

In parallel with the guest rooms and lounge carriages being repurposed and refurbished, the Kruger Station was renovated, and the new Bridge House and bridge components were built:

- *Kruger Station:* The facilities underwent an extensive renovation to house a family restaurant, full-service bar, coffee shop, grab 'n go, edutainment, a 360° cinema, kids' cornerand merchandise outlet. *The facility was re-opened before the opening of Kruger Shalati.*

Source: Andrea Kleinloog and Keith Stennard

Exhibits 46 and 47: Renovation of Kruger Station and completed project

- *Bridge House:* This facility was built using standard portal frames. This method is widely used in South Africa and was adopted for the design, but to a significantly higher standard of internal fit-out (e.g., the building was extensively insulated for guest comfort). This type of building fits in with the local architectural vernacular very well and it can be built quickly and efficiently. In addition, the semi-skilled labor needed for most of the work is readily available.


Source: Keith Stannard and Kyle Lewing

Exhibits 48 and 49: The Bridge House interior and exterior

- *Swimming Pool:* The double swimming pool, made from repurposed cylindrical water tanks, were installed adjacent to the Bridge House.


Source: Andrea Kleinloog and Mia Louw

Exhibits 50 and 51: Assembly of the double swimming pool and completed project

- *Bridge Components:* A third factory, located in Nelspruit (±125km. from Kruger Shalati) built the external walkway for the bridge, the services channel segments and the pier-top sewerage holding tanks, as well as the deck and suspended swimming pool for the lounge car.These components were then progressively transported to the site and installed onto the bridge. This project work had to be coordinated with the completion of the carriages so that all components could be installed in the correct order (e.g., the relevant walkway and services channel sections had to be put in place after the corresponding carriage was positioned), including the bridge deck and pool.

g) Fit-out and Set-up

The carriages were refurbished and transported complete with their hard furnishings. As explained, most of the loose fittings, furniture, and soft case goods were transported separately to a warehouse in Skukuza for set-up in the carriages on the bridge to reduce the risk of damage during transportation. These were installed by the hotel pre-opening team before the carriages were winched to their final position. This helped to increase their understanding of, involvement in, and commitment to the hotel.

h) Pre-opening

A successful new hotel opening is achieved by ensuring simultaneous technical, operational, and commercial readiness before opening the asset for paying guests:

- *Technical readiness* pertains to ensuring the new building is physically fit for associate and guest occupancy (e.g., testing, commissioning, defect rectification).

- *Operational readiness* pertains to ensuring the building and associates are ready to deliver optimal guest experience (e.g., recruitment and training of all employees, purchasing of Hotel Operating Equipment & Supplies).
- *Commercial readiness* pertains to ensuring optimal business ramp-up (e.g., sales and marketing, e-distribution, revenue management).

To ensure opening readiness, the hotel development project manager was appointed as the hotel pre-opening general manager to plan and execute the pre-opening activities and transition from project to ongoing hotel operations.

The pre-opening processes included:

1. *Recruitment and Training:* Most of the hotel operations staff were recruited locally from the population of the traditional landowners, as part of the hotel's commitment to the local community. The project's hotel partner assisted with the development of the hotel's Standard Operating Procedures, Job Descriptions, and training plan, and delivered the pre-opening training.
2. *Purchasing:* The carriages were refurbished and transported complete with their hard furnishings. The remaining FF&E and several HOE items were shipped separately to the site for installation by the hotel pre-opening team. To set-up the hotel's Hotel Operating Equipment and Supplies (HOES) supply chain, the hotel partner leveraged its existing supplier relationships.
3. *Outsourcing:* Various local businesses were invited to partner with the hotel to provide services.

a. Traditionally, hotels and resorts have often incorporated laundry facilities, but one modern trend is to outsource this operational activity. Nearly all accommodation facilities in and around Skukuza Camp, including Kruger Shalati, use commercial laundries in the town of Hazyview, which is approximately 60km away. This has the added benefit of moving laundry wastewater processing outside the park and reduces the workload on the local sewerage treatment plant.

b. A local bakery was invited to use the hotel's kitchen and provide all the hotel's bakery products. This is enabling the business to expand capacity while learning additional business skills. It is hoped that eventually, the bakery business will be able to expand into its own premises and serve baked goods to other nearby accommodation and other venues, in addition to the hotel.

4. *Sales & Marketing:* Because the hotel is within the KNP, it was able to leverage off the Park's existing sales and marketing platform, as well as the systems of its hotel- and tour operator partners. Nonetheless, the hotel's dedicated website had to be developed and tested prior to opening.
5. *Finance & Licensing:* Because the carriages are stationary, they did not have to be approved to railcar standards, which are significantly more stringent than regular building standards. Moreover, the park management is the approving authority for structures within the park and so the approvals were obtained as part of the tender submission and acceptance process. Therefore, separate approvals were not required.
6. *Set-up:* The pre-opening team installed the remaining FF&E and several HOE items, which were shipped separately to the site. The team then performed the usual final cleaning, testing of the in-room systems equipment (electrical, plumbing, and drainage), and set-up of guest amenities and supplies. Last, the team conducted a final inspection before approving each room fit for paying guest occupancy.
7. *Opening:* The decision was made to soft open the hotel with 8 carriages plus the lounge carriage with elevated pool, allowing the hotel to start trading before Christmas 2020.

V. Hotel Operations Stage

a) Post Opening

The remaining carriages were delivered staggered and the remaining non-carriage hotel rooms near the Bridge House were completed post-opening.

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Source: Mia Louw

Exhibit 52: The non-carriage hotel rooms

b) Operations and Maintenance

The unique nature of the hotel presented several operational and maintenance challenges. For example:

- The Environmental Clearance requires an independent ECO to conduct inspections of the property for the entire working life of the operating hotel (initially 3 to 4 times per year).
- Because no cooking facilities were permitted within the train carriages, all food must be brought from the Bridge House or Kruger Station. This necessitates additional staff to move food & beverage and other materials over quite long distances between the various hotel front-and back-of-house spaces.
- Because the guest room access walkway is only wide enough for one small, motorized golf cart, a lot of luggage carrying, and maintenance work involves moving items by hand. This is another reason why various FF&E items in the carriages were designed to be small and easily moved and are not permanently fixed into place.
- Because the bridge deck is 15+ meters above the river, hidden (and removable) cleaning platforms had to be incorporated into the undercarriages to safely clean the external surfaces of the carriage windows. In addition, the maintenance staff needed special training and equipment for working at height.
- The use of pesticides and biocides is not allowed inside the park, requiring housekeeping to consider natural and non-toxic alternatives to kill cockroaches and other pests.
- Food waste is sorted onsite and then moved off-site. The hotel meets minimum SANParks standards and is working with the ECO to exceed these standards.
- The elevation above a pristine riverine environment required very specific measures to be put in place to mitigate items dropping or blowing into the riverbed. Retrieval of items requires an armed SANParks guard to accompany the clean-up team.

VI. Conclusions

This paper started by stating that two key drivers of this modular construction-with-a-twist project were authenticity and a strong ESG ethos. [17] Here, the authors review the achievements and lessons learned from this novel hotel development project.

It is widely accepted that refurbishing equipment and buildings tends to be more difficult and expensive than building a new structure from scratch. However, the *Kruger Shalati: The Train on the Bridge* was a modular construction project by default, as railway carriages are by definition modules, given the extreme difficulty and complexity of building a high-quality hotel in such a challenging location with traditional construction methods. The extensive EIA required, and developmental constraints and operational conditions imposed on the hotel signal the strong desire of the relevant authorities to protect the natural, cultural, and economic value of the KNP. The developer has also made considerable efforts to engage with and support the local community during the development of the hotel and its ongoing operations.

Regarding authenticity, the final exterior product does mirror what the carriages would have looked like in the 1930s and 1950s, making the extreme efforts of all stakeholders worthwhile.

[17] Getaway. (2020, November 11). *Kruger Shalati Train on a Bridge Hotel celebrates sustainability*. Getaway Magazine. www.getaway.co.za/travel-news/kruger-shalati-train-on-a-bridge-hotel-celebrates-sustainability/

Kruger Shalati: The Train on the Bridge has certainly raised the bar for developers of future novel hotel concepts. What were the major challenges encountered by the project team, the key success factors, best practices, and lessons learned from this project?

According to the *Chief Executive Officer*, the major challenge was the fact that such a project had not been done before and therefore there was no one to advise the project team on *what* to do and *how* to do it. "There were so many challenges on so many different levels, and the team was learning while the project was progressing. The biggest challenge was the physical engineering of the train: building it outside and then getting it onto the park. Due to the ecologic sensitivity of the park, the logistics of transportation are impressive. When can the truck come in? Where can the truck come in? How will the (massive) truck create the least amount of disturbance?"

According to the *Environmental Impact Assessment Practitioner*: "From the environmental perspective, do not assume that despite of the development happening mostly in a brownfield site, the broader context of a development in a national park means that the assessment needed to be more thorough than originally expected, particularly from the authorities' perspective."

According to the *Project Coordinator*, the most critical success factor was the decision to develop the prototype, and getting the first carriage and various sequential elements right, while starting on the second carriage before the prototype was fully completed, to avoid delaying the production process adversely. He observed that: "because of complexity and difficulty, the project consisted of two-thirds development administration and one-third project delivery." Another critical success factor was the fact the hotel management team and operator's technical services were involved "right from the get-go to help plan the many technical and design-related and operational interdependencies. This made for a very well-integrated, well-coordinated, well-communicated collaboration of every single key element."

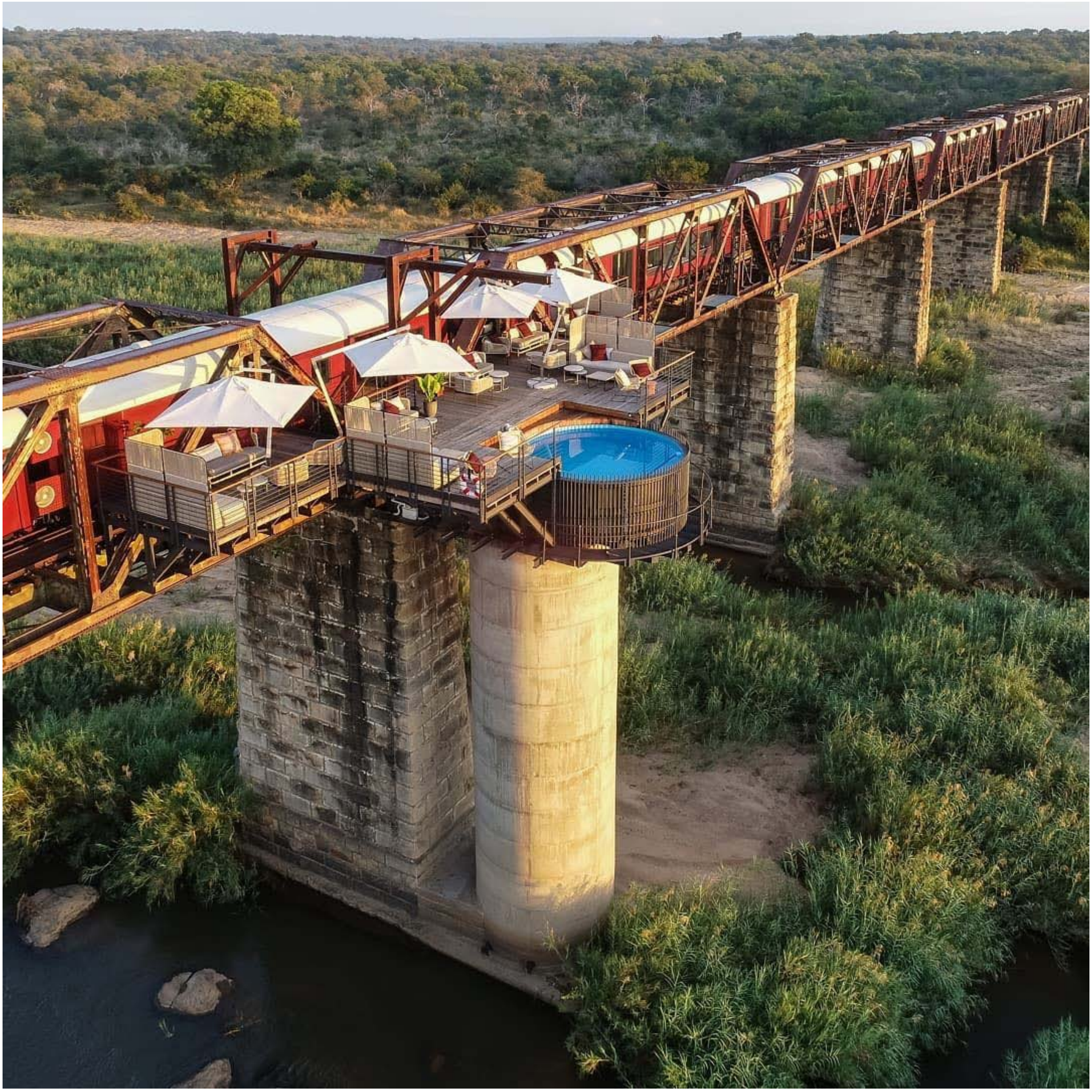
According to the *Interior Designer*, one of the main challenges was scope management, due to the uncharted nature of the projects, resulting in an evolution of the brief under a catch-all contract. "People do not realize what it means to retrofit a train until you stick your head inside one." One of the main takeaways was on preconceived assumptions: "Don't assume! trains are waterproof, rigid, of identical size: they are not…" One of the key success factors was the operational input on the designs from the hotel operator: "How do you clean around the bathtub? How do you clean the windows on the outside?" "Designs must be a little bit forgiving, be flexible and adaptable."

According to the *Pre-opening General Manager*, the three main lessons for similar future projects are:

1. *Schedule & Budget:* Schedule: however long you *think* the project will take to be completed, double it. Budget: however much you *think* the project will need to be completed, triple it.
2. *Risk & Uncertainty:* Conduct a very thorough risk assessment and think of every possible "what if" scenario (e.g., happens if your Project Manager gets malaria?) [18] and build in contingency (i.e., does the budget include sufficient capital for events like Covid?). "Accept the unexplained unforeseen: it will happen!".
3. *Team:* "This kind of project takes its toll on a human being, so take care of the people and give them support."

The *authors* are of the opinion that two of the key success factor were the foresight to carefully select the strategic partners and project team members, and identify all key stakeholders at the beginning. The project team displayed all the hallmarks of good project management: strong leadership, excellent communication and strong emphasis on planning. Interestingly, the developer now has considerable expertise and the facilities to make building modules, which could be a significant future business opportunity.

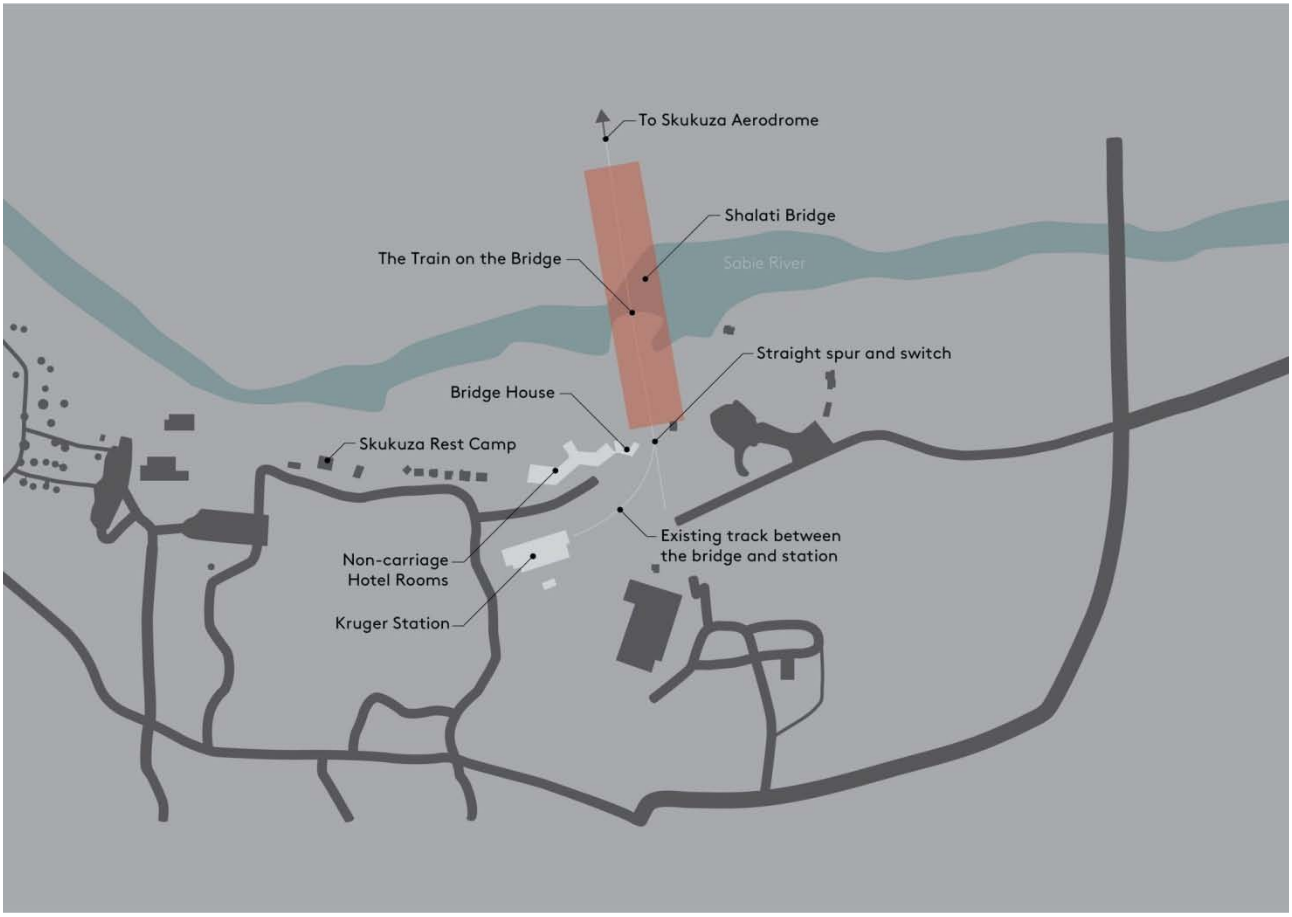
[18] Fortunately the project manager is a well-salted South African who has experienced almost all the continent can throw at you…



Source: Kruger Shalati Pty Ltd.

Exhibit 53: Kruger Shalati: the Train on the Bridge

Appendix A



Source: Courtesy of HesseKleinloog Studio

Map of Skukuza Rest Camp, Kruger Station, and the Shalati Bridge

Appendix B

Source: Courtesy of HesseKleinloog Studio

TOB interior design drawing of a typical carriage guest room

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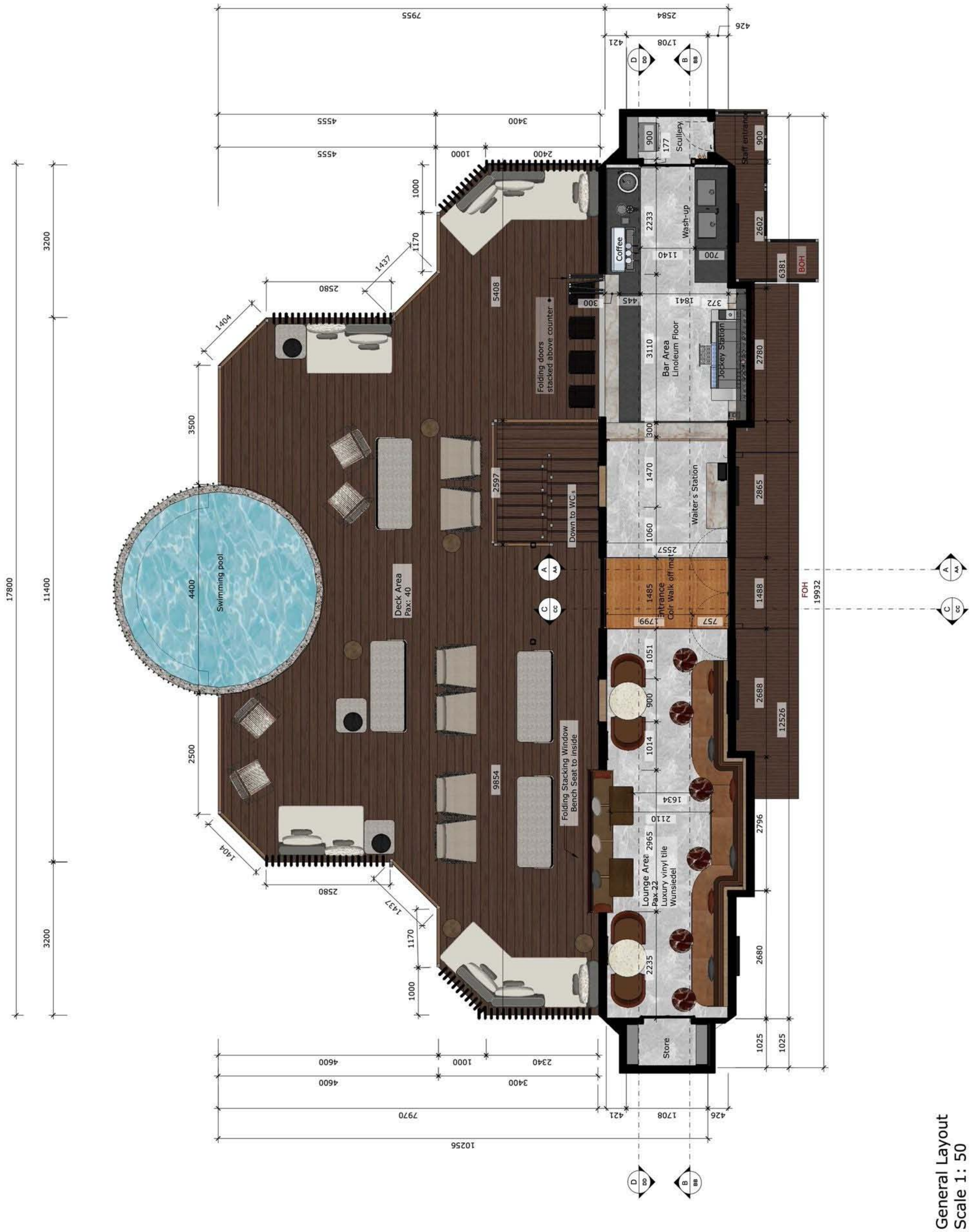
Appendix C



Source: Courtesy of HesseKleinloog Studio

TOB interior design drawing of the lounge carriage

Appendix D

Source: Courtesy of HesseKleinloog Studio

TOB interior design drawing of a typical non-carriage hotel room

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Abbreviations

DEA	Department of Environmental Affairs
DFFE	Department of Forestry, Fisheries and the Environment
DOT	Department of Transport
DSAC	Department of Sport, Arts and Culture
ECO	Environmental Compliance Officer
EIA	Environmental Impact Assessment
ESG	Environmental, Social, and Governance
FF&E	Furniture, Fixtures & Equipment
HIA	Heritage Impact Assessment
HOES	Hotel Operating Equipment & Supplies
HSA	Historic Structure Assessment
JV	Joint Venture
KNP	Kruger National Park
PPVC	Prefabricated Prefinished Volumetric Construction
SAHRA	South African Heritage Resources Agency
SOP	Standard Operating Procedure

SPV	Special Purpose Vehicle
PPP	Public-Private Partnerships
TIA	Traffic Impact Assessment
TOB	Top of Beam
UA	Universal Accessibility
VIA	Visual Impact Assessment

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Shadowing Pathologies of Diaphragm Wall Concretes: General Overview

By Maria Kmeid

Abstract- This paper provides a general overview regarding shadowing pathologies that have been observed on diaphragm walls after excavation. This phenomenon, also termed mattressing by the European Federation of Foundation Contractors and the Deep Foundation Institute, on wall panels, as its name suggests, is the imprint of the reinforcement cage in the concrete block. While some mattressing is not necessarily evaluated as defect, durability issues put at risk the integrity of the structure. In some cases, the steel reinforcing bars are directly exposed to the open air, promoting corrosion phenomena, and thus harming the entire structure. Upon investigating the preliminary findings of the scientific literature, this article has defined the factors that are likely to affect the occurrence of these anomalies. These factors may be divided into three main families: diaphragm wall components, executed techniques during construction, and interactions between the components throughout the different construction stages. Recommendations presented by previous studies are also discussed.

Keywords: *diaphragm wall, shadowing pathology, mattressing, deep foundations.*

GJRE-E Classification: *LCC: TA1-2040*

SHADOWINGPATHOLOGIESOFDIAPHRAGMWALLCONCRETESGENERALOVERVIEW

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Keywords: diaphragm wall, shadowing pathology, mattressing, deep foundations.

I. Introduction

The diaphragm wall technique, which has been around since the early 1960s, involves in creating reinforced concrete walls in the ground. It is an operation that avoids the risk of soil destabilization by fulfilling the function of a retaining wall. The waterproof wall can also act as a vertical support element making of it another type of foundation. Due to this dual function, its field of application is seen in both building and public works (metro stations, car parks, covered trenches).

The construction of a diaphragm wall is executed in panels. A typical panel length is 4 to 7 m depending on several aspects like the dimensions of the drilling tool and the maneuverability of the reinforcement cage, as well as the quantity of concrete to be delivered on site. The thickness varies between 0.5 and 3 m, and walls deeper than 50 m are very rare. Excavations are carried out until the designed depth is reached and the panel is consequently formed by placing the reinforcement cage and then pouring the concrete in the trench continuously stabilized under a support fluid consisting of a drilling slurry. Once the concrete has hardened, excavations within the now concrete-wall-enclosed area can proceed.

In some cases, as the soil from one side of the structure in the newly open area is being removed, imperfections on some concrete panels may appear. One type of defects would then be shadowing pathologies. The reinforcements of these walls are sometimes visible, which causes structural (reduction in panel cross sectional area), aesthetic (rebar exposure) and durability (accelerated corrosion) problems. The additional cost of correcting the work becomes potentially very important in terms of time and money [1] and makes this problem an essential issue for the profession.

II. Physical Phenomena

Shadowing pathologies or Mattressing also referred to as « Honeycombs » or « Quilting » are defined as imperfections observed on both pile and panel surfaces after planing operations. Vertical and horizontal linear features arise on the concrete wall along the reinforcement cage while materials other than concrete may be trapped in the shadow of the reinforcing bars. In some cases, this phenomenon is widely spread all over the diaphragm wall, that it could be considered as the imprint of the reinforcement cage on the concrete block. While some mattressing *(Figure 1 & 2)* is not necessarily evaluated as defect since it does not have any impact on the bearing capacity [2], accelerated corrosion phenomena put at risk the durability of the structure [3]. Besides the fact that cover thickness is reduced, the event becomes further critical if the steel rebars are directly exposed. In the absence of sufficient concrete cover, the necessary protection (barrier) for steel rebars against oxygen, moisture and chlorides is no longer provided [4], hence the effect of the shadowing pathologies on the structural service life of diaphragm walls. There are varying degrees of mattressing where ones can be more dangerous than others. Most of the time, excavations take place only from one side of the wall whereas the other side remains in direct contact with the soil. Thus, if visible defects *(Figure 3)* regardless of their degree of occurrence can be identified and repaired, there are still interrogations on the quality of the non-excavated and non-planed wall surfaces.

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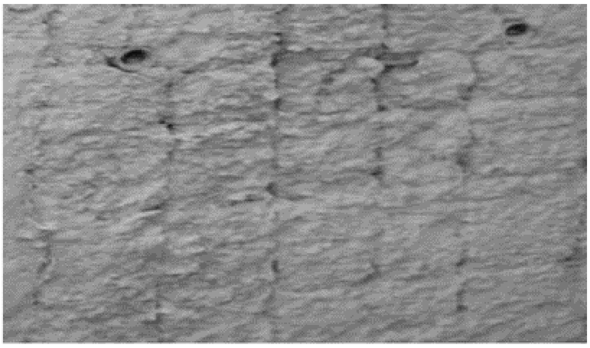

Figure 1: Mattressing [5]

Figure 2: Mattressing [8]

The formation of this type of pathology may depend on several mechanisms until now poorly identified. If some [5] are associating the mattressing phenomena with restricted concrete flow or a dense reinforcement, Carter [6] might relate it to borehole stability and moisture content of the surrounding soil.

To better understand the problem of imperfections on diaphragm walls, a general overview regarding previous studies is established. Hence, this paper defines the present status concerning "shadowing pathologies". The purpose of this work is to reveal different points of failure highlighted by several investigations allowing to underline the probable causes of the disorders.

Figure 3: Panels with exposed rebars [9]

III. General Interpretation

Several reasons can lead to the occurrence of shadowing pathologies. Factors that can be found in the literature may be divided into three main families:

- Diaphragm wall components
- Executed Techniques during construction
- Interactions between the components throughout the different construction stages.

In the following sections, the general concept of each family will be described as well as some underlined items of interest that might contribute directly or indirectly to the existence of the pathology.

a) *Diaphragm Wall Components*

The aim of the proposed investigation is to study specifically all the parameters that are involved when diaphragm wall panels are being built. Multiple elements could be influential: the soil, with its physical and hydraulic activities, drilling slurry characteristics before concreting, the quality of the rebars and concrete with its rheological behaviors but also its physical - chemical and mechanical properties.

i. *Soil*

Nowadays, it is possible to complete diaphragm walls technique in almost all types of soil [10]. Thus, with no restriction on soil type and when using the right equipment, execution of panels is carried out conveniently with no special considerations according to each type.

However, detailed field monitoring on four subway station sites during the construction of the Suzhou metro in China *(Figure 3)*, has shown exposure of rebars where diaphragm wall panels where constructed in silty sand to silty clay layer [9]. In fact, depending on the soil profile and the configuration of the diaphragm wall (length of panels and construction sequence), horizontal displacements of the inner trench wall face can be important. Stability of the excavated trench as well as ground response including settlement and lateral deformations depending on the soil type can therefore be related to the occurrence of some arising defects like mattressing imperfections. Another study [11] has exposed situations in which soil (usually sand or silt) was not handled properly. In some cases, coatings of granular soil prevented longitudinal reinforcement bars from bonding to the concrete.

Several conclusions were made regarding soil moisture content and groundwater horizontal flow. A study [6] suggested that when drilling in cohesive soil, excess pore water will certainly dissipate endorsing an increase of the void ratio. This event will allow swelling of the surrounding soil. On the contrary, if the soil is now hydrophilic, during the concreting process, water existing in the concrete will be attracted by the nearby ground [12]. Hence, the rising concrete loses its fluidity and slows down between the cage and soil interface. This phenomenon could thus induce shadowing pathologies.

Another factor related to the soil component is the level of the water table. While some [13] might think that the presence of groundwater is the first element leading directly to the honeycombing disorders, a study [14] has revealed that it cannot be considered as the primary cause of anomalies as other parameters like materials properties and borehole cleanliness showed more significant effects.

ii. *Slurry*

Drilling slurry also called support fluid in Civil Engineering is a stable suspension generally made of polymers or colloidal clay used to support the sides of open trenches during excavations. In Europe, Bentonite clay is the most common mud utilized in diaphragm walls construction. Many research works have dealt with this type and very few observations have been made regarding polymer suspensions. According to [15], the occurrence of mattressing on laboratory placed shafts was much more remarkable for specimens cast in bentonite slurry compared to polymers suspensions, but the studies have been processed without respecting the bentonite slurry recommendations, so these conclusions would have to be confirmed.

Bentonite is a natural clay, which mainly contains smectites. It has typical characteristics such as very fine particle size, and very high specific surface as well as great sensitivity to hydration. With very little dry substance, it can produce stable suspensions and that is because of its water-retaining power and large grain swelling capacity. By this means, the stabilizing fluid consists in mixing bentonite powder, dosed between 30 and 50 kg per m^3 of water. The mixing process is very crucial in developing slurry's rheological properties. Higher initial viscosity and gel strength are measured with greater agitation and longer mixing time [16].

The mix has a density slightly greater than that of water and consequently the fluid is more viscous. Hence, the final mixture can provide stability for the open trenches without infiltrating into the adjacent permeable soil. Some observations have shown that a dense slurry which exerts adequate hydrostatic pressure for stabilization purposes can be trapped at the bottom of the trench [17]. This incident might be related to the quality of the walls. However, Mullins and Ashmawy [14] have shown that despite reliable values for the density and the Marsh viscosity, some panels with fluids showing high sand content suffered from a serious problem of rebar exposure.

During drilling phases, the slurry is loaded with sediments from the excavated soil and must thereby be de-sanded before concreting. If the sand content is greater than 4%, the slurry should either be sent directly to the desander and then return to the excavation in a closed circuit or be completely removed and replaced by a clean mix. De-sanding treatment can be automatic by mud recycling in sand separator sieves. Otherwise, the treatment can be chemical by adding sodium carbonate to increase the pH and restore the support fluid properties. Most commercial bentonite have a pH range between 9.5 and 10.5. However, the pH of the slurry can be reduced if contaminated by acidic groundwater [16]. Regarding pH modification, a study has shown that when pH measures relatively acid values, the stress necessary for the material to flow (yield stress), increases. On the other hand, if pH units increase, yield stress decreases [18]. The study also reveals that the chemical structure of the bentonite would be probably attacked in a very highly acidic media. A correlation between the contamination of the slurry and its rheological properties may be distinguished.

Another advantage of this support fluid would be its thixotropic behavior. In the absence of shear stress, this viscous fluid is altered and will form a gel like material. In contact with a porous surface like at the interface of the soil, the bentonite slurry forms naturally, by jellification and filtering, a very low permeable membrane called filter cake [19]. The role of this membrane consists in creating a barrier against the surrounding soil. Fluid exchange between the drilling slurry and soil interstitial solution would be restricted. Hence, the stabilizing fluid would resist the hydrostatic and lateral pressures generated by the water table and the adjacent soil. *Figure 4* shows theoretically how a bentonite filter cake is formed on an inner trench wall face.

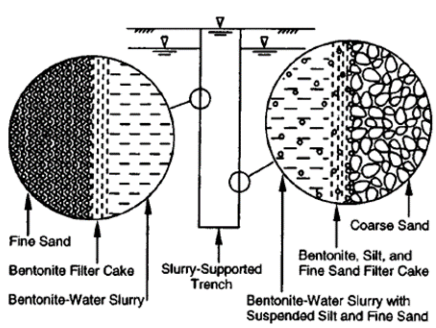

Figure 4: Filter cake formation over trench face of excavation [20]

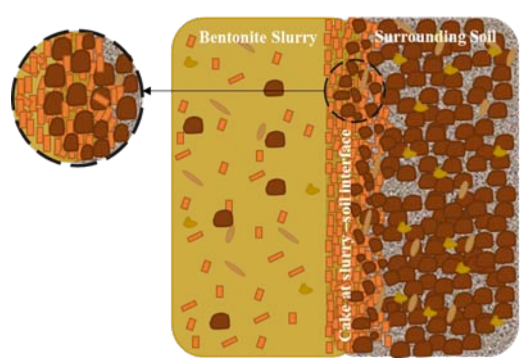

Figure 5: Bentonite filtration [19]

So far, the creation of filter cake has not been the center of many researches. Some studies [19] [20] have presented it as a combination of bentonite and excavated soil. It is formed as the drilling slurry is being pumped into the trench under excavations when bentonite particles are being pushed near the interface and filtered out by the nearby permeable soil *(Figure 5).* As it is mentioned earlier, this phenomenon occurs automatically with no specific intentions. For that matter, there is no real guarantee that the bentonite slurry had formed a filter cake all along the excavated trench. Filz et al [20] have identified some criteria to ensure filter cake formation. However, the effectiveness of the support fluid remains uncertain in providing sufficient lateral forces. Furthermore, if bentonite mud is supposedly being filtered throughout the permeable interface, there are no definite information about the thickness of this membrane.

For example, a thin filter cake, could be associated with poor impermeability whereas a thicker membrane is supposed to endorse the application of hydrostatic pressure by limiting the infiltration of groundwater into the trench. However, a slurry which forms a good membrane may be too resistant to flow and therefore might not allow good spreading of the poured concrete [17]. Another consequence due to a thick filter cake is the reduction of the panel thickness. The latter is associated to a reduction of the cover zone and thus poor concreting quality.

To determine the filtration properties of the support fluid, a pressure driven test based on filter loss measurements is implemented. The apparatus, called Baroïd filter press, consists of a cell filled with drilling slurry, maintained under a pressure of 100 psi for 30 minutes. The volumes of fluid loss measured at the end gives an idea of the behavior of the material. Afterwards, the thickness of the cake is determined. These values are then compared to the recommended values *(Table 1)* which do not consider the type of soil encountered. This test is applied on site, in the exact same way (pressure of 100 psi) regardless of the soil type, the panel length or the pressures generated by the excavation. And the resulting cake thickness is assessed depending only on the slurry characteristics and do not consider soil – slurry interface.

The European Standards for special geotechnical work, diaphragm walls section, specifies general characteristics for bentonite suspensions for each of its three different stages. The properties to be attained are indicated in the Table 1.

Table 1: Characteristics of support fluid [21]

Property	Values for different stages		
	Fresh	Re-use	Before Concreting
Density in g/cm^3	< 1.10	< 1.25	< 1.15
Marsh Value in seconds	32 to 50	32 to 60	32 to 50
Fluid Loss in cm^3	< 30	< 50	N/A
pH	7 to 11	7 to 12	N/A
Sand Content in % volume	N/A	N/A	< 4
Filter Cake in mm	< 3	< 6	N/A

iii. *Rebars*

Mattressing phenomena are characterized by marks following the trail of the vertical and horizontal bars of the reinforcing cage. In some cases, the rebars are exposed. Some aspects related to this component may therefore be linked to the origination of the anomalies.

The depth of diaphragm walls is usually very important. Consequently, reinforcing cages are being assembled from long and massive bars to assure appropriate lengths. Such heavy weights will generate stresses that develop in the bars. Loadings may cause significant and unpredictable deformations, possibly leading to buckling phenomena. For that reason, it is important to evaluate the quality of the steel bar as it must be rigid enough for not to deform during handling operations [10]. A change in shape can cause verticality defects of the reinforcing cage along with a much serious problem like the reduction of the concrete cover or even bars exposure.

In addition to great depth, diaphragm panels carry the advantage of fulfilling retaining walls function. The reinforcement strength must be determined as suitable for the full design life of the structure. With regards to these factors, design calculations may result in integrating large and thick rebar diameters with little and narrow clear spacing. Furthermore, the cages will be subjected to significant pressures due to the

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concrete flow. Thereby, it must be taken into account to incorporate enough horizontal steel [10]. The clear spacing is determined according to Eurocode 2 [22]. In some cases, the values recommended may limit the ability of the concrete to flow throughout the steel rebars [2]. In fact, a trace of the reinforcement cage has been observed on site where excessive steel has been applied [7]. A study detailing concrete flow in drilled shafts showed that single reinforcement cages led to fewer defects than doubled cages [4].

iv. *Concrete*

Tremie concrete for deep foundations are one type apart from normal concretes because of their specific properties in the fresh state and their application without vibration. The diaphragm wall concrete must be sufficiently fluid to properly occupy the entire volume of the excavation [10] and at the same time, appropriately compact to correctly pile up by simple gravity without infiltrating into the slurry. This characteristic is guaranteed when enough concrete flowability and workability retention meet appropriate stability [2]. Flowability or workability describes the ability of fresh concrete to behave as a liquid and pass through the gaps of the reinforcing cage [23]. Workability retention or workability life illustrates the prior property as a function of time [23]. It estimates the duration that could maintain a fresh concrete with sufficient workability. For tremie concrete, this duration must correspond to the time a panel take to be placed. As for stability, this property defines the ability of fresh concrete to retain its water under pressure. Once discharged, the concrete is subjected to pressure generated by the surrounding soil on the sides and the fresh newly poured concrete above. Under these circumstances, the fresh concrete must act as a soft solid and "deform" instead of losing its water. The dual challenge, to alter between liquid state and soft solid, depends on the rheology of the concrete. The rheology is defined by the response of the material under the effect of an applied force. With the increase in stress, the strength that binds the matrix together would decrease allowing the fluid to flow. Nonetheless, there won't be any flow under lower stresses where the mix behaves like a solid. The rheology is represented by two main properties: the yield stress and the plastic viscosity. In order for the diaphragm wall concrete to flow easily under its own weight, the latter should maintain a very low yield stress as well as a small plastic viscosity [24]. Depending on the rheological properties of the concrete, the latter may be too resistant (high viscosity) during placement that when encountering the reinforcing cage, is unable to wrap around the rebars and cover the external sides leaving behind voids along the bars. Some studies have linked observed damages on panels described as honeycombs, with either insufficient concrete quality and lack of stability or poor bonds with reinforcement and lack of workability [5]. Another study describes the mattressing phenomena as inclusions in the cover zone caused by an insufficient concrete flow due to reduced workability performance [1].

The rheology of concrete does not only depend on its age when concreting but it is also a function of its composition. The type of aggregates used in the concrete mix has a direct impact on its workability. Crushed aggregates have an angular shape and a rough surface, which significantly increase the yield stress and the plastic viscosity, thereby reducing the flowability of the mixture. On the other hand, the smooth surface of round or natural aggregates reduces the friction of the internal particles and leads to an increase in fluidity [25]. Furthermore, aggregates with a relatively large diameter (D_{max}) restrict the flow of concrete between the rebars. For that reason, the specified D_{max} shall not exceed the minimum of 32 mm and ¼ of the clear space between the vertical bars [26]. A well graded aggregate particle distribution is essential, since grading minimizes the risk of instability [27]. A reduced flow related to insufficient concrete workability is related to a lack of fines in the aggregates distribution combined with little water content [1].

As for the binder, its type is conditioned mainly by the level of aggressiveness of the nearby environment. However, its composition is related to the rheological properties of the paste. It is recommended to use supplementary cementitious materials (SCMs) to improve concrete workability [21]. On a one hand, the addition of slag reduces the plastic viscosity and a study has shown that it also reduces the yield stress of the mixture regardless of the water - to - cement ratio [28]. Adding fly ash, on the other hand, increases the viscosity of the mix, reducing thereby concrete's tendency to bleed and increasing the stability of the mix [29].

The fineness of the cement has as well an influence on the workability and stability of the concrete mix. A fine cement requires more water to hydrate. This means that, for the same W/C, lesser water would be free to flow between the particles. A recent study has proposed to increase the specific surface of the cement (Blaine method) to 4000 m^2/kg for diaphragm walls concrete mixes [30]. Other works suggest to partly replace the cement with ultra-fine additions significantly finer than the cement to decrease the viscosity and the yield stress [2].

If the quantity of water is reduced to avoid segregation and bleeding, it is essential to find other means to ensure good workability. The specific properties of diaphragm wall concrete are quite often ensured by the addition of water reducing admixtures. The superplasticizer makes it possible to improve the fluidity and facilitate concrete flow by reducing the intensity of the interactions between the grains of cement. This change is however, causing a risk of gravitational instabilities which results in an upward vertical migration of water within a freshly poured concrete [31]. On a one hand, this mechanism can, when mixing to the cement, give rise to side effects like excessive segregation, if not well dosed [32]. On the other hand, an insufficient application of admixtures in the tremie concrete can contribute indirectly to mattressing imperfections since these defects are related to insufficient lateral flow [1].

The practical considerations and proportioning of the mix design previously determined are not enough to guarantee desired concrete quality.

Test methods are applied on trial mixes to verify that the rheological properties fall in the accepted ranges. It has been shown that poor concrete quality is, in some cases the consequence of inadequate mixing speed. Numerous tests describe the rheological state of the tremie concrete. In practice, the tests carried out on site are two. The slump test in accordance with NF EN 1538 [21] must fall in the range of 210 +/- 30 mm and a slump flow between 600 +/- 30 mm.

There is also another test that gives a measure of the stability, the recently developed BAUER filter press. This testing device provides a method for investigating the water retention ability of fresh concrete under pressure. The guide values for the stability of the deep casting concrete recommends a filtration value≤ 22 ml known as 15 l/m^3 for panels with a depth greater than 15 m. However, to follow up on recent research studies, it has been proposed to bring this value to 10 l/m^3[12].

b) Executed Techniques

The execution of diaphragm wall panels constitutes of a succession of operations. Prior to the construction work, attention must be drawn to local conditions of the site to ensure good implementation of the walls. A study of the paneling and the order of execution must be well-thought-out to limit the vagaries during the construction [33]. The construction methodology is explained in the following sequences. The first operation comprises into boring a trench, constantly supported by the stabilizing fluid. Once the excavation process is achieved, the reinforcing cage is introduced into the trench and the tremie pipes are placed at the center of the panel. Then concrete placement begins where the latter should displace the slurry upwards to be consequently evacuated. Although the success of this technique depends on the properties of the materials, the right application of these procedures is important in the good implementation of the diaphragm walls.

Nowadays, there are several international codes and standards of practice in the scientific literature that cover the different points of this technique. The aim of this section is to apprehend some missteps that could be related to the mattressing pathology.

i. *Boring Process*

The diaphragm walls are drilled from the platform level using various types of mechanical devices depending on the soil encountered [10]. The drilling tools must respect the exact dimensions of the panels as the thickness is conditioned by the absolute width of the drilling tool (usually 50 cm to 150 cm). The cover of the reinforcing cage depends consequentially on the boring operations since no temporary casing is used and the concrete may have difficulties in flowing to the top (little space between the ground and the reinforcement). Several studies ([14], [21] and [11]) have mentioned borehole cleanness for being one of the primary cause for arising defects. If the bottom of the excavation has not been cleaned out correctly, settled materials may be pushed to the sides of the excavation and eventually become attached to the steel rebars [11]. During drilling operations, it is the verticality of the tool that conditions the proper execution of the foundation element. In fact, the European standard [21] allows a tolerance of 1% with respect to the depth, for the verticality of the panels. On several sites, a tolerance of 0.5% is applied and is limited to a maximum of 20 cm. Deviations from the face of the trench are deeply linked to the general stability of the panel. Some of the factors that influence these deviations is the type of tool used, the method of soil extraction and the speed of excavation [17]. The same study underlines the necessity of a slow excavation speed in order to minimize the disturbance of the soil at the internal face of the wall, by allowing a proper formation of the filter cake. Investigations held by Tong *et al* [9] on several construction sites determined that exposed rebars were observed on sites where the speed of excavation was slightly higher than others. Another study [11] has indicated that when excavating a granular stratum too quickly, the drilling operations may produce an undercut zone disturbing the hole stability.

ii. *Stability of the Excavation*

The previously described thixotropic slurry continuously ensures the stability of the open excavation. The support fluid supply is provided simultaneously as the soil is being extracted, so that the rate of supply replaces directly the volume of the excavated soil.

To avoid any landslides, pumps are being kept in motion to ensure the continuity of the fluid supply and may be left running to recirculate the slurry when delivery is not required. While continuous pumping was considered harmful for synthetic polymer based fluids, as significant degradation of the fluid properties was observed, it has been shown that the circulation through a centrifugal pump turned out to be beneficial for bentonite muds since it prevents settlement and improves hydration [19]. On the contrary, leaving mineral slurries in an excavated trench of a granular soil without agitation leads to the formation of a thicker filter cake [11]. The resulting impermeable membrane is thus too dense to be easily replaced by the flowing concrete. *Figure 6* illustrates a thick filter cake formed on the side of a borehole in granular strata.

The continuous motion allows the level of slurry to be maintained in the excavation. The latter has an influence on the lateral soil displacement of the open trench. When the level of slurry was lowered to 1 m below its original level, a 60% increase of the horizontal soil displacement was detected [9].

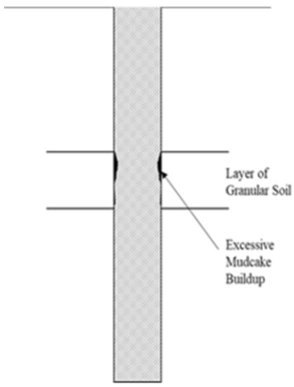

Figure 6: Thick filter cake formation due to stagnant slurry [11]

iii. *Reinforcement Cage*

After bringing a trench wall excavation to stability, the reinforcing cage is installed into the panel. Anomalies in the concrete block like "shadowing pathologies" can also be the result of incorrect placing of the reinforcing cage. Any element to be introduced into the excavation, is liable to movements during concreting. This may create retention zones for slurry or polluted concrete during the concreting of the panel [33].

If verticality defects are mainly related to change of shape of the rebars, non-compliance with the recommendations of the standards [21] can lead as well, to a deviation from the side of the wall. As it goes down, spacers should be placed every 3 to 5 m on each side to ensure the centering of the cage in the trench.

The standard also requires not less than 75 mm as minimum cover. However, Delisle [34] suggests that it is essential to provide 100 mm to prevent cover defects.

iv. *Concreting*

In the case of diaphragm walls, concrete placement remains the most delicate operation. Any small misstep risks causing damages to the final structure.

Prior to concreting, the base of the excavation should be cleaned of any loose debris. The debris can be trapped in the initial concrete discharge and may accumulate in the interface layer [2]. Hence, the now polluted concrete finds more difficulties in covering every part of the excavation.

Concreting is usually done using the tremie pipe method, which consists of a pipe and a filling hopper at the top. The vertical column whose base reaches the bottom of the trench, helps guide the concrete flow. If the first concrete is not properly discharged, it ends up being dispersed and trapped at the lower and the lateral parts of the borehole (*Figure 7*) and does not therefore rise uniformly and entirely when the pouring proceeds. This phenomenon affects the quality of concreting and disrupts the lateral friction between the cementitious material with the excavation boundaries [35]. Any disturbance of the tremie pipe position can also lead to segregation problems and pollution incidents.

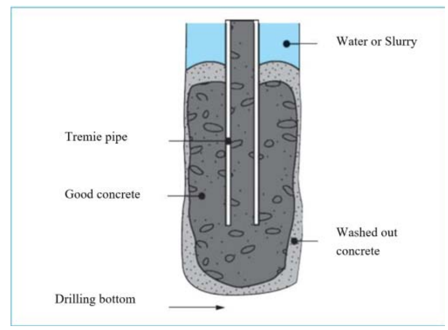

Figure 7: Distribution of the dispersed concrete following a priming defect [35]

Depending on the panel length, it may be necessary to use several tremie pipes simultaneously to ensure a uniform rise. In order to guarantee the integrity of the panel, the concrete rising speed shall not be less than 3m/h [21].

A study using concretes of different colors helped to better understand the process of concreting in diaphragm walls. Experiments (*Figure 8)* on freshly poured panels indicate that the concrete sitting in the central area is being pushed outside the reinforcement cage when new fresh concrete is added [7].

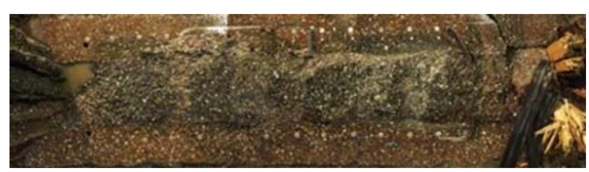

Figure 8: Difference of concrete inside and outside the reinforcement cage [7]

Figure 9 shows mattressing features observed on one panel, where steel bars significantly influence the horizontal flow of concrete in the cover zone and no significant flow upwards has occurred. During the first concrete discharge, areas between the rebars and the surrounding soil were not filled with concrete, due to dense reinforcements. However, when enough pressure at the outlet of the tremie pipe is attained, the previously unfilled areas were eventually completed.

Figure 9: Concrete flow in highly dense reinforcement areas [7]

If the concrete placement is interrupted (*Figure 10)*, after a certain time, the pressure difference between the concrete inside and outside the pipe is no longer enough to allow its rise in the borehole. This can be the cause of serious imperfections [34]. A prolonged concrete interruption induces the instability of the bentonite suspension, and a filter cake forms on the surface between the fresh concrete and the bentonite [7].

Figure 10: Interruption trace of concreting on a panel of diaphragm wall [7]

c) *Interactions*

Regarding the following section, there is not an abundance of available information. However, when looking at the issue with a smaller scale, several interactions that were observed in the past, are discussed in this article. It includes interactions between each two components throughout all the construction stages.

i. *Soil and Slurry*

To better understand the role of bentonite slurry in the diaphragm wall technique, it is important to recognize the interactions between the stabilizing fluid and the surrounding soil.

According to Besq *et al* [36], it is necessary to take into account the nature of the excavated soils before choosing the properties of the support fluid. A bentonite suspension having enough shear strength may be required to reduce penetration into the permeable soil [21]. Surface filtration into the ground is much to be preferred than deep filtration in order to form a cake as quickly as possible at the interface and avoid loss of slurry into the soil [16].

A first interaction can be represented by the filter cake formation. Based on the results of [37], a filter cake will form depending on soil particles gradations in the case of fine sand and suspended silt. With regards to the soil permeability and the density of the slurry, this filter cake can be either too thick or too thin. The consequences were previously discussed in this paper and thus have consecutively an impact on the good quality of the panels. In cohesive soils with high clay content, the slurry is charged with suspended fines and therefore becomes heavier and slows down the drilling tool in the trench. Heavier slurry has also an impact on the filter cake as it increases its thickness and hence reduces the contact pressure of the clamshell grabs [19]. Based on other research works concerning the stability of deep diaphragm walls constructed in a sandy soil, when the bentonite suspension is maintained at a level higher than the level of the water table, the pressure difference tends to force the bentonite into the adjacent soil. Thus, the filter cake formation consists not only of bentonite, but also of silt and silty sand [20]. For that reason, higher densities of the support fluid were measured in the cover zone, explaining difficulties of the concrete flow, especially when it can no longer effectively push the bentonite upwards between the reinforcing cage and the soil interface.

Bentonite slurry could possibly be diluted by the groundwater and contaminated by fine soil particles dispersed in the fluid. As a result, its rheological properties can then be modified. Several imperfections discussed earlier in this paper, were observed. It should be noted, that the contact time for the slurry in the excavation is also very crucial in the occurrence of the anomalies. According to[38] , the bentonite suspensions exposure shall not exceed 36 hours for some excavations.

Chemical reactions between the support fluid and ground water or ground particles can also take place in the excavation [19]. Chemical species can be either ionic compounds from calcium and magnesium or in the form of a mineral like gypsum. For the first specie, effects like breaking molecular bonds can be a problem. Gypsum, on the other hand, has a direct effect on the slurry which becomes too fluid and the filter cake penetrable.

ii. *Slurry and Rebars*

To evaluate the influence of the support fluid when in contact with the steel rebars, some studies have been carried out to verify the adhesion of the bars, previously immerged in bentonite slurry, to the hardened concrete. While the bond between the concrete and vertical bars is seen slightly reduced, greater reduction in the adherence of horizontal steel was observed. The probable explanation is that the rise of the concrete along the longitudinal reinforcement cleans them perfectly, while, in the case of the horizontal bars, only the lateral parts are well scraped and a film of slurry remains trapped along the lower and upper parts [34]. Several materials previously settled in the bentonite

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suspension may become loosely attached to the rebar as the fluid rises [11]. If not well treated, the slurry could remain contaminated and may be too resistant to flow so when moving upwards do not allow good cleaning of the steel bars [17]. Another study [38] that applied pullout testing confirmed that the bond strength between the concrete and the rebars was reduced (up to 70%), due to buildup of the slurry on the bars. The residual slurry noticed on the reinforcement increased when the apparent viscosity increased.

iii. *Slurry and Concrete*

Mattressing phenomena can be linked to interactions at the interface of the supposedly two immiscible fluids. A study [1] suggested that poor concrete quality incites for the two fluids to be mixed. In fact, if the concrete cannot easily pass through the reinforcing cage, the bonds that binds the matrix will be broken, creating a thin channel of de-bonded concrete. Hence, a fluid like the slurry, which already flows in the excavated trench, penetrates the thin channel, between the de-bonded concrete. This phenomenon creates a permanent separation layer preventing the concrete from re-bonding and consequently giving rise to the mattressing defects.

In the literature [39], several cases are described in which the concreting process has resulted in inclusions of bentonite. If pouring resumes after an interruption, previously poured concrete, which has stiffened due to its immobilization encounters difficulties in regaining the flow through the cage whereas the fresh concrete comes out of its initial flow, and forms a new layer, thus trapping the slurry mixed with the sandy soil.

Figure 11 shows severe honeycombs features due to reestablishing concrete flow. When fresh concrete arrives, the upper face of the old stiffer concrete in contact with the settled materials of the slurry is pushed outward and through the reinforcing cage [11].

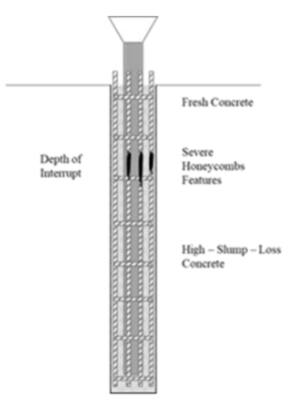

Figure 11: Severe honeycomb features following an interruption of the concreting [11]

In contact with concrete, thixotropic slurry has its rheological properties modified [40]. In addition to its thickening, a high pH values were measured, as well as an increase of the viscosity. Chemical reactions also occur between the support fluid and the concrete and more specifically the cement particles. The filter cake under the effect of Ca^{2+} ions from the cement changes and hardens, thereby inducing a difficulty for the concrete to completely remove it from the walls of the trench. A study concerning the physico-chemical interaction between cement and bentonite [41], confirms ionic exchanges between the two solutions. However, the experimental work carried out, was not enough to cover all the phenomena regarding the evolution of the hydraulic performances of bentonite in contact with cementitious solutions.

iv. *Concrete and Soil*

Interactions between the freshly poured concrete with the surrounding soil occur before the hardening of the concrete. The cementitious materials are often poured to great depths (20 to 50 m), therefore, the fresh concrete located at the bottom of the structure is subjected to important pressures generated by the surrounding soil. Under the effect of these pressures combined to gravity forces, instabilities like bleeding, may appear [31]. Thus, the now drained concrete loses its fluidity. Larisch [1] defined the mattressing pathology as inclusions of soil in the cover zone when insufficient concrete flow arises. The displacement of the internal face of the trench wall mentioned previously, depends on several aspects like the soil profile, the depth of the panel or the presence of water table. Nonetheless, if a denser fluid like the concrete now provides the lateral pressures formerly engendered by the support fluid, these displacements might be moderated. However, with reduced workability performance, the concrete cannot rise properly specially in the cover zone and will not provide enough lateral pressures at the wall interface.

IV. Pathology Overview (Recommendations)

In addition to codes and standards of practice, some research studies, which have investigated mattressing issues, have proposed the following recent recommendations regarding composition properties and placement procedures.

With regards to support fluid properties:

When the European Standards (NF EN 1538) allows a 4% sand content for the bentonite slurry before concreting, a study [14] showed that it should not exceed 1%. About almost the same amount of sand that can be suspended in the slurry falls to the bottom of the excavation within the first two hours.

For the concrete composition:

- Mullins and Ashmawy [14] has defined a CSD factor, clear spacing to maximum aggregate diameter, in order to estimate head differential

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measurements of the concrete inside and outside the reinforcing cage. The CSD must be greater than 5.

- The same study [14] also proposed not less than 101.6 mm for concrete slump loss. However, for full scale field applications, a value between 114.3 to 127 mm is more appropriate since with the use of admixtures slumps between 177.8 to 228.6 mm can be reached. For other studies [5], concrete mixes with slump values of 260 mm showed excellent performances towards segregation stabilities.
- A less viscous concrete is more likely to push the first usually contaminated batch to the surface than laterally into the rebars. Therefore, tremie concrete should more behave as a self-consolidated rather than normal concrete [1] since mattressing defects are related to design mixes with insufficient workability. To ensure appropriate viscosity, it is proposed to use admixtures like water reducers and viscosity modifiers.

Regarding placement techniques:

- To limit segregation when the first concrete is being discharged, it is proposed to pre-charge the tremie with either neat cement or mortar mix before beginning the concreting [14].

V. Discussion

The present status of the shadowing pathologies, necessitates further research and more detailed studies. Indeed, despite carrying out the recommendations, disorders continue to appear.

To specifically investigate the origins of shadowing pathologies, it is important to study all the parameters that are involved in the construction of diaphragm walls.

Although bentonite-based support fluid is used to stabilize open trenches, it cannot be considered as a stable material itself as its properties may vary depending on some factors like the nature of the soil encountered. It could be interesting for instance, to study the relation between the nature of the excavated soil and the properties of the support fluid and investigate the interactions at the interface. The purpose of the experiment is to properly conclude on the formation of the filter cake.

Since chemical reactions of cement particles can also alter rheological properties of the support fluid. It is therefore proposed to examine what the bentonite slurry can undergo, when in contact with different solutions, like the concrete, soil particles or even water in the ground. This kind of experiment will allow to correctly understand the state of the support fluid at each construction stage so it would be easier to predict concrete flow in the stabilizing fluid.

As for concrete flow, it should be considered to test different concreting speeds and different concrete age as it has been shown that it directly affects good spreading between the reinforcing cages in the cover zone.

Shadowing pathologies is a phenomenon that affects structural, aesthetic and durability issues of diaphragm walls. For that matter, it shall be investigated analytically using available data and field monitoring results and through experimental work by testing the parameters previously discussed, and finally using equations and finite element models to better understand the occurrence of the phenomena involved.

VI. Summary and Conclusion

"Shadowing pathologies" is a serious problem since the defects are related to the durability of the structure. The rebars can directly be exposed to the open air, facilitating corrosion events of the reinforcements, and harming thereby the entire structure. If the visible imperfections can be repaired, some other hidden defects cannot be detected. Therefore, preventing mattressing defects, becomes of great interest.

This article consists of a general overview describing the present status regarding "shadowing pathologies". The factors affecting the occurrence of the disorders that can be found in the literature, may be divided into three main families. The general concept behind every family is described. So far, the imperfections can be either caused by components that do not meet appropriate properties or if activities for the placement techniques do not fall in the ranges of acceptance of the recommendations. These malfunctions combined to poor workmanship or interaction effects emphasize the imperfections to become defects. The identification of a few events may help to converge towards failures and malfunctions generating the appearance of the disorders in the diaphragm walls.

All authors declare that they have no conflicts of interest.

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Fundamentals of Electro Kinetics and Ionic Interactions for Durability Enhancement of Cement Concrete

By R. Selvaraj

Introduction- Durability of concrete structures is of great concern among civil engineering community. The concrete is one of the most widely used construction materials due to its relatively competitive affordability, versatility, easy availability of its raw materials, workability and mouldability to any shape and size. (1) Concrete is a composite material that consist of binding medium and aggregates particles. Once the concrete in set, it has three phases namely cement paste, the aggregate and the interfacial transition zone (ITZ) between them (2,3). The durability of cementitious materials is seriously affected by the service environments of the concrete. The service environment comprises several aggressive ions and are transported into the concrete through the pores, capillary pores, voids, cracks, microchannels, nanochannels and these ions react with the cementitious materials and as a result deterioration of concrete as well as embedded reinforcing steel is caused. Among these concrete defects, the capillary porosity and pores connectivity from the surface of concrete to the interior of concrete is of great concern from durability point of view. (4). Surface coatings or overlays on concrete can prevent entry of aggressive ions from environment to the concrete. However, the durability of coating or overlays are questionable.

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Fundamentals of Electro Kinetics and Ionic Interactions for Durability Enhancement of Cement Concrete

R. Selvaraj

I. Introduction

Durability of concrete structures is of great concern among civil engineering community. The concrete is one of the most widely used construction materials due to its relatively competitive affordability, versatility, easy availability of its raw materials, workability and mouldability to any shape and size. (1) Concrete is a composite material that consist of binding medium and aggregates particles. Once the concrete in set, it has three phases namely cement paste, the aggregate and the interfacial transition zone (ITZ) between them (2,3). The durability of cementitious materials is seriously affected by the service environments of the concrete. The service environment comprises several aggressive ions and are transported into the concrete through the pores, capillary pores, voids, cracks, microchannels, nanochannels and these ions react with the cementitious materials and as a result deterioration of concrete as well as embedded reinforcing steel is caused. Among these concrete defects, the capillary porosity and pores connectivity from the surface of concrete to the interior of concrete is of great concern from durability point of view. (4). Surface coatings or overlays on concrete can prevent entry of aggressive ions from environment to the concrete. However, the durability of coating or overlays are questionable.

In recent years, the application of electrokinetic processes has been demonstrated to provide deeply penetrating metallic cations into the concrete from the surface of concrete and thus reduces the porosity to a greater extent. During the electrokinetic (EK) treatment, the charged nano particles (e.g., nano Sio_2, C_a, N_a, and K) in ionic form are driven into the capillary pores and voids and block the pores. Some ionic species and particles react with the cement hydrates and precipitate and settle in the pores and this causes pore blocking and pore filling of concrete. This effect is greatly reduces the transport of nanoparticles and ionic species in to the concrete.

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The electrokinetic technique was first reported in 1992 by Lageman (5). In the past decades, several researchers (6-10) have demonstrated deeply penetrating and highly effective porosity reduction using electrokinetic treatments applied to cement mortar and concrete. In one (10) study, by using alumina coated silica nanoparticles achieved electrokinetic porosity reduction as much as 57% in hardened cement paste. It is also reported (11-13) that them is an effective ionic transport into cement mortar and also significant reduction in corrosion of embedded steel reinforcement when ionic solutions and nano silica particles used in suspension.

II. Electrokinetic Phenomenon

The movement of water through capillaries and pores of a porous medium with the application of electric field was first studied by F.F. Reuss in Russia in 1808 (14). This phenomenon was first treated analytically by Helmholtz in 1879, which was later modified by Pellet in 1903 and Smoluchowski in 1921. This phenomenon is widely known as the Helmholtz-Smoluchowski model, which relates electro-osmatic velocity of a fluid and charged porous medium under an electric gradient. The first application of electrokinetic was made by Casagrande in 1939 (14), for consolidating and stabilising soft fine-grained soils. Numerous laboratory studies and very few field applications have been conducted to investigate the electrokinetic processes till date. This electrokinetic technique has been applied successfully to same extent including increasing pile strength, stability of soil, removal of salts from the agricultural soils, removal of heavy metals from subsoils, removal of microorganisms which are causing damage to concrete sub structures in soil of low permeability, removal of contaminating chemical species from saturated and partially saturated porous soils, including removal of various inorganic and organic contaminants as shown in fig 1.

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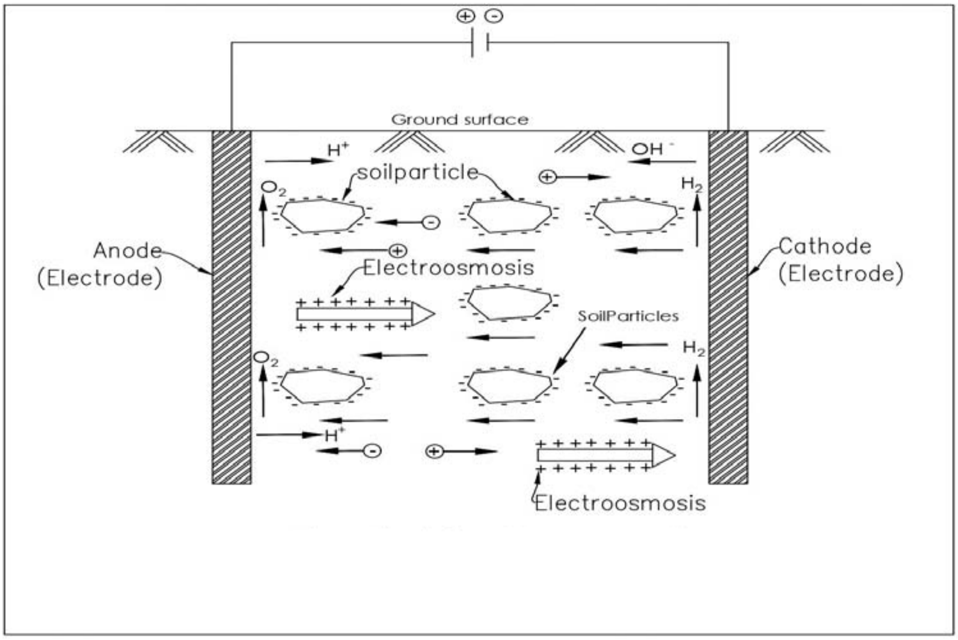

Fig. 1: Principles of Electrokinetic Transport in solurated porous Media (Ref. 15)

a) *Principles of Electrokinetic: Transport Phenomena*

Electrokinetic processes are relatively new and promising technology being investigated for their potential applications in hazardous waste management specifically in case of high clay containing soils (14). United States Environmental Protection Agency (USEPA) has designated electrokinetic method as a viable in-situ process for decontaminating of low permeable soils. Electrokinetic process is neatly explained by the following fig 2.

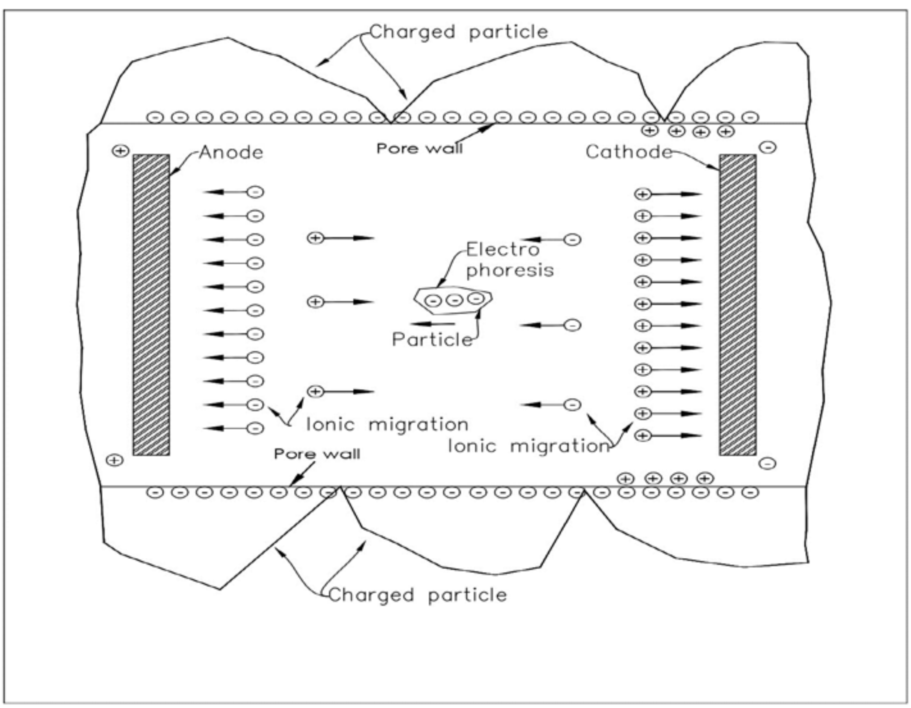

Fig. 2: Electrokinetics Electroosmasic, Electro phoresis and Electromigration is cement paste pores

The transport of ions and ionic species is induced in the pore solution on application of D.C. electric field, mainly by electromigration. This applied electric field induces water flow in a saturated porous medium is called electroosmosis and there in possibility of movements of charged small particles in the pore solutions is called electrophoresis (16). The transported ions and particles in the capillary pores and voids react with the hydrated cement pastes in the pore walls and converts into complex phases and thus settles in the pores and also attaches in the pore walls. This resulting complex salts blocks the pores and voids, therefore the permeability in greatly reduced. This pore blocking process in finally increases the compressive strength of the concrete. It also significantly prevents the ingress of aggressive ions from the immediate environment of the concrete and thus the durability and servicelife of the structure in greatly enhanced. (11-19)

i. *Electromigration*

Most of the porous materials carry a surface charge and have pores with presence of unbalanced charges with bound and unbound ions along the pore wells (20). When an electric charge is applied the ions in the pore solution gets charged and is attracted by the oppositely charged electrodes and ions. Unlike in solutions, the ions in the porous materials are not able to move by electromigration directly to the opposite pole by the shortest route. Instead, they have to find their way along the tortuous pores. Presence of air-filled voids or particles filled voids block the direct path. The ions are normally transported in the continuous pores but not in the closed ones and the ions are transported in the pore solutions (21) fig 3 explains this pathways. The electromigration rate of a pores media depends on the pore volume, geometry of the pores and the water content.

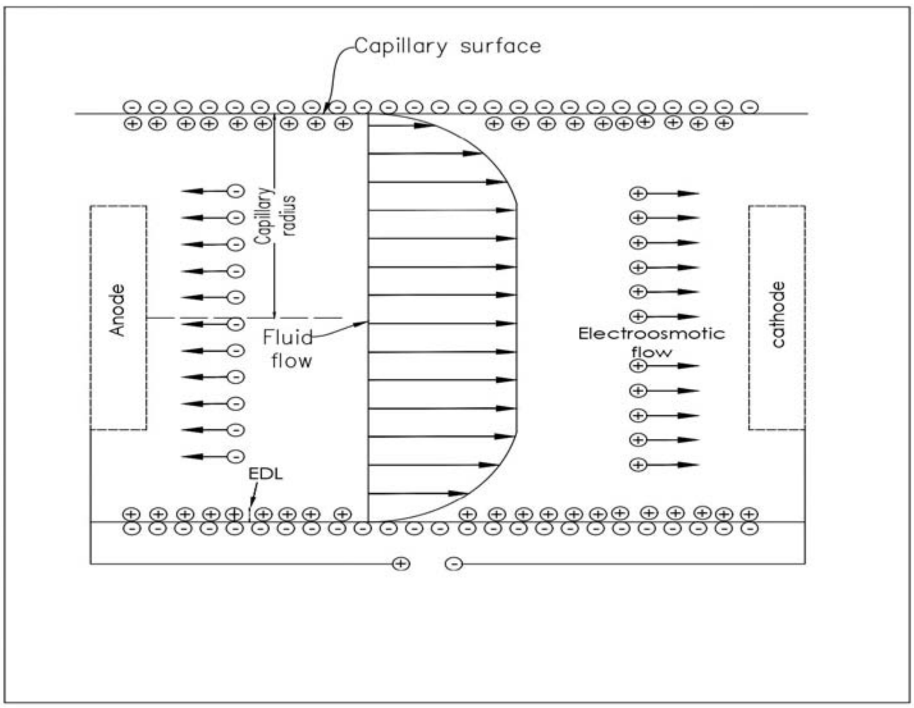

Fig. 3: Surface charges and Electroosmatic flow through pore

When DC electric field is applied across the electrodes in a saturated porous medium. The negatively charged ions migrate to anodes and positively charged cations move towards cathode. The classical theory of electro chemistry defines the flex due to electromigration is given by (22).

$$J = \frac{D_Z ECT}{RT} \qquad \text{................1}$$

Where J in the flex in (Kg/m^2/s)
Z is the valency of the ion
F is the Faraday constant (96,485C moe^{-1})
E in the applied electric field (Volt/m)
R in the gas constant (8.3143 J moe^{-1}K^{-1})
T is the temperature (°K).

The fig 4 shows the positively and negatively changed particles and fig 5 shows the components of a charged particle.

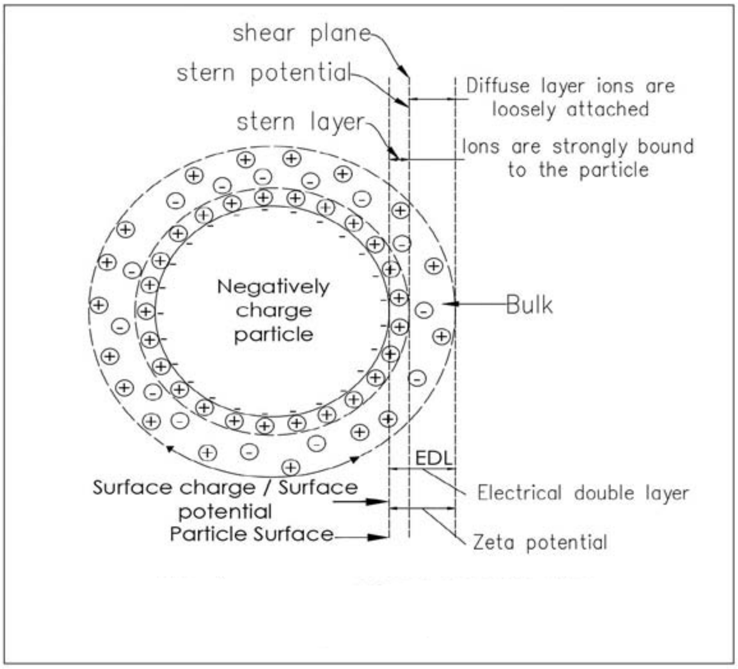

Fig. 4: Various components of a particle

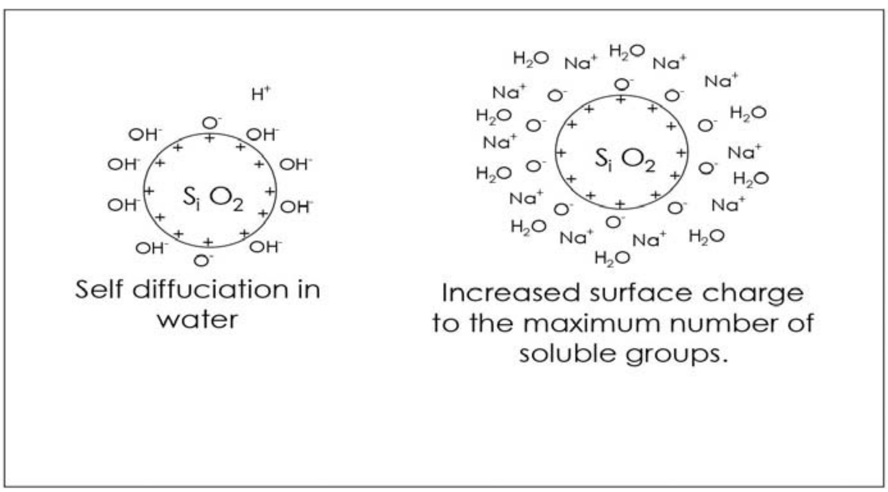

Fig. 5: Positively Charged Nano Particles

The ionic mobility of many cations falls in the range of 1x10-8 to 10x10 -8 (m2/VS) (23) Table 1 The movement of ions towards electrodes in the functions of ionic mobility (24-26) and the concentration of the electrolytic solution or the pore water. The ions travel with velocity given by (24).

$$v = \frac{I\, \upsilon_i\, \rho_w}{A\tau\theta} \quad \text{................2}$$

When I is the applied current
V_i is the ion velocity
A is the area of cross section
ρ_w in the pore water resistivity
τ is the tortuosity
θ is the volumetric moisture content

The following table 1 presents the ionic mobility of selected ions in free electrolyte at 25°C (27).

Table 1: Ionic mobility of same selected ions in free electrolyte at 25°C (27)

Element	Ionic Mobility (10^{-8} m^2/s)	Element	Ionic Mobility (10^{-8} m^2/s)
H^+	36.23	Na^+	5.19
AL^{3+}	6.32	Ph^{3+}	7.36
Ca^{2+}	6.17	Zn^{2+}	5.47
Cd^{2+}	7.36	OH^-	20.6
Cr^{2+}	6.94	Cl^-	7.19
Ca^{2+}	5.56	No^{-3}	7.40
Fe^{3+}	5.60	SO_4^{2-}	8.29
K^+	7.62	CO_3^{2-}	7.46

ii. *Electroosmosis*

Electroosmosis is the term given to the movement of the bulk aqueous solutions through the pores of a porous medium due to applied electric field. The electroosmosis was first observed in 1800s and was used in geotechnical engineering to clayey soils in 1930s (28). The electroosmotic effect is a result of the complex electrical interventions that exist at the interface between solid and liquid.

When the electric field applied across a saturated porous media, the ions in the pore fluid act as conducting medium and the movement of water is observed towards anode and cathode depending on overall surface charges of the porous material. The anions and cations will move towards opposite electrodes. The electroosmosis is significant in fine pores materials (29-32). It is important to note that in the most porous materials, the electroomatic velocity is towards the cathode and the electroosmotic is enhancing the transport of cations towards the cathode. But the electromigration is the dominant mechanism (33). Several factors influence surface charge of cementitious materials and thus the electroosmotic effect.

Theoretically predicting electroosmotic flow becomes more difficult when the solid mass chemically reacts with pore water. The equation described as (34).

$$V_e = K_e i_e \qquad \ldots\ldots\ldots\ldots\ldots\ldots 3$$

When Ve is electroosmotic velocity (L/T)
Ke is electroosmotic Permeability (L^2/VT)
and ie is the potential gradient (V/L)

The Ke, the electroosmotic permeability of the medium is a function of dielectric constant of the medium, viscosity of pore water, zeta-potential and porosity of the medium. The Ke is given by (28)

$$K_e = \Sigma e n/\mu \qquad \ldots\ldots\ldots\ldots\ldots 4$$

Σ is the permittivity of the medium
e is the Zeta potential
n is the porosity and
μ is the liquid velocity

The fig shows various layers of the particle and represents the solid liquid interface and charge distribution in spore sections.

iii. *Electrophoresis*

Electrophoresis is the movement of charged particles (Colloidal Particles) present in the pore water on application of electric field. The mobility of the particle in functions of the Zeta protentional on the particle surface. The electrophoretic velocity of a particle was first described by Helmholtz and later refined by smoluchowski and is given by the relation.

$$V = \tau e E/\mu \qquad \ldots\ldots\ldots\ldots 5$$

Where V is the particle Velocity
E is the applied electric field
e is the dielectric permittivity of the medium
μ is the viscosity of the pore fluid and
τ is the zeta potential of the particle surface

The electrophoretic mobility (μ_e) of a particle can also be defined as (35).

$$\mu_e = \Sigma\tau/\mu \qquad \ldots\ldots\ldots\ldots\ldots\ldots 6$$

The mobility of colloids and particulates in porous medium also depends upon flocculation, sedimentation and depositions of particles in pores.

b) *Microstructural Properties of Concrete*

As has been stated earlier, the concrete is mixture of cement paste and aggregates. On a macroscopical scale the cement paste itself consist of unreacted cement grains, amorphous hydration product (Crystals of calcium hydroxide needles of ettringite and fibrous crystals of calcium silicate hydrates C-S-H) and pores (36). If pozzolanic materials are added to the

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conventional concrete, the microstructure of concrete is modified by the pozzolanic reaction. Pore structure of the concrete is modified or densified homogeneity of the cement paste is improved porosity of cement paste is significantly reduced and thus it improves compressive strength of concrete. The pore connectivity determines the permeability and this parameter determines the transport properties of concrete or cement paste (37). Lesser permeability results durable concrete.

To achieve high strength and more durable concrete the capillary porosity shall be reduced and this can be achieved by reducing the gel porosity i.e. by changing C-S-H (Calcium silicate Hydrate) Structure from porous to more crystallize phase (micro structural change). This micro structural change in the cement paste greatly reduces the porosity reduced permeability and pore size distribution. The pores and the pore connectivity is shown in Fig. 6.

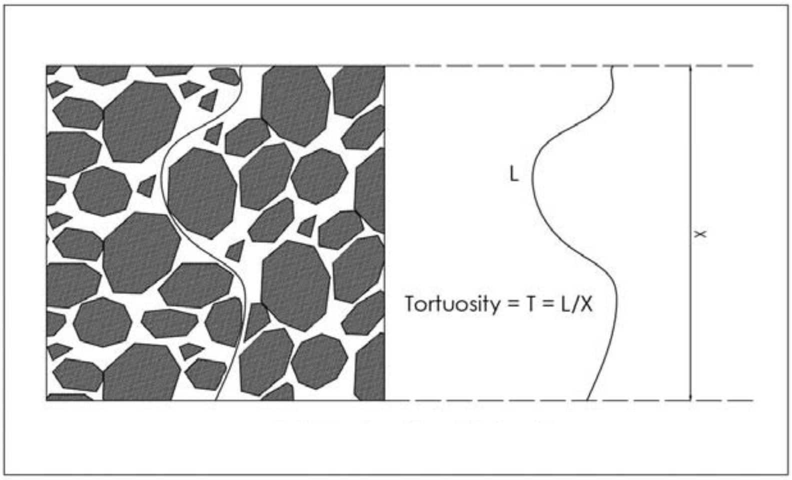

Fig. 6: Pictorial Explanation of Tortuosity

c) Calcium Silicate Hydrate (C-S-H)

When Portland Cement in mixed with water, anhydrous Oxides (Mainly CaO and SiO2) react with water and forms a solid and water in the pores. The solid part consists of Ca^{2+}, OH^- and silicate ions (38,39) When pore water gets more Ca^{2+} ions, the P^H of the pore water is increased more than 10 and it becomes super saturated. The main source of cohesion of cement paste is the nano particles of C-S-H, which is formed upon the dissolution of the original tricalcium silicate (C_3S) present in the cement. The Ca^{2+} ions have strong physical affinity to negatively charged silicate particles. It should be noted that once the cement constituents are in contact with water, the constituent phases begin to dissolve at the surface of the grains, mainly C3S becomes negatively charged. The pore solution contains Ca^{2+}, K^+, Na^+, OH^-, S_iO_2, Al_2O_3 and SO_4^- ions (40,41) and gets super saturated with respect to C-S-H (CaO-S_iO_2-H_2O) = C-S-H.

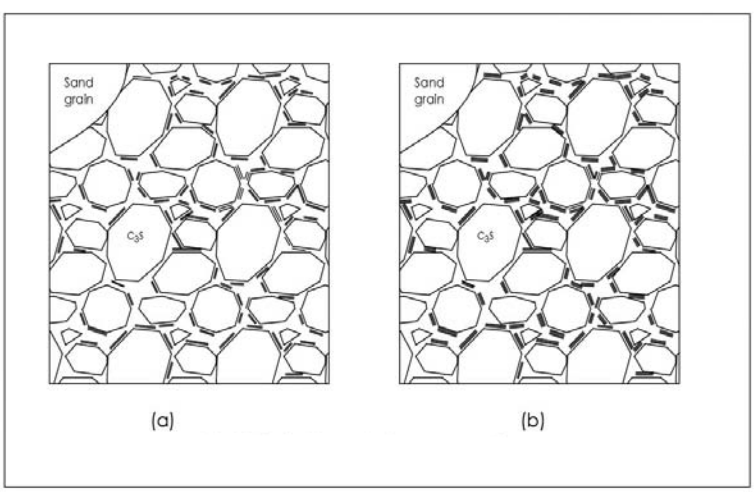

Fig. 7: Hydration of C_3S component

The process of dissolution and precipitation continues. Initially the PH is increasing until the precipitation of Calcium hydroxide occurs in the pore water. Among the precipitated hydrates in the pores, the main component is C-S-H which constitutes around 60% of the fully hydrates cement paste. This is generally recognized as responsible for the setting and hardening of a cement. (42-44) because it precipitates at the surface of the hydrous calcium silicate grains. The strength of the paste increases during hydration process because of augmentation of the number of contact points and the cement grains created by C-S-H particles. A fully hydrated cement paste can exhibit a high compressive strength when as its tensile strength is low. This is probably due to the fact that the elastic limit of the material is small (44).

The process of leaching of calcium from cementing materials is adversely affect the long term performance of the concrete structures in many facilities. However, series of dissolution /precipitation reaction can occur resulting from diffusion of ions through the cementing materials during its service life, or internal ions diffuse out and disturb the chemical equilibrium in the pore solution (45). It is also reported (46) that the leaching out of Ca^{2+} from the cementitious materials has the effect of increasing the chloride ingress. Saito (47) also reported that the calcium leaching increases the porosity in the cement hydrates. The mobility of ions in pore water takes place due to concentration gradient (ie ionic diffusion). The another driving force of ions into pore solution is electrical potential in the pore solution when the electric field is applied.

The dissolution of $(Ca\ (OH)_2)$ and the decalcification of C-S-H occur to maintain the equilibrium of Ca^{2+} between solid hydrates and pore solution. When the concentration of Ca^{2+} is decreased in pore solution by migration then dissolution of $(Ca\ (OH)_2)$ starts, following this depletion decalcification of the C-S-H occurs (48). The dissolution and decalcification of C-S-H are given by the following chemical equilibrium equations.

$$(Ca\ (OH)_2) \longrightarrow Ca^{2+}\ OH^-$$

$$X\ CaO\ S_1O_2\ zH_2O \longrightarrow (X\text{-}S_1)\ CaO\ (1\text{-}S_2)\ S_iO_2$$

$$(z\text{-}S_1)\ H_2O + S_1\ Ca\ (OH)_2 + S_2S_iO_2$$

d) Surface Change of Cementitious Materials

Cementitious materials acquire a surface electric charge when they come in contact with aqueous solution and also the electric charge is created by dissolutions of surface sites of the cement hydrates and adsorption of ions on the surface. Therefore, the surface charge mechanisms are due to

i. By the contact of the aqueous solutions
ii. By the dissociations of hydrated cement particles and
iii. By the adsorptions of the ions on the surface of the cement hydrates

The $(Ca(OH)_2)$ possess positive surface charges while others show negative surface in water.

The (C-S-H) has (SiOH) surface groups and its dissociation at high P^H solutions gives a negatively charged surface. Formation of high amount of $= SiO^-$ is responsible for the negative surface area of the cement paste (49). The electrokinetic behaviour of Hydrated cement can be charged depending on the extension of ion adsorption is ionic concentration in the pore solution. If the multivalent ions are present in the pore solution, the specific adsorption will occur. This specific adsorption significantly affects the surface charge. Initially (C-S-H) is partially compensates the negative charge. At high concentrations of Ca^{2+} ions the specific adsorption of Ca^{2+} over compensates of the surface and leading to net positive charge. At higher P^H further binding of Ca^{2+} would result in strong positive density when the pore wall is positively charged the chloride ions (cl^-) and attracted more than Ca^{2+} ions (49,50). This positive and negative surface charges depends on hydration of cement, concentration of pore solution and if any admixtures are added to the concrete.

e) Ion and Hydrated Cement Paste Interactions

The study of interfaces between solid surface pore walls or the hydrated cement paste and contact pore solution is very important to know several properties of cementitious material. Adsorption of Ca^{2+} on the hydrated cement paste occurs when the pore walls are negatively charged. Chloride binding or adsorption occurs when the pore walls are positively charged. If these chlorides are binded with pore walls, it has direct influence on the corrosion of reinforcing or pre-stressed wires in concrete. Chloride binding is influenced by several parameters including cement composition mineral additives used pore water compositions and chloride concentration on surface area etc. Therefore, the surface chemistry is influenced by the ions. The adsorption of cations on the surface of cement hydrate surface decreases in the order: $Ca^{2+} > K^+ > Na^+$ and the adsorption of anions on the surface is $SiO_4^{2-} > cl^-$., The sodium ions does not absorbed on surface (51).

f) Pore Blocking and Densification of Cement Mortar and Concrete

The electrophoresis uses a potential field to move charged particles that are suspended in the field phase in to porous medium (cement mortar or concrete). These particles leads with the surrounding charged surfaces. This bonding results in cementations process with the surfaces by suitable surface reaction with the particles and yielding a new composite in the

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pore walls. This results in deposition of complex material in the pores and thus the density of the porous material is increased and the pore diameter is reduced significantly. This process of pore filling or pore blocking includes the strength, compactness and durability of the material (52-55). This pore filling material binds chemically in the pore spaces (see fig. 8). This pore filling treatment prevents ingress of aggressive species such as chlorides carbon di oxide and thus corrosion of embedded steel is prevented. The finely divided cationic nano particles such as Ca 2+, Na+ K+ react with (Ca(OH)2) to form cementing hydrates and this enhances the strength (56,57) of concrete. A maximum current density of 1A/m^2 is continuously applied for a period of 6-12 weeks. The continuous generation of (OH)- ions assist in restoring the passivity of steel. Thus pore blocking treatment reduced the permeability by a factor of three.

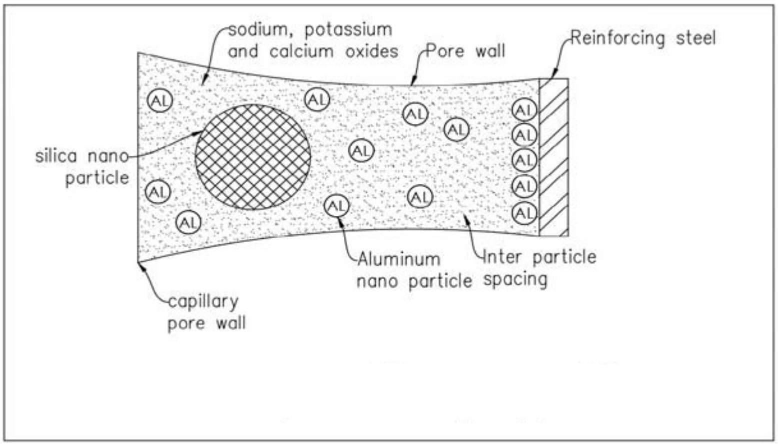

Fig. 8: Pore blocking: Positive nano particle and oxide deposits inside capillary pore

III. Conclusion

1. The electrokinetic treatment is also applicable for removing the contaminants and heavy metals from the soil.
2. The formation of C-S-H improves tensile strength of concrete.
3. Pore blocking treatment blokes the pores voids cracks and all other defects by depositing complex salt in it. It reacts with pore walls and chemically binds. This results in compactness of concrete increases density, increases mechanical strengths by reducing porosity and pore connectivity.
4. Ingress of external aggressive agents like Chloride and CO_2 in presented by pore blocking and thus corrosion of embedded steel in avoided and hence durability of concrete is increased significantly.

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21. Adding unnecessary information: Do not add unnecessary information like "I have used MS Excel to draw graphs." Irrelevant and inappropriate material is superfluous. Foreign terminology and phrases are not apropos. One should never take a broad view. Analogy is like feathers on a snake. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Never oversimplify: When adding material to your research paper, never go for oversimplification; this will definitely irritate the evaluator. Be specific. Never use rhythmic redundancies. Contractions shouldn't be used in a research paper. Comparisons are as terrible as clichés. Give up ampersands, abbreviations, and so on. Remove commas that are not necessary. Parenthetical words should be between brackets or commas. Understatement is always the best way to put forward earth-shaking thoughts. Give a detailed literary review.
22. Report concluded results: Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.
23. Upon conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print for the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects of your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form which is presented in the guidelines using the template.
- Please note the criteria peer reviewers will use for grading the final paper.

Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

The introduction: This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear: Adhere to recommended page limits.

Mistakes to avoid:

- Insertion of a title at the foot of a page with subsequent text on the next page.
- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.

- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

Title page:

Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

Abstract: This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

Reason for writing the article—theory, overall issue, purpose.

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

Approach:

- o Single section and succinct.
- o An outline of the job done is always written in past tense.
- o Concentrate on shortening results—limit background information to a verdict or two.
- o Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

Introduction:

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

The following approach can create a valuable beginning:

- o Explain the value (significance) of the study.
- o Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
- o Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- o Briefly explain the study's tentative purpose and how it meets the declared objectives.

Approach:

Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

As always, give awareness to spelling, simplicity, and correctness of sentences and phrases.

Procedures (methods and materials):

This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

Materials may be reported in part of a section or else they may be recognized along with your measures.

Methods:

- Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- Simplify—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

Approach:

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

What to keep away from:

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings—save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.

Content:

- Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation of an exacting study.
- Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

What to stay away from:

- Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- Do not include raw data or intermediate calculations in a research manuscript.
- Do not present similar data more than once.
- A manuscript should complement any figures or tables, not duplicate information.
- Never confuse figures with tables—there is a difference.

Approach:

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

Put figures and tables, appropriately numbered, in order at the end of the report.

If you desire, you may place your figures and tables properly within the text of your results section.

Figures and tables:

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

Discussion:

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an argument should be.

Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully described.

Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact, you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved the prospect, and let it drop at that. Make a decision as to whether each premise is supported or discarded or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."

Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work.

- You may propose future guidelines, such as how an experiment might be personalized to accomplish a new idea.
- Give details of all of your remarks as much as possible, focusing on mechanisms.
- Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
- One piece of research will not counter an overall question, so maintain the large picture in mind. Where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

When you refer to information, differentiate data generated by your own studies from other available information. Present work done by specific persons (including you) in past tense.

Describe generally acknowledged facts and main beliefs in present tense.

The Administration Rules

Administration Rules to Be Strictly Followed before Submitting Your Research Paper to Global Journals Inc.

Please read the following rules and regulations carefully before submitting your research paper to Global Journals Inc. to avoid rejection.

Segment draft and final research paper: You have to strictly follow the template of a research paper, failing which your paper may get rejected. You are expected to write each part of the paper wholly on your own. The peer reviewers need to identify your own perspective of the concepts in your own terms. Please do not extract straight from any other source, and do not rephrase someone else's analysis. Do not allow anyone else to proofread your manuscript.

Written material: You may discuss this with your guides and key sources. Do not copy anyone else's paper, even if this is only imitation, otherwise it will be rejected on the grounds of plagiarism, which is illegal. Various methods to avoid plagiarism are strictly applied by us to every paper, and, if found guilty, you may be blacklisted, which could affect your career adversely. To guard yourself and others from possible illegal use, please do not permit anyone to use or even read your paper and file.

Criterion for Grading a Research Paper (Compilation) by Global Journals

Please note that following table is only a Grading of "Paper Compilation" and not on "Performed/Stated Research" whose grading solely depends on Individual Assigned Peer Reviewer and Editorial Board Member. These can be available only on request and after decision of Paper. This report will be the property of Global Journals.

Topics	Grades		
	A-B	**C-D**	**E-F**
Abstract	Clear and concise with appropriate content, Correct format. 200 words or below	Unclear summary and no specific data, Incorrect form Above 200 words	No specific data with ambiguous information Above 250 words
Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

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