The Bridge Through the College (Part-1): Conception and Construction of Reinforced Concrete Bridge Across College Campus

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Abstract: "The bridge through the college" highlights how contracts and agreements signed many decades ago have to still be respected and fulfilled. A public highway planned to originally be laid on top of a filled-out irrigation canal passing through the campus of a college that commenced in 1977 was later replaced with a elevated bridge that has finally finished completion in 2023 and is now open to public. The bridge is designed as reinforced concrete girder bridge with concrete slab top poured composite with the girders. This article explains in detail the engineering, design and construction of a reinforced concrete girder bridge through the campus of Velagapudi Ramakrishna Siddhartha Engineering College in Vijayawada city of India. The challenges associated with design and construction are also discussed. Finally, the lessons learnt at the end of the completion of the bridge are enlisted and recommendations to improve efficiency of our design and construction methods are made.

Keywords: Concrete, Bridge, Engineering, Construction, Pier, Girder, Reinforcement

1. Introduction and Features of the Bridge

Velagapudi Ramakrishna Siddhartha Engineering College located in the outskirts of Vijayawada metropolitan area was the first private engineering college in the undivided state of Andhra Pradesh established in 1977. When the college committee known as Siddhartha Academy was planning the layout for the construction of education buildings inside the 24 acre land, a part of the land going along the irrigation canal referred to as 'Panta Kalva' was already identified as obsolete and that need to be filled over with for a potential future construction of a highway that connects Kanuru village to Poranki village. An agreement was made between the local government authorities and the college administration that in the event the government eventually decides to build a highway over the land fill on the obsolete irrigation canal, it would be handed over to the government for this purpose. The college later developed into a major campus with buildings for academic classrooms, faculty rooms and laboratory facilities. However, in 2020 the government decided there is still need for a highway at this location and Siddhartha academy graciously respected the agreement in the larger interests of public and the communities around. However, in order to not disrupt the student community in the campus, the academy proposed to build a bridge instead of a highway at its own cost. The local government authorities accepted this proposal. The bridge was completed and opened to the public in 2023 connecting the towns of Kanuru and Poranki.

The bridge has a total length of 409 m with two approach embankments and 12 bridge spans each of length 17m. The main span crossing the at-grade driveway on the college campus has a vertical clearance of about 4.5m high for easy flow of traffic

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underneath the bridge. The bridge foundations are built as isolated pad footings with reinforced earth walls supporting the embankment approaches at each end of the bridge.

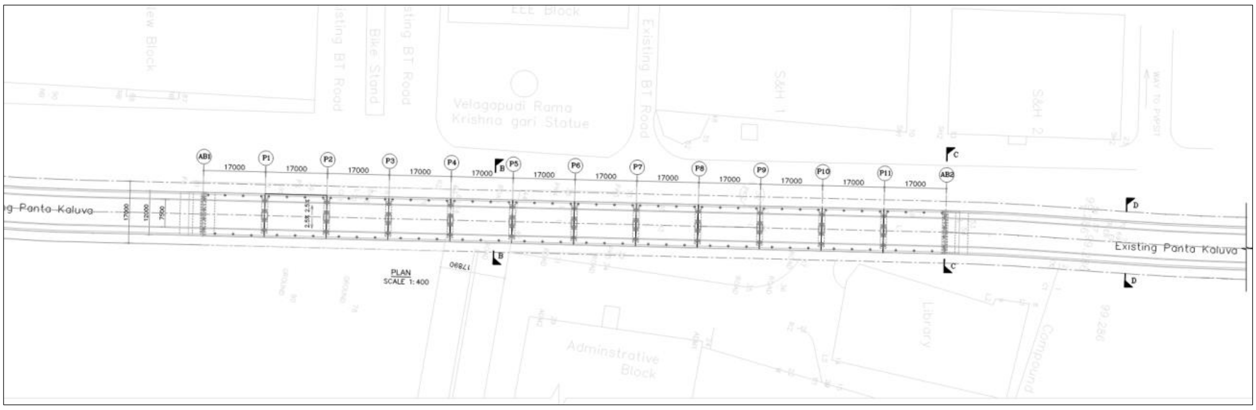

Figure 1: Plan Layout of the bridge

The challenge for the construction of the bridge though was to efficiently engineer and build this bridge with least disturbance to the college's educational activities and its student community. With more than 5000 full time students on the campus on any day, it was not easy to coordinate the bridge planning, survey, earthwork, and construction activities. This bridge needed detailed planning for each phase of activities.

The bridge was decided to be designed and built as reinforced concrete girder bridge. These bridges are chosen in these parts of India because they are ideally suited for rugged use with least maintenance intervention requirements but yet are very cost effective. Reinforced concrete bridges are more durable and have higher service life with lower maintenance costs over their life cycle as compared to steel or other materials. The nearest competition was a steel bridge; however steel is susceptible to corrosion and regular inspections maintenance schedule is required for its connections and joints. Also steel bridge was way more expensive than concrete for this length of a bridge and so steel was ruled out.

To give an overall idea about the layout and geometry of this bridge, its total length is 409 m. The total deck width of the bridge is 12m. The carriageway width of 7.5m accommodates one lane of traffic in each direction. Two sidewalks (or pedestrian footpaths) about 1.75m and one on each side of the carriageway are provided. Reinforced concrete crash barriers are installed at the outer edges of deck slab on each side. The four reinforced concrete superstructure girders spaced at 3m center to center and an edge overhang of 1.5m support the deck slab at its crash barriers. These girders sit on bearing pads supported by the pedestals of the hammer head pier caps. The circular piers transfer the loads from the deck and girder through the pier caps to the isolated pad footings.

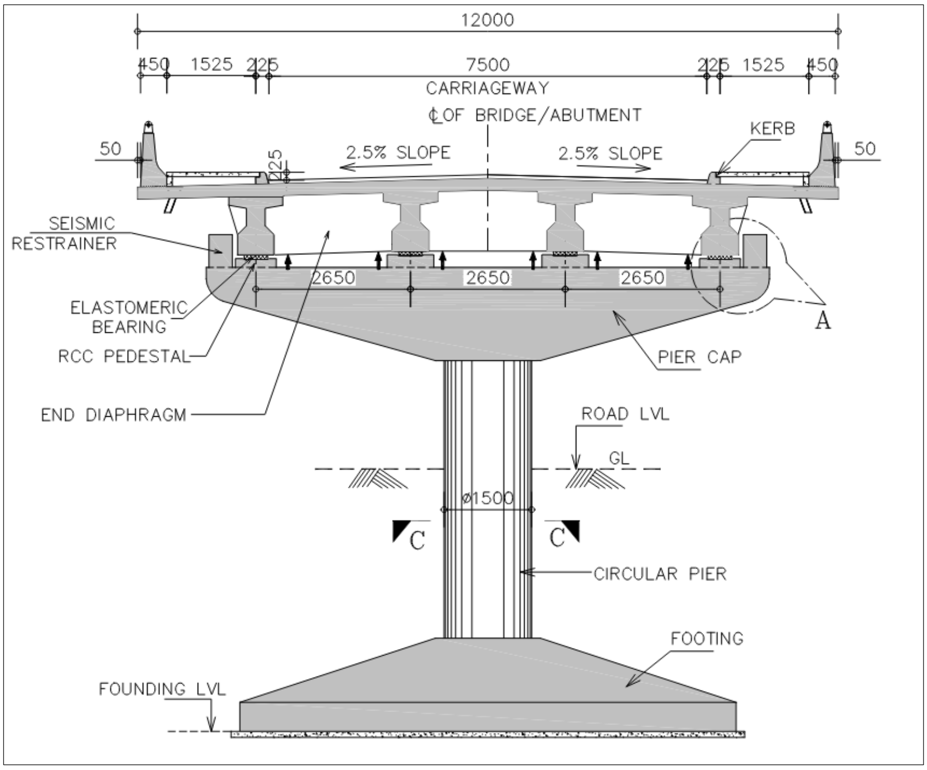

Figure 2: Cross section layout of the bridge

The bridge has a total of 12 elevated spans all of them same length as 17m. In total, there are about X number of piers and foundations. All spans are simply supported with expansion joints provided in the topping slab over the support piers.

Regarding the geometry of bridge component members, each of the four girders are 1.2m deep excluding the topping concrete slab. The cast-in-place composite concrete topping is 8” thick. The piers are circular in shape with a diameter of 1.5m. These piers transfer the loads to the ground through isolated pad footings. The crash barriers are 0.45m wide at base and narrow to 0.2m at the top. The pier caps are 9.65 m long; they are 1.6 m deep at the start and tapper to 0.5 m thickness at their ends. There are four pedestals on the top of each pier cap with one under each girder seat. The girders are connected by a common diaphragm at their ends on top of the pier cap.

The construction of the bridge is a hybrid precast and cast-in-place. The girders are fabricated at the job site where plenty of land is available thus making their construction categorized as hybrid precast. This mode of construction is adopted when it is not feasible to cast girders in a manufacturing facility nearby and ship the members to the job location. Hybrid precast construction retains the advantages of precast fabrication such as greater quality control and speed of fabrication without being restrained by shipping and transportation issues for heavy concrete members. The piers and foundations are cast-in-place, the precast girders are erected on the piers and deck slab is poured at the site finally.

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2. Engineering and Design

The first author lead the analysis and design of the bridge members and supervised its construction on a need basis to ensure compliance to design specifications. Indian Roads Congress (IRC) documents the specifications and code of practice for road bridges in India (IRC 5 2015, IRC 6 2017, IRC 22 2015, IRC 112 2011); these specifications along with Bureau of Indian Standards code of practice for the design of reinforced concrete structures such as IS 456 (2000) and pertinent international codes are referred in the design of the bridge members. Popular books document the process of analysis and bridge designs (Johnson 2017, Jagadeesh & Jayaram 2020). The analysis of the bridge girders is performed using line model in STAAD structural analysis software. Though line model gives higher moments and shear as compared to a 2D or 3D model due to lack of distribution of forces in other directions (Vemuri and Jonnalagadda, 2023a), this method of analysis was performed keeping in mind the little around time available for submitting designs for this bridge. IRC:6 specifies the code of practice for "Loads and Load Combinations" to be applied in the analysis and design of bridge girders. The Class 70R loading specified by IRC 6 is normally applied for the analysis of bridge girders for all permanent bridges in India.

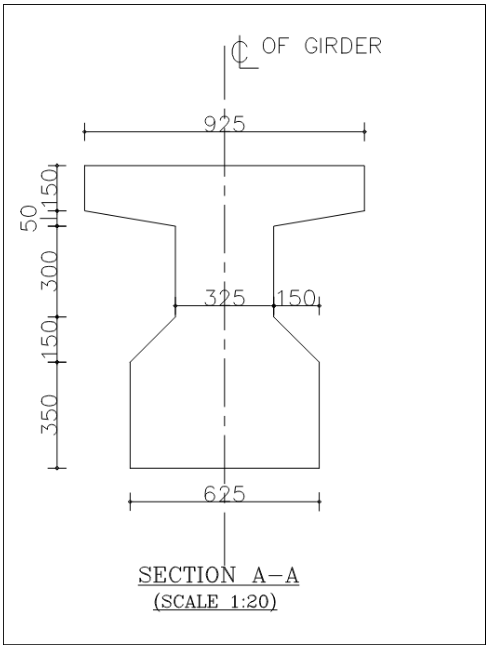

Figure 3: Precast Girder Geometry

As shown in Figure 3 above, the precast girders are 1m deep and the depth is arrived based on a span to deflection of 17. The girders stems are 325mm thick which is set based on shear sufficiency of the section. The bottom flange is 625 mm wide whereas the top flange is 925mm wide. The top flange thickness tapers from 200mm to 150 mm at the edge of the precast flange.

The piers are circular and are 1.5m in diameter. There are 11 piers in total and two abutments in the bridge. The pier caps are 9.65 m wide at the top with a thickness of 1.6m at the face of the column and tapering to 0.5m at ends. There are four pedestals on top of the pier caps one under each of the girders. Figures 4 and 5 show the geometry and layout of piers, pier caps and foundations including pedestals and seismic restrainers. The bridge is located near the city of Vijayawada which is located in seismic zone-III (IS 1893-1, 2002); as such the lateral forces governing the design would be seismic forces, wind does not control the lateral loads on this bridge (Vemuri & Jonnalagadda, 2023b). Wind in general is more governing in taller structures

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(Vemuri & Jonnalagadda, 2023c) whereas this structure is low profiled and rises only 6m above ground level at its highest point. The seismic restrainers help dissipate the seismic forces and also lock in the superstructure from moving out of place in the event of earthquake.

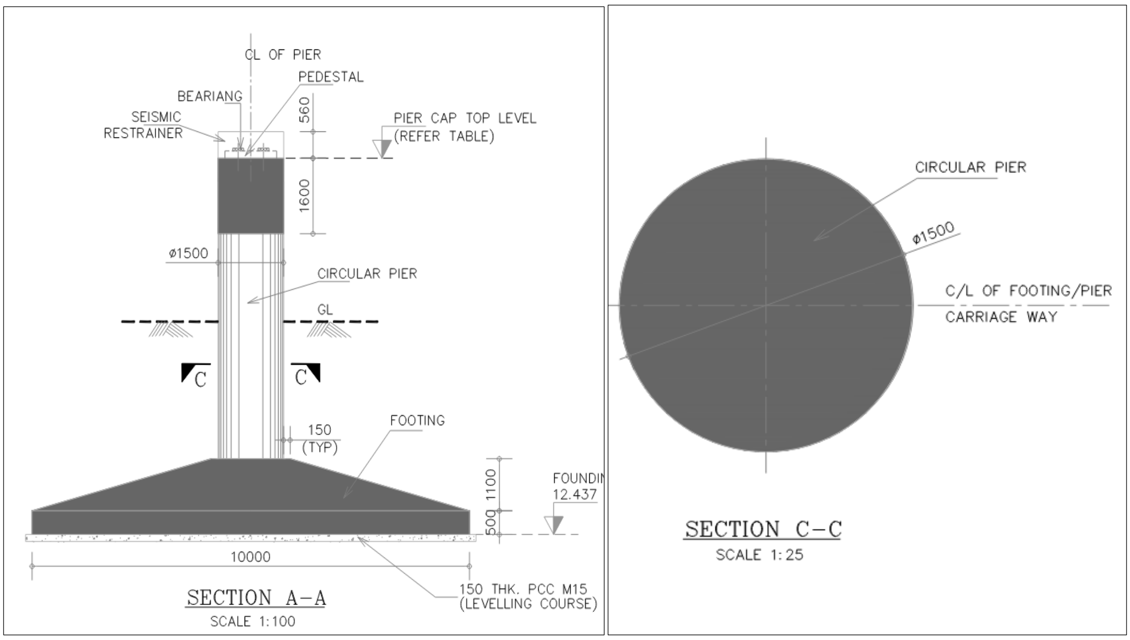

Figure 4: Pier Geometry

The pier foundations are isolated pad footings of 10m length and 8.5 m wide. The foundations are laid at about 4.5m below the ground level for most of the piers. The trapezoidal footings have a thickness of 1.6m at the face of the column and taper to reduce to 0.5m at their edges.

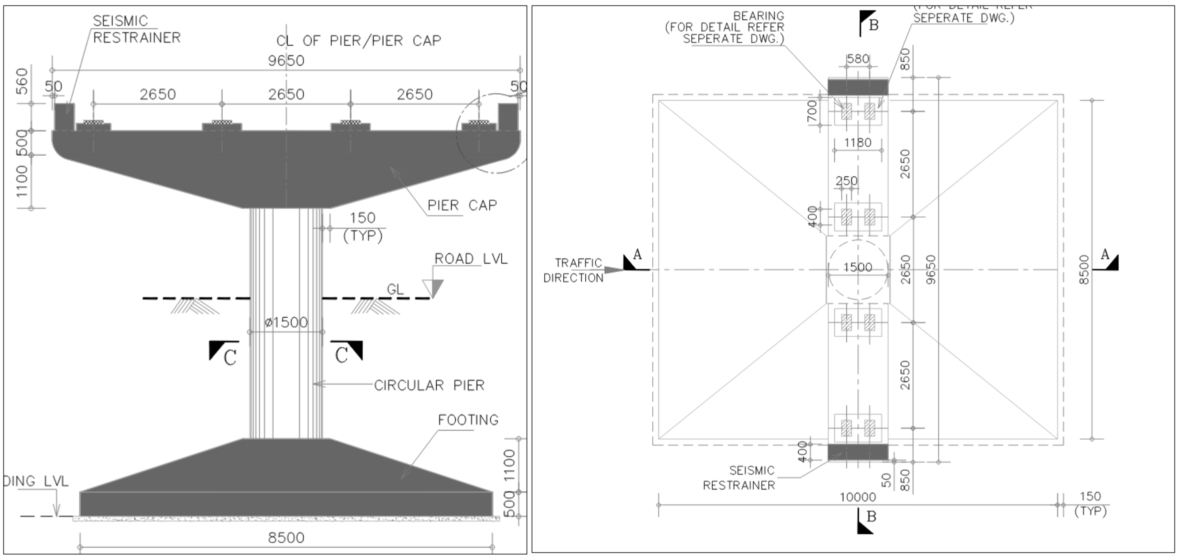

Figure 5: Pier, Pier Cap and Foundation Geometry

3. Construction of bridge

The foundations are chosen as open pad footings with a safe allowable bearing capacity of 15t per sq m. The trenches are excavated to the foundation level (12.437m) which is about 4 to 5m below ground level. The trenches are cleared off any water and levelled with plain cement concrete of M15 grade to create flat surface for placing foundation reinforcement grid. Wooden boards are used as side face formwork around the edges of the foundation. The pier reinforcement is spliced to the foundation reinforcement bars as identified in pier drawings. After the rebar cages in piers and foundations are tied together, concreting is done for the foundations. Grade M35 concrete is used for foundations. Figure 6 shows the arrangement of reinforcement in the foundation and its casting.

Figure 6: Foundation reinforcement and Casting

The pier reinforcement cage is tied, and the circular steel shuttering is used to cast the concrete inside. The piers concrete is of grade M45 whereas the pier cap is of grade M40. The seismic restrainer and bearing pedestal at the top of the pier cap are cast along with the pier cap using the same M40 grade concrete. The piers are cast in two lifts typically and the shuttering for pier caps is shown in Figure 7 below.

Figure 7: Pier and Pier cap Construction

The foundation and pier construction are very typical cast-in-place construction seen in most of the reinforced concrete bridge projects. As such there is no specific novelty in the engineering and construction of these components. However, the superstructure girders are made precast and erected into their place. The job site provided a yard for precast girders to be cast off the site. The girder reinforcement and the form work are arranged in the yard next to the job site and the girders are cast using M45 grade concrete. When the girders reach their 28 day characteristic strength (verified by laboratory concrete cube testing), the girders are lifted using crane and erected on the bearing pedestals on top of the pier caps as shown in Figure 8.

Figure 8: Precast girder reinforcement cage &formwork (L), casted girder (R)

Precast concrete construction can ensure quality member production on time with efficiency and economy in their fabrication (Jonnalagadda & Vemuri, 2023a). This project utilized the benefits of precast construction for the fabrication of the girders. If the same girders were cast-in-place, they would have to wait until pier-caps are completed. Also they would need costly shuttering work from the ground which would be a major nuisance to the student community travel and the required traffic diversions below the bridge. All these additional activities would add huge cost and time to the project creating some major challenges typical for cast-in-place construction (Jonnalagadda and Vemuri, 2023b)

The girders are erected on top of the completed pier caps. The girders sit on elastomeric bearing pads that are fixed to the top of the pedestals cast on these pier caps. The pedestal height is adjusted to achieve required cross camber for drainage as well as superelevation purposes along curved bridge locations. Figure 9 shows the girders placed using cranes on tops of pier caps with the interface shear steel extending over the top of these girders for concrete topping slab bars to run through and concrete cast over the entire girder length.

Figure 9: Precast Girder Erection and Placement

The composite topping slab is poured by arranging shuttering below the bridge supported on the ground. A slab 200mm thick is poured in composite with the girders. The concrete used for slab is of same grade as precast slab which is M35. Drainage spouts are provided in the deck slab as per standard practice. Expansion joints are provided on top of each pier as these are simply supported spans. Figure 10 shows the studded plate expansion joints within the slab before and after the slab is poured.

Figure 10: Expansion Joint reinforcement and Casting

Finally crash barriers were poured along either edge of the flyover and the construction of the bridge is completed after erecting a total of 48 girders and casting composite slab on 12 spans each of 17 m long and building reinforced earth wall along the two approaches at each end of the bridge. This project can be considered as hybrid construction model with precast and cast-in-place methods used together. As this paper is being written, sound barrier installations were being done on top of the crash barriers to minimize the impact of vehicular noise to the college facilities.

4. Missed Opportunities for Novel and Sustainable Practices

In infrastructure development, sustainability and resilience is becoming a major consideration. Global warming is causing climate change that triggers extreme weather events around the world. This requires us to adapt our infrastructure design and construction to be more resilient to extreme weather hazards (Jonnalagadda et al, 2023). In view of these global changes, sustainable and resilient construction practices will be major factors in infrastructure building process. These practices not only reduce the rate of deterioration of structures but also cut the life cycle cost of the structures (Jonnalagadda, 2016). As such on this project there have been some missed opportunities towards implementing sustainable practices. To enlist, some of the following could have been tried.

1. Instead of pouring 200mm of cast-in-place slab on temporary formwork supported from ground, a 75mm precast slab panels supported on girders could have served as temporary formwork. These panels act in composite with about 100-125 mm cast-in-place slab. This would have saved quite a bit of time and effort in preparing the formwork for the slab and improved the quality of slab concrete (PCI 2014, PCI MNL-120 2017)
2. Crash barriers are one of the most suitable bridge members that can be precast. The precast barriers are connected with dowels along their length and shear interface stirrups ensure composite action with the cast-in-place slab. This would improve the quality of work as well as save time and effort once again.
3. The expansion joint strips are the most vulnerable parts of a bridge for deterioration. The life span of these joints is very limited with many needing replacement or repairs within 10 years. As such using Ultra-High Performance Concrete (UHPC) at the expansion joint locations will not only significantly improve the durability of the joint regions (Jonnalagadda & Chava 2023) and minimize maintenance costs (Jonnalagadda & Vemuri, 2023c) but also provide excellent riding comfort to users and reduce accidents.
4. This bridge passes through a vibrant student campus; so aesthetics would be highly welcomed (Leonhardt, 1968). Aesthetically pleasing spans such as Concrete Arch, Steel Arch, Cable stayed or any novel structural form would make great candidates for the main span (crossing the student campus road at grade). This opportunity is missed, instead a traditional bridge form has been finalized.
5. Installation of a solar panels on the bridge and generating enough to power the light the bridge in the dark would have greatly improved bridge aesthetics with little to no extra operational costs. This is still viable even after bridge completion and may be given consideration.

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