Kochi Chapter

Indian Geotechnical Conference
IGC 2022
15th – 17th December, 2022, Kochi

Innovative Precast Arch Bridge Technology: A Case Study in India.

Kalpana Nallewar[1], Dr. Deepak Manjunath[2] and Mr. Atanu Adhikari[3].

[1]National Design Manager, Terre Armee India.
[2]Head, Design and Engineering, Terre Armee India
[3]Chief Technical officer, Terre Armee India

Abstract: Construction of structures over water bodies pose a serious challenge to design engineers as various potential cost and options must be considered by the project stakeholders. It is a challenge for designers, site team, contractors etc. as the construction needs must be precise and meticulous in such difficult ground conditions. TechSpan® is a buried precast concrete arch. It generally consists of either single or half arch units that meet at the crown, supported by a footing sized for site specific conditions. The backfill around the arch contributes to the resistance of the entire structure, constraining lateral deflections of the arch under vertical loads (soil-structure interaction). This paper focuses on a case study which involves the construction of TechSpan® structures spanning three water bodies over challenging ground conditions. This article covers safety, design, engineering, and construction methods.

Keywords: TechSpan, Precast, Arch Bridge, Arching effect, CLSM

1 Introduction

TechSpan® is a buried precast concrete arch, which consists of half arch units that meet the crown, supported by a footing. The span ranges from about 6 m to more than 22 m and the height ranges from about 30% to 70 % of the span. The backfill around the arch contributes to the resistance of the entire structure, constraining lateral deflections of the arch under vertical loading. The funicular curve of TechSpan® minimizes the tensile forces in the arch, thus creating an axially compressed structure, leading to increased durability and costs savings. The system is designed to accommodate high fills, heavy live loads and varying loading conditions which includes the height of head wall and the traffic loads often associated with mining, industrial and railway applications.

The components defining a TechSpan® arch are shown in Figure 1 and each component is described below:

1. Arch footings: This can be either cast-in-place or precast.

2. TechSpan® precast arch: It consists of male and female arch elements or single arch depending on the transportation limitations.

3. Cast-in-situ crown beam: It is provided for longitudinal connection in most cases, for stitching the crown in special cases where a 2-pin arch is required.

4. Waterproofing/Geotextile joint protection: This is required at the joints of arch units and head wall.

5. The backfill zone: It is divided into three zones i.e., Zone 1, Zone 2 and Zone 3, and compacted in layers on both sides of the arch.

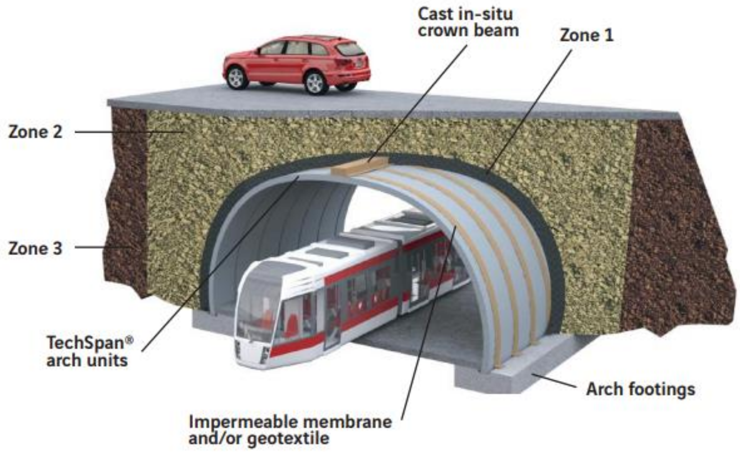

Figure 1:Components of TechSpan® System

2 Project Description

2.1 Background of the Project

The project site is at Dronagiri, Navi Mumbai. The project includes construction of three large precast arch structures near holding ponds at 3, 3A & 4 which were designed and supplied by Terre Armee India, using the TechSpan® arch system. Arch sections used in the project were 9 m in span, had 4.5 m rise and 0.3 m thickness. The maximum fill height over the arches in the final design was 1.15 m above crown level. A multi span segmental precast concrete arch bridge structure with a carriageway width of 34m was built. Each arch unit was 1.985m wide. These units were modelled as a two pinned structure. The spandrel walls and wing walls are formed from Reinforced Earth® Retaining walls using TerraClass™ facing elements & EcoStrap™ as reinforcing elements. All these challenges required careful design of the arch to minimize bending moments in the finished structure, and to deal with the very high axial forces at the base of the arch. Figure 2 gives the location of TechSpan® system in google image for the project.

Figure 2:Google Image of Location of three Bridges

The backfill used for headwall was Controlled low strength material (CLSM) concrete, which is a free-flowing concrete of compressive strength 2.5 MPa. The use of CLSM was proposed in lieu of soil due to the difficulties associated with the compaction of traditional backfill material in layers in area of the adjoining arches was difficult. The soil reinforcing element, EcoStrap™, consists of discrete channels of closely packed high tenacity polyvinyl alcohol (PVA) fibers encased in a Low-Density Polyethylene sheath (LDPE).

A typical cross section of a 9 m span arch is shown in Figure 3.

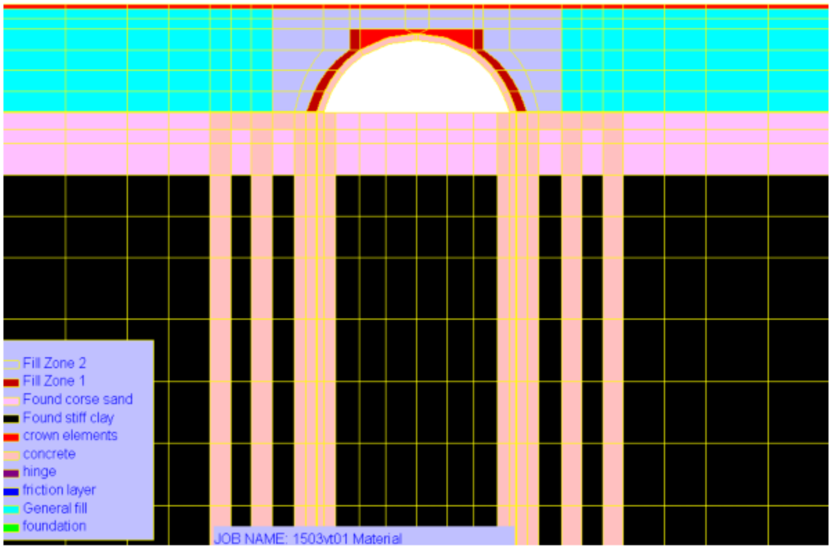

Figure 3 TechSpan Arch 9m Span, 4.5m Rise

3 Challenges and Solutions

For this unique and innovative project, we faced several challenges during design as well as during construction. Some of the challenges are discussed in the following section.

3.1 Challenges Encountered in Design

In the 4.8 km stretch, there are three holding ponds along the proposed coastal road alignment where CIDCO needed to provide bridge spanning structures so that water movement to holding ponds during tidal variation is not affected.

1) Presence of Marine Clay varying in depth from 4 to 14m below ground level, the area is surrounded by creek connected to sea.
2) Influence of high salinity.
3) The high flood level (HFL) of 2.5m
4) Space constraint in head wall between two arches.

All these design constraints were carefully investigated and solutions for each challenge was drawn out by conducting various site visits & having detailed discussion with clients.

3.2 Solutions

1) The presence of marine clay also posed difficulty for foundation of proposed TechSpan® structures, hence it was decided to rest the TechSpan® structures on the pile foundation.

2) The headwall along the TechSpan® structures were to be built up using Reinforced Earth® technology. Because of the high salinity and the HFL, the reinforcement used in Reinforced Earth® wall was proposed to be EcoStrap™. These reinforcements are perfectly suited to high pH (basic environment) as it is the case when recycled concrete or lime (or cement) stabilized soils are used as the select backfill. EcoStrap™ polymeric strips also provide additional benefits in terms of stiffness and capacity to sustain higher temperatures.
3) The space between the two arches is less which in turn creates difficulty in backfilling and compacting. A solution to this problem was found by using controlled low strength material (CLSM). This is low strength concrete used as slurry in place of backfill soil.

Figure 4 EcoStrap™ Reinforcement

3.3 Challenges Encountered in Erection

1) The area is surrounded by a creek. Prior to arch erection, an access road had to be constructed for the arches to be transported and then subsequently placed.
2) The access road was constructed by filling the creek. This access road was used for transporting the arches.
3) Being single arch units, the weight of one arch unit was approximately 20 tonnes. The crane had to lift the arch and place it in position, since placing the crane on the access road was not possible, hence it was decided to place the crane on the pile foundation and then erect the arches.
4) A special construction sequence had to be developed for the same. The picture depicting construction sequence is as below

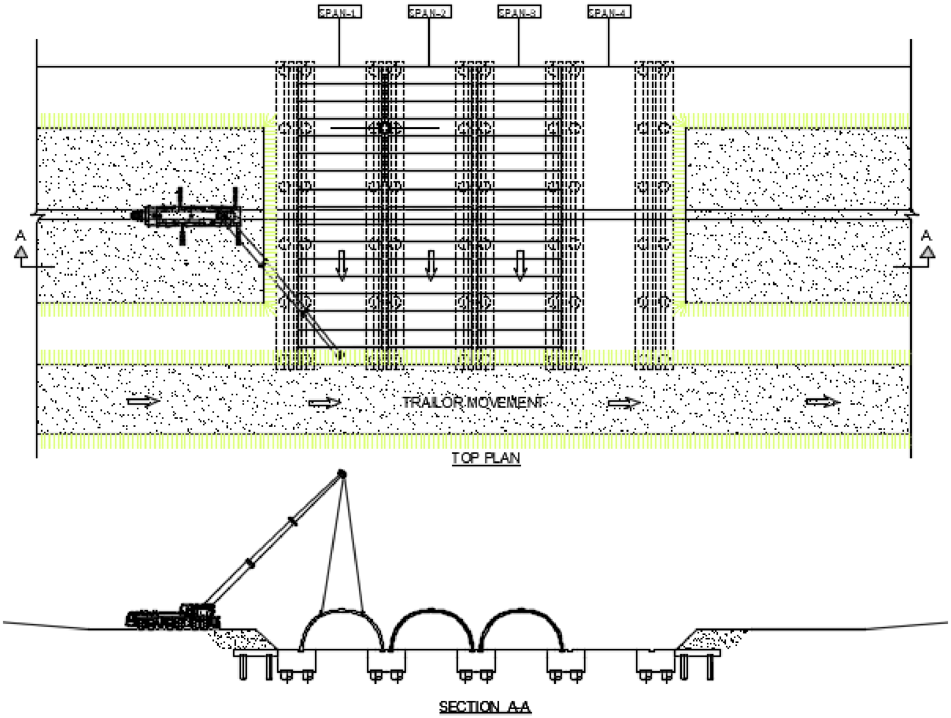

Figure 5 Construction sequence of Arch from approach road

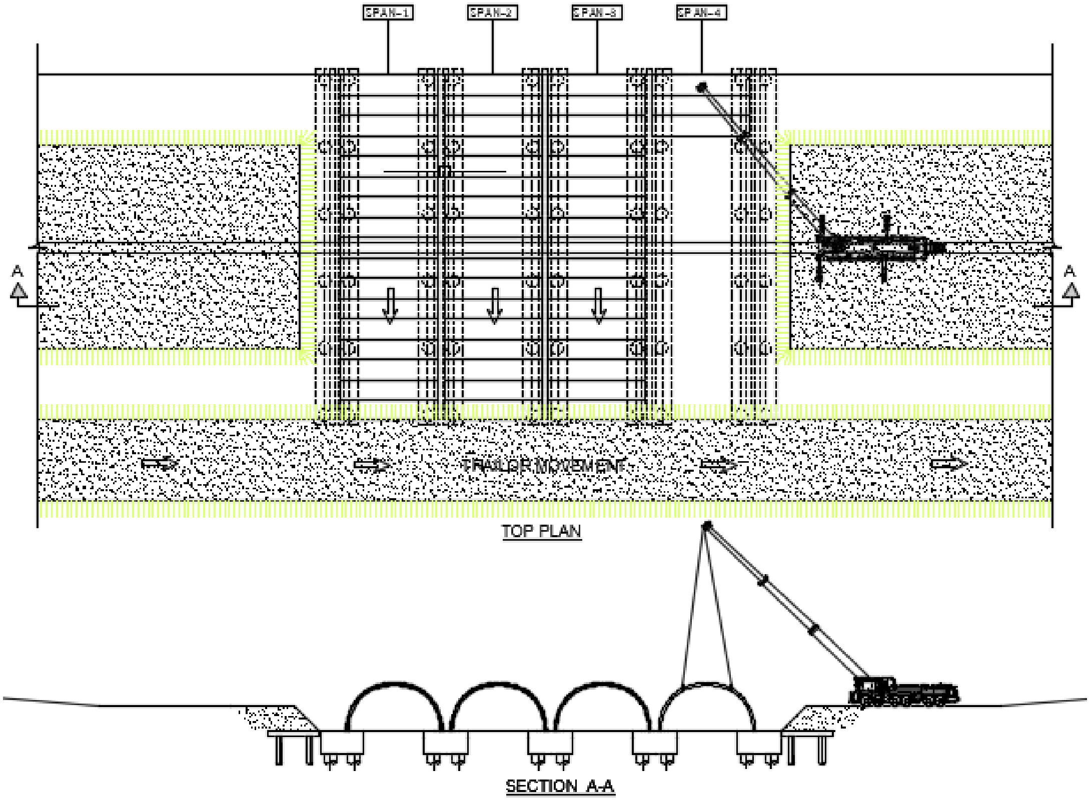

Figure 6 Construction sequence of Arch from approach road

Considering all these difficulties in mind, Terre Armee India proposed the use TechSpan® segments of single piece (two pin structure). Several discussions and site visits were conducted, and TechSpan® arch structures were proposed for all three bridges.

4 TechSpan® Arch Design

The basic analysis for these structures followed the standard practice for TechSpan® arch structures, using Terre Armee India's in-house software, (TechSpan® Arch FEM (Finite element method). Other EXCEL spreadsheet programs have also been used for processing FEM data. The information pertaining to the design is as below:

1. A 2D, plane strain, finite element analysis was undertaken, modelling the arch, the foundations and backfill within the zone of influence of the arch.

2. An elasto-plastic soil model was used, with soil stiffness and Poisson's ratio related to confining pressure.
3. Soil loads were applied in stages reflecting the sequence of filling employed on site.
4. For each backfill layer the fill is added to the model.
5. A layer of "friction elements" is placed between the arch and the soil, allowing the soil to slip relative to the arch.

4.1 Loading conditions

The design was analysed for all critical load cases as mentioned below:

1. Load Effects due to Lifting/Handling/Erection (Static Analysis)
   a) This situation occurs when the arch unit is turned to connect the chains to the extrados lifters, prior to erection.
   b) Lifting for erection: This case considers the hogging moment (tension on the extrados) due to the cantilever beyond the extrados lifting points.
   c) Lifters: This section of the analysis concerns the sizing and location of the lifting inserts in which they are cast into the sides and extrados of the arch units.

2. Load Effects due to Backfilling/Permanent & Live Loads (FEM Analysis)
   The behaviour of the arch structures during backfilling and under permanent/live loading is modelled using a (FEM) program, AZTECH. The load effects on the arch structure during each step of the backfilling/live loading are extracted from the output data using an EXCEL spreadsheet program and presented graphically. This spreadsheet program also presents the design capacity of the arch section on the graphs and compares this with the load effect for any specified design step. Using this spreadsheet, the reinforcement required to satisfy ULS moments is derived. These reinforcement layouts at the critical sections are then checked separately for combined axial/shear/moment effects at both ULS and SLS to confirm the rebar requirements.

3. Live Load
   Live loading on the completed structure can be modelled as either a surcharge (kN/m²) or line loads (kN/m) applied to the surface of the backfilled arch. For this structure, the imposed live the live loads are modelled in accordance with IRC 6:2010 [1]

4.2 Results from FEM Analysis

The FEM analysis was carried out for all critical load cases and subsequent filling till Finished Road Level (FRL). These results are depicted graphically and are presented in terms of ULS moment per metre width of arch. The bending moment diagrams also depict the ultimate moment capacity of the arch section for both positive sagging moments (tension on the intrados) and negative hogging moments (tension on the extrados). Figure 4 gives the typical complete section of TechSpan® at 6.20 m of FRL and Figure 5 gives the shear force and bending moment diagram for the section.

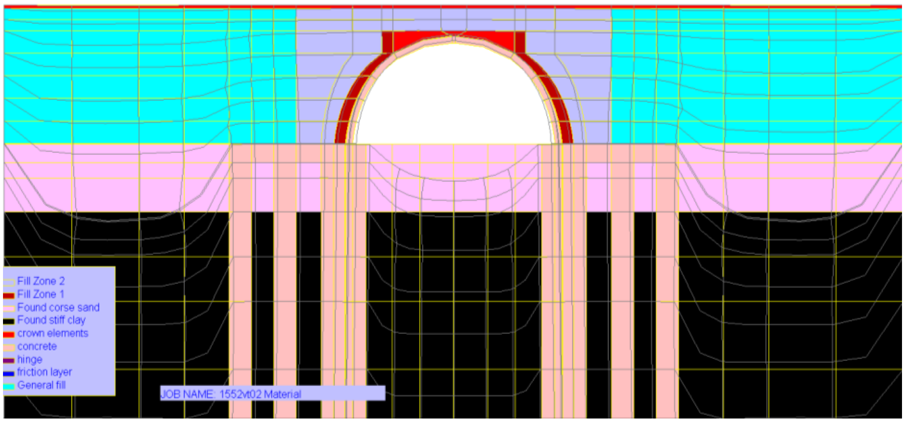

Figure 7 Completed Model of TechSpan Arch

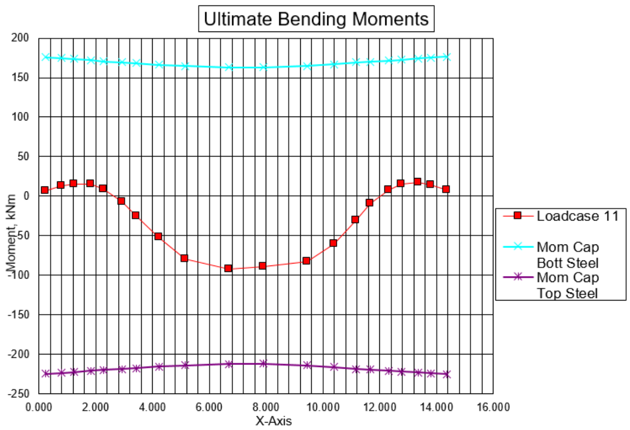

Figure 8 Shear Force and Bending moment analysis

4.3 Design Standard Used

Imposed load as per IRC 6:2010 [1], and the initial reinforced concrete design for the purpose of analysis & check has been done by BS 5400 :1988 [Part 4 & 5] and further validated as per IS 456:2010 1].

4.4 Specific Features and Advantages

i. Arch sections are precast facilitating simultaneous construction activities and solving space constraint problems. Controlled low strength material (CLSM) is being used as retaining fill.
ii. Aesthetically pleasing and structurally strong.
iii. Cost Effectiveness – Overall cost is at par or lower when compared to conventional methods and maintenance requirements are minimal. The standardized method reduces construction time by 50-60%.
iv. Using thin sections results in lesser consumption of concrete, reducing carbon emissions, thereby making TechSpan® environmentally sustainable.
v. Technical Advantages – The standardized precast process ensures better quality control and superior durability. The design is based on soil-structure interaction property, which makes the sections more efficient and environment friendly.

4.5 Project Photos (During construction and completion)

Figure 9 Installation of arch and filling of CLSM,along with laying of soil reinforcement (EcoStrap™)

Figure 10 Completed Arch bridge structure with TechSpan and head wall with Reinforced Earth wall

5 Conclusion

i. A case study which involves the construction of TechSpan® structures spanning three water bodies in a marine clay environment at Dronagiri, Navi Mumbai has been presented. The project was developed by City and Industrial Development Corporation (CIDCO) and involves construction of a 34m wide road from NH-4B near Navghar to Bokadvira adjoining

Navi Mumbai Social Economic Zone (NMSEZ) at Dronagiri, Navi Mumbai.

ii. The erection of the TechSpan® arches for all three bridges was completed in a record time of three months.

iii. The adoption of TechSpan® system resulted in cost savings of the order of 50-60% when compared to conventional solution options. Hence, TechSpan® system is an innovative and cost-effective solution alternative in cases where precast arch structures are to be constructed over natural and manmade features besides various other applications.

iv. Some of the advantages of the system include a standardized precast process which ensures better quality control, superior durability and redundancy in design due to arching effect. The design is based on soil-structure interaction, which makes the arch sections more efficient, environment friendly & cost effective and provides a higher safety factor during service conditions.

References:

1) IRC 6 (2010). Standard Specifications and Code of Practice for Road Bridges. Indian Road Congress. New Delhi.
2) BS 5400 (Part-4 &5). British Standards. United Kingdom
3) IS 456 (2010). Plain and Reinforced Concrete-Code of Practice. Indian Standards. New Delhi.
4) Pierre Segrestin, Terre Armee Internationale, France & William J. Brockbank, Reinforced Earth Company Ltd, Canada," Precast Arches as innovative alternative to short span bridges"
5) Doug Jenkins, "Analysis & Design of Arch structures for the Oman Southern Expressway