INTEGRAL ABUTMENT DESIGN - PRACTICES IN THE UNITED STATES

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ABSTRACT

Jointless bridges with integral abutments have been used for decades in the United States. Some of the first states to routinely use continuous construction with integral abutments were Ohio, South Dakota and Oregon, dating from the late 1930’s and early 1940’s. California followed suit in the 1950’s. With the National Interstate Highway System construction boom in the late 1950’s and mid-1960’s, Tennessee and other states began moving toward continuous bridges with integral abutments, as standard construction practice.

Through the intervening years, more and more states have utilized Jointless bridge construction in varying degrees. However, no National Standards or uniform policy regarding permissible bridge lengths, skews, details or design procedures have ever been clearly established, although certain general concepts have become common in practice. This paper will attempt to capture the state-of-practice in the United States, but will lean toward practices favored by the Tennessee Department of Transportation, an acknowledged leader in the field.

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INTRODUCTION

On March 16-18 of 2005, the Federal Highway Administration, in cooperation with West Virginia University, conducted a conference on Integral Abutment and Jointless Bridges. Among the many papers submitted was a summary of a survey sent to State Departments of Transportation, the District of Columbia and similar agencies. The purpose of the survey was to obtain a snapshot of current practices, policies and design criteria being employed nationally.

The survey included questions regarding the number of integral abutments designed, built and in service, the criteria used for design and construction, including span lengths, total bridge length, skew and curvature limitations imposed as well as any reported problems experienced with jointless bridge construction.

According to the 39 agencies who responded to the survey, there are approximately 13,000 jointless bridges on public highways; 9,000 equipped with fully integral abutments and 4,000 with semi-integral abutments (integral superstructure/backwall connections that move according to the thermal demands, but independent of the vertical load support system). The aggregate number of jointless bridges is double the number reported in a similar survey for a previous Integral Abutment Jointless Bridge Conference held in 1995.

Analysis of the survey found that there was a lack of uniformity in usage and ranges of applicability. For instance, 59 percent of responding agencies had over 50 jointless bridges in service, 31 percent had from 101 to 500 in service, 3 percent had from 501 to 1000 and 15 percent had over 1000 such bridges in service. Permissible lengths for jointless prestressed concrete girder bridges ranged from 45.7 to 358.2 m, allowable skews from 15 degrees to 70 degrees and curvatures from 0 degrees to no limit. State Route 50 over Happy

Hollow Creek in Tennessee is an example of the upper limits of an integral abutment jointless bridge that can be achieved. The structure is 358.2 m in length on a 4 degree , 45 minute curve (figure 1). Steel deck girder bridge lengths range from 36.6 to 167.7 m.

Seventy-seven per cent of the responding agencies indicated that they will design integral and semi-integral abutments whenever possible. The reasons for utilizing such construction are not universally held but the following listing represents the majority view of the agencies.

REASONS FOR JOINTLESS CONSTRUCTION

Design Efficiency

Tangible efficiencies are achieved in substructure design due to an increase in the number of supports over which longitudinal and transverse superstructure loads may be distributed. For example, the longitudinal load distribution for the bent supporting a two-span bridge is reduced by 67 percent when integral abutments rather than expansion abutments are used. Depending upon the type of bearings planned for an expansion abutment, transverse loadings on the same bent can be reduced by 67 percent as well.

Enhanced Load Distribution for Girders at Bridge Ends

Integral abutments provide substantial reserve capacity to resist potentially damaging overloads by distributing loads along the continuous and full-depth diaphragm at bridge ends.

Tolerance Problems are Reduced

The close tolerances required when utilizing expansion bearings and joints are eliminated with the use of integral abutments. Bridge seats need not conform exactly to girder flange slope and camber corrections, since the girder loads are ultimately carried by the concrete comprising the end diaphragm. Minor mislocation of the abutments creates no fit-up problems.

Rapid Construction

With integral abutments, only one row of vertical (not battered) piles is used and fewer piles are needed. The entire end diaphragm/backwall can be cast simultaneously and with less forming. Fewer parts are required. Scheduling problems with suppliers and manufacturers are avoided.

Greater End Span Ratio Ranges

For normal expansion bearing conditions, the ratio of the end-span to the adjacent interior-span length must be held to approximately 0.6, unless uplift conditions are to be accommodated. If uplift can occur, expensive hold-down devices must be added to expansion bearings. Utilizing integral abutments allows for much shorter end spans, if desired, since the abutment acts as a counterweight and the uplift capacity of the piling may be used. By adjusting the pouring sequence to cast the abutment around the girder ends first, computed uplift due to dead loads can be eliminated.

Added Redundancy and Capacity for Catastrophic Events

Integral abutments provide added redundancy and capacity for all types of catastrophic events. In designing for seismic events, considerable material reductions can be achieved through the use of integral abutments by negating the need for enlarged seat widths and restrainers. Further, the use of integral abutments eliminates loss of girder support; the most common cause of damage to bridges in seismic events. As stated in the Final Report of FHWA/RD-86/102, Seismic Design of Highway Bridge Foundations Vol. II,2 integral abutments are the preferred design feature for more active seismic regions. Joints introduce a potential collapse mechanism into the overall bridge structure. Integral abutments have consistently performed well in actual seismic events and have significantly reduced or avoided problems of backwall and bearing damage that are associated with seat-type jointed abutments. The dampening arising from soil-abutment interaction has been proven to significantly reduce the lateral loads taken by intermediate substructure columns and footings. Tests on several short (less than 61 m) bridges, listed in the FHWA report, found as much as 15 percent damping for the longitudinal mode of response of the bridge deck system. The report also recommends that integral abutments be proportioned to restrict displacements to 4 in. or less to minimize damage (see p. 138, ibid., for design procedure).

INTEGRAL ABUTMENT DESIGN

While integral abutments have been used successfully for 50 years, their implementation has not been an exact science, but rather a matter of intuition, experimentation and observation. Inspection of many bridges with failed expansion bearings has revealed that anticipated catastrophic damage has not always occurred. The ability of bents and pile-supported abutments to accommodate thermal movements has often been underrated. Despite the lack of analytic tools, engineers have been pushing the envelope by constructing longer and longer jointless bridges, thus building on the lessons learned.

The reason that exact design approaches have not been fully developed is that the analysis of a pile under lateral loads is a problem in soil-structure interaction. Since the deflected shape of the loaded pile is dependent upon the soil response, and in turn, the soil response is a function of pile deflection, the system response cannot be determined by the traditional rules of static equilibrium. Further, soil response is a non-linear function of pile deflection. The ultimate problem for the structural engineer is the determination of the practical point of fixity of the buried pile.

In recent years, elasto-plastic soil/structure analysis tools have allowed engineers to better correlate mathematically what they have known to be achievable based on years of experience. Several methods have been developed that attempt to model soil-pile interaction. However, the most promising method of analysis is found in Report No. FHWA-5A-91-048, COM624P – Laterally Loaded Pile Analysis Program for the Microcomputer, Version 2.03

The methods used in Reference 3 recognize that the solution to the problem of laterally loaded piles requires: 1) differential equations to obtain pile deflections and, 2) iteration, since soil response is a non-linear function of the pile deflection along the length of the pile. Further, the solutions presented recognize that as the backfill is acted upon for several cycles, it becomes remolded. Thus, an array of load-deflection, moment and shear conditions can be investigated.

Important to the solution is the development of a pseudo-modulus of elasticity for the embankment soils that are acted upon by piles subjected to lateral loads. The most popular technique used in the United States is the p-y method. Using this procedure, pile response is obtained by an interactive solution of differential equations using finite-difference techniques. The soil response is described by a family of non-linear curves (p-y curves) that compute soil resistance p as a function of pile deflection y. A thorough discussion of the procedure can be found in Reference 3.

Beyond general agreement concerning the p-y method, how to arrive at pile vertical capacities and abutment design vary widely by agencies. Two informative publications are available that discuss viable design procedures: “Volume II, Chapter 5 of the AISI/NSBA Highway Structures Design Handbook”4 and “The State of the Art of Precast/Prestressed Integral Bridges”5. Both documents contain extensive reference source listings.

INTEGRAL ABUTMENT DETAILS

Components of jointless bridges generally are subjected to the same forces as other continuous bridges with expansion joints at their ends. Exceptions to this rule apply only when integral abutments are tall and the structure is designed as a frame.

The most desirable end conditions for an integral abutment are the stub or propped-pile cap type which provides the greatest flexibility and hence, offers the least resistance to cyclic thermal movements. Under these conditions, only the abutment piling and wings are subjected to higher stresses. These stresses have proven through the years to have not caused unacceptable distress. One should expect minor cracking of the wingwalls.

Using the pile-supported stub-type abutment, prestressed girder bridges up to 244 m in length and steel bridges up to 122 m may be routinely constructed (figure 2). Longer bridges may be constructed, with due consideration give to the forces and movements involved. The details and discussions in this section, however, are specifically applicable to overall lengths of structure up to 244 m that have abutments free to expand or contract through a range of 5 cm at each end. Greater thermal movements or fixity at one abutment will reduce the length achievable, unless thoughtful consideration of details used.

PILE CONFIGURATION

Piles driven vertically and in only one row are highly recommended. In this manner, the greatest amount of flexibility is achieved to accommodate cyclic thermal movements. Likewise, in seismic events, the dampening forces are engaged to the largest extent by the embankment backfill rather than by the cap and piling, thereby reducing the damage resulting from large displacements.

PILE ORIENTATION

A survey taken in 1983 demonstrated that states differ in opinion and practice with regard to pile orientation. Fifteen states orient the piling so that the direction of thermal movement causes bending about the strong axis of the pile. Thirteen others orient the piling so that that direction of movement causes bending about the weak axis of the pile. Both methods have proven to be satisfactory to the respective agencies. Orienting the piling for weak-axis bending offers the least resistance and facilitates pile-head bending for fixed head conditions. However, due to the potential for flange buckling of steel H-piles, the total lateral displacement that can be accommodated is more limited than when piling is oriented for strong-axis bending.

APPROACH PAVEMENTS

Due to the difficulties in obtaining proper embankment and backfill compaction around abutments, approach pavements are recommended; especially for new construction (figure 3). Approach pavements offer many benefits other than acting as a bridge between the abutment and more densely compacted embankments. Approach pavements provide a transition from the approach to the bridge if embankment settlement occurs. Such transitions provide a smooth ride, thereby reducing impact loads to the bridge. Approach pavements also provide greater load distribution at bridge ends, which aids in reducing damage to the abutments; especially from overweight vehicles. Finally, properly detailed approach pavements help control roadway drainage, thus preventing erosion of the abutment backfill or freeze/thaw damage resulting from saturated backfill.

The approach slab must be anchored into the abutment backwall so that it moves in concert with the bridge. Otherwise, cyclic expansions will force the slab to move with the bridge without a mechanism to pull it back when the bridge contracts. As debris fills the resulting opening, repeated cycles will ratchet the slab off its support. The anchorage used to fasten the approach slab should be detailed to act as hinge so that the slab can rotate downward without distress as the embankment settles. Figures 3 through 5 depict desirable features of approach pavements.

BACKFILL

The survey discussed earlier indicated that porous, granular backfill is used by 75 percent of the respondents. The selection of this type of backfill offers two benefits: 1) such material is more easily compacted in close spaces, and 2) the material aids in carrying any water intrusion away from the abutments. Well-graded material is desirable. Uniformly graded material does not compact well and provides less interlocking of particles, thus acting more like marbles.

DRAINAGE

As with expansion abutments, the use of a vertical stone column about two feet in width is recommended (figure 4), with a height reaching from the bottom of the abutment beam or pile cap to the top of the roadway subgrade. This drain should be placed between the abutment backwall and the embankment backfill and should wrap around the backwall – between the parallel wingwalls and the roadway embankment – since any settlement of the approach pavement will create a potential gap through which surface runoff will flow. A perforated drain pipe, overlying an impervious layer of soil or plastic, should be placed at the base of the vertical stone column and should be sloped to provide drainage away from the abutment area.

PROVISIONS FOR EXPANSION

In all cases where the approach roadway or a ramp is constructed of concrete, provisions for an expansion joint must be provided. Where the anticipated total movement at an abutment exceeds ½ in. and the approach roadway is asphalt, an expansion joint should also be considered. The reason for the latter is that larger movements can damage asphalt adjacent to the end of the approach pavement in the expansion cycle. During the contraction phase, a significant gap is created through which water can infiltrate the subgrade. If regular maintenance can be arranged to fill this gap with a suitable joint sealer in cold weather, no joint will be needed.

If expansion joints are provided, the joints should only be located at the roadway end of the approach pavement. It is a certainty that the joint system will fail at some future time. If the joint is located between the abutment backwall and the approach pavement, then the slab jacking process mentioned above will occur.

It is recommended that joints similar to the one detailed in Figure 5 be used, and not joints that contain metal hardware for anchorage. This will avoid the problem of replacing or raising the joint should subsequent paving projects dictate that an overlay be placed on the bridge. The joint shown in Figure 5 may be replicated in the same manner in which it was originally installed atop the existing joint.

CONSTRUCTION SEQUENCE

The following sequence is recommended when constructing steel bridges with integral abutments to reduce the effects of thermal movement on fresh concrete and to control moments induced into the supporting pile system:

- i) Drive the piling and pour the pile cap to the required bridge seat elevation. Pour the pile caps for the wingwalls concurrently.
- ii) Set the beams/girders.
- iii) Pour the bridge deck in the desired sequence excluding the abutment backwall/diaphragm and that portion of the bridge deck equal to the backwall/diaphragm width. In this manner, all dead-load slab rotations will occur prior to lock-up, and no dead-load moments will be transferred to the supporting piles.
- iv) Pour the backwall/diaphragm and end area of the slab.

v) Place the vertical drain system and backfill in 6 in. lifts until the desired subgrade elevation is reached. Place a bond breaker on the abutment surfaces in contact with the approach pavement.
vi) Pour the approach pavement starting at the end away from the abutment and progressing toward the backwall. If it can be so controlled, approach pavements should be poured in the early morning so that the superstructure is expanding, and therefore, not placing the slab in tension.

EXTENDING THE BRIDGE LENGTH LIMITS

The foregoing discussion under Abutment Details stipulated that the total length of jointless integral abutment bridges is maximized predicated on the freedom of each abutment to move a total of 5 cm at each end.

The selected allowable total movement was based on an opinion. The length limit of jointless bridges is ultimately determined by the longitudinal displacement that an abutment can withstand without sustaining damage that threatens serviceability. Full scale integral, pile-supported abutment tests conducted at the University of Tennessee, Knoxville, have determined that for the abutment beam and supporting pile elements, several limits, based on Tennessee DOT standard details:

i) For 35.6 cm square precast prestressed piles±3.8 cm (total 7.6 cm of movement) is repeatedly achievable elastically. In extreme events, such as earthquakes, ±10 cm movements will sustain little damage.
ii) For standard 0.76 m wide abutment beams with 25 cm steel piling, the serviceability limit for the abutment is ±3.8 cm (7.6 cm total movement) for 65 cm embedment of piles. For 130 cm embedment, ±5.0 cm (10 cm total movement) can be achieved. In an extreme event, the 130 cm embedment would allow ±15 cm total movement with little damage.

SUMMARY

The use of jointless bridges with integral abutments is growing in the United States, because of the benefits achieved in lowering first cost in construction and minimizing future maintenance. Further benefits of this type construction are design efficiency, added system redundancy, ease of construction and greater flexibility in span arrangement (particularly with fully continuous beam systems). Routine movements of up to 5 cm may be conservatively achieved at each abutment, given circumstances that allow unrestricted movement. Design procedures and analytical tools are available for system analysis, if desired.

Figure 1. State Route 50 over Happy Hollow Creek.
Eight-span Precast/Prestressed Bulb-t beams with composite concrete deck. Length, 358 m.

Figure 2. State Route 34 over the Southern Railway and Whitehorn Creek.
12-span Precast/Prestressed Box beams with composite concrete deck. Length 250 m.

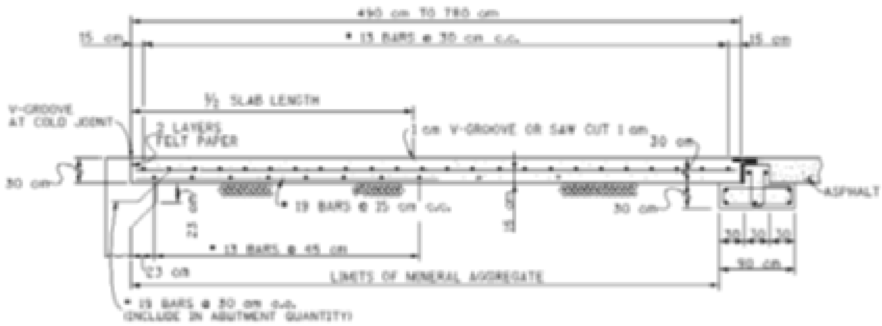

FIGURE 3

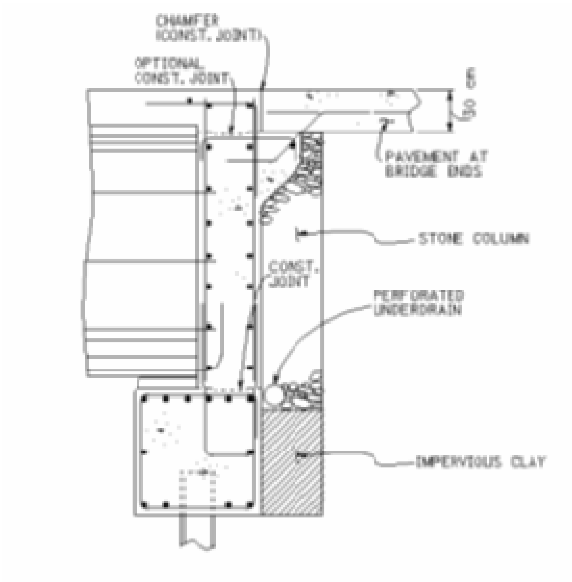

FIGURE 4

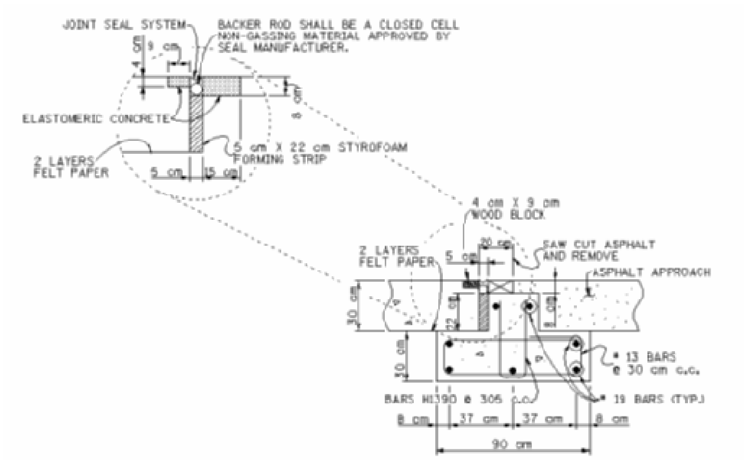

FIGURE 5

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