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Skewed Bridges with Integral Abutments

L.F. GREIMANN, A.M. WOLDE-TINSAE, AND P.S. YANG

As background to a theoretical investigation to establish tentative recomendations on maximum safe lengths and skew angles for concrete and steel skewed bridges with integral abutments, a survey of the highway departments of all 50 states was made to obtain information on the design and performance of skewed bridges with integral abutments. The findings of the survey are summarized, including various design criteria and limitations being used; typical pile orientations being used in bridge design by the different states and types of analysis used for thermal expansion and contraction; assumptions being made regarding selected design parameters; specific construction details being used, such as approach slab, backfill, and pile cap; long-term performance of skewed bridges with integral abutments; and previous research on skewed bridges with integral abutments. The variation in design assumptions and length limitations among the various states in their approaches to the use of integral abutments is discussed. The problems associated with thermal-induced abutment movement and the solutions developed by the different states for most of the ill effects of abutment movement are summarized. In view of the lack of theoretical and experimental research in this area, it is hoped that the survey will provide some useful empirical experience and information on the design of skewed bridges with integral abutments.

The routine use of integral abutments to tie bridge superstructures to foundation piling began in the United States about 30 years ago (1-4). Kansas, Missouri, Ohio, and Tennessee were some of the early users. This method of construction has steadily grown more popular. Today, more than half of the state highway agencies have developed design criteria for bridges without expansion joint devices.

Most of the states that use integral abutments began by building them on bridges less than 100 ft long. Allowable lengths have been increased based on good performance of successful connection details. Full-scale field testing and sophisticated rational design methods were not commonly used as a basis for increasing allowable lengths. This led to wide variations in criteria for the use of integral abutments from state to state. In 1974, the variation in the criteria between Kansas and Missouri was 200 ft (1). A survey conducted by the University of Missouri in 1972 (5) indicated that allowable lengths for concrete bridges with integral abutments were 500 ft in some states and only 100 ft in others.

Continuous steel bridges with integral abutments in the 300-ft range have performed successfully for years in such states as North Dakota, South Dakota, and Tennessee. Continuous concrete structures 500-600 ft long with integral abutments have been constructed in Kansas, California, Colorado, and Tennessee (6). In Iowa, the maximum bridge length for which integral-abutment construction is allowed has been limited to 265 ft (1). The Federal Highway Administration (FHWA) recommends integral abutments for steel bridges less then 600 ft long and for unrestrained bridges, those in which the abutment is free to rotate as with a stub abutment on one row of piles or an abutment hinged at the footing (6).

The primary purpose for building integral abutments is to eliminate bridge deck expansion joints and thus reduce construction and maintenance costs. A sketch of a bridge with integral abutments is shown in Figure 1. Conventional bridge bearing devices often become ineffective and are susceptible to deterioration from roadway runoff through open or leaking deck joints. A cross section of a bridge with stub abutments and deck joints is shown in Figure 2.

In an integral-abutment bridge with flexible piling, the thermal stresses are transferred to the substructure by way of a rigid connection. Various construction details have been developed to accomplish the transfer; one such detail from the state of Iowa is shown in Figure 3. The abutments contain sufficient bulk to be considered a rigid mass. A positive connection to the girder ends is generally provided by vertical and transverse reinforcing steel. This provides for full transfer of temperature variation and live load rotational displacements to the abutment piling.

PREVIOUS RESEARCH

Several of the states that use integral abutments have performed research to develop guidelines for the use of integral abutments. A summary of these research efforts follows.

California

California (7) began informal studies of some of its long structures without expansion joints about 15 years ago. Efforts consisted of identifying appropriate structures and conducting periodic inspections to monitor performance. A total of 27 bridges, varying in length from 269 to 566 ft, were studied; 18 of the bridges had integral abutments, and the others had semi-integral abutments.

Although a final report on this study is not yet available, the Office of Structures Design, California Department of Transportation (Caltrans), in

Figure 1. Cross section of a bridge with integral abutments.

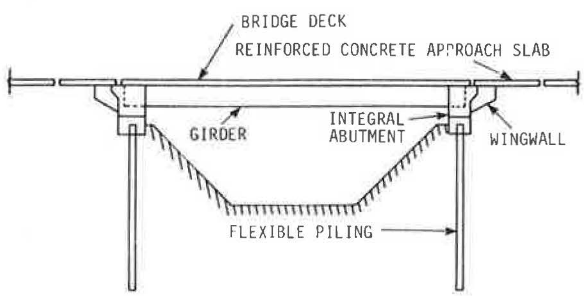


Figure 2. Cross section of a bridge with expansion joints.

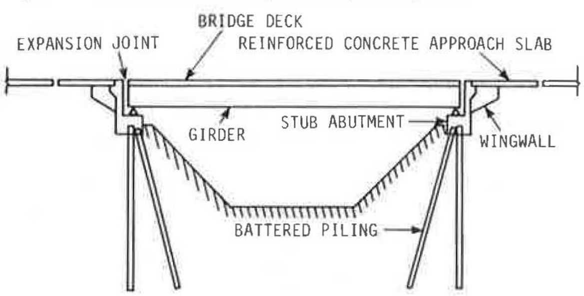
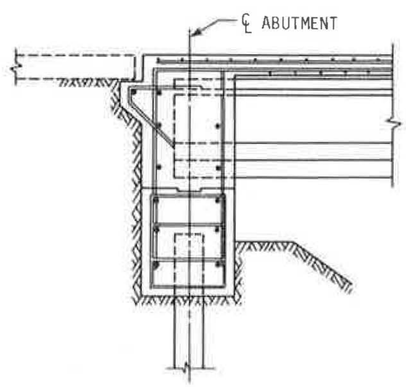


Figure 3. Integral abutment details (Iowa).



informal communications has reported the following interim findings:

1. There is no apparent distress at end bent columns.
2. There is no cracking on girder soffits related to the lack of deck joints.
3. No structural distress is apparent at the abutments.
4. There have been some problems with erosion and piping of abutment support soils due to small amounts of water flowing down behind the abutments.
5. There are no apparent deck cracking problems associated with expansion stresses.

The interim report recommends that a reinforced concrete approach slab be used with all jointless structures.

In 1971 and 1972, Caltrans and FHWA sponsored a research project to correlate theoretical solutions for laterally loaded piles with full-scale field tests in bridge embankments. Most of the work was done by Yee of the University of California at Sacramento. Yee reached the following conclusions (8):

1. The use of a linear variation in soil modulus with depth is a good approximation.
2. The influence of the soil below about 12-20 ft on pile stresses was practically negligible.
3. The effective length of the pile was about 15 ft for a free-head condition and about 21 ft for a fixed-head condition.

The results of this research were used to develop guidelines for the use of integral abutments in California. They are used when up to 1.5 in of total movement due to thermal forces is expected in a reinforced concrete bridge. In addition, to avoid rotation problems at the abutment, the end span is limited to 160 ft. The use of integral abutments is limited on prestressed bridges to those where the elastic shortening due to posttensioning is less than 0.375 in and the end span is less than 115 ft long.

Iowa

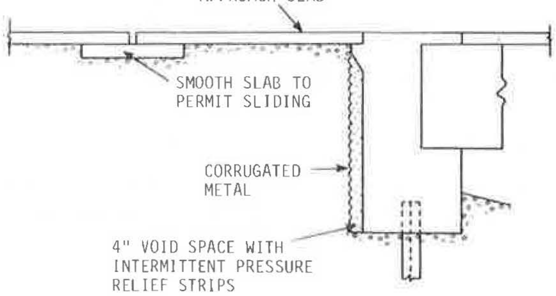
A final report on nonlinear pile behavior in bridges with integral abutments was published by Iowa State University in February 1982 (2). The research was sponsored by the Iowa Department of Transportation (DOT). The report included a survey of the highway departments of all 50 states to find the extent of use of integral abutments and the different guidelines used for analysis and design of nonskewed bridges with integral abutments. The variation in design assumptions and length limitations among the various states in their approaches to the use of integral abutments is discussed. The problems associated with lateral displacements at the abutment and the solutions developed by the different states for most of the ill effects of abutment movements are summarized in the report.

An algorithm based on a state-of-the-art nonlinear finite element procedure was developed and used to study piling stresses and pile-soil interaction in bridges with integral abutments. The finite element idealization consists of beam-column elements with geometric and material nonlinearities for the pile and nonlinear springs for the soil. An idealized soil model (modified Ramberg-Osgood model) was introduced in this investigation to obtain the tangent stiffness of the nonlinear spring elements.

Several numerical examples are presented in order to establish the reliability of the finite element model and the computer software developed. Three problems with analytic solutions were first solved and compared with theoretical solutions. A 40-ft H-pile (HP 10 x 42) in six typical Iowa soils was then analyzed by first applying a horizontal displacement (Δ_H) to simulate bridge motion and no rotation at the top and then incrementally applying a vertical load (V) until failure occurred. Based on the numerical results, the failure mechanisms were generalized to be of two types: lateral and vertical. It appears that most piles in Iowa soils (sand, soft clay, and stiff clay) failed when the applied vertical load reached the ultimate soil frictional resistance (vertical type of failure). In very stiff clays, however, lateral failure occurs before vertical failure because the soil is sufficiently stiff to force a plastic hinge to form in the pile as the specified lateral displacement is applied.

Preliminary results from this investigation showed that the vertical load-carrying capacity of H-piles is not significantly affected by lateral displacements of 2 in in soft clay, stiff clay, loose sand, medium sand, and dense sand. However, in very stiff clay (average blow count of 50 from standard penetration tests), it was found that the

Figure 4. Integral abutment system with pressure relief strips.



vertical load-carrying capacity of the H-pile is reduced by about 50 percent for 2 in of lateral displacement and by about 20 percent for lateral displacement of 1 in.

On the basis of the preliminary results included in the report, the 265-ft length limitation in Iowa for concrete bridges with integral abutments was termed to be very conservative. A summary of state length limitations for bridges with integral abutments is given below (9):

Maximum	No. of States by Bridge Type		
Length (ft)	Steel	Concrete	Prestressed
800	-	1	1
500	-	1	2
450	-	1	3
400	2	3	4
350	1	3	1
300	8	8	8
250	2	1	-
200	5	1	2
150	1	-	-
100	-	1	-

Missouri

In 1972, the University of Missouri conducted a survey and feasibility study of integral and semi-integral abutments (5). The following conclusions were drawn from the survey:

1. The use of superstructures connected to flexible substructures was becoming generally acceptable.
2. Design limitations were more restrictive for steel than for concrete bridges.
3. There was no simple design criterion that accounted for shrinkage, creep, temperature, or substructure flexibility.
4. Induced stresses resulting from thermal effects, creep, shrinkage, backfill movement, and the like are recognized by bridge engineers as potentially significant, but there is wide variance in methods of considering them.
5. Bridge design engineers are interested in induced stresses and associated problems, are generally uncertain as to the significance of and suitable methods for consideration of these stresses, and would welcome a simple, rational design criterion and specific recommendations as to design details.

North Dakota

In August 1979, the State of North Dakota built a 450-ft prestressed concrete box beam bridge on a 0° skew near Fargo. The piles in the integral abutments were instrumented with strain gauges and had inclinometer tubes attached. Jorgenson of the Civil Engineering Department, North Dakota State University, was commissioned to monitor the movements and strains in the bridge for one year. He had a preliminary report prepared in late summer 1981 (10). It appears that the maximum total movement at each end of the bridge is about 2 in. This is equivalent to a temperature variation of about 117°F.

The installation contains a unique feature designed by Moore Engineering of West Fargo, North Dakota. A special expansion joint material several inches thick is placed behind the abutment backwall. Behind it is a sheet of corrugated metal. The mechanism is designed to reduce passive earth pressures on the abutment and to help reduce the formation of a void space on contraction of the superstructure. The system is shown in Figure 4 (10).

South Dakota

In 1973, South Dakota State University conducted full-scale model tests on integral abutments to determine induced stresses in the superstructure and the upper portion on the piling (1). The model consisted of two HP 10 x 42 steel piles on 8.5-ft centers cast into a rigid concrete abutment with two plate girders about 26 ft long. The 32-ft piles were driven into silty clay over glacial till to a bearing capacity of 23 tons. The pile tops were welded to the bottom flanges of the girders.

Various lateral displacements within ±1 in were induced at the abutment by jacking at the free end during four construction stages. The results of interest are with the slab and backfill in place. Strains in the piling corresponding to stresses of up to 42 ksi were measured. This occurred just below the bottom of the concrete abutment. Several conclusions were drawn by the investigators (they were referred to as qualitative results that would require further verification):

1. Stresses were induced in the girders that in some cases were additive to dead and live load stresses. The induced stresses were generally within the 40 percent overstress allowed by the American Association of State Highway and Transportation Officials (AASHTO).
2. Horizontal movements greater than about 0.5 in will cause yielding in the piles.
3. Free-draining backfill is recommended since frozen soil against the abutment can greatly increase induced girder stresses by limiting free movement.
4. The use of approach slabs that allow rotation and translation of the abutment and, if possible, avoid continuing compaction of the backfill by traffic is recommended.

As part of this study, a questionnaire was sent to 10 north-central states. Two trends can be identified when this survey is compared with the responses of the same states to the survey recently conducted by Iowa State University (2). Idaho, Missouri, North Dakota, and South Dakota have substantially increased their bridge-length limitations for use with integral abutments. Iowa, Kansas, Nebraska, and Wisconsin have retained the same limits. Two states still do not routinely use integral abutments. Also of interest is the fact that since 1973 three of the states have begun to routinely use integral abutments with steel bridges; four of them already had and one still has not.

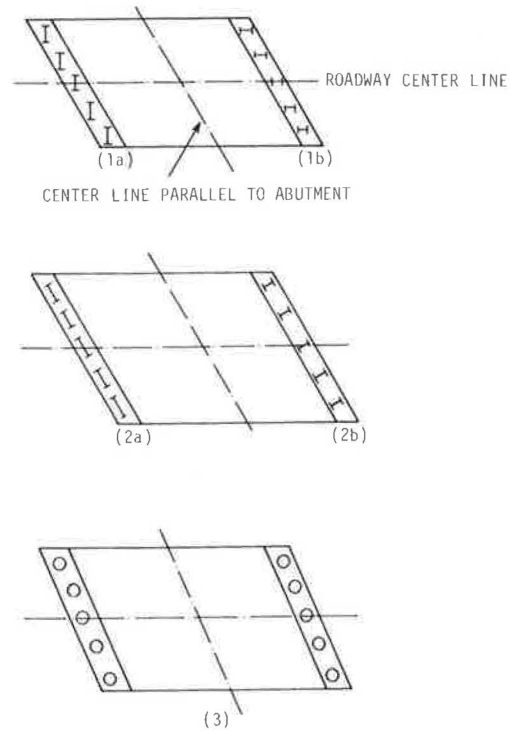
SURVEY OF CURRENT PRACTICE ON SKEWED BRIDGES WITH INTEGRAL ABUTMENTS

As background to a theoretical investigation to establish tentative recommendations on maximum safe

Figure 5. Questionnaire for skewed bridge with integral abutments.

Part One. Questionnaire for Skewed Bridges with Integral Abutments.

1. If you design skewed bridges with integral abutments, which of the kinds of pile orientations shown below do you use in the integral abutments? If neither, please sketch the type of pile orientation you use.



2. If you use either orientation, what structural assumptions are made for (1) the top of the pile, (2) thermal expansion or contraction (one direction or both directions) and (3) diagonal thermal expansion or contraction?

3. When you design skewed bridges with integral abutments, how do you treat the approach slab, backfill, and pile cap?

4. Any additional comments on skewed bridges with integral abutments?

lengths and skew angles for concrete and steel skewed bridges with integral abutments, a survey of the different states was made to obtain information on the design and performance of such bridges. This paper summarizes the findings of the survey, including

1. Various design criteria and limitations being used;
2. Typical pile orientations being used in bridge design by the different states and types of analysis used for thermal expansion and contraction;
3. Assumptions being made regarding selected design parameters;
4. Specific construction details being used, such as approach slab, backfill, and pile cap; and
5. Long-term performance of skewed bridges with integral abutments.

Method of Investigation

Responses to previous surveys concerning the use of integral abutments (2,4) have indicated that most state highway departments have their own limitations and criteria in designing integral abutments. The bases of these limitations and criteria are shown to be primarily empirical.

Today, the use of integral abutments in design has been accepted by 28 state highway departments and the District Construction Office of FHWA Region 15 (2). A survey questionnaire was prepared in cooperation with the Office of Bridge Design, Highway Division, Iowa DOT, to obtain information on the use and design of skewed bridges with integral abutments. A copy of the questionnaire is shown in Figure 5.

The survey questions concerned pile orientations in the integral abutments. The states were asked what structural assumptions were being made in determining fixity conditions on pile head and directions of thermal expansion and contraction of the integral abutments of skewed bridges. In addition, questions included the treatments of approach slab, backfill, and pile cap. Sketches of different types of pile orientations in integral abutments were also included in the questionnaire.

Trends of Responses

Of the 28 responses received, 26 states indicated that they use an integral type of abutment on skewed bridges. Among these states, Virginia has designed its first integral-abutment skewed bridge with a small skew (10°) and a relatively small anticipated movement at each abutment (±3/8 in). The states of Connecticut and Oklahoma indicated that they do not use integral abutments on skewed bridges. Although Connecticut has not constructed any integral abutments on a skew, they have constructed one nonskewed bridge with integral abutment. The other state, Oklahoma, indicated that it felt integral abutments on skews are inappropriate because of the integral displacement.

One of the purposes of this study is to present methods of analysis and design details of integral abutments on skewed bridges. Many of the states that use integral abutments on skewed bridges provided useful empirical experience that sheds some light on this problem.

Summary of Responses

The following discussion of questionnaire responses received from states that use integral abutments on skewed bridges is keyed to the survey question numbers shown in Figure 5. A comprehensive summary of the survey responses is given in Table 1.

Question 1

The pile orientations in the integral abutments on skewed bridges shown in the first survey question in Figure 5 can be classified into two parts: (a) the web of the pile perpendicular or parallel to the roadway centerline--e.g., types 1a and 1b, respectively; and (b) the web of the pile parallel and perpendicular to the centerline of the abutment--e.g., types 2a and 2b, respectively. The responses indicated that 6 states use type 1a orientation, 1 state uses type 1b, 10 states use type 2a, and 16 states use type 2b. In addition, 3 states use circular piles (type 3) in integral abutment on skewed bridges.

One major difference between skewed and nonskewed bridges with integral abutments is that when both are subjected to thermal expansion and contraction the skewed will have thermal-induced biaxial bending stresses on piles if pile orientation 2a or 2b is specified. This becomes a three-dimensional analysis problem. For types 1a, 1b, and 3, pile orientations will have the same thermal effects as with nonskewed integral-abutment bridges (2). The responses showed that 15 of 26 states have adopted the pile orientations so that bending will be primarily about the strong axis.

A second questionnaire was sent out to investigate whether there are any theoretical, experimental, or empirical bases for the orientation of the piles and to find out whether any distresses or problems associated with orientation of the piles have occurred. The responses received from the second questionnaire indicated that most states do not have any clear theoretical, experimental, or empirical bases.

Idaho officials assumed some creep in the soils surrounding the piles and that a redistribution of stresses will occur since thermal forces are generally applied gradually. In addition, the restraint provided by the integral abutment was assumed to reduce the magnitude of the thermal movement; orienting the piles with the strong axis parallel to the centerline of the bearings was assumed to give more rigidity for earthquake loads when liquification of embankment is assumed. Vermont oriented the piles to resist the force of earth pressure from the abutment backfill rather than the force of thermal expansion.

California explained its policy of orienting the web of piles perpendicular to the centerline of the abutment (Figure 5) as follows: For a square bridge, such orientation of piles results in bending about the strong axis of the piles due to both thermal forces and active soil pressure. When the bridge is skewed, however, temperature forces would act along the centerline of the roadway, not parallel to the pile web, and active soil pressure would act against the strong axis of the pile. A particular concern is rotational action caused by the active soil pressure on skewed bridges. Temperature effects are somewhat compensated for by predrilling for driven piles and filling the voids with pea gravel or sand.

Colorado respondents replied that they were unaware of any distress in the piling. In a few cases, with cast-in-place, posttensioned bridges with integral abutments, cracks have been detected in the abutment wall at the intersection of the superstructure with the abutment. The state suspected that the cracks are due primarily to the movements of the superstructure caused by elastic shortening and creep from the posttensioning forces.

North Dakota has been using this method of building bridges for about 18 years and so far was unaware of any problems.

According to Iowa bridge engineer Gee (3), pile orientation 1a is not considered in design because of construction work difficulty in arranging the reinforcement in the integral abutments. Thermal-induced biaxial bending stresses on piles can be avoided by using type 3 circular pipe piles. The major disadvantages are that their vertical bearing capacities are usually less than those of the steel H-piles and they are stiffer than H-piles about the weak axis.

Question 2

The second survey question, regarding structural assumptions (Figure 5), revealed the following. Two states indicated that at the pile top a roller assumption was made, eight reported a pinned assumption, one assumed partial fixity, and eight states assumed the pile top to be totally fixed. These assumptions were actually based on the restraint conditions on the pile top. In Iowa, the pile top is completely restrained by spiral reinforcement in the pile cap and total fixity is assumed. For a pinned assumption, the top portion of piling is enclosed with a flexible material before casting in the concrete abutment (3).

Only a few states consider thermal, shrinking, and soil pressure forces when calculating pile loads. For a long skewed bridge with integral abutment, temperature-induced stresses become very critical to the piling load capacities. If pile orientations 2a and 2b are adopted, the thermal expansion or contraction along the roadway center can be divided into two components, one parallel to the pile web (transverse) and the other perpendicular to it (longitudinal). Thus, the piles in integral-abutment skewed bridges will be subjected to biaxial bending due to thermal movement. It is also possible that in long skewed bridges diagonal thermal expansion and contraction will cause a serious problem. However, none of the states indicated concern about it. The following are some of the remarks made regarding thermal effects on integral abutments on skewed bridges:

1. Assume that the pile is fixed a certain depth below the bottom of the pile cap and any thermal movement is accomplished by bending in the pile.
2. Thermal expansion parallel to the pile cap can be resisted by the friction force between the backfill and the end wall.
3. For large skews, one state batters selected piles (say, every other pile) 3 in/ft to resist rotation caused by road fill against the abutment backwall.
4. Use shear keys on the bottom of the pile cap to prevent lateral movement of the pile cap on extreme skews (±40°).

Table 1. Summary of responses by the different states.

State	Pile Orientation 1a	1b	2a	2b	3	Structural Assumption: Pile Head	Thermal Expansion and Contraction: Longitudinal	Transverse	Diagonal	Design Consideration: Approach Slab	Backfill	Pile Cap	Comment
Arkansas	-	-	-	-	-	-	-	-	-	-	-	-	-
Arizona	No	No	No	Yes	No	Roller	Yes (due to roller)	Restrained by abutment cap	No	Tied to abutment with dowels and moves back and forth with superstructure	No	No	-
California	No	No	No	Yes	No	Hinge	No	No	No	-	-	-	Battered piles used to resist active earth pressure
Colorado	Yes	Yes	Yes	Yes	No	-	-	-	-	Bridge length >200 ft, use approach slab	No	No	Steel bridge ≤250 ft; concrete bridge ≤350 ft; no problem in skew; use predrilled oversized hole
Connecticut	No	No	No	No	No	No	No	No	No	No	No	No	-
Georgia	Yes	No	No	No	No	Free translation; free rotation; roller	Yes	Yes	No	Expansion joint between approach slab and bridge slab	-	-	-
Iowa	No	No	Yes	No	No	Fixed	Yes	No	No	Neglect	Neglect	Neglect	Conservative design
Idaho	No	No	Yes	Yes	No	Fixed	Yes	Yes	-	Expansion joint specified between rigid pavement and approach slab; no special treatment specified for flexible pavement	Use free-draining granular material as backfill	Rigid pile cap	Skewed three-span steel girder bridge with integral abutment was built; rotational forces from lateral earth pressure on end wall caused failure in pier anchor bolts on exterior girder
Indiana	No	No	No	Yes	No	Hinge	No	No	No	20-ft approach slab integrally attached to bridges	Use select granular fill	Pile cast in pile cap 1 ft	150 ft maximum
Kansas	No	No	Yes	Yes	No	Hinge	Yes	Yes	No	Uses slab support at backwall and pavement rests on slab with about 30 ft from end of wearing surface	Backfill compaction has settlement just off end of bridge	Pile caps not used	Cast-in-plate bridges with end of steel beams into abutment concrete, reinforcing to make them essentially integral
Kentucky	Yes	No	No	No	No	Partially restrained	Yes	No	-	No special treatment with flexible pavement	Special granular backfill specified	-	Bridge length 300 ft, max skews ≤30°, pile prebored for distance of 8 ft before bottom of pile cap
Missouri	No	No	No	Yes	No	Fixed	No	No	No	-	-	Use shear key on bottom of pile cap to prevent lateral movement of pile cap on extreme skews (±40°)	Piles designed for direct load only: <500 ft for prestressed bridges, <400 ft for steel bridges
Montana	No	No	No	Yes	No	No	No	No	No	Not fixed to abutment	Granular material as backfill	No	≤30° skews
North Dakota	No	No	No	Yes	No	Fixed	Yes	Yes	No	Assume approach slab has no effect	Select granular material	Abutment wall is pile cap and is re-	Hold skew to max of −30°

Table 1. Continued.

	Structural Assumption									Design Consideration			
	Pile Orientation						Thermal Expansion and Contraction						
State	1a	1b	2a	2b	3	Pile Head	Longitudinal	Transverse	Diagonal	Approach Slab	Backfill	Pile Cap	Comment
North Dakota continued												inforced to resist bending below super-structure	
Nebraska	Yes	No	No	No	No	-	Yes	No	No	Same as square bridges with integral abutments	Select granular material	Abutment wall is pile cap and is reinforced to resist bending below super-structure	15° skew for integral abutment
New Mexico	No	No	Yes	No	No	Fixed	Yes	No	No	Used on some bridges and not on others	Do not use specified backfill anymore	-	Have built bridges with 15° skew; skew angle neglected
New York	No	No	Yes	No	No	-	No	No	No	Construction joint provided between approach slab and bridge slab	Granular fill behind backwall and wing walls	No	Neglect stress caused by rotation, designed to take vertical load only; in skewed bridges, neglect some twisting induced in piles when structure deflects, use predrilled oversized hole
Ohio	No	No	Yes	No	No	-	No	No	No	Tie approach slab to abutment	Same as nonintegral abutments for usual short bridge	Pile cast in pile cap 2 ft	Oil country pipelines not used in integral abutments because they are stiffer than H-piles about weak axis
Oklahoma	No	No	No	No	No	-	-	-	-	-	-	-	Integral abutments only with zero skews
Oregon	No	No	No	Yes	No	Hinge	-	-	-	Approach slab was tied to pile cap	-	Pile cast in pile cap 1 ft	-
South Dakota	Yes	No	Yes	No	No	Fixed	Yes	No	No	Tied with bridge to prevent erosion of shoulder	-	No	-
Tennessee	No	No	No	Yes	No	-	Yes	No	No	Construction joint between abutment backwall and approach slab	No	No	-
Utah	No	No	No	No	Yes	Hinge	-	-	-	Expansion joint between approach slab and bridge slab	96 percent of optimum	No	Steel piles used primarily through granular material over bed rock; no problem in thermal movements
Virginia	No	No	Yes	No	No	Fixed	No	No	No	No approach slab	Used 1.5 ft of porous backfill with 0.5-in diameter pipe underdrain	Uniform width and parallel to bridge skew	Max skew 10°; relatively small movement at each abutment (±3/8 in)
Vermont	No	No	No	Yes	No	Fixed	Yes	No	No	Approach slab anchored to abutment	No special treatment	Rigid pile cap	≤30° skew
Washington	Yes	No	No	Yes	Yes	Hinge	Yes	No	No	Approach slab at-	Backfill	Designed	Calculate mo-

Table 1. Continued.

State	Pile Orientation					Structural Assumption				Design Consideration			Comment
							Thermal Expansion and Contraction						
	1a	1b	2a	2b	3	Pile Head	Longitudinal	Transverse	Diagonal	Approach Slab	Backfill	Pile Cap	
Washington continued										tached to abutment with allowance for expansion	earth pressure applied normal to abutment	as cross beam on simple supports	ments of inertia along roadway center
Wisconsin	No	No	No	Yes	Yes	-	No	No	No	Designed for vertical load only	-	Designed as reinforced continuous beam over piling	Piles designed for vertical loads ≤30° for slabs; ≤15° for prestressed or steel girders
Wyoming	No	No	No	Yes	No	Plastic hinge	Yes	Yes	No	Neglect	Neglect	Assumed to be a mass attached to end of girder	Max length ≤300 ft
FHWA Region 15	No	No	Yes	No	No	Hinge	No	No	No	-	-	Pile cast in pile cap 1 ft	-

5. If the bridge design has a small skew (<10°) and a relatively small anticipated move- ment at each abutment (±0.375 in), no special consideration need be given beyond that of a 0° skew condition.

Question 3

Most states indicated that a free-draining granular material is used as backfill behind the abutment. One state uses 1.5 ft of porous backfill from subgrade to bottom of integral abutment along with 6-in-diameter pipe underdrain. Beyond that, normal material available at the job site is used. Some respondents, however, indicated that backfill compaction has always been somewhat of a problem with settlement just off the end of the bridge. Otherwise, no special treatment has been used. Several states indicated that rigid pile cap has been used, and pile was cast into pile cap 1-2 ft long. Two states indicated that pile cap is designed as reinforced continuous beam over the piling.

The survey responses show, in general, that the approach slab can be tied to the abutment with dowels and can move back and forth with the superstructure if a construction joint is provided between the approach slab and the bridge slab. The reply from South Dakota stated that at least one approach slab panel with curb-and-gutter section attached to the bridge end is necessary to prevent erosion of the shoulder behind the abutment wing. One state indicated that, whereas its criteria specify an expansion joint between rigid pavement and the approach slab, no special treatment is specified for flexible pavement. In Colorado, the approach slab was used if the bridge length was greater than 200 ft.

Question 4

The following are some additional comments on skewed bridges with integral abutments:

1. Some of the piles in the abutment have to be battered to resist the active earth pressure acting behind the abutment.
2. Rotational forces from the lateral earth pressure on the end walls cause a failure of the pier anchor bolts on the exterior girders.
3. For a cast-in-place bridge, the end of steel beams may be cast into the abutment concrete, reinforcing to the extent that they are considered essentially integral.
4. Piles may be prebored for a distance of 5-20 ft below the bottom of the pile cap.
5. Because the piles are oriented to allow bending about the weak axis, any stresses caused by rotation will only occur in the outermost flange fibers and not the web and center portions of the flanges. When the abutment is skewed, some twisting may be induced in the piles when the structure deflects, but this can be assumed to be of a minor nature and may be neglected.

SUMMARY AND CONCLUSIONS

Previous research work in the area of integral abutments includes surveys of detailing and design criteria used by the state highway agencies, full-scale model tests, and monitoring of the performance of actual bridge installations. The present survey responses indicated that 26 states use integral-type abutments on skewed bridges. Most states design integral abutments on skewed bridges based on empirical experience and no theoretical analysis is introduced in design.

For integral abutments on skewed bridges, 15 states orient their piles with the web of the piles perpendicular to the centerline of the abutment (type 2b) so that bending will be primarily about the strong axis. Thus, thermally induced biaxial bending stresses will be introduced into the piles. But the survey responses show that most states ignore the thermally induced bending stress due to transverse thermal movement. Kansas indicated that transverse thermal movement can be eliminated by using shear keys on the bottom of the pile cap. The major reasons given for using pile orientation 2b are as follows:

1. The restraint provided by the integral abutment will reduce the magnitude of the thermal movement. Orienting the pile with the strong axis parallel to the centerline of the bearings gives more

rigidity for earthquake loads when liquification of embankment is assumed.

2. Thermal expansion is actually very small, and the backfill material around the abutment and the piling seems to yield sufficiently so that no distress is apparent. The piling was oriented to resist the force of earth pressure from the abutment backfill rather than the force of thermal expansion.

3. Temperature forces would act along the centerline of the roadway, not parallel to the pile web, and active soil pressure would act against the strong axis of the pile. Temperature effects are somewhat compensated for by predrilling for driven piles and filling the voids with pea gravel or sand.

No special treatments are usually given to backfill and pile cap on skewed bridges, and they might be constructed in the same way as on nonskewed bridges. As for the approach slab, it can be tied to the abutment with dowels or an expansion joint may be provided between the approach slab and the bridge slab. Some states put an expansion joint a certain distance behind the approach slab. In this case, the approach slab will act integrally with the abutment.

It has been more than 15 years since the first integral abutments on skewed bridges were constructed. No serious problems or distresses have yet been discovered. In view of the lack of theoretical and experimental research in this area, it is hoped that this survey will provide some useful empirical experience and information on the design of skewed bridges with integral abutments.

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Behavior of Abutment Piles in an Integral Abutment in Response to Bridge Movements

JAMES L. JORGENSON

A field study of the behavior of abutment piles for a bridge that has integral abutments, piers, concrete box girders, concrete deck, and six 75-ft spans is discussed. To compensate for anticipated thermal movements, two unique features were built into the bridge. Expansion joint material was placed between the back side of the abutment and the soil backfill, and compressible material was placed on the webs of the abutment piles to create low soil resistance to pile movement. Over a one-year period, monthly readings were taken of bridge length (by using steel tape), gap between soil backfill and back side of abutment, openings in the expansion joints on the concrete approach slabs, vertical elevation of abutments and piers, slope indicator readings on the four corner abutment piles, and temperatures of concrete deck and air. A formula involving air temperatures was developed to estimate the maximum change in bridge length due to thermal changes. The changes in bridge length agree with changes measured from steel tape and expansion joint openings. The study concluded that these changes did not result in equal abutment movements at each end of the bridge, and the maximum abutment movement resulted in stresses at the top of the piles sufficient to initiate a yield stress in the steel but not sufficient to form a plastic hinge. An analytic model was used to predict stresses in the abutment piles due to movements of the abutments.

Bridge engineers recognize that changes in air temperature result in changes in the temperature of bridge materials, which in turn result in movements of the bridge. So long as the bridge components