Zeitschrift: IABSE proceedings = Mémoires AIPC = IVBH Abhandlungen

Band: 7 (1983)

Heft: P-58: Performance of integral bridge abutments

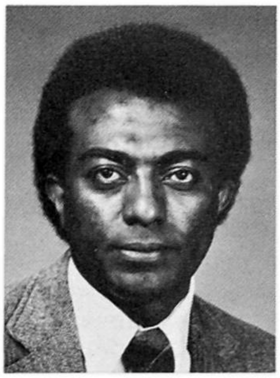
Artikel: Performance of integral bridge abutments

Autor: Wolde-Tinsae, Amde M. / Greimann, Lowell F. / Johnson, Bruce V.

DOI: https://doi.org/10.5169/seals-37486

Performance of Integral Bridge Abutments
Le comportement de culées intégrées aux ponts
Die Leistungsfähigkeit integraler Brückenwiderlager

A. M. WOLDE-TINSAE **L. F. GREIMANN** **B. V. JOHNSON**
Dep. of Civil Eng., Iowa State Univ., Ames, IA, USA



Amde M. Wolde-Tinsae, born in Addis Ababa, Ethiopia, received his B.E.S., M.S. and Ph.D. degrees from Johns Hopkins, UC at Berkeley and SUNY at Buffalo, respectively. Presently he is Associate Professor of Structural Engineering at Iowa State University.

Lowell Greimann received his structural engineering Ph.D. degree at the University of Colorado, Boulder in 1968. He is now a professor at Iowa State University and is involved in research in the finite element area.

Bruce V. Johnson, born 1949, received a degree in Transportation Engineering from the California Polytechnic State Univ. and a Masters degree in Structural Engineering from Iowa State Univ. He is currently the Assistant Bridge Engineer in the Iowa Div. of the Fed. Highway Adm.

SUMMARY

The highway departments of all fifty states, USA, were contacted to find the extent of application of integral abutment bridges, to survey the different guidelines used for analysis and design of integral abutment bridges, and to assess the performance of such bridges through the years. The variation in design assumptions and length limitations among the various states in their approach 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.

RÉSUMÉ

Les départements des travaux publics des cinquante Etats composant les USA ont été contactés afin de déterminer l'ampleur des cas où les culées sont intégrées monolithiquement aux ponts, afin d'obtenir une vue d'ensemble sur les critères de dimensionnement et sur le comportement à long terme de ces culées. L'article discute ces critères et les longueurs maximales de ponts où une telle solution est envisageable. Les problèmes liés aux déplacements transversaux et aux tassements des culées et les solutions développées par les Etats pour y remédier sont présentés.

ZUSAMMENFASSUNG

Die Strassenbauverwaltungen aller fünfzig Staaten der USA wurden befragt, um den Grad der Anwendbarkeit integraler Brückenwiderlager herauszufinden, die verschiedenen Richtlinien, die zur Untersuchung und zum Entwurf angewandt werden, zu prüfen und die Leistungsfähigkeit solcher Brücken über Jahre hinaus abzuschätzen. Die Unterschiede zwischen den einzelnen Staaten hinsichtlich der Voraussetzungen für den Entwurf und der Längenbegrenzungen und ihr Vorgehen in der Anwendung integraler Widerlager wird diskutiert. Die Probleme, die mit seitlichen Verschiebungen am Widerlager verbunden sind, und die Lösungen, die von den einzelnen Staaten für die Mehrzahl der nachteiligen Wirkungen von Widerlagerbewegungen entwickelt wurden, werden zusammengefasst.

1. INTRODUCTION

1.1. Background

Prior to World War II most bridges with an overall length of 50 feet (15.24 m) or more were constructed with some form of expansion joints. Periodic inspection of these bridges revealed that expansion joints tended to freeze and close and did not operate as intended. Closer inspection of such bridges also indicated that there was no serious distress associated with the frozen or closed expansion joints. This led to the advancement of the case for continuous construction.

Continuity in steel stringer and other types of bridges has been accepted practice since the early 1950s. In addition to the inherent economy of continuous beams, wherein negative moments over interior supports serve to reduce midspan positive moments, one line of bearing devices was automatically eliminated at each interior support. The predominant problem with these continous bridges was at the abutments, where some kind of expansion joints were required. An example of a bridge with expansion joints is shown in Fig. 1 and details of an abutment are shown in Fig. 2 [1]. The expansion joints at the abutments allowed penetration of water from the backfill and roadway into the bearing areas and onto bridge seats. The joints could then be forced closed, resulting in broken backwalls, sheared anchor bolts, damaged roadway expansion devices and other problems. Maintenance costs associated with these problems accelerated the development of integral abutments.

Figure 3 shows an example of a bridge with integral abutments and Fig. 4 shows details of typical integral abutments; each is supported by a single row of vertical piles extending into the abutments [2-6]. In addition to being aesthetically pleasing, integral abutments offer the advantage of lower initial cost and lower maintenance cost. Expensive bearings, joint material, piles for horizontal earth loads and leakage of water through the joints are all eliminated.

Kansas, Missouri, Ohio, North Dakota, and Tennessee were some of the early users of integral abutments to tie bridge superstructures to foundation pilings. 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 using integral abutments began by building them on bridges less than 100 feet (30.48 m) long. Allowable lengths were increased on the basis of 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

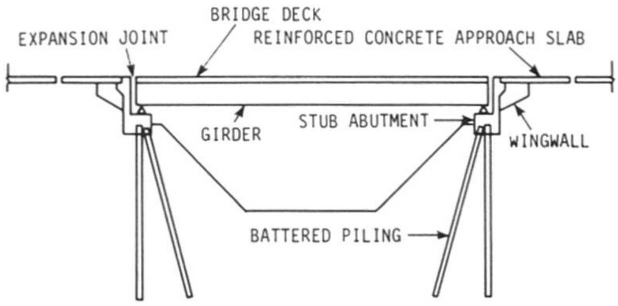


Fig. 1. Cross-section of a bridge with expansion joints.

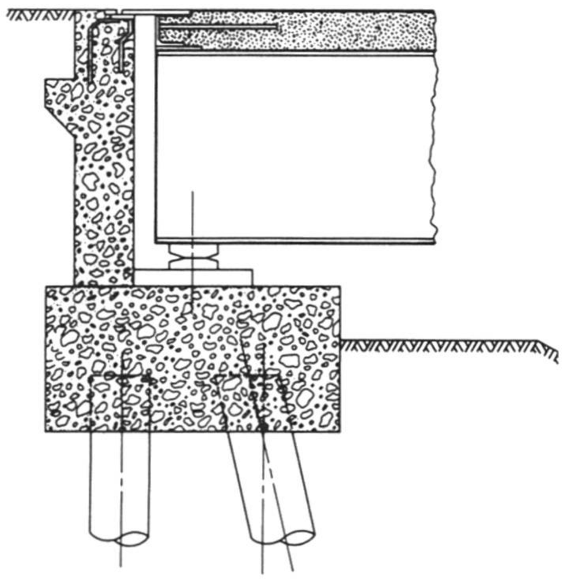


Fig. 2. Abutment detail.

abutments from state to state. In 1974 the variation in maximum allowable length for concrete bridges using integral abutments between Kansas and Missouri was 200 feet (60.96 m) [2]. A survey conducted by the University of Missouri in 1973 [6] indicated that the allowable length for integral abutment concrete bridges in some states was 500 feet (152.4 m) while in others it was only 100 feet (32.48 m).

Continuous steel bridges with integral abutments have performed successfully for years in the 300-foot (91.44 m) range in such states as North Dakota, South Dakota and Tennessee. Continuous concrete structures 500-600 feet (152.4-182.88 m) long with integral abutments have been constructed in Kansas, California, Colorado and Tennessee [7]. In Iowa the maximum bridge length for which integral abutment construction is allowed has been limited to 265 feet (80.78 m) [2]. The Federal Highway Administration recommends integral abutments for steel bridges less than 300 feet (91.44 m) long, for pre- or post-tensioned concrete bridges less than 600 feet (182.88 m) long, and for unrestrained bridges, that is, bridges where the abutment is free to rotate as with a stub abutment on one row of piles or an abutment hinged at the footing [7].

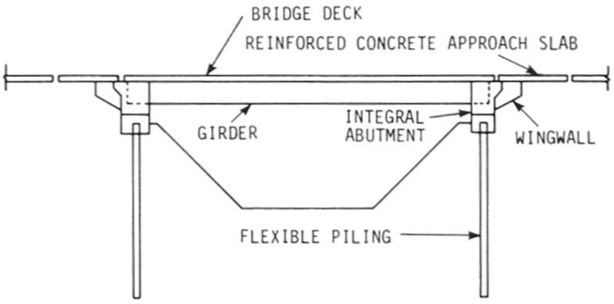


Fig. 3. Cross-section of a bridge with integral abutments.

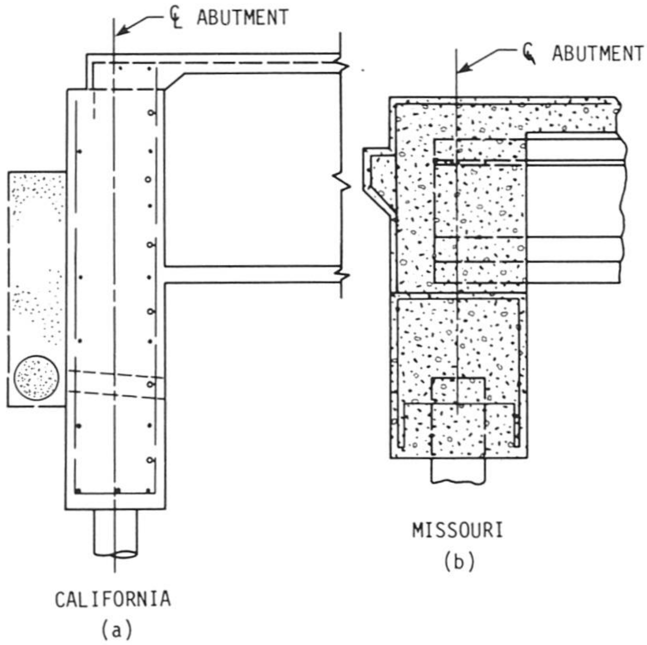


Fig. 4. Integral abutment details.

In an integral abutment bridge with flexible piling, the thermal stresses are transferred to the substructure via a rigid connection. Various construction details have been developed to accomplish the transfer as shown in Fig. 4. 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.

The semi-integral abutments shown in Fig. 5 are designed to minimize the transfer of rotational displacements to the piling [3,6]. They do transfer horizontal displacements, and they also allow elimination of the deck expansion joints. Rotation is generally accomplished by using a flexible bearing surface at a selected horizontal interface in the abutment. Allowing rotation at the pile top generally reduces pile loads.

A survey of the fifty states and a review of the literature showed that there has not been a rigorous scientific theoretical or experimental study performed to establish limits for integral abutment bridges. The limit of allowable horizontal movement that will cause objectionable pile stress and what constitutes an objectionable pile stress have not been well defined. This partly explains the wide variation in design criteria for integral abutment bridges that exists among the different state highway agencies.

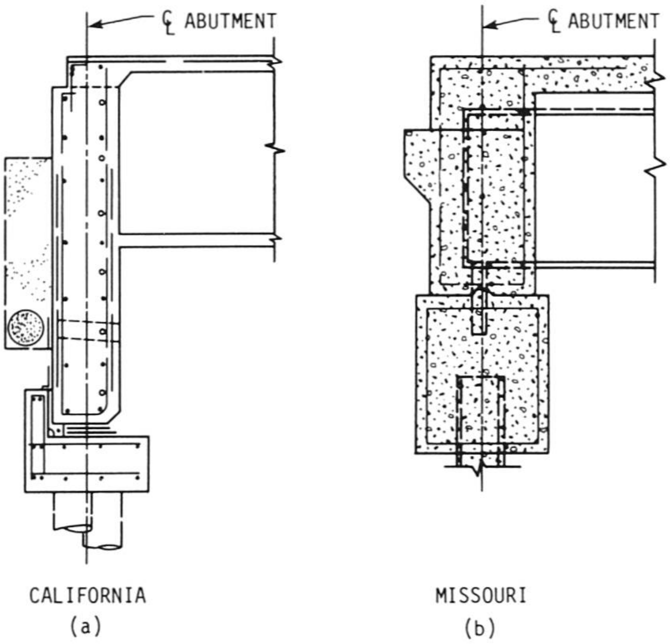


Fig. 5. Semi-integral abutment details.

1.2. Objective

As background to a theoretical investigation to establish tentative recommendations on maximum safe lengths for steel and concrete bridges with integral abutments, a survey of the different states was made to obtain information on the design and performance of integral abutment bridges. This paper summarizes the findings of the survey including

- Various design criteria and limitations being used;
- Assumptions being made regarding selected design parameters and appropriate level of analysis;
- Specific construction details being used;
- Changes in trends since previous surveys were taken; and
- Long-term performance of bridges with integral abutments.

A more comprehensive report on the survey is included in a research report by Wolde-Tinsae, Greimann and Yang [8].

2. METHOD OF INVESTIGATION

Surveys concerning the use of integral abutments have previously been conducted [2,6]. They have indicated that there are marked variations in design limitations and criteria for their use. Many states have not felt comfortable using a system that does not contain some "free space" for temperature variation displacements.

Some of the variations among the states occur because of different temperature range criteria. Also, depending on the extent of deicing salt use, some states may experience greater problems with bridge deck expansion joint devices than others. Naturally, it is difficult to justify altering existing construction techniques by either beginning the use of integral abutments or using them for much longer bridges if the possibilities of decreased distress and maintenance are not readily apparent.

A survey questionnaire was prepared in cooperation with the Office of Bridge Design, Highway Division, Iowa Department of Transportation, to obtain information concerning the use and design of integral bridge abutments. Based on a review of the survey, several states were later contacted to gain a better understanding of successful design details and assess the performance of relatively long integral abutment bridges. A summary of the results of correspondence and telephone conversations with bridge engineers in Tennessee, Kansas, Missouri, North Dakota, California, and Iowa is included in Section 4 of this paper.

The questionnaire was sent to the 50 states and Puerto Rico. Since the District Construction Office, Region 15, Federal Highway Administration is involved in bridge construction on federally owned property, a questionnaire was also sent to the design department in Arlington, Virginia. The questionnaire and the responses from each of these agencies are contained in Appendices 1 and 2.

The survey questions were directed at limitations in bridge length, type, and skew. The states were also asked what assumptions were made in determining fixity conditions and loads for design of the piling and superstructure. A detailed drawing of the type of integral abutment used in Iowa was included in the questionnaire.

Most of the states that use integral abutments, as shown in Appendix 2, have developed specific guidelines concerning allowable bridge lengths, design of the backwall, type of piling, etc. The basis of these guidelines is largely empirical. It had been hoped that some of the states using integral abutments had performed an analysis regarding anticipated movements and pile stresses. The questions regarding fixity and design loads were included to determine what level of analysis was felt to be appropriate.

Much of the progress in the use of integral abutments has come about by successive extension of limitations based on acceptable performance of prototype installations. In order to learn more from the several states who have pioneered the use of integral abutments, questions were asked regarding costs and performance.

3. TRENDS IN RESPONSES

Of the 52 responses received, 29 indicated that their states use integral-type abutments. A few of these, such as New Mexico and Virginia, are just beginning to use them: their first integral abutment bridge was either recently designed or currently under construction.

Of the 23 who did not use these abutments, there were four groups of responses:

- Fourteen states have no plans to consider using this type of abutment.
- Five states responded that they have not previously considered the possibility of fixing the girder ends to the abutments.
- Three states have built some integral abutments or semi-integral endwalls but currently do not use them in new bridge construction.
- One state indicated that it was investigating the possibility of using integral abutments.

The following are some of the reasons given for avoiding the use of integral abutments:

- The possibility of a gap forming between the backwall and the roadway fill (two states);

- Increased substructure loads (one state);

- The possible attenuation of a bump at the ends of the bridge (one state);

- The lack of a rational method for predicting behavior (one state);

- The possible additional stress on approach pavement joints (two states); and

- Cracking of the backwall due to superstructure end span rotation and contraction (two states).

One of the purposes of this study is to present methods of analysis and design details that will reduce the potential ill effects of these concerns. Many of the states currently using integral abutments have effectively solved most of these problems [9, 10].

The following is a discussion, keyed to the survey question numbers, of the responses received from states using integral abutments. A summary of the responses is contained in Appendix 2.

1. Most of the states using integral abutments do so because of cost savings. Typical designs use less piling, have simpler construction details, and eliminate expensive expansion joints. Some states indicated that their primary concern was to eliminate problems with the expansion joint. A few said that simplicity of construction and lower maintenance costs were their motivation.

2 & 3. Table 1 shows bridge length limitations currently being used. In summary, 70 percent or more of those states using integral abutments feel comfortable within the following range of limitations: steel, 200-300 feet (60.96-91.44 m); concrete, 300-400 feet (91.44-121.92 m); and prestressed concrete, 300-450 feet (91.44-137.16 m). Three states use longer limitations for each structure type. They typically have been building integral abutments longer than most states and have had good success with them. The move toward longer bridges is an attempt to achieve the good performance observed on shorter bridges for structures at the maximum practical length limit. This achieves the maximum benefit from what many regard as a very low maintenance, dependable abutment design.

   The difference in concrete and steel length limitations reflects the greater propensity of steel to react to temperature changes. Although the coefficients of expansion are nearly equal for both materials, the relatively large mass of most concrete structures makes them less reactive to ambient temperature changes. This is reflected in the design temperature variation specified by the American Association of State Highway and Transportation Officials (AASHTO), which is much lower for concrete.

4. Only a few states responded to the question regarding limitations on piling. Five states use only steel piling with integral abutments. Three others allow concrete and steel but not timber. No length limitations for timber piling were given by states other than Iowa. Timber piling is allowed in Iowa for bridges less than 200 feet (60.96 m) in length. If the length is greater than 150 feet (45.72 m), the top of the pile which is embedded in the abutment is wrapped with 1/2 inch (0.127 cm) to 1 inch (0.254 cm) thick padding material. This allows some rotation of the abutment, reducing the bending stress on the

Table 1. Integral abutment bridge length limitations (1981).

Maximum Length feet (meters)	Number of States		
	Steel	Concrete	Prestressed
800 (243.84)		1	1
500 (152.4)		1	2
450 (137.16)		1	3
400 (121.92)	2	3	4
350 (106.68)	1	3	1
300 (91.44)	8	8	8
250 (76.2)	2	1	
200 (60.96)	5	1	2
150 (45.72)	1		
100 (30.48)		1	

pile. Only four of the 29 agencies indicated that the webs of steel piles were placed perpendicular to the length of the bridge. In subsequent phone calls to a few other states, it was learned that others also follow this practice. At least one state began using integral abutments with steel piling placed in the usual orientation (with the pile web along the length of the bridge). This led to distress and cracking at the beam-abutment interface, and the state eventually began to rotate the piles by 90 degrees for greater flexibility.

5 & 6. Twenty-two states indicated that the superstructure was assumed pinned at the abutments. Five assumed partial fixity, and one assumed total fixity. Seventeen responses noted that at the pile top a pinned assumption was made; four reported a partial fixity assumption; and five states believe the pile top is totally fixed. Six of the states which assume a pinned condition actually use a detail designed to eliminate moment constraint at the joint. In the absence of a detail which allows rotation, the appropriate assumption depends largely on the relative stiffness of the pile group and the end span superstructure. For example, if a single row of steel pilings with their webs perpendicular to the length of the bridge was used with a very stiff superstructure, the joint would probably behave as if it were pinned in response to dead and live loads and as if it were fixed in response to temperature movements. If the stiffness of the pile group were increased, some degree of partial fixity would result depending on the ratio of stiffnesses.

7. Only a few states consider thermal, shrinkage, and soil pressure forces when calculating pile loads. Several states noted on the questionnaire that only vertical loads are used in design. Of those that do consider

pile bending stresses, eight use thermal forces, three use shrinkage forces, and ten consider soil pressure.

8. Most states indicated that bending stresses in abutment pilings were neglected. There were three states, however, that assumed a location for a point of zero moment and used combined bending and axial stresses. Also, prebored holes were used by three states to limit bending stresses by reducing the soil stiffness near the surface.

9. Most states indicated that a free-draining backfill material is used behind the abutment. Some responses, however, indicated that problems were encountered such as undermining associated with granular soils. One state said, "Have recently experienced problems with noncohesive material behind this type of abutment. Backfill material should be cohesive and free from cobbles and boulders." Six other states use common roadway fill behind the abutment.

10. All except four states rest the approach pavement on the integral abutment. One state indicated that a positive tie connection was used to connect the slab. No comments regarding the practice of resting the slab on a pavement notch were noted. A few states indicated that they had experienced problems when reinforced approach slabs were not used.

11 & 12. All except three states reported lower construction and maintenance costs using integral abutments. Of the three, one said costs were the same, and two did not respond to the question. The following are some isolated comments that were made about construction and maintenance problems using integral abutments:

a. Longer wingwalls may be necessary with cast-in-place, post-tensioned bridges for backwall containment;
b. The proper compaction of backfill material is critical;
c. Careful consideration of drainage at the end of the bridge is necessary;
d. Wingwall concrete should be placed after stressing of cast-in-place, post-tensioned bridges;
e. The effects of elastic shortening after post-tensioning should be carefully considered, especially on single span bridges;
f. Proper placement of piles is more critical than for conventional abutments;
g. Wingwalls may need to be designed for heavier loads to prevent cracking;
h. Adequate pressure relief joints should be provided in the approach pavement to avoid interference with the functioning of the abutment;
i. Possible negative friction forces on the piles should be accounted for in the design; and
j. Wide bridges on high skews require special consideration including strengthening of diaphragms and wingwall-to-abutment connections.

4. REVIEW OF DESIGN AND DETAILS IN SELECTED STATES

Correspondence and telephone visits were conducted with six states to discuss in greater depth the items covered on the questionnaire and to become more familiar with their design rationale for integral abutments. They were Tennessee, Kansas, Missouri, North Dakota, California, and Iowa. Some of the items covered in the visits are discussed below.

4.1. Tennessee

Tennessee has extensive experience with integral abutment construction and performance. It is estimated that over 300 steel and 700 concrete bridges have been built with integral abutments. Mr. Ed Wasserman, Engineer of Structures, Tennessee Department of Transportation, indicated that the state is very pleased with the performance of these structures and has noted no undue stress on the abutments [11].

The maximum length limits using integral abutments were arrived at by setting a limit of expansion or contraction of 1 inch. This figure was developed empirically over a period of several years. By using a simplified column analysis with an unsupported length of 10 feet the state calculated the piling stresses to be just slightly over yield when deflected only 1 inch. Tennessee uses the average AASHTO temperature change of 35° F for concrete structures and 60° F for steel. The maximum bridge lengths (2L) for this allowable deflection (Δ) are about 800 feet (243.84 m) for concrete and 400 feet (121.92 m) for steel:

$$L\ \text{concrete} = \frac{\Delta}{\alpha_c(\delta T)_c} = \frac{1/12}{(0.0000060)(35)} = 396\ \text{feet}\ (120.7\ \text{m})$$

$$L\ \text{steel} = \frac{\Delta}{\alpha_s(\delta T)_s} = \frac{1/12}{(0.0000065)(60)} = 214\ \text{feet}\ (65.23\ \text{m}) \qquad (1)$$

where

α_c = Coefficient of thermal expansion for concrete

$(\delta T)_c$ = Allowable temperature drop or rise for concrete

α_s = Coefficient of thermal expansion for steel

$(\delta T)_s$ = Allowable temperature drop or rise for steel

Tennessee has not completed any research work to verify the assumptions used to develop design criteria other than observing the good performance of constructed bridges. Abutment details used by Tennessee are very similar to those used in Iowa. Timber piles are not used.

4.2. Kansas

Kansas has not participated in formal research activities to formulate design criteria for integral abutments. The length limitations and details used have been developed empirically through many years of experience. The following length limitations have been established: steel, 300 feet (91.44 m) ; concrete, 350 feet (106.68 m) ; and prestressed, 300 feet (91.44 m). Mr. Earl Wilkinson, Bridge Engineer, Kansas State Highway Commission, indicated that a few cast-in-place bridges up to 450 feet (137.16 m) long had been built in the past with integral abutments, but this is not the general rule [12].

Point-bearing steel piles with 9000 psi (6.33×10^6 kgs/sq meter) allowable bearing are used most often. Some concrete filled steel shell piling or prestressed concrete piles are occasionally specified.

4.3. Missouri

Missouri had planned to instrument the piling of an integral abutment several years ago but was unable to do so because of construction timing. No other investigations of integral abutments have since been planned.

Criteria for use of integral abutments have been developed primarily from following the success of other states, notably Tennessee. The maximum length limit for steel bridges has recently been increased from 300 to 400 feet (91.44 to 121.92 m) . Over 100 concrete bridges (mostly prestressed) and over 40 steel bridges have been built with integral abutments over a period of 12-15 years [13].

4.4. North Dakota

North Dakota has built over 300 bridges with integral abutments [14]. Most of these have concrete superstructures. They have had good performance except in two areas. First, the superstructure was originally connected to the backwall with dowel bars which were placed with insufficient cover. In some places the concrete over the dowel bars on the inside face of the backwall cracked because of thermal forces caused by contraction of the superstructure. Second, the piles were originally placed with the webs parallel to the long axis of the bridge. This orientation caused some distress in the backwall since the piles offered relatively large resistance to lateral bridge movements. The problem was eliminated when the piles were installed with the webs perpendicular to the long axis of the bridge.

North Dakota was an early user of integral abutments. Their design criteria are based mainly on their own experience. No formal analysis methods are employed to calculate stresses in the piles. Steel and concrete bridges are currently limited to 300 feet (91.44 m) while prestressed bridges are built up to 450 feet (137.16 m) in length.

Last year the state built a 450-foot (137.16 m) prestressed concrete box beam bridge on a 0 degree skew near Fargo, North Dakota. The piles in the integral abutments were instrumented with strain gauges and had inclinometer tubes attached. Dr. Jim Jorganson, 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. It appears that the maximum total movement at each end is about 2 inches (0.508 cm) [15]. This is equivalent to a temperature variation of about 117° F.

The installation contains a unique feature which was designed by Moore Engineering, 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 upon contraction of the superstructure. The system is shown in Fig. 6 [15].

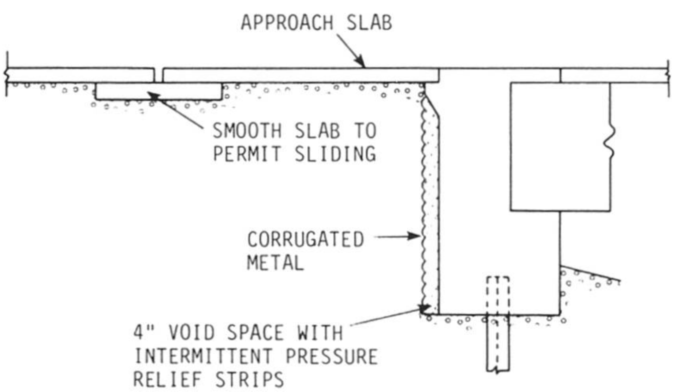


Fig. 6. Integral abutment system with pressure relief strips.

4.5. California

California has engaged in several projects investigating the performance of laterally loaded piles in bridge embankments [16]. This work has been done at California State University at Sacramento and by the California Department of Transportation, Bridge Department. As a result of the research a correlation between the coefficient of subgrade reaction used in an elastic design method and the standard penetration blow count was suggested. Maximum bending moments in steel H-piles were predicted within 15 percent of measured values.

California does not analyze pile stresses due to bending at each bridge site. Guidelines have been developed to aid designers in determining the type of abutment to use. They are currently using integral abutments with concrete bridges up to 320 feet (97.54 m) long. Because of the effects of elastic shortening on application of post-tensioning forces, the length limitation for prestressed bridges is about 100 feet (30.48 m) less. Design of the endwall is based on specified horizontal loads depending on the type of piling used.

4.6. Iowa

Iowa began building integral abutments on concrete bridges in 1965. One of the first was on Stange Road over Squaw Creek in Ames [17]. This prestressed beam bridge is about 230 feet (70.10 m) long with no skew. A visit to this bridge in August 1981 to determine if any apparent distress was evident showed that both approaches were generally in good shape with no major cracking noted. The abutment walls, wingwalls, and beams showed no cracking or distress related to thermal movement.

Mr. Henry Gee, Structural Engineer, Office of Bridge Design, Iowa Department of Transportation, inspected at least 20 integral abutment bridges yearly for about 5 years after construction. They varied in length from 138 to 245 feet (42.26 to 74.68 m) with skews from 0 to 23 degrees. The inspections were terminated since no distress or problems were found which related to the lack of expansion joints in the superstructure.

Iowa's length limitation for integral abutments in concrete bridges is 265 feet (80.77 m). This is based on an allowable bending stress of 55 percent of yield plus a 30 percent overstress since the loading is due to temperature effects. The moment in the pile was found by a rigid frame analysis which considered the relative stiffness of the superstructure and the piling. The piles were assumed to have an effective length of 10.5 feet (3.2 m), and the soil resistance was not considered. The analysis showed that the allowable pile deflection was about 3/8 inch (0.095 cm).

5. SUMMARY AND CONCLUSIONS

The highway departments of all fifty states were contacted to find the extent of application of integral abutment bridges, to survey the different guidelines used for analysis and design of integral abutment bridges, and to assess the performance of such bridges through the years. The survey showed a wide variation in design assumptions and limitations among the various states in their approach to the use of integral abutments. The survey also showed that the variations among the different states are due largely to the empirical basis for development of current design criteria, thereby underscoring the need for a simple, rational method of accurately predicting pile stresses.

The states that use integral abutments indicated that they were generally satisfied with the performance of the bridges and that these bridges were economical. Some problems have been reported, however, concerning secondary effects of inevitable lateral displacements at the abutment. These include abutment, wingwall and pavement distress and backfill erosion. Only a few states noted that any difficulty had been encountered. Other states reported that solutions have been developed for most of the ill effects of abutment movements. They include:

- additional reinforcing and concrete cover in the abutment;
- more effective pavement joints which allow thermal movements to occur; and
- positive control of bridge deck and roadway drainage.

The length limitations on integral abutment bridges used by the different states in 1980 are summarized in Appendix 1. Many of the states have been progressively increasing length limitations for the use of integral abutments over the last thirty years. Improvements in details have also taken place which generally can eliminate the possibility of serious distress occurring with abutment movements of up to 1 inch. These progressive steps in the state of the art of integral abutment bridge engineering have occurred over the past thirty years primarily as the result of the observance of satisfactory performance in actual installations. Very little work, however, has been done to monitor the actual behavior of integral abutments except in checking for obvious signs of distress in visible elements of the bridge.

From comments received from state highway departments on integral abutment bridges, the writers infer that the benefits from using integral abutments are sufficient to justify the additional care in detailing to make them function properly.

6. ACKNOWLEDGMENTS

The study discussed in this article was conducted by the Engineering Research Institute of Iowa State University and was sponsored by the Iowa Department of Transportation, Highway Division, through the Iowa Highway Research Board.

The authors wish to express their gratitude to the bridge engineers in all fifty states for the 100 per cent return rate on the survey questionnaire. In particular, special thanks go to those who provided additional information concerning their design and detailing procedures. The authors also wish to extend sincere appreciation to the engineers of the Iowa DOT for their support, cooperation, and counseling. A special thanks is extended to Charles A. Pestotnik, Henry Gee, Vernon Marks, Kermit L. Dirks, and Wallace W. Sanders, Jr.

REFERENCES

1. "State Highway No. 44 Over Pine Creek, Mellette County, South Dakota," United States Steel Bridge Report, ADUSS 88-7126-01, March 1977.
2. Lee, H. W., and Sarsam, M. B., "Analysis of Integral Abutment Bridges," South Dakota Department of Highways, Pierre, South Dakota, March 1973.
3. "Bridge Planning and Design Manual," Vol. IV, Detailing, California Department of Transportation, Sacramento, June 1979.
4. "Design Manual," Section 3.72, Sheet 4.3.1, Bridge Division, Missouri State Highway and Transportation Commission, Jefferson City, October 1977.
5. Gee, H., "Length Limit of a Bridge Using Integral Abutments," Office of Bridge Design, Iowa Department of Transportation, Ames, February 13, 1969.

6. Emanuel, J. H., et al., "An Investigation of Design Criteria for Stresses Induced by Semi-Integral End Bents," Report, University of Missouri, Rolla, 1972.

7. "Integral, No-Joint Structures and Required Provisions for Movement," Federal Highway Administration, U.S. Department of Transportation, T5140.13, January 28, 1980.

8. Wolde-Tinsae, A. M., Greimann, L. F., and Yang, P. S., Nonlinear Pile Behavior in Integral Abutment Bridges, Final Report, DOT Project HR-227, ISU-ERI-Ames 82123, February 1982, 188 pages.

9. Yang, P. S., Wolde-Tinsae, A. M. and Greimann, L. F., "Nonlinear Finite Element Study of Piles in Integral Abutment Bridges," ERI Project 1501, ISU-ERI-Ames-83068, September 1982.

10. Greimann, L. F., Wolde-Tinsae, A. M. and Yang, P. S., "Skewed Bridges with Integral Abutments," Transportation Research Board, 62nd Annual Meeting, Washington, D.C., January 17-21, 1983.

11. Wasserman, E., Engineer, Office of Structures, Tennessee Department of Transportation, Nashville, Telephone Conversation, May 1981.

12. Wilkinson, E., Bridge Engineer, Kansas State Highway Commission, Topeka, Telephone Conversation, May 1981.

13. Moberly, J., Structural Engineer, Bridge Division, Missouri State Highway and Transportation Commission, Jefferson City, Telephone Conversation, May 1981.

14. Durrow, F., Assistant Bridge Engineer, North Dakota State Highway Department, Bismarck, Telephone Conversation, May 1981.

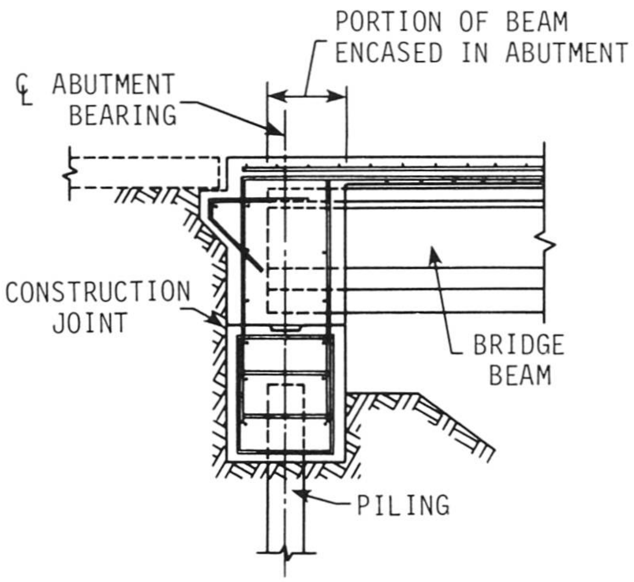
15. Jorgenson, J. L. , Behavior of Abutment Piles in an Integral Abutment Bridge, Final Report, North Dakota State University, No. ND(1)-75(B), November 1981.

16. Cassano, R. C., Chief, Office of Structures Design, California Department of Transportation, Sacramento, Correspondence, 900.05, June 10, 1981, and telephone conversations, June 1.

17. Gee, H., Structural Engineer; Lundquist, W., Bridge Design Engineer; and Miller, G., Geotechnical Engineer; Iowa Department of Transportation, Ames, Conversations, June 1981.

APPENDIX 1. QUESTIONNAIRE FOR BRIDGES WITH INTEGRAL ABUTMENTS

1. Do you use bridge designs with integral abutments and without expansion devices, similar to the following sketch? yes_____ no_____
   Primary (one) reason why, or why not:_______________
   If the answer is no, skip the remainder of the questionnaire and please return.



2. With what type of bridges do you use integral abutments?
   steel______ prestressed concrete______ poured-in-place concrete______

3. What are your maximum length limits (in feet)?

	0°	0° - 15°	15° - 30°	30° < skew
steel	______	______	______	______
prestressed concrete	______	______	______	______
poured-in-place	______	______	______	______
concrete	______	______	______	______

4. What limits, if any, do you place on the piles? (bearing vs. friction, soil type etc.)
   steel pile _______________
   timber pile _______________
   concrete pile _______________

5. What type of structural assumption is made for the end of the girder?
   pinned (moment equal zero) ______
   fixed (rotation equal zero) ______
   partially restrained ______ restrained by pile______ restrained by soil on abut.______
   other assumptions_______________

6. What type of structural assumption is made for the top of the pile?

pinned (moment equal zero) ___
fixed (rotation equal zero) ___
partially restrained ___

Is the joint detailed as a pin? ___
restrained by girder ___
restrained by soil on abut ___

other assumptions ______________________________

7. What loads do you include when calculating pile stress?

thermal ___ temperature range ______________
shrinkage ___
soil pressure on abutment face ___

8. How is bending accounted for in the pile?

Neglect or assume bending stresses do not affect pile performance ___
Assume location of pile inflection point and analyze pile as bending member ___
Reduce bending by prebored hole ___
Other ______________________________

9. What type of backfill material do you specify on the backside of the abutment?

____
____
____

10. Does the approach pavement rest directly on the abutment?

yes ___ no ___

11. Briefly evaluate the performance of integral abutment bridges in your state. (Compare to bridges with expansion devices.)

Construction
relative cost more ___ same ___ less ___
special problems ______________________________
____

Maintenance
relative costs more ___ same ___ less ___
special problems ______________________________
____

Appendix 2. Summary of Responses to Questions 1, 2, 3, 5, 6, and 7.

		Steel			Concrete			Prestressed					Pile Loads		
			Length (ft)			Length (ft)			Length (ft)		Girder End	Pile Top			
State	Reason	Use	≤30*	>30*	Use	≤30*	>30*	Use	≤30*	>30*	Fixity	Fixity	Thermal	Shrinkage	Soil Pressure
AK	Cost	Y	300	---	Y	---	115	Y	416	104	Pin	Pin	Y	N	Y
AZ	Maint	Y	253	N	Y	330	N	Y	404	N	Pin	Pin	Y	Y	Y
CA	Cost	Y	---	---	Y	320	320	Y	230	230	Pin	R. Res	N	N	N
CO	Cost	Y	200	---	Y	400	---	Y	400	---	Pin	Pin	N	N	Y
CT	---	Y	200	---	N	---	---	N	---	---	Pin	Fix	Y	N	N
GA	El. Jt	Y	300	---	Y	300	---	Y	300	---	Pin	---	N	N	N
IA	Cost	N	---	---	Y	265	---	Y	265	---	Pin	Fix	Y	N	N
ID	Cost	Y	200	N	Y	400	N	Y	400	N	Pin	Pin	N	N	N
IN	Cost	N	---	---	Y	---	100	N	---	---	---	---	N	N	N
KS	El. Jt	Y	300	300	Y	350	350	Y	300	300	Pin	Pin	Y	Y	N
KY	Cost	N	N	N	Y	300	N	Y	300	N	Fix	Fix	Y	N	Y
MO	El. Jt	Y	400	---	Y	400	400	Y	500	500	Pin	Pin	N	N	N
MT	Cost	Y	300	N	Y	100	N	Y	300	N	Pin	Pin	N	N	Y
ND	Maint	Y	350	---	Y	350	---	Y	450	---	Pin	Fix	N	N	N
NE	El. Jt	Y	300	---	N	300	---	Y	N	---	Pin	Pin	Y	N	N
NM	El. Jt	Y	---	---	Y	---	---	Y	---	---	P. Res.	P. Res.	Y	Y	Y
NY	Cost	Y	305	---	---	---	---	---	---	---	Pin	---	Y	N	N
OH	Cost	Y	300	300	Y	300	300	Y	300	300	Pin	Pin	N	N	N
OK	---	Y	200	N	Y	200	N	Y	200	N	P. Res.	P. Res.	N	N	N
OR	El. Jt	Y	N	N	Y	350	300	Y	350	300	Pin	Pin	N	N	N
SD	Cost	Y	320	---	Y	450	---	Y	450	---	Pin	Fix	N	N	N
TN	El. Jt	Y	400	400	Y	800	800	Y	800	800	Pin	Pin	N	N	N
UT	El. Jt	Y	300	250	N	---	---	Y	300	250	Pin	Pin	N	N	N
VA	Simp.	Y	242	---	N	---	---	Y	454	---	Pin	Pin	N	N	Y
VT	Cost	Y	150	100	N	N	N	N	N	N	P. Res.	P. Res.	Y	N	N
WA	Cost	N	---	---	Y	350	---	N	---	---	Pin	Pin	N	N	N
WS	Cost	Y	200	200	Y	300	N	Y	300	300	P. Res.	Fix	N	N	N
WY	Simp.	Y	300	300	Y	500	500	Y	500	500	Pin	Pin	N	N	N
R15	El. Jt	N	N	N	Y	270	160	Y	300	240	P. Res.	Pin	N	N	N

Y Yes
N No
--- No Response
* Bridge skew in degress
Note: 1 ft = 0.3048 m

Appendix 2 (Continued). Summary of Responses to Questions 8, 9, 10, and 11.

		Pile Bending			Approach	Construction Cost			Maintenance Cost		
State	Neglect	Infl. Pt.	Prebore	Backfill	Pavmt. on Abutment	More	Same	Less	More	Same	Less
AK	Y	Y	N	Gran.	N	N	N	Y	N	N	Y
AZ	Y	N	N	Cohes.	Y	N	N	Y	N	N	Y
CA	Y	N	N	Perv.	Y	N	N	Y	N	N	Y
CO	Y	N	Y	Gran.	Y	N	N	Y	N	N	Y
CT	Y	N	N	Perv.	Y	N	N	Y	N	N	Y
GA	Y	N	N	Rd. Fill	Y	N	N	Y	N	N	Y
IA	N	N	Y	Gran.	Y	N	N	Y	N	N	Y
ID	Y	N	N	Rd. Fill	Y	N	N	Y	N	N	Y
IN	Y	N	N	Gran.	Y	N	N	Y	N	N	Y
KS	Y	N	N	Rd. Fill	Y	N	N	Y	N	N	Y
KY	N	Y	Y	Gran.	N	N	N	Y	N	N	Y
MO	Y	N	N	Rd. Fill	Y	N	N	Y	N	N	Y
MT	Y	N	N	Gran.	Y	N	N	Y	N	N	Y
ND	Y	N	N	Gran.	Y	N	N	Y	N	N	Y
NE	Y	N	N	Rd. Fill	Y	N	Y	N	N	N	Y
NM	N	Y	N	Rd. Fill	Y-N	N	N	N	N	N	N
NY	Y	N	N	Gran.	Y	N	N	Y	N	N	Y
OH	Y	N	N	Gran.	Y	N	N	Y	N	N	Y
OK	Y	N	N	---	Y	N	N	Y	N	N	Y
OR	Y	N	N	Gran.	Y	N	N	Y	N	N	Y
SD	N	N	Y	Gran.	Y	N	N	Y	N	N	Y
TN	Y	N	N	Gran.	Y	N	N	Y	N	N	Y
UT	Y	N	N	Gran.	Y	N	N	Y	N	N	Y
VA	Y	N	N	Gran.	N	N	N	N	N	N	N
VT	Y	N	N	---	N	N	N	Y	N	N	Y
WA	N	N	N	Gran.	Y	N	N	Y	N	N	Y
WS	Y	N	N	Gran.	N	N	N	Y	N	N	Y
WY	Y	N	N	Gran.	Y	N	N	Y	N	N	Y
R15	Y	N	N	Perv.	Y	N	N	Y	N	Y	N

Y Yes
N No
--- No Response

Appendix 2 (Continued). Summary of Responses to Question 4.

State	Steel	Timber	Concrete
AK	*	*	*
AZ	9 ksi in Brg., <9 ksi in Fric.	Not used	In friction only
CA	Assume 5 kips Lat. Resis./pile	Same as steel	13 k. Lat. R./pile
CO	*	Not used	Not used
CT	Use in bearing	---	---
GA	Use in weak axis	Not used	Not used
IA	Use in weak axis, Fric. only	Use of Br. Length < 150'	Not used
ID	*	Not used	Not used
IN	Use H-pile or shell	---	---
KS	Mostly used in bearing	Mostly used in bearing	Mostly used in Brg.
KY	Use in Brg. or friction	---	Used in friction
MO	10' minimum length	Not used	Used in friction
MT	9 ksi in bearing	Used in friction	Not used
ND	*	*	*
NE	Used in weak axis	---	---
NM	Use steel only	Not used	Not used
NY	*	Not used	*
OH	*	Not used	*
OK	Use in bearing	Not used	Not used
OR	*	Not used	*
SD	*	*	*
TN	*	Not used	*
UT	Use in single row	Use in single row	Use in single row
VA	Upper portion allowed to flex	---	---
VT	15' minimum length	Not used	Not used
WA	Use in bearing or friction	Use in Brg. or Fric.	Use in Brg. or Fric.
WS	Use in bearing or friction	Use in friction	Use in Brg. or Fric.
WY	Use in bearing or friction	Not used	Not used
R15	Use in weak axis	Not used	Not used

*No limitations.

---No response.

Note: 1 ft = 0.3048 m, 1 k = 453 kg, 1 ksi = 70.3 kg/sq cm