STUDY OF PRECAST CONCRETE STRUCTURES IN INDIAN HIGHWAYS

ABSTRACT: Precast reinforced concrete structures are gaining widespread popularity as an alternate to traditional forms of construction. This paper discusses the use of precast elements for highway construction in India, focusing on the advantages and challenges encountered in their application. The study highlights the benefits of precasting in terms of cost-effectiveness, speed of construction, and quality control. It also addresses the technical considerations required to ensure the structural integrity and durability of precast concrete components in various environmental conditions.

INTRODUCTION

Precast reinforced concrete structures offer a reliable and efficient construction method, especially suitable for highway projects. These structures are advantageous because of their ease of production, pre-casting, transportation, and on-site assembly. The use of precast elements in highways is not only time-saving but also cost-effective compared to traditional cast-in-place methods.

One such example is the construction of a precast reinforced concrete arch structure for the proposed NH-58 project. The structure was designed to meet the project's requirements and was built using precast elements fabricated off-site. The use of precast concrete arches has gained recognition in various parts of the world, and their application in India is steadily increasing.

The project was implemented by M/s Gayatari Projects Ltd., and the arch was constructed over a nalaah having a base width of 9.2m and top width of 12m. The planed twin cell box had about 4 to 5m fill over the top slab.

The original structure plan required the construction of a conventional cast in place box structure over a nalaah having base width of 9.2m and top width of 12m. The planned twin cell box had about 4 to 5m fill over the top slab.

Precast Reinforced Concrete arch structure was proposed and approved as an alternate to the conventional cast in place structure. Depending upon various technical and practical considerations, the arch has been cast in four segments, one base slab termed as invert, two side walls along with footings, and one crown termed as vault. The width of each element was kept as 2.49m. Arch action associated with sophisticated computer programs enabled designing the structure for complex soil structure interaction thereby reducing the design thickness of the arch to 350mm. The cross section and the plan of the structure are shown in fig. 1 and fig. 2 respectively.

Fig. 1 Cross Section of the structure

Fig. 2 Plan of the structure

STRUCTURE GEOMETRY

The step by step design procedure involves (a) determination of optimal shape, (b) analysing the structure for various loads and load combinations (c) designing the structure for the shear forces and bending movements.

Determination of Optimum Shape

Analysis of these structures begins with deciding the optimum shape based on project specific conditions. The technical considerations include factors like clear envelop, structure top level (including backfill above the crown), height to span ratio etc. Practical conditions include logistics, cost of mould fabrication, lifting capacity of
available cranes, transportation of segments and other factors related to cost economics. The shape of the arch adopted for this project is presented in fig. 3.

**Jointing System**
The segments are jointed to each other with the help of simple ball and socket joint. Segments form dry joints by simply placing one segment over other as shown in Figure 4 and any special treatment is not required.

**ANALYSIS AND DESIGN**
The analysis, design, and performance of the structures surrounded all around with soil, require an understanding of soil-structure interaction. Such structures usually cannot resist the loads to which they are subjected, including soil, without utilizing the strength of the surrounding soil in a complex interaction. The analysis of these structures is carried out using Finite Element Method taking soil structure interaction and Marston Effect into consideration.

**Soil Structure Interaction**
The soil-structure interaction of these structures is affected by the structure’s material, size and stiffness, method of construction, type and placement of the backfill material, induced loads etc. Flexible structures interact extensively with the surrounding soil, and the soil offers part of the resistance to the induced loads. Under the effect of vertical loads, every point of these structures undergoes both vertical as well as horizontal deformations. The horizontal deformations are directed outside from the structure and hence strain the lateral backfill, which is also under compressive forces due to self weight and other vertical forces. The backfill responds to these deformations by virtue of its stiffness. The lateral backfill resist the structure deformations and hence, provide lateral stability to the structure through complex soil structure interaction.

The soil structure interaction is taken into affect by reaction modulus method wherein the foundation soil and lateral backfill are modelled as a series of springs of calculated stiffness acting at different levels. The force exerted by these springs on the structure at any level is directly proportional to the displacement at that level.

**Stiffness of Lateral Backfill**
The stiffness of the backfill is not only an intrinsic property of the soil but it also depends upon the shape and dimensions of the conduit. It can be calculated using Equation (1).

\[
\frac{1}{K_b} = \frac{1.33}{3E_p} \times R_o \times \left( \lambda_2 \frac{R}{R_o} \right)^{\alpha} + \frac{\alpha}{4.5E_p} \times \lambda_3 \times R \quad (1)
\]

where, \(k_b\) = lateral backfill stiffness; \(E_p\) = pressuremetric modulus of backfill soil; \(R\) = radius of associated rigid foundation; \(Ro\) = reference radius; \(\lambda_2, \lambda_3\) = geometrical parameters; \(\alpha\) = soil structure coefficient.

**Foundation Soil Stiffness**
The stiffness of the foundation soil can be readily calculated from the method of bulk modulus of elasticity testing. The foundation soil is represented by applying vertical springs of equivalent stiffness at desired locations. It can be readily calculated using Equation (2).

\[
\frac{1}{K_v} = \frac{1.33}{3E_B} \times R_o \times \left( \lambda_2 \frac{R}{R_o} \right)^{\alpha} + \frac{\alpha}{4.5E_A} \times \lambda_3 \times R \quad (2)
\]

where, \(k_v\) = foundation soil stiffness; \(E_A\) = spherical pressuremetric modulus; \(E_B\) = deviator pressuremetric modulus; \(R\) = radius of associated rigid foundation; \(Ro\) = reference radius; \(\lambda_2, \lambda_3\) = geometrical parameters; \(\alpha\) = soil structure coefficient.

**Marston Effect**
The response of buried structures to loads is not only the function of load characteristics, but also depends on the relative rigidity of the structure with respect to the surrounding soil. The weight of the soil column above the structure is not exactly the same as it would have been if there was no structure. The weight of the soil column is either more (in case relatively rigid or incompressible structure is buried under a relatively compressible fill) or less (in case relatively flexible or compressible structure is buried under a relatively incompressible fill) than it would have been; had there not been any structure. This effect is referred as Marston effect and is presented in Figure 5.
Indian Experience in construction of Precast Reinforced Concrete Arch Structures

In case of concrete structures buried in soil, as the concrete is relatively rigid as compared to surrounding fill, the structure is said to "attract" load, increasing the vertical stress on the structure beyond what would normally be calculated. Marston coefficient is defined as the ratio of the vertical stress above the structure to the stress at the same location if the structure were not present. It depends on fill height, its compressibility, and the shape and rigidity of the structure. For concrete structures embedded in soil it is greater than 1.

**Fig. 5 Marston Effect**

**Elementary Load Cases**
The analysis and design of these structures has to be made for various intermediate stages of the construction. The structure should have adequate factor of safety at all construction stages. Various construction stages are (a) own weight of individual segments as they are stored in the casting yard, (b) own weight of erected structure prior to backfilling, (c) vertical load of the backfill and its horizontal influence on the structures till backfill reaches the joint between vault and the side walls without considering soil structure interaction (d) till it reaches the crown considering soil structure interaction, (e) till it reaches about 1 m above the crown considering soil structure interaction, (f) till it reaches final fill level considering soil structure interaction, (g) different levels and positions of construction equipment and its horizontal influence considering soil structure interaction, (h) different positions of spread service loads and its horizontal influence considering soil structure interaction.

**PRECASTING OF UNITS**
Casting of the segments is carried out at casting yard under controlled conditions. The casting of concrete segments has been taken up in steel moulds which are flexible and have been transported to the casting yard using trucks. One mould each has been prepared for the casting of vaults (26 numbers) and side walls (52 numbers). The critical casting activity being side walls, the casting of units was completed in about 120 working days. Figure 6 shows a steel mould used for casting of Vaults.

**Fig. 6 Mould for casting Vault**

The area earmarked for placement of the mould is levelled by laying a thin layer of plain cement concrete to ensure rigid platform for casting. The reinforcement cage is prepared by proper cutting and spacing of steel reinforcement bars. It is made with all precision as specified in construction drawings and as guided by construction in charge. Reinforcement bars are tied or welded together. Figure 7 shows the preparation of reinforcement cage at the casting yard.

**Fig. 7 Preparation of Reinforcement Cages**

The inner surface of the moulds is cleaned with the help of hessian cloth followed by application of de-shuttering oil or releasing agent on the inner surface of the mould. Reinforcement cages are then placed in the respective moulds and the lifting anchors are welded to the cage at the locations specified in construction drawings. Concrete of specified grade and slump is then placed in the moulds per the approved methodology.

Once the concrete is initially set and there is development of required lifting strength (normally 24 hrs from the casting), the moulds are then unscrewed and segments are lifted and stacked properly. The lifting mechanism is a two-
point sling which is attached to lifting anchors cast inside the unit. Once the curing time is over, transportation of these segments is carried out on flatbed trailers of adequate load carrying capacity. Figure 8 shows the transportation of the vault units to the site location.

**ERECTION OF UNITS**

During erection of segments, the execution team ensured proper assembly of segments in relation to drawings. Thereafter, all joints were sealed with appropriate joint sealing and water proofing methodology. These operations though seem to be simple in themselves, need to be carried out methodically and carefully, and ensuring adaptation of all necessary safety measures. Schedules for lifting equipment, transport, site access, potential ground water problems, extra construction material were made well in advance.

Excavation was made in accordance to the construction methodology and must be in close conformity to the dimensions specified in the construction drawings. The foundation bed must be compacted to specified grade by applying requisite compactive effort and the compaction achieved was checked by sand replacement method.

The erection of segments was started from one end and proceeds towards other end. The ball and socket joints were made free from any debris/dust before erection of segments. The installation of the units has been completed in 9 working days by deploying a team of 6 persons accompanied with a crane and operator.

A multi tier water proofing was than taken up at all the joints (vertical as well as horizontal) as shown in Figure 9. Firstly a layer of metal strip was fixed over the joints. This is followed by torching an elastomeric layer over it with the help of a regulator and propane gas. Thereafter, one layer of geomembrane sandwiched between two protective layers of non woven geo-textile was provided.

The backfill was than placed and compacted in layers (not exceeding 250 mm) simultaneously on both sides of the structure to ensure uniform distribution of loads. The zone extending 1m on either side of the structure and over the top of the crown is light compaction zone and was compacted using light compaction vehicles. The photograph of completed structure is presented in fig. 10.

**CONCLUSION**

The cost economics is a direct function of materials and time saved specially in BOT projects where early collection of revenues is of paramount importance. Many projects in our country are running behind schedule just because of non availability of land. This problem can be solved to a greater extent by adopting precast concrete arch structures. The technology offers not only aesthetically beautiful structures but also technically sound and immensely durable engineering product. The segments can be cast and kept ready and the erection can be taken up immediately as soon as the land is made available.

**REFERENCES**

1. Sylvayn, Plume (2000), Plasticity in soil structure interaction applied to cut and cover tunnels, *EPFL, Lausanne, Switzerland*