Paper Title: **USE OF INTEGRAL PIERS TO ENHANCE AESTHETIC APPEAL OF GRADE SEPARATION STRUCTURES**

Author: Bekir Sisman, P.E.

HNTB Company, Arlington, VA

Chung C. Fu, Ph.D., P.E., Director/Associate Professor, the Bridge Engineering Software & Technology (BEST) Center

Department of Civil & Environmental Engineering

University of Maryland

College Park, MD 20742

Tel: 301-405-2011

Fax: 301-314-9129

E-mail: ccfu@eng.umd.edu

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USE OF INTEGRAL PIERS TO ENHANCE AESTHETIC APPEAL OF GRADE SEPARATION STRUCTURES

By Bekir Sisman, HNTB and Chung C. Fu, University of Maryland

ABSTRACT

Today, designers quite often are challenged by number of geometric constraints in design of bridges on complex highway interchanges; problems with vertical and horizontal clearances between roadways and overhead structure often occur. In last twenty years number of concepts has been developed to overcome these challenges. The use of integral pier cap has been demonstrated economical and also aesthetically pleasing on number of bridge projects. These designs involved the concealing the massive pier cap within the superstructure limits by this creating a pier cap interface with the substructure component of their structures. Although these designs were able to offer cost-saving alternative designs which were tailored to the specific constraints and requirements of each project. This also resulted in aesthetically pleasing structures by creating transparency and slenderness with the bridge crossing. Therefore, it is suggested that the lessons learned from these projects can be carried over to typical grade separation structures. In this paper we will be presenting several examples of bridge projects and their impact on value added to overall project cost and to the affect on the aesthetic appearance of structures on its surrounding environment.

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INTRODUCTION

Piers are essential elements in bridge structures because they carry the superstructure and transmit the loads to the foundation. In general, bridge piers have different configurations, shapes, and sizes. Bridge piers can be in the form of hammer-head, multi-column bent, pile bent, solid wall, single column, or integral, depending on the form of the superstructure, clearance requirements, soil conditions, and aesthetics. Traditionally, the bridge superstructure is usually supported on top of the pier cap by means of bearings.

Based on the survey conducted (Poston, Diaz and Breen, 1986) in 1980's, predominant bridge pier usage is in multiple pier bents (83%) with far fewer single piers (17%). However, more and more single piers are used in the 1990's and 2000's. In a separate paper by Billington and Breen (2000), several types of substructure systems, individual columns, walls, hammerhead bents, and multi-column bents, were discussed. Three major ideas were presented by Billington for cast-in-place substructure system:

- Aesthetics, efficiency, and economics – the interrelationship of these disciplines in engineering design
- Vision – the importance of having an overall design concept for a project
- Coherence – the integration of the engineered design and the design concept with each decision to form a coherent, attract structure.

In general, most bridge engineers are usually involved with more mundane highway interchange bridges of relatively short spans. However, in some respect, these more routine bridges require as much, if not more, aesthetic consideration than bridges over canyons. The structure in spectacular setting may not be noticed, because the scenery may dominate the environment. On the other hand, overpass structures in flat rural setting cannot escape notice, and they may be one of the few variations for the motorists on long and sometimes tedious expressway journeys. There has been considerable restraint on designers to find solutions for a project involving; geometric restrictions of particular site, increasing emphasis on highway safety, the use of standard details for economy, and the emphasis on durability, and ease of maintenance. These restraints often prevent designers from choosing the most pleasing aesthetic solution.

At congested interchanges, the use integral pier has been demonstrated in numerous projects to be accommodating the limitation of stringent horizontal and vertical clearance requirements. In addition to solving clearance problems, integral pier cap options are found to be much more aesthetically pleasing than the conventional piers by expressing transparency and slenderness within the crossing, whereas hammerhead piers or multi-column bents introduce visual expressions of inefficient structural function; excessive usage of materials. In the case of severely skew crossings, integral pier structures have demonstrated to be the most economical solution by improvements to span arrangements, framing plan layouts and required embankment fill at approach roadways.

AESTHETICS OF GRADE SEPARATION STRUCTURES

Applying aesthetics to bridge design is very complex. There are many variables to take into consideration that it would be very difficult to develop a set of rules that just anyone could use. However, there are few principles of design that can be applied to grade separation type structures and are used by anyone who incorporates aesthetics into the design of their bridges. These design principles include such things as order and balance, proportion, simplicity, clarity or function, color, form, texture, and how they complement each other (Bakht, Leonharrdt, Dorton, Billington, Wittfolt, Wasserman, and Menn).

The aesthetic element of bridge design is also complicated further by differing people's tastes. Since views on beauty differ so widely that it may appear that there could be never a clear understanding whether a bridge can be considered beautiful or not. But, a truly beautiful bridge will have the balance of visual elements that will always have pleasing appearance throughout life of the structure, as it is illustrated by (Figures 1,2 3 and 4).

In general, alignment of bridge structures requires careful consideration for reasons of both safety and economy. But quite often not much thought is given for grade separation structures, the alignments are dictated by geometric tie-ins at the approach roadways. Therefore, the overpass alignments may result in roadways crossings at undesirable skew angles. Such an alignment also adds complications to the design, cost and construction of such structure, most importantly, adversely affecting the aesthetical appeal of the overhead structures shown on (Figure 5).

Since bridge aesthetics has a vast effect on the public, and every opportunity should be used to provide attractive structures at such location. To achieve such structures, consideration should be given to the use of continuous superstructures. Another major aspect that should be considered is the use well proportioned superstructures and substructures. The shallow superstructure depth can be achieved by suitable span arrangements and also the fascia girder can be arranged to enhance the perceptions of shallower depth by slab overhanging length. On the other hand, the use of a single column details would state that the structure was well thought through, and it would express efficiency by number of supports as well as in the size of the column. This efficiency expresses transparency and slenderness of the structure; transparency is conveyed through use of a single column and slenderness is express by span arrangement and superstructure depth. The bridges that lack a suitable degree of transparency will appear as solid walls from a wide range of viewpoints. Therefore, the conventional hammerhead or wall type piers are not recommended for grade separation type structures, particularly on severe skew crossings. Thus by elimination of the heavy pier cap by use of integral piers results in concealment of massive pier cap common with hammerhead piers; the resulting un-interrupted main lines of the structure that would allow it to directly reflect the lines of movement of the overpass structure. In this manner, one would achieve the same goals as the same kind of clean and simple structure lines that has been very successful with aesthetically appealing in monolithic concrete bridge construction.

Our sensitivity to aesthetics would expected to change over time as people explored new design concept, as well merging new materials and technologies into the construction field and lessons learned from past experience. While mentioned guidelines revived present rules of thumb and comparative examples, their goal is to encourage the bridge designers to develop his own talents and insights as he thinks about aesthetic appearance of any structure. Hopefully, it would the result in lightness, slenderness, continuity, openness and aesthetically pleasing structure in future projects. Finally, to use of design ingenuity and creativity in using integral pier on bridge project will provide that desired attractive structure consistent with the efficiency and economical use of materials.

METHODS TO INTEGRATE BRIDGE SUPERSTRUCTURE WITH SUBSTRUCTURE

There are a number of ways to integrate bridge superstructure with the substructure, one of the most common method is concrete construction, namely cast-in-place concrete box girder bridges, as shown in Figure 6, due to inherent nature of the material the superstructure can be monolithic with the substructure where frame action can be anticipated. Also, in early 1960's, due geometric constraints in urban settings, a framed-in steel pier caps were also used to support plate girders. In general, these caps were steel box girder sections which have been proven to be very successfully for this application, mainly due their torsional rigidity. However, more recently, in an innovative manner, steel I-girders framing into a concrete pier cap was developed. This concept of the integral pier cap is believed to be developed by the Wilbur Smith and Associates, Columbia, South Carolina. The first bridge was built for Tennessee Department of Transportation in 1978, at the I-75/I-640 Interchange in Knoxville, Tennessee. This innovative concept involved passing plate girders through the pier caps, rather than traditional manner, supported on top of the cap; it is a post-tensioned pier cap system. Three additional structures with integral pier configurations were constructed between 1978 and 1982. All have proved serviceable with no cracking after nearly twenty-five years in service.

More recently, there have been a number of versions of integral piers involving steel plate girder construction in order to improve substructure layouts on skewed crossings, and vertical and horizontal geometric constraints, eliminate detrimental effects of skewed substructure, and enhance bridge performance under seismic loads. Some of the concepts involve using steel framing-in caps which integrate with the concrete columns; others are various versions of traditional post-tensioned concrete caps with varying structural boundary conditions.

Two types of integral pier caps for steel girder bridges, (1) integral post-tensioned pier cap type, and (2) integral steel cap girder type, are discussed here.

1. Integral post-tensioned Pier cap type (Michael, Castrodale, Gordon, and Tabsh)

In recent years this concept has been very popular in construction short span structures. It involves construction of columns to the bottom of lower flange or to bottom of the pier cap. Then girders are erected on temporary supports placed near the column locations. Then the pier cap reinforcement is placed in about the same manner as conventional construction, perhaps some additional stirrups are placed to enhance shear flow between girders and lastly post-tensioning ducts are installed. The concrete cap is poured up to bottom deck slab. After removal of the cap formwork, post-tensioning system is placed and stressed. There many advantages offered by post-tensioning system of the pier cap in comparison with reinforced concrete, a considerable saving in concrete and steel, since, due to the working of the entire concrete cross-section more slender designs are possible as well as good crack behavior and therefore permanent protection of the steel against corrosion. Lastly, fatigue characteristics of high strength steel is much better than fatigue prone details commonly employed in steel pier caps. A typical detail of concrete pier cap is shown in Figure 7.

2. Integral steel cap girder type (Ales, Hohmann et al)

Rocker bearings are commonly used as part of the connection between a concrete pier and a steel cap girder supporting continuous steel bridge girders. Twin bearings at each concrete pier are designed to resist moments in the transverse direction caused by eccentric truck traffic. In the longitudinal direction (parallel to traffic flow) the rocker bearing combined with long anchor bolts are designed to produce an ideal pin support so that the continuous longitudinal bridge girders are not restrained at the pier. The main reason for the free rotation concept is to avoid fatigue in the steel cap girder details caused by alternate span loading. This connection is essentially a fixed support in the transverse direction and a pinned support in the longitudinal direction. A typical detail of steel pier cap is illustrated in Figure 8.

CASE STUDY OF BRIDGE SUBSTRUCTURE USING INTEGRAL PIERS

Integrally framed steel cross girders have been used in high exposure locations because they minimize the size of the pier, provide for more flexible pier location, and emphasize the continuity of the superstructure. However, these elements are non-redundant. Integral pier caps should be used only in situations where the physical requirements or importance of the location are so extreme that they can be accommodated in no other way. In such cases the burden is on the designer to develop ways to reduce the problem of selecting these structure types.

Case Study 1 - State Route 385 over Pleasant Ridge road in Memphis, Tennessee (Figure 9), where integral piers were employed to overcome vertical clearance restrictions and severe skewed substructures. This bridge represents a unique, economical and aesthetically appealing solution to a complicated roadway crossing with simple slender single column to overcome severe skew. A typical post-tensioned integral pier cap was implemented for the structure.

Case Study 2 – First integral pier project in Pennsylvania was at a service roadway near the Greater Pittsburgh International Airport. This structure was the Ramp FR-A over S.R. 6060, roadway crossings at a very severe skew. During a state value engineering process this structure was identified as potential problem due to the geometric constraints on the proposed conventional construction scheme. During review period the integral pier scheme was deemed as a possible solution to overcome vertical clearance requirements. For the final design, the severely skewed substructure layout was replaced with radial abutments and integral pier. The modified structure resulted in much simple framing plan and graceful superstructure. The pier construction for structure was based on Tennessee DOT integral pier experiences. Subsequently, PennDOT has constructed several more structures based on experience gained from this project.

Case Study 3 – Recently experience in urban areas in Texas has resulted longer span requirements for grade separation structures and flyover ramp bridges in major interchanges. By using integral piers (Figure 8), a shallow superstructure depth for these situations has provided substantial cost savings in highway construction. The lower costs were realized reduction in approach embankment fill height and lengths. By lowering of roadway profiles also resulted in the successive levels of an interchange requiring less vertical clearance needs overall.

Case Study 4 - For the Sunrise Boulevard Bridge over S.R. 7 (Figure 10) in Broward County, Florida, design for a future interchange configuration resulted in horizontal and vertical clearance constraints at the pier locations. These geometric restrictions necessitated the use of integral pier caps. In this case, pier caps transverse beam consist of concrete diaphragms that are post-tensioned and the final painted finishes for the ends of the caps were made to match the longitudinal I-girders.

COST SAVINGS

The cost savings in use integral pier structures can be realized in many areas; in case of skew crossings, improved framing plan and cross frame layout, overall cost reduction from skewed substructures, and most importantly, by satisfying geometric constraints requirements. In situations by where lowering of the roadway profile for the overhead structure can be realized, there would be subsequent savings on the approach roadway heights and lengths. In the case of most of the example bridge projects stated earlier, cost estimate for other options were not developed to make cost comparisons, since integral pier scheme was the only solution. However, in recent projects in Pennsylvania involving tight vertical and horizontal clearances has resulted in savings of overall project wide of $250,000 per 6-inch reduction in vertical profile (Gordon). The anticipated cost for integral pier involves following items; Temporary shoring, post-tensioned and some insignificant increase for structural steel. These cost items are estimated to be less than 10 percent of the bridge cost for one level structure with spans less than 150 ft. Therefore, one can justify the use integral pier bridges for grade separation structure in order to enhance the aesthetically pleasing appearance.

The lowering of a roadway profile would have significant impact on overall limits of the bridge and the approach embankments. In order to accommodate a conventional pier supporting girders, there must be ample vertical clearance to build the cap over the travel lanes. This additional required height can be little as pier cap depth, otherwise, there would be an opportunity to lower the whole structure as much as a pier cap depth, nominal pier cap can as little as 4 ft or as high as 10 ft. This cost saving will be significant if the soil condition at the approach embankment is not capable of supporting an additional overburden result of higher profile. And there are significant cost savings also associated with height of the roadway embankments, and this will reflect also on shallower abutments and associated wingwalls or the approach retaining structure, and overall bridge length can be shorten. In addition, the lowered roadway also would affect the pier heights which in turn could result in reduction of foundation size, excavation and shoring.

The framed-in girder pier cap condition also eliminates the need for bearing devices. The reconfiguration of the superstructure framing layout based on radial supports will simplify fabrication of steel girders as well as intermediate diaphragms and also it will minimize misfits during structural steel erection. The overall behavior of skew-supported structures is greatly improved by revised framing conditions. The integrated substructure improvements will result in a better performing bridge with less maintenance requirements in the long term.

The improved bridge layout would also eliminate very long expansion joint details. One of the most contributing bridge components to bridge deterioration is the performance of expansion joints (Wasserman, 1987). In the case of skewed joints, quite often, it is countered with the fact that the expansion joint device must be sized much larger than actual movements are in order to accommodate the skew. Also, the performance of a skewed expansion joints are quite often difficult to predict their performance, especially for wide bridge structures.

SUMMARY

Bridge aesthetics have a vast impact on the public, and every opportunity should be used to provide aesthetically pleasing structures. Although in case studies aforementioned stated that integral piers were utilized in order to overcome the geometric constraints, by using integral piers resulted many improves demonstrated that other than just satisfying the geometric design requirements, and also cost savings were realized, most importantly, aesthetically pleasing structures were the end product. Therefore, the lessons learned from these complicated conditions can be carried over to design of typical grade separation to achieve same aesthetically pleasing bridges.

Finally, the use of design ingenuity and creativity in the choice of substructure components, such as pier and abutment forms, will usually provide an attractive structure consistent with the efficient and economical use of materials. The integral pier cap construction provides an additional dimension to bridge aesthetics and a useful tool in designing the efficient use of steel girders.

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Figure 1 – I-15 Tropicana Flyover Ramp, Las Vegas, Nevada

Figure 2 – A Typical Flyover Ramp with Integral piers in North Carolina

Figure 3 – An Interchange in Texas with bolster type bearings

Figure 4 – Curved Ramp Steel Bridge Single Column Pier

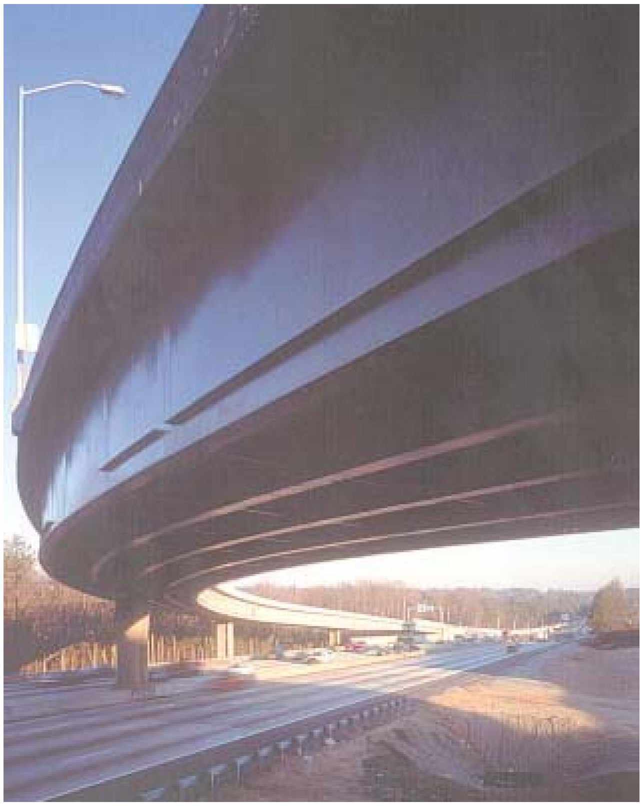

Figure 5 – GA400 Flyover Ramp in Atlanta, Georgia

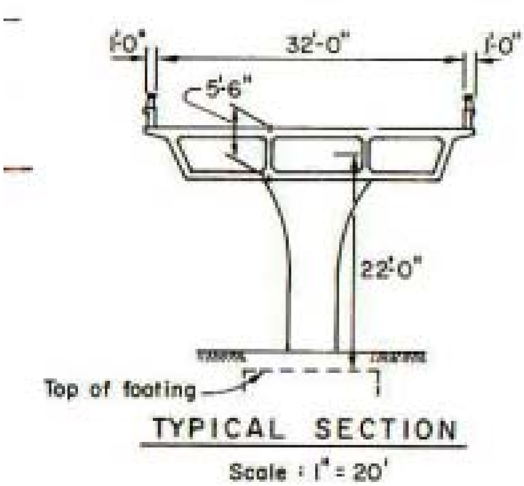

Figure 6 – Typical Concrete Bridge Pier

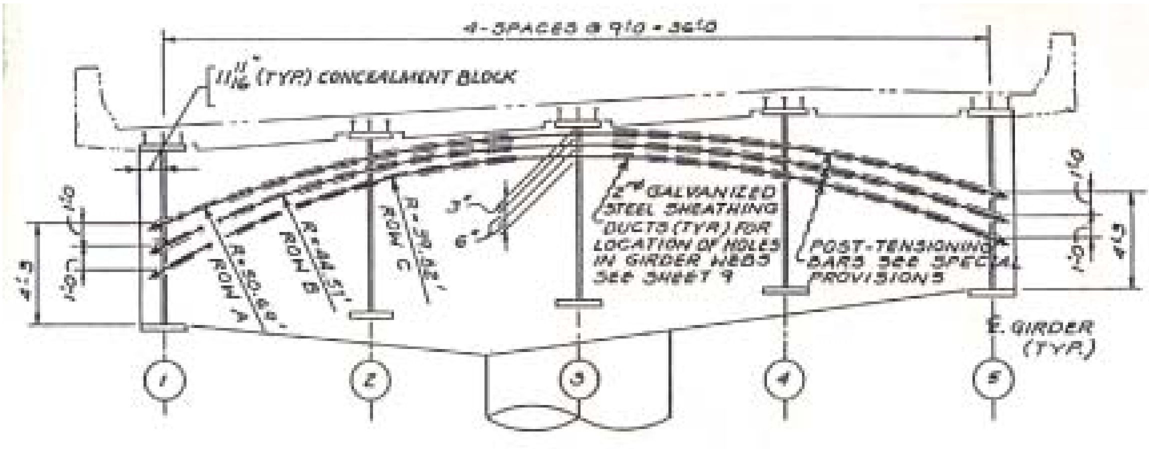

Figure 7 – Typical Post-tensioned Concrete Integral Pier Cap

Figure 8 – Texas Steel Girder Flanges Spliced at Integral Pier Cap

Figure 9 – Tennessee State Route 385 over Pleasant Ridge Road

Figure 10 - Florida Sunrise Boulevard over SR7 Bridge