FOUNDATION TYPES FOR INTEGRAL ABUTMENTS

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ABSTRACT

Clearly, integral abutments can be used for much longer precast prestressed concrete girder bridges than steel girder bridges due to the smaller thermal expansion coefficient of precast concrete members. Understanding the application of different integral abutment foundation types for various site conditions would broaden the application of integral abutments for precast prestressed concrete girder bridges.

In this paper, integral abutment foundation design concepts, such as fixed-head pile, pinned-head pile, hinged abutment, fixed-base pile, prebored hole, and sleeved pile are presented. Depending on bridge length, skew, and site conditions, H-pile, precast prestressed-concrete pile, pipe pile (steel encased concrete pile or metal shell pile), timber pile, combined H-pile (or W-section) and drilled shaft, caisson wall, drilled shaft, sheet pile, and spread footing can be used to support integral abutments. Several design methods for typical integral abutment bridges are reviewed in this paper as well.

With increasing interest in accelerated bridge construction (ABC) around the country, this paper reviews several departments of transportation policies on the use of precast prestressed concrete piles for integral abutments. In a recent prefabricated bridge designed by Parsons, the schedule saving for using precast pile caps at integral abutments and cost comparison of ABC with conventional cast-in-place concrete are presented.

Keywords: Integral Abutments, Foundation**,** Precast Prestressed Concrete Girders, Accelerated Bridge Construction, Bridges.

INTRODUCTION

By eliminating expansion joints and expansion bearings, integral abutment bridges reduce the cost for construction and maintenance. This type of bridge can increase design efficiency, add redundancy and capacity for catastrophic events, enhance load distribution for girders at bridge ends, speed up construction, reduce tolerance problems, and provide greater end span ratio ranges.

Clearly, integral abutments can be used for much longer precast prestressed concrete girder bridges than steel girder bridges due to the smaller thermal expansion coefficient of precast concrete members. Understanding the application of different integral abutment foundation types for various site conditions would broaden the application of integral abutments for precast prestressed concrete girder bridges.

In this paper, integral abutment foundation design concepts, such as fixed-head pile, pinned-head pile, hinged abutment, fixed-base pile, prebored hole, and sleeved pile are reviewed. The typical foundation type for support of integral abutments is the steel H-pile. Depending on bridge length, skew, and site conditions, other types of foundations, such as precast prestressed-concrete pile, pipe pile (steel encased concrete pile or metal shell pile), timber pile, combined H-pile (or W-section) and drilled shaft, caisson wall, drilled shaft, sheet pile, and spread footing can be used to support integral abutments. Several design methods for typical integral abutment bridges are reviewed[1].

With increasing interest in accelerated bridge construction (ABC) around the country, this paper reviews several departments of transportation policies on the use of precast prestressed concrete piles for integral abutments. In a recent prefabricated bridge designed by Parsons, the schedule saving for using precast pile caps at integral abutments and cost comparison of ABC with conventional cast-in-place concrete are presented.

DESIGN CONCEPTS

For an integral-abutment bridge, the overall concept is to accommodate the expansion and contraction due to temperature change by flexibility in the abutment foundations and pavement expansion joints, rather than by bridge expansion joints. The thermal expansion and contraction over the length of the bridge can be easily determined; creep, shrinkage and elastic shortening may be added. Some states limit the total amount of movement to be taken by integral-abutment foundations in the range from ½-inch to 4-inches[2]. Other states limit movements indirectly by limiting bridge length[3]. An overview of some design policies on integral abutments is presented in Table 1.

Once movements and the owner’s policy on the use of integral-abutment are known, the designer can use structural principles and detailing to design the integral abutments, considering soil-structure interaction. The different design concepts for integral abutments, such as fixed-head pile, pinned-head pile, hinged abutment, fixed-base pile, prebored hole and sleeved pile, are outlined as follows:

Table 1. Overview of State Departments of Transportation Design Policies on Integral Abutments

State	Bridge Length Limits [1]	Skew Limits	H-Pile orientation	Prebored Hole Depth	Pile Embedment
Colorado	640 feet (steel) 790 feet (conc.)		strong		1 foot
Illinois	310 feet (steel) 410 feet (conc.)	30	strong		2 feet
Indiana	500 feet (steel) 500 feet (conc.)	30	weak	8 feet	2 feet
Iowa	400 feet (steel) 575 feet (conc.)	45	weak	10 to 15 feet	2 feet
Maine	200 feet (steel) 330 feet (conc.)		weak		2 feet
Michigan	300 feet (steel) 400 feet (conc.)	30	strong	[2]	2.5 feet
Minnesota	300 feet	20	weak		2.5 feet
Nebraska		30	weak	[2]	
New Jersey	450 feet	30	weak	8 feet	
New York	330 feet	45	weak or strong	8 feet	
North Dakota	400 feet	30	weak		3 feet
Ohio	400 feet	30	weak		
Pennsylvania	590 feet (steel) 390 feet (conc.)	20-45	weak	10'	1.5 feet
Tennessee	500 feet (steel) 800 feet (conc.)		strong		1 foot
West Virginia	2 inches	30	weak	10 to 15 feet	1 foot

Notes:
[1] Total jointless bridge length or maximum total superstructure movement.
[2] Predrilled hole to be determined by geotechnical engineer.
Conc. indicates a concrete superstructure
Steel indicates a steel superstructure
Blank indicates either that there is no state standard or that the information was not available to the authors.

FIXED-HEAD PILE

Fixed-head pile is the most commonly used detail for integral-abutment bridges. The top-of-pile connection is detailed to provide continuity between the pile and superstructure by means of embedment, as indicated in the typical Colorado detail[4] in Fig. 1.

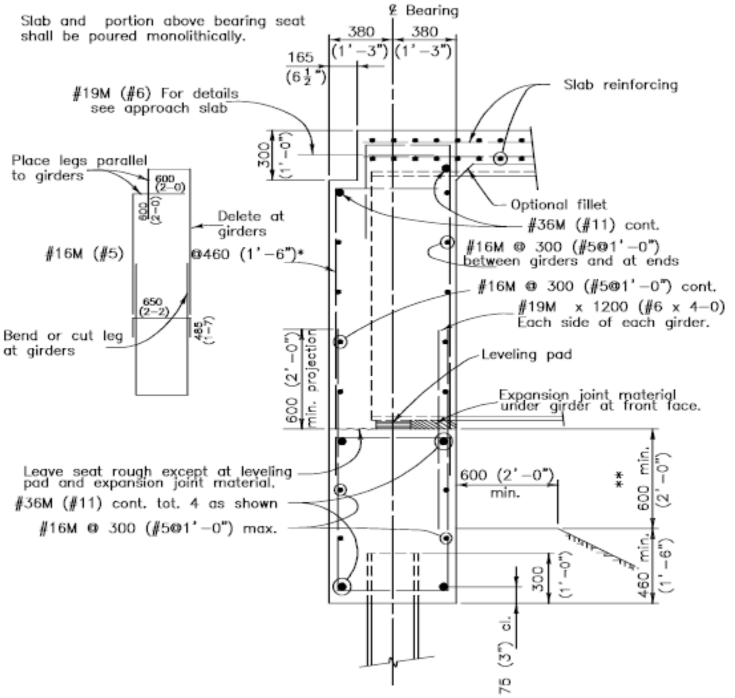
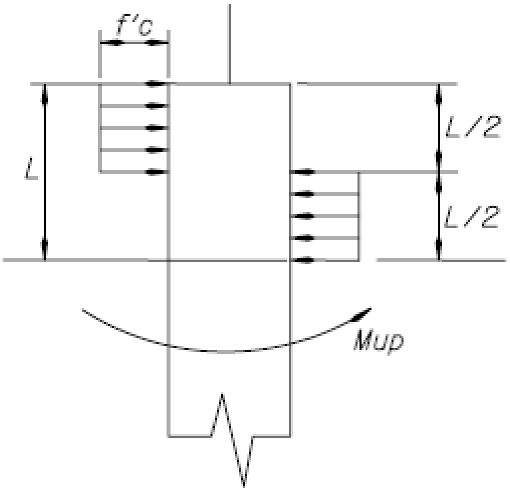


Fig. 1. Fixed-Pile Head Detail (Colorado)[4]

Simple computations show that 12-inch embedment in 3 ksi concrete is sufficient for fixity of an HP 10x42 oriented for strong axis bending[5]. In tests conducted by the University of Tennessee, a 12-inch embedment resulted in some cracking, but adequate performance at large, lateral displacements. A 24-inch embedment increased moment development at the pile head[6]. Some states use 12-inch embedment while others use 24-inch or 30-inch embedment. The following equation is used in Oregon to determine the embedment length with a minimum of 12-inches[7]:



$$Mup = \phi\, f'c\, D\left(\frac{L}{2} \times \frac{3L}{4} - \frac{L}{2} \times \frac{L}{4}\right)$$

$$Mup = \phi\, f'c\, D\, L^2\, (3/8 - 1/8)$$

$$4Mup = \phi\, f'c\, D\, L^2$$

$$L = \sqrt{\frac{4Mup}{\phi\, f'c\, D}}$$

Where f'_c is the concrete strength. D is the pile diameter or H-pile depth. ϕ is the strength reduction factor. M_{up} is the factored moment at the top of the pile.

Some states such as Indiana extend the piling to directly connect superstructure girders as shown in Fig. 2. The advantage of this detail is that the stub abutment may be cast in a single pour.

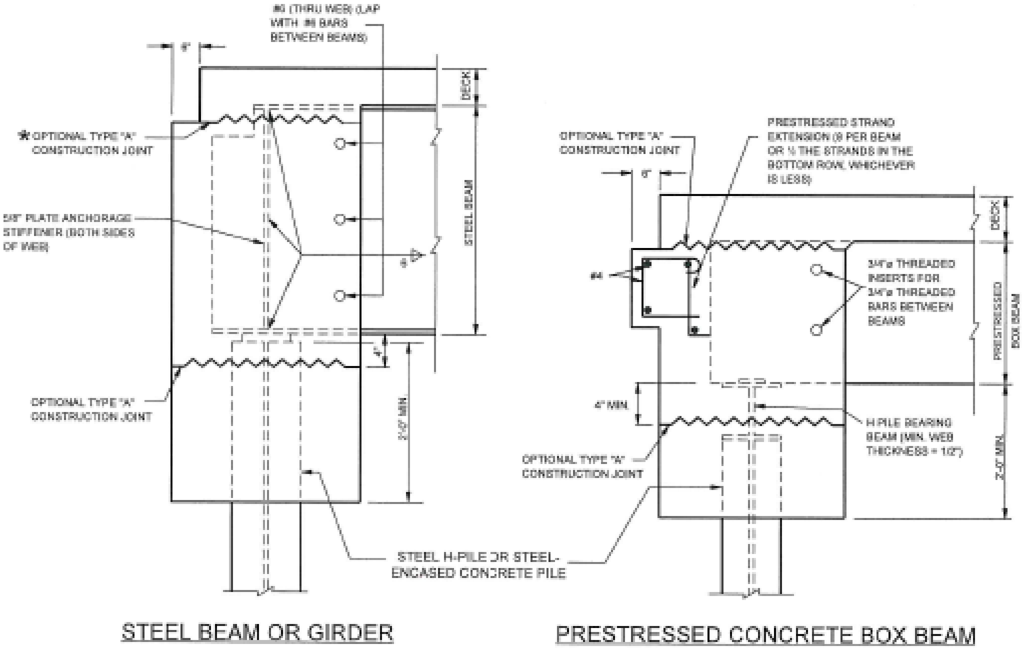


Fig. 2. Beams Attached Directly to Piling (Indiana)

PINNED-HEAD PILE

Pinned-head pile can be used in situations where it is desirable to reduce the pile bending stress induced by the rotations at the end of the superstructure under live loads and composite dead loads, reduce maximum bending stress in the pile or move the maximum bending stress in the pile downward. Fig. 3 illustrates the use of padding to create a pinned connection at the head of a timber pile[8].

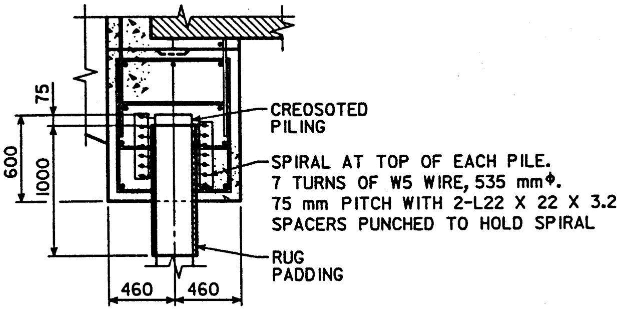


Fig. 3. Pinned-Pile Head Detail (Iowa) (Unit: mm)[1]

PRESTRESSED-CONCRETE PILES

Prestressed-concrete piles have been tried on an experimental basis in Iowa with essentially the same padding detail as for timber piles[9]. The University of Nebraska has tested a different padding and slip detail for prestressed-concrete piles. The detail had a plastic foam cap 2-inch thick, topped with an elastomeric pad and sliding bearing plate[10].

HINGED ABUTMENT

Hinged abutment can be used to reduce the pile bending stress induced by the rotations at the end of the superstructure under live loads and composite dead loads. Using a hinged-abutment head also has the effect of shifting the maximum bending stresses in the pile downward away from the pile head. Some states prefer to provide hinging action by detailing the abutment, rather than the pile connection with capacity to rotate as illustrated in Fig. 4. Virginia has revised its hinged-abutment detail on the basis of testing by isolating the upper and lower parts with a ½-inch neoprene bearing strip and transferring shear with a padded dowel[11]. Researchers called this type of abutment as semi-integral, but others consider the abutment integral[12].

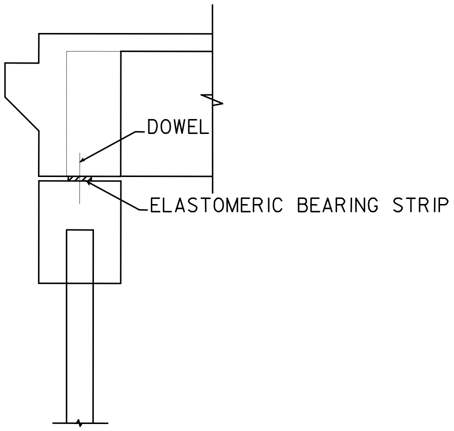


Fig. 4. Hinged-Abutment Concept

Michigan DOT employs a detail similar to Fig. 4 except 1-inch joint filler is used between the stub abutment base and backwall instead of an elastomeric bearing strip. Even though it is waterproofed, the joint introduced into the abutment by these details does provide an avenue for water to seep through.

FIXED-BASE PILE

Fixed-base pile can be used for situations where bedrock is close to the surface. The rock can be cored to a predetermined depth and steel H-piles anchored in concrete in the core holes, as shown in Fig. 5. Details for the I-235 bridge in Des Moines, Iowa, show a variable amount of coring in response to a sloping bedrock surface. The elevation of the bottom of the holes was set to give the piles sufficient length to flex as the bridge expands and contracts[13]. With a relatively shallow depth to reach bedrock the designer should check ductility to ensure that the pile can sustain plastic deformation[14,15].

To increase flexibility the piles may be placed in prebored holes filled with flexible material. Most states make the holes 10-feet deep as shown in Table 1. Deeper holes may be used for special conditions[8]. The holes are typically filled with a deformable material, such as bentonite slurry, loose sand, or pea gravel. In addition to increasing pile flexibility, prebored holes have the advantage of eliminating downdrag from compressible fills.

PILE SLEEVE

Pile sleeve is typically used in cases where a mechanically-stabilized earth (MSE) wall is placed in front of abutment. Due to the construction sequence for an MSE wall, prebored holes are not feasible. Therefore, the piles should be placed in corrugated-metal pipe (CMP) sleeves at least twice the diameter of the pile to avoid additional lateral pressure on the MSE wall[13]. In Iowa the sleeves are filled with saturated sand up to the elevation where a prebored hole would begin, as shown in Fig. 5. Above the top of sand the sleeves are filled with bentonite slurry. As with prebored holes the sleeves can be used to eliminate downdrag on the piles and minimize the potential damage during compaction of backfill material behind the MSE wall.

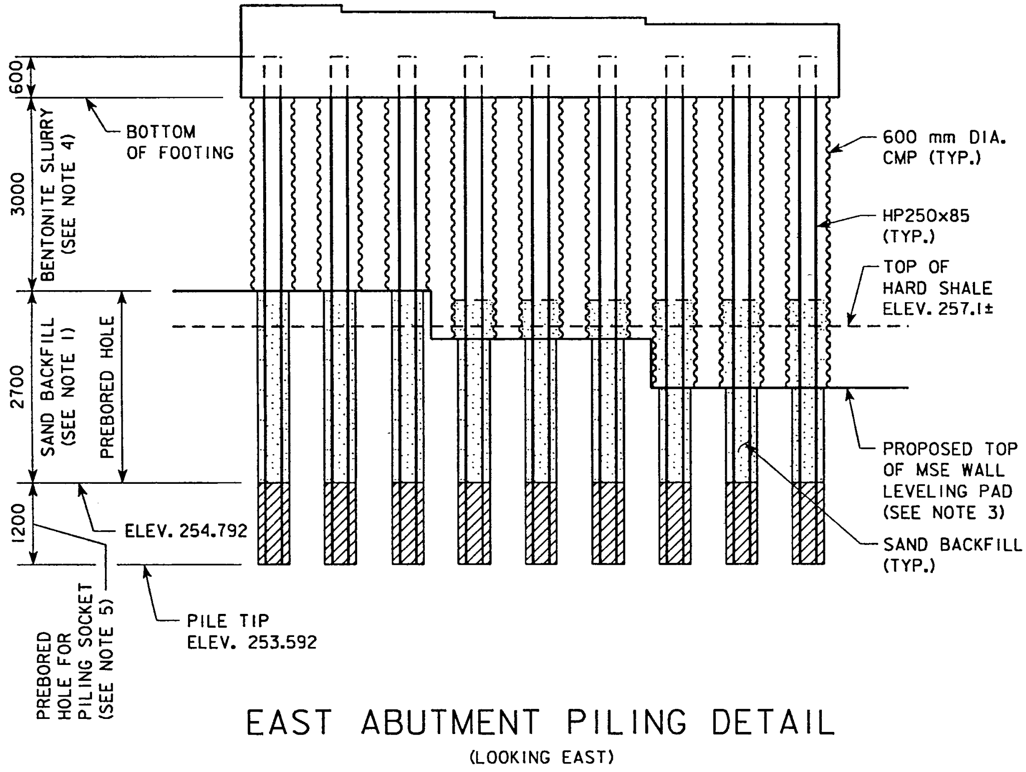


Fig. 5. Fixed-Base and Sleeved-Pile Details[1]

ASYMMETRY

Asymmetry occurs when the structural unit has only one integral abutment. Such a case occurs with a long viaduct that has intermediate expansion joints. It is not feasible to have two integral abutments with a single jointless bridge unit. In a recent Iowa U.S. 20 project, Parsons designed four asymmetric integral-abutment-bridge units as the first units of long approach viaducts to main river bridges. These structures are either three-span approach bridge units or three-span ramp bridges. The first two piers adjacent to the integral abutment are fixed piers and an expansion joint is located at the third pier with many viaduct spans following. These designs used wire-faced MSE behind the integral abutments to relieve the earth pressure and piles were set in CMP sleeves. The fixed point or the point of no movement falls between pier 1 and pier 2.

The integral abutment concepts described above are not all of the possibilities. More are described in the next section under foundation types, and a new concept, precast integral abutments, will be covered in the last section.

Although the designer needs to carefully consider unusual bridge configurations and site conditions, soil-structure interactions often are not easily quantified. Engineering judgment is important and must be part of the design process.

FOUNDATION TYPES

The most common foundation for integral abutment bridges is the steel H-pile. However, in some soils a displacement pile is needed. Some states permit precast prestressed concrete piles, pipe piles, and timber piles. For relatively short bridges, even relatively stiff foundations such as drilled shafts and spread footings are in use.

STEEL H-PILE, WEAK AXIS AND STRONG AXIS BENDING

Nearly half of the states responding to a recent survey preferred steel H-piles oriented for weak axis bending; whereas, one-third preferred the piles oriented for strong axis bending[3]. Because several researchers have measured strains on fixed head H-piles approaching yield strains, there is concern for pile yield. An argument for weak-axis orientation is that only the tips of flanges will yield under large-bending stresses, leaving the basic core of the pile to carry vertical load. Because of the possibility of yield, Iowa prefers H-piles with relatively compact flanges. Live, impact, and superimposed dead load in end spans cause fixed-pile-head moment due to rotation of the pile in compatibility with the girder rotation. Therefore, Iowa limits maximum end-span lengths to 155 feet for prestressed concrete beam bridges and, depending on skew, to 150 feet for continuous-welded, plate-girder bridges. Overall bridge lengths are limited to 575 feet for 0-degree skew and 425 feet at 45-degree skew for prestressed-beam bridges. Overall bridge lengths are limited to 400 feet for 0-degree skew and 300 feet for 45-degree skew for continuous-welded, plate-girder bridges. Iowa policy permits longer end spans with prebored holes deeper than the standard 10 feet[8].

PRESTRESSED CONCRETE PILE

Considering the concern about pile flexibility and behavior under high-bending stresses, very few states permit use of prestressed concrete piles for integral abutments. A recent national survey conducted by Iowa State University researchers indicated that seven agencies permit use of prestressed concrete piles in integral abutments. Because Iowa counties have an interest in using prestressed concrete piles, researchers recently tested a county bridge in service that used two layers of carpet padding at pile heads, similar to the Iowa timber pile detail in Fig. 3[9].

Although an Iowa designer used padding, and Nebraska researchers have investigated a padded pile head/sliding plate detail[10], Tennessee uses prestressed concrete piles simply embedded in integral abutments. Tennessee regularly uses prestressed concrete piles in western Tennessee because of soil conditions different from eastern and central Tennessee, where H-piles are used. Tennessee limits one-directional pile head movement to 2-inches for H-piles, but tests suggest that 1 1/2-inches also would be a reasonable limit[6]. In testing, the prestressed concrete piles were embedded 12 inches in the abutment without padding and driven without prebored holes into undisturbed firm to moderately firm clay.

PIPE PILE

Pipe pile is also called steel-encased concrete pile, metal-shell pile, and cast-in-place pile. Several states permit pipe piles in integral abutments; however, because the piles are not as flexible as H-piles the states set shorter maximum bridge lengths. Illinois permits 14-inch diameter metal-shell piles for structure lengths up to 200 feet[16]. New Jersey and New York permit cast-in-place (CIP) piles for structures with lengths of 165 feet or less[17,18].

TIMBER PILE

At this time Iowa is the only state known to permit timber piles in integral abutments[10]. Timber piles may be used without padding for a bridge length of less than 150 feet. Padding is required for bridge lengths of 150 feet to 200 feet (Fig. 3). Skew must not exceed 30 degrees. For bridge lengths less than or equal to 130-feet, prebored holes are not required. For lengths more than 130-feet, 10-foot, prebored holes filled with bentonite slurry are necessary[8].

COMBINED PILE AND DRILLED SHAFT

When adjacent structures are sensitive to vibration, or driving problems may occur for H-piles, there is an innovative option. H-piles or W-shapes can be used in the top portion of the foundation, and the bottoms of the H-piles or W-shapes can be embedded in cast-in-place drilled shafts, either full length or partial length, as shown in Fig. 6. This hybrid foundation system, called stabbed shaft or stabbed pile, can provide the flexibility that is needed for integral abutments, and at the same time avoid any problems associated with pile driving. H-piles or W-shapes in the foundation are designed as frame members. The typical H-pile allowable stress of 6 ksi or 9 ksi is not applicable because there is no driving operation involved[19]. In the recent Southeast Corridor Multi-Modal Project (T-REX) in Denver, Colorado, several integral bridges utilized stabbed pile system where W-section was placed in the upper portion of the foundation and extended to the bottom of the drilled shaft to eliminate the need of reinforcement. Stabbed piles were also used for the 9th Street Bridge over I-235 in Des Moines, Iowa and the U.S. 20 Bridge over Locust Street in Dubuque, Iowa. In the Iowa bridges the H-pile was placed in the upper portion of the foundation and extended about 6-feet into top portion of the reinforced drilled shaft. Drilled shafts were used at the 9th Street Bridge because pile driving induced vibration could not be tolerated by nearby structures. At the U.S. 20 Bridge, drilled shafts were used to limit vertical migration of subsurface hydrocarbon contaminates.

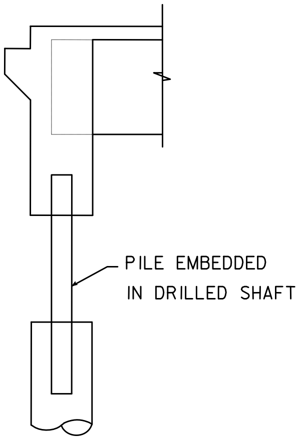


Fig. 6. Stabbed-Pile Foundation Concept[1]

CAISSON WALL

In locations where MSE-retaining wall is not feasible because of right-of-way restrictions or in regions of cut, caissons (The term caisson is used here for drilled shaft to call attention to the different concept.) can be used to construct a wall that provides both earth retention and foundation to support integral abutments. In comparison with conventional construction, caisson-wall construction can reduce the structure footprint significantly. On the T-REX project a 4-foot diameter caisson wall was used to support integral abutments for a spread box girder bridge as shown in Fig. 7. The caissons were closely spaced at 4.5-feet center-to-center. The gaps between the caissons were sealed with shotcrete[19].

Since drilled shafts are not as flexible as H-piles, drilled shafts are rarely used to support integral abutments, and the stabbed pile discussed above is the better choice. However, on the T-REX project caisson walls were used in short simple-span integral-abutment bridges and in long-span semi-integral abutment bridges in which expansion devices with sliding plates and elastomeric pads were used to reduce the demand for foundation flexibility[19]. With expansion devices those abutments could be considered semi-integral.

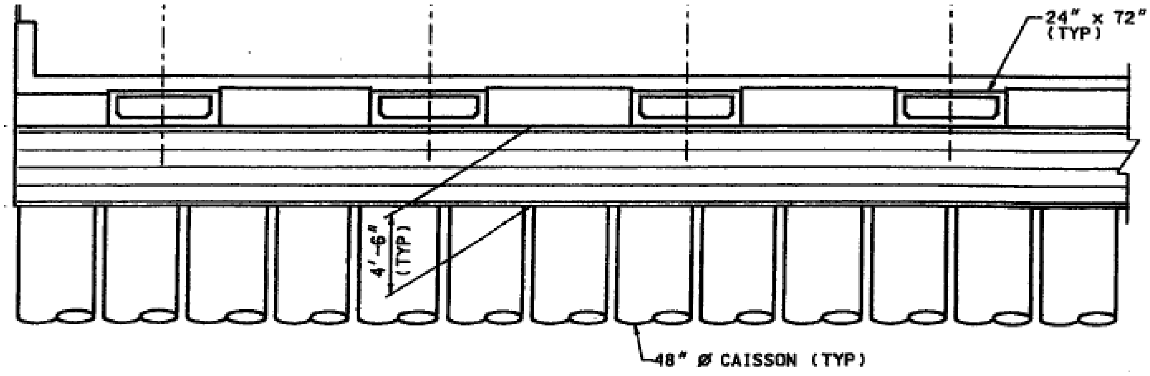


Fig. 7. Caisson Wall Elevation (Colorado)

SHEET PILE

Evidently sheet-pile abutments have had greater use in Europe than in the United States. Sheet-pile, integral abutments are used in the United Kingdom[20]. In a few cases, integral-sheet, pile abutments have been used for short bridges in the United States[21].

SPREAD FOOTING

Spread footings are not used often in the United States for integral abutments, and use is limited to relatively short bridges. In Maine this type of foundation may be used to support integral abutments for steel structures up to 80-feet long and concrete structures up to 140-feet long with abutments up to 8-feet tall and skews up to 25 degrees[22]. Tennessee allows spread footings on rock for movement of 1/4-inch or less at each abutment[12]. In 2008 a single-span 50-feet long precast prestressed voided slab bridge was constructed in Oregon with 11-foot tall integral abutments founded on spread footings.

The foundation types described above are not all of the possibilities. Many creative solutions for challenging integral abutment applications can be conceived and designed as long as the foundation provides adequate flexibility for the superstructure movement.

DESIGN METHODS

There are several methods for conducting an analysis of integral-abutment piles. Research at Iowa State University has led to two cantilever-pile analysis alternatives; one considers only elastic stresses and a second considers plastic stresses and displacement demand[14]. The method was validated for two bridges[23].

Wasserman has developed an equivalent column procedure by using the COM624P pile-analysis program[5] (similar to LPILE), and the method has been corroborated by research at University of Tennessee[6].

Another rational approach, although more complex, is use of the COM624P program and a two-dimensional frame model. The three-dimensional finite element model often used by university researchers may not be practical for design engineers.

To encourage use of integral abutments and speed design of typical bridges, many states have developed design rules based on typical site conditions, analysis, preferred details, and experience. These design rules vary considerably because some states arbitrarily impose conservative limits. What is interesting at this time is that researchers with different viewpoints, such as lateral-load test results, low-cycle fatigue analysis, and ductility analysis are proposing very similar bridge length limits. Differences in climate and superstructure material establish the amount of movement. That movement obviously has an effect on maximum bridge length. Skew and yield strength of H-piles also have some effects. Although prebored holes seem necessary for longer spans, the testing by the University of Tennessee suggests that ultimate performance may be satisfactory without the holes[1].

PRECAST INTEGRAL ABUTMENTS

For the past few years, the interest of the use of accelerated bridge construction (ABC) by different states and agencies has been growing rapidly, and integral abutments can be part of an ABC project. Accelerated bridge construction using prefabricated bridge components and systems has many advantages over conventional cast-in-place construction. Prefabrication speeds up construction and increases quality of concrete members by fabricating in a controlled plant environment with reduced dependency on weather. Prefabrication also increases construction safety by avoiding forming, rebar placement, concrete placement and curing at bridge sites. The reduction of traffic closure duration and environmental impact are other benefits for using ABC.

PRECAST FOUNDATION

As described above, only a few states allow the use of precast, prestressed concrete piles for integral abutments and these precast piles are limited to shorter span integral abutment bridges. However, several tests conducted by University of Tennessee show prestressed concrete piles can be used for much longer integral abutment bridges. Their recommendation for allowable superstructure one-way movement is 1.5-inch.

New Jersey and Tennessee are two states allowing the use of precast, prestressed concrete piles for integral abutments. The bridge length limit is 150 feet in New Jersey.

PRECAST PILE CAP

Clearly, it is beneficial to use prefabricated pile caps for integral abutments. Precast integral abutments weigh much less than conventional abutments such as full height abutments, and they are much easier to handle during erection because only single row of piles are to be adjusted into precast pile cap pocket voids. The challenge to use precast pile cap is to provide proper connection details between pile head and pile cap. This is especially true for moderate and high seismic regions.

Precast/Prestressed Concrete Institute (PCI) provides some guidelines for precast pile cap construction. PCI recommends two methods for preparing the area for installation of a precast pile cap. The first is to pour a low-strength concrete sub-footing to level the surface. The second method is to provide small level areas under the proposed leveling devices. After the precast pile cap is in place, self-consolidating concrete is recommended to fill the void around the piles[24].

APPLICATION

Recently, Parsons designed Michigan's first prototype prefabricated bridge. The Parkview Avenue Bridge over U.S. 131 is a four-span, precast, prestressed concrete I-girder structure. Figs. 7 and 8 show the bridge elevation and typical cross section. The prefabricated systems or components used in this bridge are full depth deck panel, precast pile cap at abutments, precast pier caps and columns. The only non-prefabricated components are cast-in-place pier footings, steel H-piles at abutments and concrete barriers. During the bridge type study, both precast, prestressed concrete I-beams and steel wide flange beams were considered as superstructure types. MDOT decided to use precast, prestressed concrete I-beams for final design.

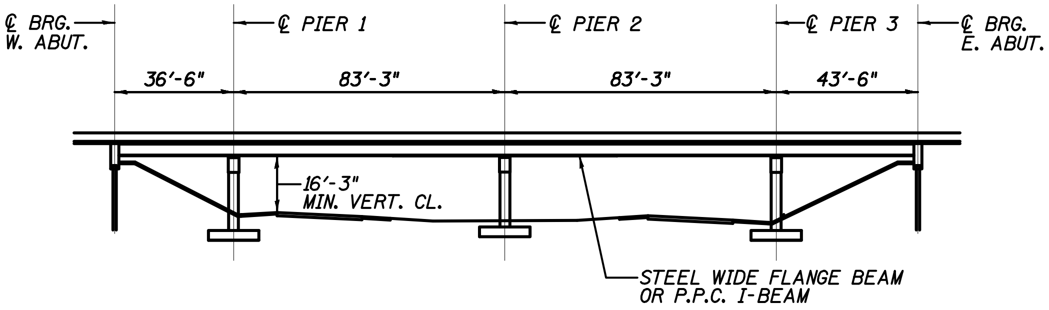


Fig. 7 Bridge Elevation

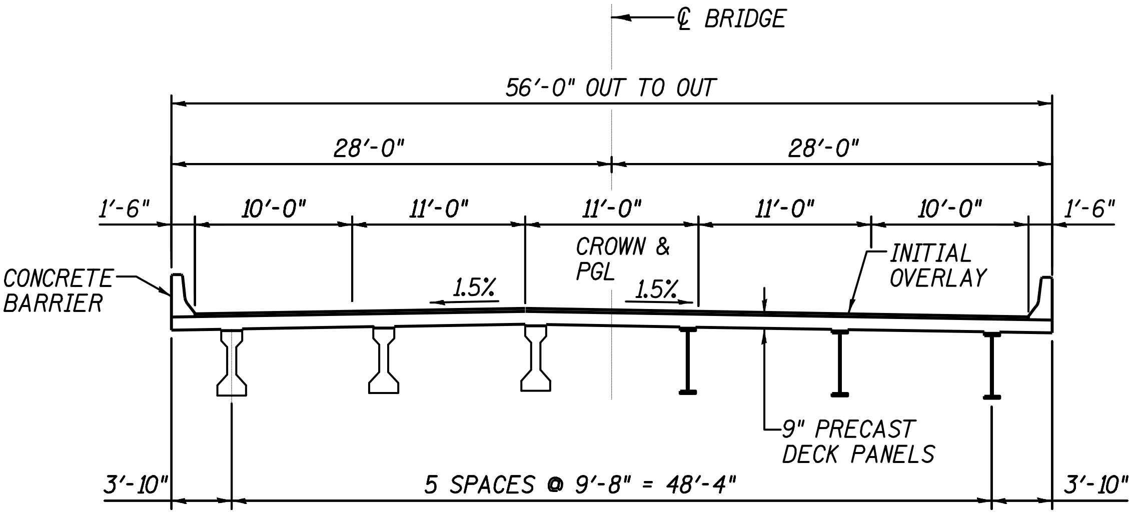


Fig. 8 Typical Bridge Section

Figs. 9 and 10 show the precast pile cap section and the erection of pile cap. Due to the weight limits, the pile cap consists of two segments that were spliced near the centerline of the bridge. The longest segment weighs about 66 tons. Once the pile cap was in place, the voids/pockets around pile head were filled with grout.

Schedule savings are presented in Table 2. Seven calendar days were saved by using precast pile caps for integral abutments, although the greatest construction schedule savings occurred with precast pier and full depth deck panels.

Table 3 shows the comparison of ABC bridge cost against conventional bridge cost but does not break out abutment costs. The cost data shows there is a premium for using prefabricated bridge systems or components, but the cost savings to reduce the traffic closure or traffic detour could be very appealing for urban area or areas where much longer detours would be required.

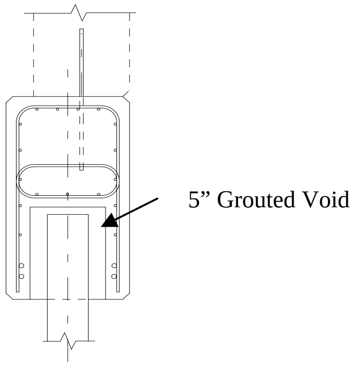


Fig. 9 Precast Integral Abutment Section

Fig. 10 Erection of Precast Integral Abutment Pile Cap[25]

Table 2 Schedule Savings[25]

Element	ABC	Conventional	Savings
Abutments	25	32	7
Piers	20	41	21
Girders	10	10	0
Diaphragms	10	10	0
Deck	22	43	21
Barriers	14	14	0
TOTAL:	73	129	56

Notes:
[1] Units are calendar days.
[2] Notice to proceed of 7-Apr-08 and completion by 27-Jun-08 (81 days)

Table 3 Project Cost[25]

Element	ABC Cost	Conv. Cost	Delta
Bridge & Approach	$2,859,512	-	-
Bridge Cost	$1,880,722	$1,315,190	43%
Bridge Cost per SF	$143	$100	43%
Bridge Deck Cost	$494,850	$325,560	52%
Bridge Deck Cost per SF	$38	$25	52%

Notes:
[1] ABC bridge deck cost includes panels, post-tensioning, forming, grouting, and closure pour.
[2] ABC for prototype bridge cost $10,100 per day of schedule saved.

CONCLUSIONS

With the advantages of simple design, easy detailing, quick construction, and minimal maintenance, integral-abutment bridges have been used in many states. The fixed-head H-pile is the most commonly used foundation type in integral-abutment bridges. Other design concepts, such as pinned-head pile, hinged abutment, fixed-base pile, and pile sleeves can also be used[1].

Depending on bridge lengths and site conditions, the foundation types that can be used for integral abutments include end-bearing H piles, friction-bearing H piles, precast prestressed-concrete piles, pipe piles (steel-encased concrete piles or metal-shell piles), combined H-piles (or W-sections) and drilled shafts, caisson walls, drilled shafts, sheet piles, and spread footings. Several methods are readily available for design of typical integral abutments[1].

Integral abutments can easily fit into accelerated bridge construction (ABC) projects. Utilization of precast integral abutment pile caps can speed up construction and increase job site safety. Depending on the site conditions and departments of transportation policies, precast prestressed concrete piles can be used with precast pile caps for integral abutment bridges as well.

REFERENCES

1. Dunker, K.F. and Liu, D., “Foundations for Integral Abutments”, *ASCE Practice Periodical on Structural Design and Construction*, February 2007, pp. 22-30.
2. Kunin, J. and Alampalli, S., “Integral-Abutment Bridges: Current Practice in the United States and Canada, Special Report 132”, *New York State Department of Transportation*, Albany, New York, 1999.

3. Maruri, R.F. and Petro, S.H., "Integral abutments and jointless bridges (IAJB) 2004 survey summary," *Proceedings of the 2005 FHWA Conference on Integral-Abutment and Jointless Bridges*, West Virginia University, March 2005, pp. 12-29. (http://www.cemr.wvu.edu/cfc/conference/Proceeding.pdf)
4. Colorado Department of Transportation, "Bridge Design Manual," *Colorado Department of Transportation*, Denver, Colorado, May 2009, Subsection No.7.2, pp.1-3. (http://www.dot.state.co.us/Bridge/DesignManual/dm_s07.pdf) (May 5, 2009).
5. Wasserman, E.P. and Walker, J.H., Chapter 5, "Integral abutments for steel bridges," *Highway Structures Design Handbook*, Vol. II, American Iron and Steel Institute (AISI), Washington, D.C., 1996.
6. Burdette, E., Deatherage, J.H. and Goodpasture, D.W., "Behavior of Laterally Loaded Piles Supporting Bridge Abutments – Phase I", *University of Tennessee*, Knoxville, Tennessee, 2000.
7. Oregon Department of Transportation, "Bridge Design and Drafting Manual 2004," *Oregon Department of Transportation*, Salem, Oregon, updated Apr. 2009, pp. 1-78. (http://www.oregon.gov/ODOT/HWY/BRIDGE/docs/BDDM/apr-2009_finals/Section 1-2004_apr09.pdf) (May 5, 2009).
8. Iowa Transportation Department, "LRFD Bridge Design Manual," *Iowa Transportation Department*, Ames, Iowa, Dec. 2008, Chapter 6.5, pp. 6.5.2-6.5.6. (ftp://165.206.203.34/dotmain/bridges/policy/65AbutLRFDJa09.pdf) (May 5, 2009).
9. Abendroth, R.E., Greimann, L.F. and LaViolette, M., "An Integral-Abutment Bridge with Precast Concrete Piles, Final Report TR-438", *Center for Transportation Research and Education*, Iowa State University, Ames, Iowa, May 2007.
10. Kamel, M.R., Benak, J.V., Tadros, M.K. and Jamshidi, M. (1996). "Prestressed concrete piles in jointless bridges." *PCI Journal*, 41(2), 56-67.
11. Arsoy, S., Duncan, J.M. and Barker, R.M. (2004). "Behavior of a semi-integral bridge abutment under static and temperature induced cyclic loading." *Journal of Bridge Engineering*, 9(2), 193-199.
12. PCI, "The State of the Art of Precast/Prestressed Integral Bridges", *Precast/Prestressed Concrete Institute*, Chicago, Illinois, 2001.
13. Dunker, K.F. and Abu-Hawash, A.A., "Expanding the use of integral abutments in Iowa." *Proceedings of the 2005 Mid-Continent Transportation Research Symposium*, Iowa State University, Ames, Iowa, 2005. (http://www.ctre.iastate.edu/pubs/midcon2005/DunkerAbutments.pdf)
14. Greimann, L.F., Abendroth, R.E., Johnson, D.E., and Ebner, P.B., "Pile Design and Tests for Integral-Abutment Bridges, Final Report HR-273 and Addendum to HR-273", *Iowa State University*, Ames, Iowa, December 1987.
15. Abendroth, R.E. and Greimann, L.F., "Field Testing of Integral Abutments, Final Report HR-399", *Iowa State University*, Ames, Iowa, 2005. (http://www.ctre.iastate.edu/reports/hr399.pdf)
16. Illinois Department of Transportation, "Bridge Manual", *Illinois Department of Transportation*, Springfield, Illinois, May 2008, pp. 2-55. (http://www.dot.state.il.us/bridges/brmanuals.html)

17. New Jersey Department of Transportation, Bridges and Structures Design Manual, *New Jersey Department of Transportation*, Trenton, New Jersey, 4th Edition, 2002, Section 15, pp. 1.15-4. (http://www.state.nj.us/transportation/eng/documents/BDME/) (May 5, 2009).
18. New York Department of Transportation, "NYSDOT Bridge Manual", *New York Department of Transportation*, Albany, New York, 1st Edition, January 2008, Section 11, pp. 11-20. (https://www.nysdot.gov/divisions/engineering/structures/repository/manuals/brman-usc/Section_11_US_2008_1st.pdf) (May 5, 2009).
19. Liu, D., Magliola, R. and Dunker, K. (2005). "Integral abutment bridges – Iowa's and Colorado's experience." *Proceedings of the 2005 FHWA Conference on Integral-Abutment and Jointless Bridges*, West Virginia University, pp. 136-147. (http://www.cemr.wvu.edu/cfc/conference/Proceeding.pdf)
20. England, G.L., Tsang, N.C.M. and Bush, D.I., "Integral Bridges, A Fundamental Approach to the Time- Temperature Loading Problem", *Thomas Telford*, London, U.K., 2000.
21. Carle, R.J. and Whitaker, S.S., "Sheet piling bridge abutments." *Presented at the Deep Foundations Institute's 14th Annual Meeting*, Baltimore, Maryland, 1989. (http://www.txi.com/downloads/products/steel/sheet_piling_bridge.pdf)
22. Maine Department of Transportation, "Bridge Design Guide", *Maine Department of Transportation*, Augusta, Maine, August 2003, Chapter 5, pp. 5-31 (http://www.maine.gov/mdot/technicalpublications/brdesignguide/chapter5substructuresfinal.pdf (May 5, 2009).
23. Girton, D.D., Hawkinson, T.R. and Greimann, L.F., "Validation of Design Recommendations for Integral Abutment Piles, Final Report HR-272", *Iowa State University*, Ames, Iowa, 1989.
24. PCI, "Guidelines for Accelerated Bridge Construction Using Precast/Prestressed Concrete Components", *Precast/Prestressed Concrete Institute Northeast*, Belmont, Massachusetts, First Edition, 2006.
25. Patrick Cassity, "Precast Bridge System for Accelerated Construction Applications", PowerPoint Presentation at *SEAOI Midwest Bridge Symposium*, April 2009.