PRECAST CONCRETE CONSTRUCTION

FOR THE DEVELOPMENT OF THE GAUTRAIN RAPID RAIL SYSTEM

GAUTRAIN
FOR PEOPLE ON THE MOVE
GAUTRAIN MANAGEMENT AGENCY

INDEX

1. INTRODUCTION

The decision to use the precast technique for the Gautrain Project was apt, considering the large volume and complexity of the structures that had to be constructed for the system. These structures included viaducts, bridges, stations struts, M-beams and so on. A project of this nature and magnitude also requires extra prudence and vigilance in managing costs, time and quality. Thus innovative strategies had to be implemented to be able to achieve the desired outcome. For an example since the industry is well developed in South Africa, items such as precast track sleepers could be outsourced to local service providers.

This case study gives an account of how the modern precast concrete construction technique was utilised in the construction of the Gautrain. Furthermore, the case study details the lessons learnt and insights gained from this process and how these can be applied in future projects.

2. PRECAST CONCRETE CONSTRUCTION IN BRIEF

In the construction industry, project managers are continually faced with the challenge of producing structures faster, better, and more economically. In response to these demands, many contractors opt to use precast concrete elements. Since the Gautrain Project was a design, construct, operate and maintain project model, it was ideal to design structures that would contain a range of precast sections of the same type.

Precast concrete is a construction technique that is common and widely used in civil engineering projects where conventional in-situ reinforced concrete construction is not ideal. Examples of this include bridge construction and, most recently, concrete structures in the petro chemical industry.

3. METHODOLOGY

3.1 Precast Yard Role

Precast concrete elements can comprise an entire structure of structural elements that are created offsite and can be supplied for incorporation into a structure on-site. Precast elements can simultaneously achieve optimal structural, decorative design and finishing requirements.

Material (rock), of the right quality, obtained from the drill and blast tunnel sections of the project was not only used as fill material in the formations but also crushed into various sizes and used as stone in the concrete at the Precast Concrete Yard.

The Gautrain's modern precast concrete yard was constructed within the rail reserve on the future bus depot site between Midrand and Marlboro. The precast concrete yard (PCY), however, had to be designed and carefully executed to take into account the number and type of elements that had to be cast and how long it had to cure and stored in order to comply with the overall project construction programme. This would allow enough time to dismantle the PCY and complete the construction of the bus depot for a planned future date in the project programme.

After the PCY had served its function, it was demolished to make way for the storage area of Gautrain's fleet of air-conditioned buses. Production of the PCY was therefore planned to have an exact start and end date that would integrate with the overall construction programme.

The PCY's main role was to be a key central resource for the construction phase of the project, and its performance was important in keeping with the overall project timeline.

Concrete elements that the PCY had to produce were as follows:

- The total number of viaduct deck segments for nine segmented deck viaducts
- M-beams for 37 bridges of different spans
- Tunnel walkways
- Bridge panels
- Parapets
- Station struts

Inputs required to the precast concrete yard to produce these elements were therefore:

- **Issued for Construction drawings (IFC)** for each structure.
- **Operational PCY facilities and equipment** such as the production lines, formwork (re-used between similar units e.g. viaduct deck segments), the reinforcement assembly area, the concrete batch plant and storage areas.
- **Consumable materials** such as reinforcing steel, concrete materials (aggregate, sand, cement, etc.) and cast-in fittings (e.g. ducts and end-plates for the viaduct deck segments). Aggregates for the PCY were produced at a mobile crushing plant on a nearby site and obtained from rock originating from the drill and blast tunnels.
- **Transport / deand rigging equipment for lifting and delivery of completed units to the construction site for installation**
- **PCY labour and management** (own and contracted).

The PCY's working schedule was determined by:

- The availability of IFC drawings;
- Match casting requirements, i.e. each viaduct deck segment had to be match cast against its partner unless it was an end unit; and
- The erection sequence for each structure as set out in the overall construction planning sequence on site. In some cases, these were subject to change depending on site and PCY conditions.

3.2 Advantages of Precast Concrete

Although these typically apply to concrete in general, precast concrete has lots of advantages compared to site-cast concrete, especially when taking into account the overall project benefits:

Concrete manufacturing and casting process is done in a controlled environment. This means it is easier to control the quality of the precast elements.

Weather is eliminated as a factor, so you can practically cast in almost any weather condition and get the same results, which means you can get the perfect mixes and methods; assuming that the entire precast yard is covered or has a roof over it.

Precast elements can be installed immediately on site. There is no waiting for it to gain strength, and the modularity of precast products makes installation easy.

Production improves through repetition as the setting up of the recasting process is replicated for the same elements.

Accelerated curing by heating the precast elements reduces the time between casts.

No construction joints need to be provided in the precast construction.

Less labour is required and labour can be less skilled.

Formwork used for preparing precast units is **made of steel with exact dimensions,** which means it's highly durable and can be re-used many times.

Precast elements can be cast to the **desired shape and finish.**

The various components of concrete for cast work in situ are **stored at a central point for transportation to the specific construction site when required.**

Work can be completed in a **shorter time.**

The amount of **scaffolding and formwork is considerably reduced** for precast elements as it is all done in one area.

Site construction programme times are shorter because they're not affected by weather, curing time and construction site conditions.

Buildability is improved because structure elements are fabricated off site for rapid erection on the construction site.

There's a **high standard of workmanship in "factory" conditions** that reduces the potential for accidents and addresses on-site skill shortages.

High quality finishes can be left exposed so that concrete's thermal properties can be exploited in low-energy buildings.

Viaduct deck sections can be matched-cast to ensure a 100% fit on site.

It's easier to control the concrete mixes, placement thereof and curing, since it's manufactured in a controlled environment.

Quantity discounts can be obtained, as delivery of material to the pre-cast yard is in bulk.

3.3 Disadvantages of Precast Concrete

If not properly designed, precast units can be damaged during lifting and transportation.

It can become **difficult to produce satisfactory connections** between the precast elements.

Special equipment is needed for **lifting and moving** the precast units.

The efficiencies achieved with precast construction are partly balanced by the additional cost in transporting and handling precast members. Because of this the precast factory should be located where transport and handling costs can be kept to a minimum.

4. SOLUTION STATEMENT

4.1. Concrete Batching Plant

A concrete twin batch plant, with electronic scales and an average generating capacity of 120 cubic metres of concrete per hour, was constructed to supply ready mixed concrete to the various areas in the PCY as well as the related construction sites in the vicinity.

A weigh bridge was also installed to ensure that loaded vehicles leaving the site didn't exceed their maximum road freight limit.

Other requirements for the PCY included:

- Setting up various production lines with the required cranes for the various elements
- Creating reinforcement assembly areas
- Constructing workshops
- Constructing cleaning and repair facilities for the formwork
- Creating bulk cement, aggregate and additives storage facilities
- Silting dams to prevent pollution
- Creating sufficient storage areas for the various elements within the reach of the applicable cranes

To suit the needs of the design and construction programme, concrete produced at the PCY needed to vary in strength up to 50MPa. The concrete mix consists of cement, aggregates (sand and stone), and water and would also include admixtures to enable easier placement into the formwork as well as allow for rapid development of concrete strength, particularly within the first three days so that it could be removed at the earliest date when an element could carry its own weight.

Each batch plant was fitted with bins containing the required sand, cement, and stone. Concrete mix requirements were captured into a computer, which activated the intelligent conveyor belt fitted with a weigh-in motion scale. This automatically ensured that the correct quantities of each material were released into the mixer from the bins.

Full time quality assurance was needed to ensure that all concrete batches complied with design requirements. After being removed from the formwork, the precast elements were stacked at the allocated storage facility for curing and until they were needed at a specific construction site.

The biggest and most important elements that were cast at the PCY were

1. M-beams
2. Viaduct segments

The pre-casting process was based on the construction programme as well as detailed construction drawings provided for each structure. Detailed method statements were prepared for each type of element that had to be constructed.

Programming for casting elements was based on the date they were required on site, working back to the date the process should then start at the PCY. In practical terms, this took into account the lead time required to have:

- All drawings completed and approved
- Ordering the required material and having it on site
- Preparing the steel reinforcing
- Putting the formwork together
- Casting the concrete
- Allow for curing of the concrete

After casting, once the concrete achieved the required strength, units were removed from the formwork to the "hospital area" for quality checking and possible repairs before being stored in the PCY storage area to cure to its designed/ full strength. When the relevant construction sites were ready to receive the required elements, an order was placed for the PCY to deliver them.

4.2 M-beams

M-beams are concrete elements that are mainly used in the construction of bridge decks by resting on piers and abutments.

M-beams measure 1m wide and can vary in height (+/- 1,5m) depending the span. The main benefit of transporting readymade M-beams to construction sites is that scaffolding is not required to construct the bridge decks on sites, which saves time.

Constructing bridge decks using precast M-beams involved the following process:

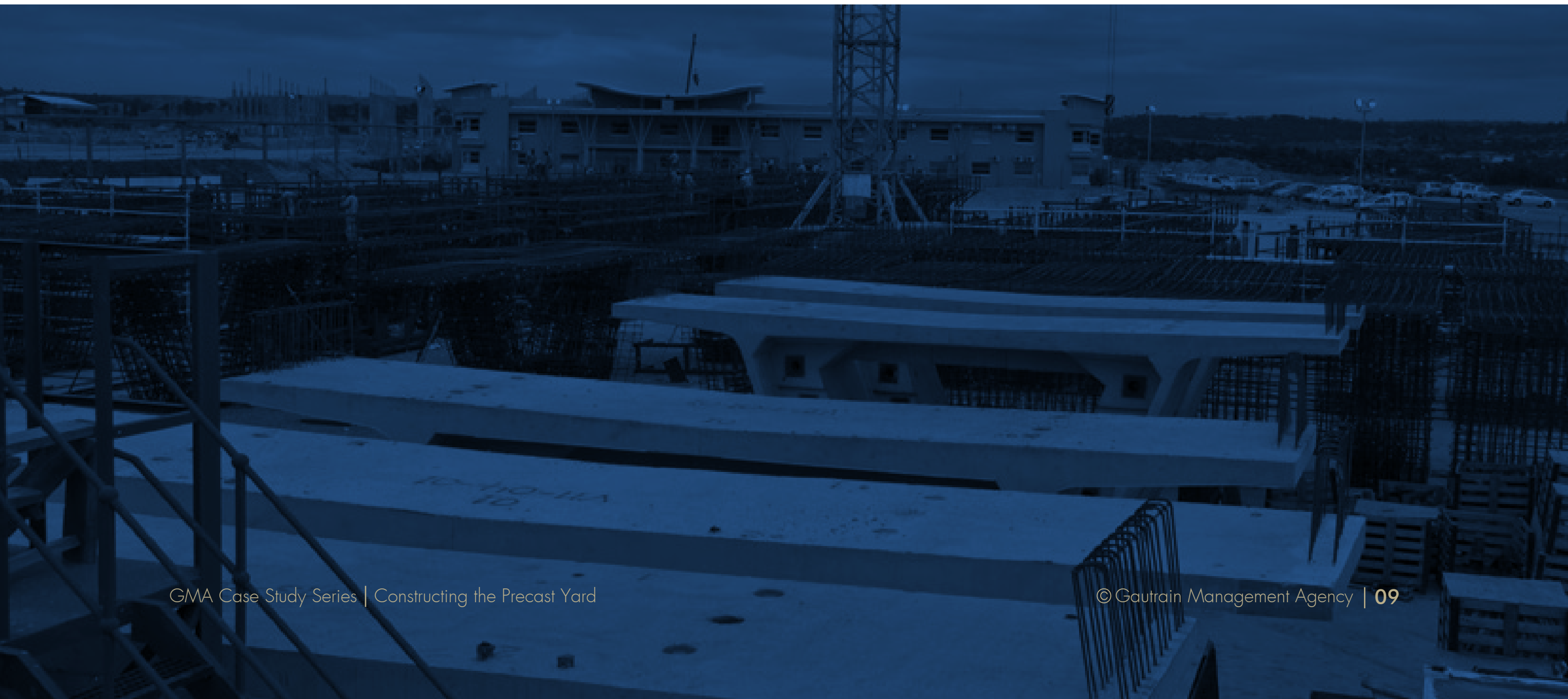
1. The **steel bed formwork** is positioned according to the required length of the beam.
2. The **reinforcing and cable ducts** are fixed into position on the bed.
3. The **side panels** are then placed in position and sealed.
4. Concrete is **poured into the formwork** and vibrated to prevent the concrete to form honeycombing.
5. The concrete is **left to cure.**
6. The **pre-stressing process** begins, after the steel cables running through cable ducts in the concrete sections are put under tension and anchored at the ends. An added advantage with pre-stressing is that, the depth of the beams can be reduced.
7. After **quality inspections** and repairs are completed, the M-beams are then **lifted by crane** from the bed and **stacked** two to three high at the allocated storage area.
8. Beams are **transported by low bed trucks** to the various construction sites for installation.
9. **Mobile cranes** place the M-beams on site in their required positions according to the bridge designs.
10. To allow for expansion and contraction of rail bridges, special **bearing pads** are inserted between M-beams and piers.

4.3. Viaduct Segments

Viaducts are multi-spanned bridges used specifically for rail that crosses over roads, rivers or valleys.

A viaduct is therefore a long bridge spanning 50m between piers. Viaduct segments are cast in sections of about 2,5m in length and can weigh up to 55 tons. They are assembled by a launching girder between piers. There are various viaducts along the Gautrain route.

The trapezoidal segments of the viaduct are match cast so that they can be attached to each other in line with the viaduct's geometric shape and vertical alignment. They are 10,1m wide to accommodate two rail lines for trains travelling in both directions. The viaduct deck segments were produced in two production lines (later increased to three).



During the Gautrain project, the process for the casting viaduct deck segments was as follows:

1. For each span, the end segments (also known as Segment-On-Piers or SOP) were **cast first in a separate mould.**

2. When ready, each **SOP was placed at the end of the casting bed.** The SOP segments were then used to match cast the second segment against the SOPs.

3. The remaining segments (third, fourth, etc.) were **progressively match cast** against their predecessors, working towards the centre of the "set" of segments needed for a span, until the full length of the span was complete.

4. When the matched cast concrete elements achieved sufficient curing strength, it is lifted **out** of the mould after being numbered, again working progressively towards the centre.

5. The resulting space freed up at the ends was then used for the next span, starting with its SOPs as described above. In this way, a **casting bed** could be used to cast the segments for up to 2 spans at a time, with approximately 50% overlap in the time required to cast the segments for each pair of spans.

6. After casting, when the concrete had achieved the required strength, the **units were lifted from the formwork** with heavy duty cranes that can handle up to 60 tons and taken to the "hospital area" for repairs and curing before being stored in the PCY storage area.

7. When the relevant structures were ready to receive the units, an **order was placed** for the PCY to deliver them by road to the sites.

8. On site the **viaduct segments were launched with a launching girder into position,** after being lifted onto a launching girder with mobile cranes. They were then "glued" together to form the shape of the viaduct and to span the distance between the piers.

9. Inside the viaduct sections are **ducts with bundles of cables** that stretch over the full length of the span. These cables are post-stressed for keeping the viaduct sections intact so that the sections can carry the required future loading stresses.

10. When the viaduct span is intact the launching girder will move to the next span.

4.4 PCY Production Statistics

The total number of elements produced in the PCY were as follows:

3218 viaduct deck segments for nine segmented deck viaducts, including rejected and re-casted segments

4232 bridge panels

5994 parapets

0km 30km

M-beams for 37 bridges adding up to a total linear length of 30 km

1782 tunnel walkways

202 station struts

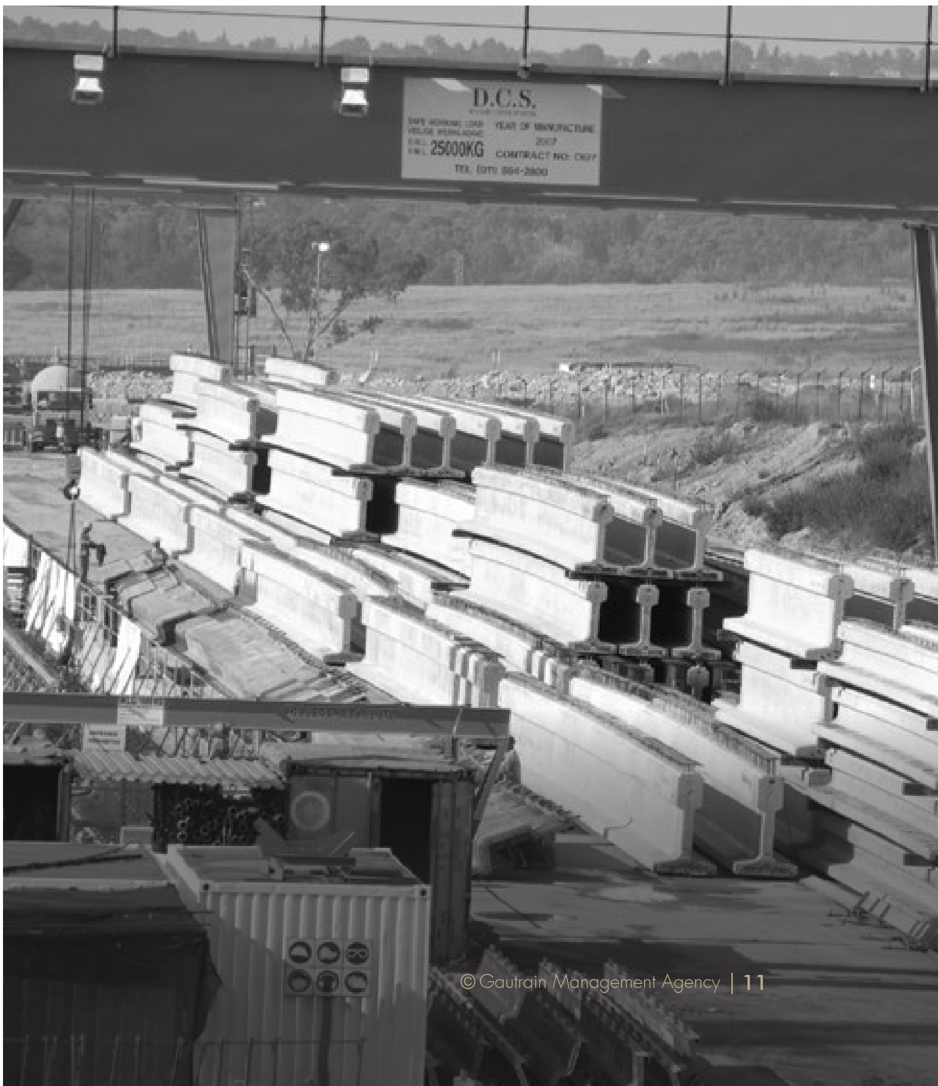
5. PROCESS MANAGEMENT CONTROL

5.1. Numbering of elements

Precast elements for the M-beams and Viaducts had to be clearly marked and numbered, as they had to be placed in position as required for each structure or match cast.

5.2. Stacking

Records had to be kept of each specific element's stacking position in the storage area for easy collection, loading and transport.



6. LESSONS LEARNED

6.1 PCY Challenges

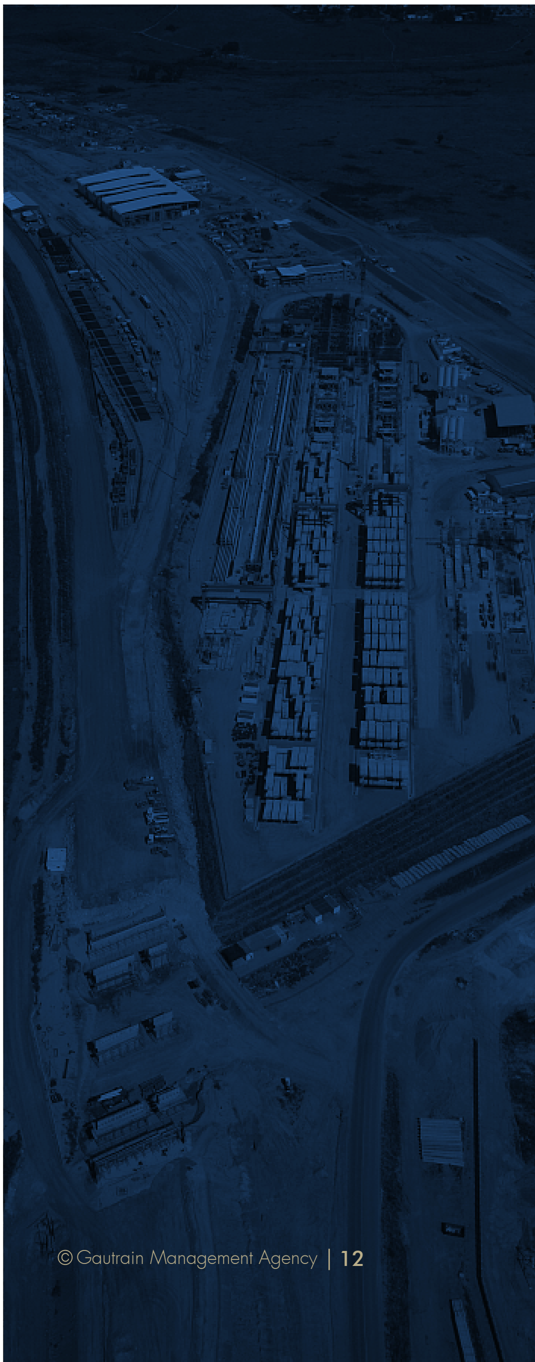
The Concessionaire suffered the following delays to do with the PCY:

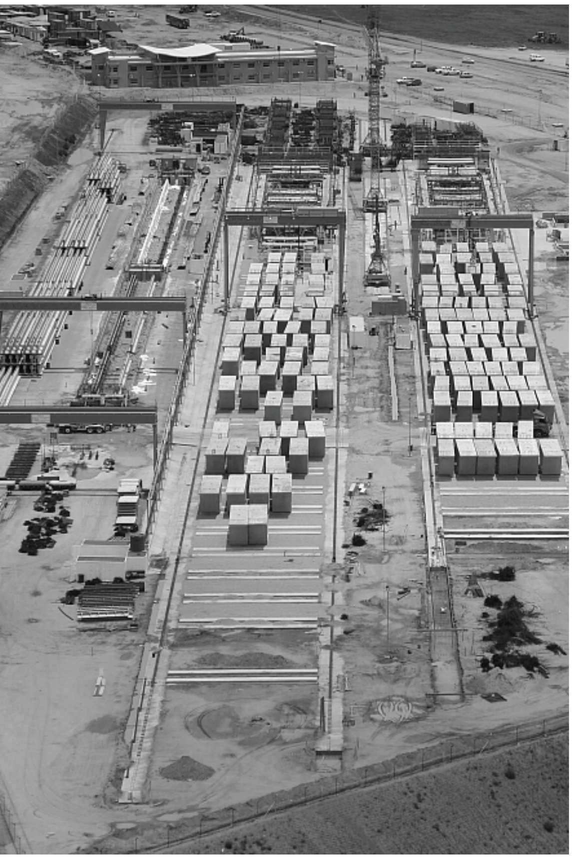
- The production learning curve was longer than anticipated.
- Production rates in the beginning were below what was required as a result of productivity and quality challenges.
- Cement supplies were delayed as they were in short supply at the time due to all the construction activities that was ongoing at the time.
- Cement that was delivered was too hot for immediate use.
- Quality problems resulted in a greater number of products being "hospitalised".
- Due to the slow viaduct production progress, a third production line had to be set up with additional associated costs including formwork, cranes, etc.
- Units had to be held longer in storage at the PCY due to production schedule changes and/or re-sequencing site construction.
- Aggregates obtained from the tunnelling operation at the PCY weren't quality checked properly and arrived at the batch plant contaminated (e.g. detonator plastic strips, timber pieces and plant matter). The material received should have been monitored and controlled by a concrete technologist monitoring the concrete batching plant. Normal aggregates received from quarries are washed and aren't contaminated.

6.2 Successes

In spite of many challenges, the Concessionaire constructed a state of the art PCY and batch plant. Successes during the project included:

- All the required precast elements were completed within the time and space available.
- The overall quality of precast elements was very good.
- The PCY management team was excellent and had extensive construction experience.
- In spite of late receipt of construction drawings and on-site delays, the PCY team managed to increase productivity towards the end to a level above what was planned, which allowed the PCY to be demobilised and the bus depot constructed in time.
- There was excellent on-site safety and training at the PCY.
- Transportation of precast elements to the various sites happened without incident.
- The successful design and use of additives in the concrete mixes to increase early strength assisted productivity and cost savings for the project.
- Match casting of viaduct segments assisted the launching and assembly process on site.
- Elements that left the PCY were quality checked and stamped and ready for use when they reached the construction site.
- Repetition and the re-use of formwork in a controlled environment added to quality and cost saving.
- The batch plant was sold off after completion of the works.
- The creation of cages for steel fixing assisted with its installation in the viaduct formwork.
- Possible pollution was managed on site through concrete channels and silting dams.





6.3 Room for Improvement

Future learnings that can be used from the completion of this project are:

- Allowances should be made for unplanned challenges and delays.
- When projects of this magnitude are launched, several external factors need to be taken into account, for example the number of other projects on the go at the time, the economic situation at the time, etc. that could impact on the supply of materials and requiring longer lead times.
- There should be good project communication and project alignment when it comes to the overall project planning and management, project and site construction progress and the suppliers (in this case the PCY).

7. CONCLUSION

The PCY planning, design, execution and pre-cast element construction forms an integral part of a construction programme and its processes. This requires a strong management and logistics team. Integration of information i.e. design, construction, project and site phasing, progress, communication and record keeping is critical. Site management relationships are also of utmost importance to ensure excellent project management and teamwork.

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