INTEGRAL BRIDGES

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INTRODUCTION

A bridge should be designed such that it is safe, aesthetically pleasing, and economical. Prior to the 1960s, almost every bridge in the U.S., Canada and England was built with expansion joints. These expansion joints often did not perform as well as intended. They required considerable maintenance, which undermined the economical operation of the bridges. Accident and vehicle damage caused by defective expansion joints raised safety concerns. Starting in the early 1960s, the use of integral bridges for new bridge construction attracted widespread interest.

The term integral bridge usually refers to bridges with short stub-type abutments connected rigidly to the bridge deck without joints. This rigid connection allows the abutment and the superstructure to act as a single structural unit (**fig. 1**). Integral abutment type bridge structures are simple or multiple span bridges that have their superstructure cast integrally with their substructure.

1. ADVANTAGES OF INTEGRAK BRIDGES

The principal advantages of integral abutment and joinless bridges include the following:

- Lower construction costs and future maintenance costs. In conventional bridges, much of the cost of maintenance is related to repair of damage at joints.

– Fewer piles are required for foundation support. No battered piles are needed.

– Construction is simple and rapid. The integral abutment bridge acts as a whole unit.

- Reduced removal of existing elements - Integral abutment bridges can be built around the existing foundations without requiring the complete removal of existing substructures.

- Simplified widening and replacement - Integral bridges with straight capped-pile substructures are convenient to widen and easy to replace. Their piling can be recapped and reused, or if necessary, they can be withdrawn or left in place. There are no expansion joints to match and no difficult temperature setting to make.

– The smooth, uninterrupted deck of the integral bridge is aesthetically pleasing, and it improves vehicular riding quality.

- Design efficiencies are achieved in substructure design. Longitudinal and transverse loads acting upon the superstructure may be distributed over more number of supports.

Integral abutments provide added redundancy and capacity for catastrophic events. Joints introduce a potential collapse mechanism into the overall bridge structure. Integral abutments eliminate the most common cause of damage to bridges in seismic events, loss of girder support. Integral abutments have consistently performed well in actual seismic events and significantly reduced or avoided problems such as back wall and bearing damage, associated with seat type jointed abutments. Jointless design is preferable for seismic regions.

2. LIMITATIONS OF APPLICATION OF INTEGRAL BRIDGE

The application of integral bridge concept has limitations.

- Integral bridges cannot be used with weak embankments or subsoil.

- Integral bridges are suitable if the expected temperature-induced movement at each abutment is 51 mm or less, and somewhat larger movements may be tolerable.

- The piles that support the abutments may be subjected to high stresses because of cyclic expansion and contraction of the bridge superstructure. These stresses can cause formation of plastic hinges in the piles, and may reduce their axial load capacities.

- The bridge material (steel or concrete) and the geometry of the bridge (curved or skewed) are important factors that affect the displacement of integral bridges.

- For composite concrete girder bridges with a total length of < 50 m integral abutments should normally be used. For steel girder bridges with a total length of < 40 m integral abutment should normally be used.

3. LOADS ON INTEGRAL BRIDGE SYSTEM

Integral bridges are subjected to primary loads due to dead and live loads, and additional secondary loads due to creep, shrinkage, thermal gradients, and differential settlements. An adequate design needs to consider both vertical loads [due to dead and live loads] and secondary loads.

3.1. Shrikage and creep

The greatest effect of shrinkage is apparent on the positive moment of single spans and on the continuity connection at abutment of continuous spans. Creep effects of continuous single span bridges are greater than shrinkage effects. Both creep and shrinkage are time dependent. Maximum shrinkage moments take place within 30 days of form removal, and creep effects continue for a longer period.

3.2. Temperature gradient

Both daily and seasonal temperature changes affect integral bridges. Each daily variation in temperature completes a cycle of expansion and contraction, and the cycles repeat over time. The greatest expansion takes place during summer days, while the greatest contraction occurs during winter nights. These extreme temperature variations control the extreme displacements of integral bridges.

Temperature gradients through the depth of the bridge beams generate secondary bending moments because the centroid of the temperature distribution curve and the centroid of the cross-section of the bridge beams may not coincide. In the temperature distribution through bridge beams, the most important factors are the maximum temperature differential and the distribution of this differential across the depth of the beams.

3.3. Differential settlement

Differential settlements can also result in secondary bending moments. AASHTO (1994) provide simple procedures to estimate differential settlements. If differential settlements are less than 38 mm, the induced moments can be ignored [1].

4. DESIGN OF INTEGRAL BRIDGE

The integral abutment and jointless bridge concept is based on the theory that due to the flexibility of the piling, thermal stresses are transferred to the substructure by way of a rigid connection between the superstructure and substructure. The concrete abutment contains sufficient bulk to be considered a rigid mass. A positive connection with the ends of the beams or girders is provided by rigidly connecting the beams or girders and by encasing them in reinforced concrete. This provides for full transfer of temperature variation and live load rotational displacement to the abutment piling (fig. 1).

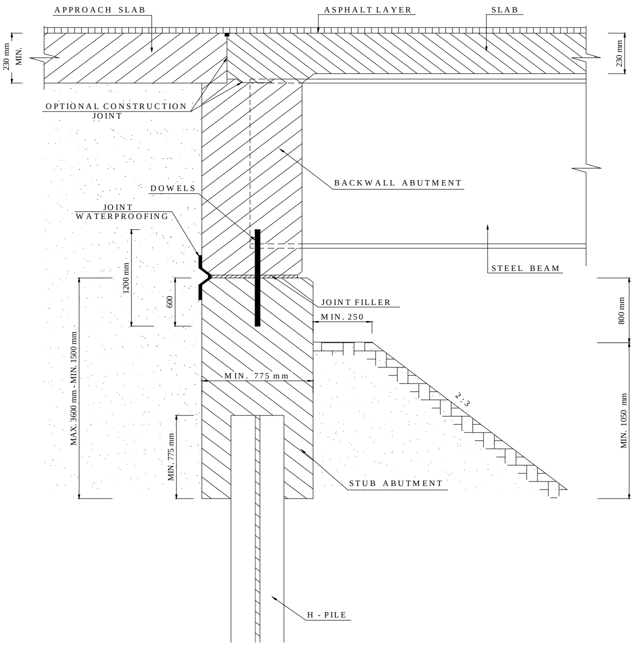

Figure 1. Integral and semi-integral bridge.

A semi-integral abutment design structure is one whose superstructure is not rigidly connected to its substructure. It may be a single or multiple span continuous structures whose integral characteristics include a jointless deck, integral end diaphragms, compressible backfill and movable bearings. In this concept, the transfer of displacement due to the piles is minimized.

4.1. Design of superstructure

The superstructures of integral bridges are subject to both primary loads (loads acting on the conventional jointed bridges, i.e., dead and live loads, earthquake loads, etc.) and temperature induced secondary loads. Integral bridges must be able to withstand these loads. Because of the rigid connections between the bridge deck and the abutments, integral bridges have improved seismic resistance compared to jointed bridges.

4.2. Design of piers

To design piers to accommodate potentially large superstructure movements, the following options are available:

a) Flexible piers rigidly connected to the superstructure.

b) Isolated rigid piers, connected to the superstructure by means of flexible bearings.

c) Semi-rigid piers, connected to the superstructure with dowels and neoprene bearing pads.

d) Hinged-base piers, connected to the superstructure with dowels and neoprene bearing pads.

A single row of piles, with a concrete cap that may be rigidly attached to the superstructure, provides a typical example of a flexible pier. This type of pier is assumed to provide vertical support only. The moments induced in the piles due to superstructure rotation or translation are small and may be ignored (fig. 1).

Rigid piers are defined as piers whose base is considered fixed against rotation and translation, either by large footings bearing on soil or rock, or by pile groups designed to resist moment. The connection to the superstructure is usually detailed in a way that allows free longitudinal movement of the superstructure, but restrains transverse movements. This type of detailing permits the superstructure to undergo thermal movements freely, yet allows the pier to participate in carrying transverse forces.

With this class of pier, the superstructure is supported on relatively tall shimmed neoprene bearing pads. A shear block, isolated from the pier diaphragm with a compressible material such as cork, is cast on the top of the pier cap to guide the movement longitudinally, while restraining transverse movements.

These piers are similar to rigid piers. Their bases are considered fixed by either large spread footings or pile groups; however, the connection of the piers to the superstructure differs significantly.

In utilizing prestressed concrete girders that bear on elastomeric pads, a diaphragm is placed between the ends of the girders. Dowels, perhaps combined with a shear key between girders, connect the diaphragm to the pier cap. Compressible materials are frequently introduced along the edges of the diaphragm, and, along with the elastomeric bearing pads, allow the girders to rotate freely under live load.

The dowels force the pier to move with the superstructure as it undergoes thermal expansion and contraction and, to a lesser extent, creep and shrinkage. Accommodation of these movements requires careful analysis during the design of the piers. Normally, the stiffness of the piers is assumed to be reduced due to cracking and creep.

This type of pier may be used to avoid the need for an expansion pier in a situation where semi-rigid piers have inadequate flexibility. A “hinge” is cast into the top of the footing to permit flexibility of the column.

Temporary construction shoring may be required, and additional detailing requirements at the top of the footing may increase cost; however, the designer should keep this alternate in mind under special circumstances where the other pier types are not feasible.

4.3. Design of the abutment

To support the integral abutment, it is customary to use a single row of piles. The piles are driven vertically and none are battered. This arrangement of piles permits the abutment to move in a longitudinal direction under temperature effects.

The most desirable type abutment is the stub type. It will provide greater flexibility and will offer the least resistance to cyclic thermal movements.

In integral abutment bridges, the ends of the superstructure girders are fixed to the integral abutments. Expansion joints are thus eliminated at these supports. When the expansion joints are eliminated, forces that are induced by resistance to thermal movements must be proportioned among all substructure units. This must be considered in the design of integral abutments.

Depending on the amount of temperature induced displacement of the abutments; earth pressures can be as low as the minimum active or as high as the maximum passive pressures. The mode of displacement of the abutment involves both translation and rotation. Experiments show that both the deformation mode and the magnitude of the deformation affect the magnitude and distribution of the earth pressure.

4.4. Design of approach system

The approach system of an integral bridge consists of the backfill, the approach fill, and the foundation soil. An approach slab and a sleeper slab, if used, are also part of the approach system.

Approach slabs are used to provide a smooth transition and span the problematic area between road pavements and bridge decks and will always be required for integral abutment jointless bridges. Their lengths shall vary from a minimum of 3,0 m to a maximum that is based on the intercept of a 1 on 1,5 lines from the bottom of the abutment excavation to the top of the highway pavement. This length is to be measured along the centerline of roadway.

There are two main types of approach slabs. One type is tied to the abutment as in integral abutment bridges. The other type has an expansion joint between the bridge deck and the approach slab as in semi integral abutment bridges.

The detailing of the joints at the ends of approach slabs in integral abutment bridges plays an essential role in the determination of its ductility and rotational capacity. The primary task of the joints is to transfer vehicular live loads and thermal loads to the approach slab. Inadequate design of joints may result in crack development in approach slabs. Both longitudinal and transverse cracking take place in approach slabs.

Both jointed and integral bridges are vulnerable to differential settlement between the approach system and the bridge abutment. This problem is often referred to as the “bump at the end of the bridge.” Causes for the bump problem, in order of importance, include: compression of the fill material, settlement of the natural soil under the embankment, poor construction practices, high traffic loads, poor drainage, poor fill material, and loss of fill by erosion The “bump” problem is further complicated for integral bridges by the cyclic compression and decompression of the backfill due to temperature cycles. When approach slabs are used, a void between the backfill and the abutment is likely to develop as the abutments move back and forth.

It is often argued that the length of the zone of surface deformation extends from the abutment a distance equal to twice the height of the abutment, and that the approach slabs should be made two to three times the height of the abutment. This argument is because displacing an abutment causes movement of a wedge of the backfill with a height equal to the height of the abutment and a length equal to $tg\left(45^0+\frac{\Phi}{2}\right)$ times the height of the abutment, which is about twice the abutment height.

CONCLUSIONS

Based on the results of a literature review, field inspections, and a finite element analysis, the following conclusions are drawn concerning the behavior of integral abutment and jointless bridges.

1. Integral bridges perform well with fewer maintenance problems than conventional bridges. Without joints in the bridge deck, the usual damage to the girders and piers caused by water and contaminants from the roadway is not observed. Integral abutment and jointless bridges cost less to construct and require less maintenance then equivalent bridges with expansion joints.

2. Simple Design - Where abutments and piers of a continuous bridges are each supported by a single row of piles attached to the superstructures, or where self-supporting piers are separated from the superstructure by movable bearings, an integral bridge may, for analysis and design purposes, be considered a continuous frame with a single horizontal member and two or more vertical members.

3. With jointless bridges, all of the movement due to temperature changes takes place at the abutments and this approach system area requires special attention to avoid development of a severe “bump at the end of the bridge.” Finite element analyses show that the zone of surface deformation extends from the back of the abutment a distance equal to about three to four times the height of the abutment.

4. The movement of the abutment into the approach fill develops passive earth pressure that is displacement-dependent. Using full passive pressure regardless o displacement is not conservative because it reduces the flexural effects of dead and live load in the bridge girders.

5. The ground around the piles moves along with the movement of the abutment. The relative movement between the pile and ground is therefore reduced, resulting in relatively low shear forces at the top of the pile.

6. The total lateral movement of the top of the pile relative to the end embedded in the ground is important because it reduces the axial load capacity of the pile. This lateral movement is one of the key variables in assessing the maximum design length of integral abutment bridges. The cyclic nature of these movements raises concern about the vulnerability of piles to cyclic loading.

7. Settlement of the approach fill will occur with time. It can be mitigated by using a properly compacted well-drained backfill, but it cannot be eliminated.

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