Studies on Major Elements of an Elevated Metro Bridge

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Abstract— A metro system is a railway transport system in an urban area with a high capacity, frequency and the grade separation from other traffic. Metro System is used in cities, agglomerations, and metropolitan areas to transport large numbers of people. An elevated metro system is more preferred type of metro system due to ease of construction and also it makes urban areas more accessible without any construction difficulty. An elevated metro system has two major elements pier and box girder. The present study focuses on two major elements, pier and box girder of an elevated metro structural system. Conventionally the pier of a metro bridge is designed using a force-based approach. During a seismic loading, the behavior of a single pier elevated bridge relies mostly on the ductility and the displacement capacity. It is important to check the ductility of such single piers. Force based methods do not explicitly check the displacement capacity during the design. The codes are now moving towards a performance-based (displacement-based) design approach, which consider the design as per the target performances at the design stage. Performance of a pier designed by a Direct Displacement Based Design is compared with that of a force-based designed one. The design of the pier is done by both forces based seismic design method and direct displacement based, seismic design method in the first part of the study. In the second part, a parametric study on behavior of box girder bridges is carried out by using finite element method. The finite element model is validated with model of Gupta et al. (2010). The parameters considered to present the behavior of Single Cell Box Girder, Double Cell Box Girder and Triple Cell Box Girder bridges are radius of curvature, span length and span length to the radius of curvature ratio. These parameters are used to evaluate the responses of box girder bridges namely, longitudinal stresses at the top and bottom, shear, torsion, moment, deflection and fundamental frequency of three types of box girder bridges. The performance assessment of selected designed pier showed that, the Force Based Design Method may not always guarantee the performance parameter required and in the present case the pier achieved the target requirement. In case of Direct Displacement Based Design Method, selected pier achieved the behavior factors more than targeted Values. These conclusions can be considered only for the selected pier. The parametric study on behavior of box girder bridges showed that, as curvature decreases, responses such as longitudinal stresses at the top and bottom, shear, torsion, moment and deflection decreases for three types of box girder bridges and it shows not much variation for fundamental frequency of three types of box girder bridges due to the constant span length. It is observed that as the span length increases, longitudinal stresses at the top and bottom, shear, torsion, moment and deflection increases for three types of box girder bridges. As the span length increases, fundamental frequency decreases for three types of box girder bridges.

Keywords: Metro Bridge

I. INTRODUCTION

The metro rail system is an electric railway transport (Passenger) system, it is used in an urban area with a high capacity and speed, frequency and the grade separation from other traffic. Metro System is used in cities, agglomerations, and metropolitan areas to transport large numbers of people at high frequency. The grade separation allows the metro to move freely, with fewer interruptions and at higher overall speeds. Metro systems are typically located in tunnels, underground and elevated viaducts above street level or grade separated at ground level. An elevated metro rail system is more preferred because it makes urban areas more accessible without any difficulty. It is more economic than an underground metro system and the construction time is much shorter.

An elevated metro system has many components, but two major components pier and box girder.

A seismic force design approach is generally used to design the metro bridge. That is important to check the ductility of single pier. Force based methods do not check the displacement capacity at the design stage. The behavior of elevated bridges mostly on the ductility and the displacement capacity of the pier during seismic loading. The IS:1893-2015 code which provided, moving towards a performance-based (displacement-based) design approach, which considered as the design as per the target performance at the design stage. The behavior of a box girder curved in plan is significantly different from a straight bridge and it is dependent on many parameters. On this aspect limited number of analysis had been done. The design parameters related to the Metro system described herewith have been worked out based on a detailed evaluation, experience and internationally accepted practices. Various alternatives were considered for most of these parameters but the best-suited ones have been adopted for the system as a whole.

The viaducts carrying the tracks will have a vertical clearance of minimum 5.5 m above road level. For meeting this requirement with the 'Box' shaped pre-stressed concrete girders, the rail level will be about 9.8 m above the road level. However, at stations which are located above central median, the rail level will be 12.5 m above the road level with concourse at mezzanine. These levels will, however, vary marginally depending upon where the stations are located. The maximum sectional speed will be 80 km/h. However, the applied cant, and length of transition will be decided in relation to normal speeds at various locations, as determined by simulation studies of alignment, vertical profile and station locations

II. DESIGN APPROACH

The analysis of a single cell closed section can be extended to multi cell section. The thickness of the cell walls is considered to be uniform. The length ABCD (s1) may be assumed to be of thickness t1, DEFA (s2) of thickness t2 and DA (s3) of thickness t3; the corresponding stresses in the segments are denoted by τ 1, τ 2, and τ 3. The relative magnitudes of the stresses can be determined by applying the equilibrium condition of the longitudinal forces (due to complementary shear stresses) at D. Considering sections 1, 2, 3 indicated in figure, equilibrium of the longitudinal forces yield;

$$\tau 1\ t1 = \tau\ 1\ t2 + \tau\ 3t3$$

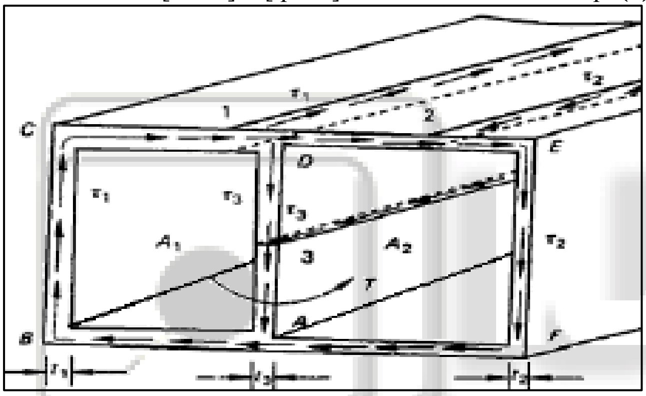
The torque applied is resisted by both the cells; Appling Equation;

$$xy1t1 = xy2\ t2 = q$$
$$T = \S\ \tau\ t\ r\ ds = \tau 1t1\ [\S\ r\ ds] + \tau 2t2\ [\S\ r\ ds]$$
$$= 2\ [\tau 1t1A1 + \tau 2t2A2]$$

The strain energy of the first cell can be related to the work done by the torque component of the cell.

We have;

$$U = \S\ [\ \tau 2\ /\ (2G)\ ]\ l\ t\ ds = [\ ql/(2G)\ ]\ \S\ \tau ds$$
$$= [\ ql/(2G)\ ]\ [\tau 1s1 + \tau 3s3] \quad \text{.......eqn (1)}$$
$$W = [Ti\theta/2] = [qA1\theta] \quad \text{.......eqn (2)}$$



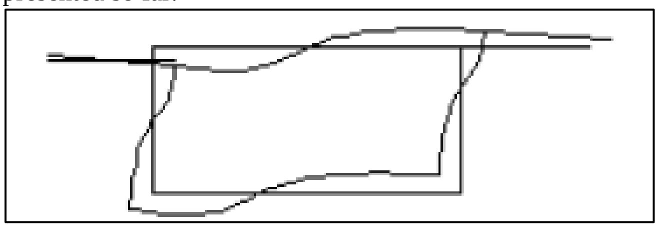
From the above equation, we obtain;

$$\theta = [\ l/2A1G]\ [\tau 1s1 + \tau 3s3] \quad \text{.......eqn (3)}$$

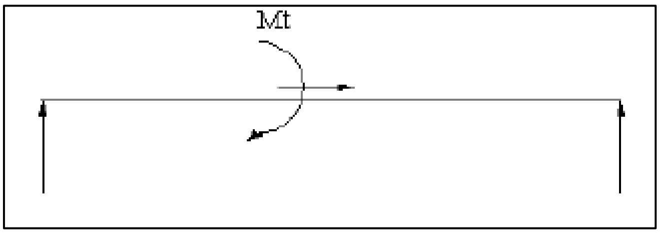
From the analysis of the second cell, we obtain;

$$\theta = [\ l/2A2G]\ [\tau 2s2 - \tau 3s3] \quad \text{.......eqn (4)}$$

The Beam on elastic foundation analogy provides a convenient guide to the diaphragm spacing and stiffness required to keep distortion stresses small in order to avoid fatigue problems from torsional loads that may complete reverse in service. Further the Beam on elastic foundation analogy lends itself to graphical presentation of the effects of design parameters on bridge response. In addition the analogy contributes to the understanding of behavior required for good design practice. A mathematical analogy exists between distortional behavior of a rectangle single cell section box beam and the flexural behavior of a beam on elastic foundation. The following arguments were presented so far.



Transverse Deformation



Pure Torsion and Distortion

A diaphragm which is infinitely stiff in its own plane but completely flexible for out-of-plan bending corresponds to a simple non-deflecting support in the beam on elastic foundation; similarly, a diaphragm which is addition completely rigid for out-of-plane bending corresponds to a fixed support in the beam on elastic foundation.

III. PROCEDURE:

A. Step-1:

Resistance of cross section to deformation which-corresponds to the beam on elastic foundation modulus ‘k’ is developed. For calculating ‘k’ the deflection ‘s1’, of the loaded nodes of the cell, for unit uniform torsional load is computed by considering a unit length of the cell made statically determinate by cutting the bottom plate at its midpoint. For calculation of ‘s1’, only St. Venant torsion is considered with no work of shears in planes of plates.

B. Step-2:

Resistance due to restraint of warping-which corresponds to BEF moment of inertia ‘Ib’ evaluated by considering amount of torsional load equilibrated by restraint of warping.

The distributed torsional ‘p’ equilibrated restraint of warping is computed using a virtual displacement ‘dw’ and the work of ‘p’ and ‘q’ (shears due to St. Venant torsion).

We have; $Pw = E*Ib*dx4/dw4$

Composition of this equation with expression for ‘pw’ developed value of ‘Ib’ can be calculated.

C. Step-3:

Properties of diaphragms- The effect of diaphragm flexibility on box girder behavior is determined by evaluating the corresponding support flexibility for the analogous beam on elastic foundation.

For diaphragms stiffness is defined as the magnitude of concentrated vertical torsional load, acting at the top of each web, which would deform the diaphragms to produce unit deflection ‘w’ for the cross section itself acting as a linkage.

D. Step-4:

Thus an analogous BEF is prepared related to box girder. A number of solutions for beams on elastic foundation are available. Thus knowing response of corresponding beam on elastic foundation, response of box girder to distortion can be found.

These are some important points, codes and clauses for designing. Now we are introduces,

– Loads, forces and their combination as per IRC-6:2017 are used.

- As per IRC-112:2011/IRC-18:2000, the compressive stress developed due loading mentioned in clause 5.2 of shall not exceed 0.5 f cj which shall not be greater than 20 MPa, where fcj is concrete strength at that time subjected to a maximum value of characteristic compressive strength of concrete(fck). The permissible stress in concrete at service stage shall not exceed 0.33fck.
- No tensile stress is allowed at service.
- The thickness of web shall not be less than d/36 plus twice the clear cover to the reinforcement plus diameter of duct hole where'd' is overall depth of box girder measured from the top of the deck slab to the bottom of the soffit or 200mm plus the diameter of the duct holes, whichever is greater as per clause 9.3.2 of IRC-18:2000.
- The web thickness shall not less than 350 mm in case of pre-stressing members.
- Minimum dimensions for haunches are provided as per clause 9.3.2.5 of IRC-18:2000.
- Minimum thickness of diaphragms shall not be less than minimum web thickness.
- The thickness of bottom flange of box girder shall not be less than 1/20th of clear web spacing at the junction with bottom flange or 200mm whichever is more.
- The minimum thickness of the deck slab with cantilever tips shall be of 200mm.
- As a construction point, we have maintain the minimum clear height inside the box girder shall be 1.5m to facilitate inspection.
- The Superstructure consists of two cell PSC box girder duly connected by three intermediate diaphragms and two end diaphragms.

Diaphragms (i.e. Cross Girders) in a multi girder, T-beam and deck slab types of Superstructure are provided to distribute the unsymetrically placed live loads on the deck. These cross girders / diaphragms are transversely stiff and are therefore very effective in distributing the live loads on the deck to several longitudinal girders in the system. In the Multi – girder bridge deck the diaphragms are intended to distribute the live loads to various main girders and are thus

Subjected to both positive and negative bending moments.

The cross girders / diaphragms add to the stiffness of the deck system against torsional buckling of the individual beam members. The cross girders / diaphragms are therefore designed for the direct loads that they support i.e., 1. Self-weight of deck slab 2. Wheel loads coming directly over the diaphragms forms the most critical load for the diaphragms. Two (2) end diaphragms and three intermediate diaphragms are provided at mid span. The deck slab is designed as supported on all four sides, and hence the self-weight of deck slab transferred to the diaphragm, is triangular. This load can however be converted in to an equivalent UDL (Ref. Reynolds Hand Book).

In the event of replacement of Elastomeric bearings, it becomes necessary to lift the superstructure from its supports and accordingly suitable locations for placement of Hydraulic jacks for lifting the superstructure from over the bed blocks are marked in the sketch below. This arrangement for lifting of superstructure induces bending moment and shear forces in the end diaphragms of the PSC superstructure for which suitable reinforcement will be provided as per calculation.

IV. Connection Details for Prefabricated Bridge Elements and System:

Precast post-tensioned pier were used to speed up the construction. Due to smaller footprint at bottom, this type of pier can be used for viaducts or for elevated rail or expressway in the median of an existing roadway section. This approach is expensive for a small bridge but it is fast and economical for multiple span bridges with heavy traffic. The piece was placed in a grout bed and intermediate joints were connected sealed and bonded with epoxy adhesive. Shear was transferred between pieces by means of shear keys in the precast pieces.

There are numerous benefits to the use of prefabrication beyond accelerated bridge construction. Prefabrication can improve the quality of bridge elements and systems since they are constructed in a controlled environment using high quality materials and standardized production processes. Improved quality leads to an extension of the structure service life. Prefabrication can also reduce bridge construction costs and life-cycle costs. A major advantage of prefabrication is that it can reduce onsite construction time, resulting in several key benefits when compared to conventional on-site construction practices;

1) Traffic: The disruption of traffic is often cited as a reason for using accelerated construction techniques. Reduction in lane closures and the number of days of traffic detours can have a measurable affect on the user costs of a highway system.
2) Safety: By reducing the amount of construction that takes place at the site, the amount of time that construction crews and motorists are exposed to the dangers of work-zones is also reduced. In addition, prefabrication can improve construction crew safety when working over water or in hazardous conditions such as when construction is adjacent to high voltage power lines.
3) Environmental: Often environmental permitting requirements limit onsite construction, for example, to certain seasons of the year. These limitations effectively reduce the number of available calendar days for construction. Prefabrication and accelerated construction can keep a project on schedule even with fewer available working days and other environmental limitations at the site.
4) Weather: As with environmental constraints, many areas of the country have limited work seasons due to severe winter weather. Prefabrication and accelerated construction can be used to complete more construction during a short construction season.
5) Improved Safety: Any change to traffic flow can increase safety risks to motorists. Reducing onsite construction time reduces these safety risks to both motorists and construction crews in the work zone.
6) Elimination of Temporary Bridges: Temporary bridges are often used for projects where detours are

undesirable and staging is not feasible. However, a short-term detour combined with accelerated bridge construction can often be used instead of a temporary bridge, thereby reducing the overall project cost.

7) Elimination of Detour Repairs: Roads used for detour routes are often not designed for the high traffic volumes over the extended periods required for conventional construction. Accelerated construction can eliminate the need for detour repairs.
8) Reduced User Costs: User costs for highly congested highways can be significant, often exceeding the additional cost of accelerated construction. Several states account for user costs for projects in the preliminary design phase of most projects in order to make educated decisions on the approach to the project. The user costs are factored into the cost for each construction option considered.

V. REHABILITATION PROJECTS:

Several types of rehabilitation projects commonly use accelerated construction techniques. Often bridge rehabilitation projects present the greatest challenges for maintaining traffic flow during construction. Common rehabilitation projects that use accelerated construction techniques are; Bridge Deck Replacement: Many states (especially in northern environments) are experiencing bridge deck life-spans that are less than the life span of the overall bridge.

New high performance materials and protective coatings can extend the life of a bridge deck. However, a large percentage of the national bridge inventory includes bridges with decks that will need to be replaced in the next 30 years.

Prefabricated bridge deck elements made with precast concrete, filled steel grids and fiber reinforced polymers have been successfully installed on existing bridges with either weekend or overnight lane closures.

Superstructure Replacement: Bridges with deteriorating bridge decks often have deteriorating support beams as well. The cost of removing lead paint on steel or repairing deteriorated concrete can approach or exceed the cost of new beams.

If a bridge deck is already scheduled to be replaced, and repairs are anticipated to the support framing, it may be cost effective to replace the entire superstructure. In this case, a full prefabricated superstructure can be a means to replace the entire bridge superstructure in as little as one night.

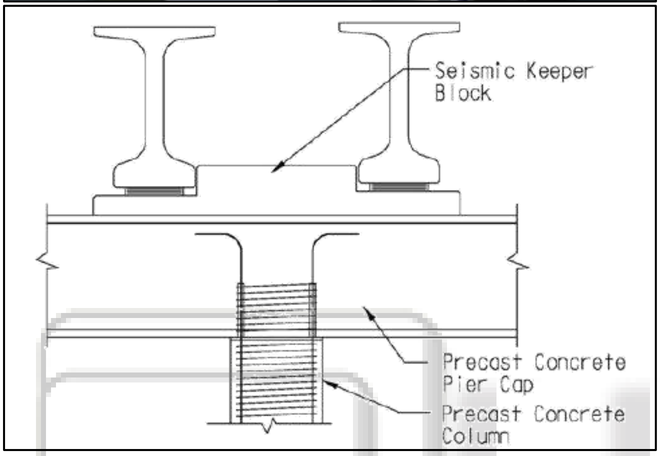
VI. CASE STUDY ON REFERENCE PICTURES:

These are pictures showing the Structure proposal and arrangements. Now we are using some references of 2-cell box girder with circular tall piers.

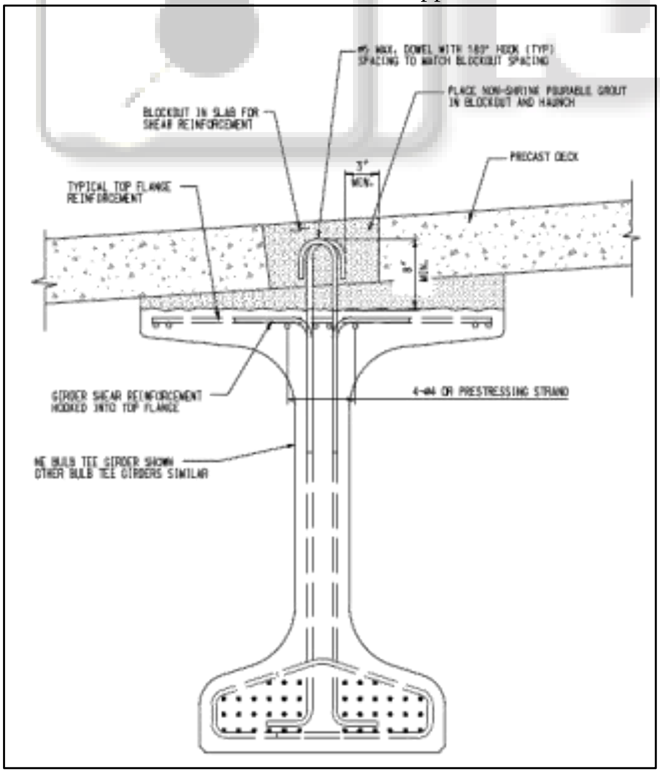
Reference Picture of Pier & Staging of Box Girder

Prestressing Cables

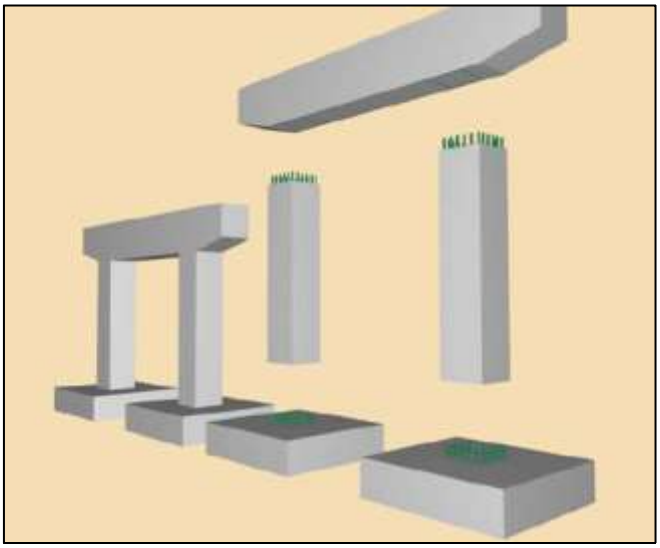
Hydraulic Jack for Post Tensioning



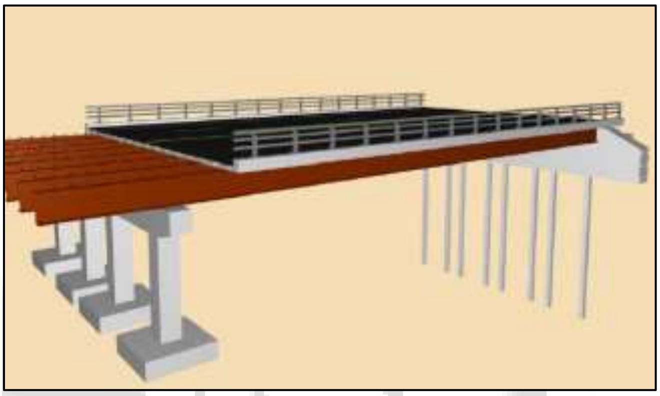
Details of Seismic Stopper



Precast Deck Connection to Bulb Tee Girder



3D View of Connection Joints



3D View of Girder with Deck slab and Column

VII. CONCLUSION

The following conclusions are drawn based on the results of this study;

- An approximate method adopted in the box girder bridge design has been taken as a case study.
- It revealed that the final stresses in concrete at transfer and service load stages very nominal when compared with allowable stresses.
- The factor of safety when checked against ultimate loads is only 2.0, and the box section selected when checked for torsional and distortional effects is found satisfactory.
- A further study is sought in these respects for optimum usage of material strengths using software packages available is suggested.
- Bridge Deck: A structural slab that spans between support elements (typically beams and girders) on a bridge. Bridge decks can be made of many materials, including reinforced concrete, steel, timber, fiber reinforced polymers, etc.
- Cable Restrainers: Structural elements that are used to restrain a bridge superstructure from excessive lateral movement during seismic events. The goal being to prevent the superstructure from falling off the substructure, which is a very common form of failure during seismic events.

- Camber: A geometric adjustment of a bridge beam that is designed to compensate for the the vertical deflection of the beam when subjected to dead loads. Camber is typically built into steel beams during fabrication. Camber is in inherent side effect of prestressed girder construction.
- Carbon Fiber: A materials that is used in fiber reinforced polymer elements (FRP) to provide the structure performance. These fibers are oriented parallel to the direction of stress.
- Cast-In-Citu Concrete: Concrete that is cast on site (as opposed to cast in a fabrication plant).
- Composite Beam Action: The process of connecting the bridge deck to the beams or girders to form a combined structural element.
- Composites: The combining of multiple structural materials to form a structural element.
- Compressive Strength: The value of uniaxial compressive stress reached when a material fails.
- Concrete: A construction material that consists of cement (commonly portland cement), coarse aggregates (such as gravel limestone or granite), fine aggregates (such as sand), and water. Often other materials are added to improve the structural properties such as chemical admixtures and other cementitious materials (such as fly ash and slag cement).
- Confinement Steel: Reinforcing steel used to contain the concrete core of a column when subjected to plastic deformations brought on by seismic loading.

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