INTEGRAL ABUTMENT BRIDGES: COMPARISON OF CURRENT PRACTICE BETWEEN EUROPEAN COUNTRIES AND THE UNITED STATES OF AMERICA

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Integral Abutment Bridges:
Comparison of Current Practice Between European Countries and the United States of America

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Abstract

In the United States of America (USA), there are more than 9,000 Fully Integral Abutment Bridges and 4,000 Semi-Integral Abutment Bridges. Integral Abutment Bridges have proven themselves to be less expensive to construct, easier to maintain, and more economical to own over their life span. European experience with Integral Abutments is significantly less, but what experience has been gained has been positive. A European Survey was conducted to illustrate the design criteria used by each individual country for Integral Abutment Bridges. The survey requested information that would be useful to a designer when comparing the design requirements and restrictions of various European countries. As an added measure of comparison, these results were compared to some recently conducted surveys of state agencies within the USA.

When looking at the results of the European Survey responses and past surveys of USA transportation agencies, it is clear that there are many similarities in design assumptions and construction practices. Yet, there are also significant differences between the various agencies. This paper attempts to highlight those similarities and differences.
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I. Introduction

A. Background

Integral Abutment Bridges are structures where the superstructure and substructure move together to accommodate the required translation and rotation. There are no bridge expansion joints and in the case of fully integral abutment bridges, no bearings. In the United States of America (USA), there are more than 9,000 Fully Integral Abutment Bridges and 4,000 Semi-Integral Abutment Bridges. Integral Abutment Bridges have proven themselves to be less expensive to construct, easier to maintain, and more economical to own over their life span (1). European experience with Integral Abutments is significantly less, but what experience has been gained has been positive. As a result, the trend is towards making Integral Abutment bridges a larger percentage of all newly constructed bridges across Europe.

To broaden the knowledge base for Integral Abutment design and construction, the International Workshop on Bridges with Integral Abutments (2) was held in Stockholm, Sweden in May of 2006. Representatives of eight different countries participated in the workshop. The goal of the workshop was to share the experiences of the participants and to further the understanding of the design, construction, and maintenance of Integral Abutment Bridges.

During the workshop, it became clear that each country represented a slightly different approach to the design of Integral Abutment Bridges. In spite of the different viewpoints, each country indicated that their designs were successful. Each representative stated that they would be constructing additional Integral Abutment Bridges in the future.

B. The Present Study

As an addition to the useful information obtained from the workshop, a European Survey was conducted in January of 2007 to illustrate the design criteria used by each individual country for Integral Abutment Bridges. The survey requested information that would be useful to a designer when comparing the design requirements and restrictions of various countries. As an added measure of comparison, these results were compared to recently conducted surveys of state agencies within the USA.

For the purpose of this survey, a Fully Integral Abutment Bridges (FIAB) is defined as a structure where the superstructure (bridge beams and deck) is directly connected to the substructure (abutments). During thermal expansion and contraction, the superstructure and substructure move together into and away from the backfill. There are no bearings or expansion joints. See Figure 1 for an example of a FIAB.
A Semi-Integral Abutment Bridge (SIAB) is defined as a structure where only the backwall portion of the substructure is directly connected with the superstructure. The beams rest on bearings which rest on a stationary abutment stem. The superstructure, backwall, and approach slab move together into and away from the backfill during thermal expansion and contraction. There are no expansion joints. See Figure 2 for an example of a SIAB.

Figure 2: Example of a SIAB used by the New York State DOT, USA (1)
**II. Survey Results**

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Table 1: Summary of Selected Criteria Used by European Respondents

Bridge designers from the following countries responded to the survey: England, Finland, France, Ireland, Luxembourg, Germany, and Sweden. A copy of the European Survey can be found in the Appendix. For the following portions of this paper, the answers from France and Luxembourg are not included. This is due to the fact that France uses a great number of three-sided reinforced concrete fixed frame structures, but no true Integral Abutments Bridges as described above. Luxembourg had limited input to the survey, due to its small size and limited bridge population. The responses of the remaining countries are compiled in the following sections.
It is important to note that the responses obtained are from practicing bridge engineers of their respective countries. These engineers work for government agencies, consulting firms, technical universities, or a combination of the above. In many cases, the engineers design structures in countries besides their own. These varied experiences give them a unique viewpoint on the issue of Integral Abutment design.

Since Integral Abutments are a relatively new concept in Europe, the codes are rapidly changing to keep pace with new information. The answers provided are accurate as of the time of the European Survey, but may be changed at any time. A unified Eurocode of bridge design may be adopted as soon as 2008.

Each country that responded to the European Survey indicated that Integral Abutment Bridges are permitted as a design option. In fact, the UK and Ireland requires that all bridges less than 200 ft. (60 m) and with a skew less than 30° be constructed as an Integral Abutment Bridge unless there are overriding reasons.

A. Fully Integral Abutment Bridges (FIAB)

1. Foundation

None of the European Survey responses indicated that pile foundations are always required for FIAB. This is in direct contradiction to many USA agency requirements. In New York State, for example, piles are required to be in a single row (I) on the belief that the single row will permit the abutment stem to translate into and out of the soil while also permitting rotation of the abutment stem. Spread footings, by their very nature, restrain the rotation of the abutment stem (see Figure 3). In spite of this condition, none of the agencies report any problems related to the restrained abutment rotations.

![Figure 3: Example of an Integral Abutment on Spread Footing Used in the United Kingdom (8)](image)

The European Survey indicated that steel piles are rarely used for FIAB in Europe. When they were used, they were typically symmetrical cross shaped piles. This pile type is being discontinued by the manufacturers. There is no indication what shape will replace
England and Ireland are exceptions in that, when steel piles are used, they typically use steel H-Piles with their strong axis perpendicular to the bridge expansion.

Steel pipe piles filled with reinforced concrete are the most common FIAB pile used in Europe. These pipe piles are typically 2.25 ft. (700 mm) in diameter but can be up to 4 ft. in diameter (1.2 m). Prestressed concrete piles are also commonly used. Cast-in-place piles are rarely used.

This is quite different from the USA, where more than 70% of State agencies reported (3) using steel H-piles for a majority of their FIAB. Of these bridges, 33% required the orientation of the strong axis of the pile perpendicular to the bridge expansion while 46% required orientating the weak axis perpendicular to the bridge expansion. The remaining percentages either had no requirement or always used symmetrical piles.

The European Survey indicates that designers are accounting for the bending forces in the piles. Although there are no requirements for procedure, designers typically make a computer model using theoretical springs to represent the soil supporting the pile along its length. Some countries, such as England and Sweden, use sleeves around the piles to prevent soil from restraining the free bending of the piles during superstructure translation (see Figure 4). The design theoretically distributes any longitudinal translation along a greater length of freestanding pile, thereby reducing the moment induced in the pile. Without the soil preventing buckling of the pile, the pile behaves more like a freestanding column and requires stronger piles to accommodate the unsupported length. In addition, there are inspection issues once the backfill is in place.
2. Backfill

The most common backfill material used by European countries is well compacted gravel or sand. In the USA (3), 69% of the responding states require well compacted granular backfill, while 15% require the backfill to be left loose in an effort to reduce forces on the moving abutment stem.

Some European countries require that the backfilling operations be conducted evenly on both sides of the structure, so as to not induce any undue lateral forces on the structure. Other countries have no requirements at all for backfilling procedure.

None of the countries require the use of an elastic ‘cushioning’ material behind the abutments. In the USA (3), 23% of the respondents use some sort of compressible material behind the abutment stem to lessen the soil pressure on the abutment stem.

When questioned about the design soil pressure behind the abutment stem, there was little agreement among the European countries. Germany uses full passive pressure. Ireland and England have formulas in their design codes (4) that estimate the soil pressure behind an Integral Abutment bridge as typically being between the classical ‘at rest’ pressure and full passive pressure. In Sweden, full passive pressure is only used if the movement is more than 0.005 times the abutment stem height. In Finland, the type of soil and the horizontal displacement of the abutment stem into that soil dictate when full passive pressure is applied (5). In the USA (3), 59% of the states surveyed accounted for full passive pressure. The remaining states used either minimum mandated loadings, active or at rest pressures, or no lateral loads were considered.

3. Approach Slabs

According to the European Survey, approach slabs are not required to be used with FIAB. However, most countries indicated that approach slabs were desirable and the length ranged from 10-25 ft. (3-8 m). Most states in the USA require the use of approach slabs to reduce impact forces on FIAB. Almost half (46%) of those states report (3) that settlement of the approach slab is a maintenance problem. Use of a buried approach slab or ‘drag plate’ makes settlement of the approach slab more easily repairable and may eliminate this concern (see Figure 5).

4. Wingwalls

A wingwall, for the purpose of this survey, is defined as the retaining walls adjacent to the abutment stem to retain the fills behind the abutments and to ensure slope stability of the approach roadway.
Each of the countries permit, and in fact encourage, the wingwalls to be rigidly cast with the abutment stem so that they move into and out of the retained soil. There are no established maximum lengths before the wingwalls are required to be placed on an independent foundation. In contrast, New York State requires rigidly cast wingwalls to be limited to 13 ft. (4 m). Wingwalls longer than this are placed on their own foundation and isolated from the movement of the abutment stem.

The European Survey respondents also indicated that there are no restrictions on the use of U-wingwalls (wingwalls that are perpendicular to the abutment stem). Typically, the U-wingwalls are cantilevered off the rear of the abutment stem. Although it is not common, some permit the use of piles beneath the U-wingwalls. This is similar to typical details used in the USA, where 66% of surveyed states permit the use of U-wingwalls but do not permit piles to be placed below them in order to allow the entire abutment to translate and rotate. Having multiple piles in the line of rotation provides a moment coupling force that restrains rotation of the abutment stem and may induce forces into the structure that were not accounted for in the design.

5. Beam Design

According to the European Survey, the bridge beams are designed using a number of methodologies. For small skews, most countries permit use of line girder analysis techniques, although the beams are analyzed twice. First, the beams are analyzed for the ‘no end restraint’ or ‘simple span’ condition. This indicates the maximum positive moment that could be induced in the beam at mid-span. Next, the beams are analyzed as ‘fully restrained’ or ‘fixed’ to determine the maximum end moments that may be induced in the abutment. Sweden permits the use of 50% of the calculated passive pressure behind the abutment to lessen the mid-span positive moments on the bridge beams. Although New York State designs all their single span FIAB as simply supported, field measurements taken of in-service FIAB in New York State indicates that the actual behavior of the beams is in-between the theoretical simple span and fixed conditions.
In England, it is highly recommended that computer models be used for all FIAB (8). Germany indicated that 3-D modeling is only used for large skews or complicated framing arrangements, while Sweden indicated that 3-D computer modeling is becoming more commonplace for all FIAB. In the USA, state agencies are split between using line-girder techniques and 3-D modeling (6), with the decision depending on structure specifics.

a. Steel Beams

The European Survey indicates that steel beams are permitted for FIAB. A single steel box girder is permitted to be the only member in the cross section. The minimum number of I-beams in cross section is two (2). Only Finland reported a limit on maximum individual span length or total bridge span length (230 ft. – 70 m). Where limits are given, the maximum allowable skew angle reported is 30°. Only Sweden indicated a maximum roadway grade (4%). No country reported a maximum bridge width. To compare, USA agencies report (3) maximum individual spans for steel girder FIAB ranging from 225-1000 ft. (65-300 m). Maximum allowable total bridge lengths range from 500-3,800 ft. (150-1,175 m).

b. Cast-In Place Concrete Beams

The European Survey indicates that reinforced concrete beams are permitted for FIAB, but are seldom used except for short span three-sided frame structures. For the purposes of this paper, cast-in-place beams that are subsequently prestressed by post-tensioning are considered as precast (PC)/prestressed (PS) beams. Where limits are given, the maximum allowable skew angle reported is 30°. Only Sweden indicated a maximum roadway grade (4%). Shrinkage of the concrete is typically accounted for in the design. New three-sided cast-in-place frames are seldom constructed in the USA. PC/PS concrete frames are more common. The requirements of these frames vary from one agency to another, and will not be discussed here.

c. Precast/Prestressed Concrete Beams

The European Survey indicates that the predominate beam used for FIAB are made of PC/PS concrete. A single PC/PS box girder is permitted to be the only member in the cross section. The minimum number of PC/PS concrete I-beams in cross section is two (2). Only Finland reported a limit on maximum individual span length or total bridge span length (230 ft. – 70 m). Where limits are given, the maximum allowable skew angle reported is 60°. Only Sweden indicated a maximum roadway grade (4%). No country reported a maximum bridge width. To compare, USA agencies report (3) maximum individual spans for PS/PC concrete FIAB ranging from 20-650 ft. (60-200 m). Maximum allowable total bridge lengths range from 500-3,800 ft. (150-1,175 m).
Maximum skew angles range from 15°-70°. Maximum degree of curvature ranges from 0°-10°. New York State limits the roadway grade to 5% (1).

B. Semi-Integral Abutment Bridges (SIAB)

The European Survey indicates that only England, Finland, Ireland and Sweden use SIAB. Although they did not respond to the European Survey, Norway is reported to use SIAB, but not FIAB (9).

1. Foundation

None of the European Survey responses indicated that pile foundations are always required for SIAB. This agrees with most USA agency requirements. In New York State, for example (1), the type of foundation is not specified, since the inclusion of a bridge bearing isolates the abutment stem from the superstructure translation and rotation (see Figure 6).

Figure 6: Example of a Semi-Integral Abutment on Spread Footing Used in the United Kingdom (8)

The European Survey indicated that the pile requirements are the same for SIAB as they are for FIAB.

2. Backfill

The European Survey indicated that the backfill requirements are the same for SIAB as they are for FIAB.

3. Approach Slabs

The European Survey indicated that the approach slab requirements are the same for SIAB as they are for FIAB.
4. Wingwalls

Some agencies choose to cast SIAB wingwalls with the stationary substructure. The movement of the superstructure is isolated from abutment stem and wingwalls. The wingwalls do not move into and away from the soil (see Figure 7).

However, some agencies take a different approach and cast the deck and the wingwalls together. The superstructure, backwall and wingwalls move together into and away from the backfill (see Figure 8).

5. Beam Design

The European Survey indicated that the beam design requirements are the same for SIAB as they are for FIAB, with the exception that the beams must be designed to accommodate the negative moments induced by the beams overhanging the bearings.
III. Conclusions

The responses to the European Survey are from practicing bridge engineers and, therefore, their responses are based on their individual understanding of the governing codes. Therefore, the responses should not be taken as policy statements of their respective countries. Even with this caveat, the compiled responses are useful in that they reflect the current application of the bridge design codes on structures that are actually being designed and built.

When looking at the results of the European Survey responses and past surveys of USA transportation agencies, it is clear that there are many similarities in design assumptions and construction practices. Yet, there are also significant differences.

Design parameters that are considered fundamental truths by one agency are completely ignored by another agency. In one country, piles are required to be driven in the ground and be of a minimum length. In another country, piles are required, but they must be placed within casings to prevent soil interaction near the pile top. In still another country, piles are avoided and spread footings are preferred to reduce differential settlement with the approach roadway. Although quite different in their approach, each method appears to be performing well in the field. Based solely on field performance, it is difficult to determine which methods are better than the others.

Part of the problem is that Integral Abutment Bridges, for all their simplicity of construction, are complicated structural systems. To thoroughly analyze a given structure, the designer must not only design for primary loads (dead, live, wind, etc.) but must also accurately account for secondary loads (creep, shrinkage, settlement, temperature effects, etc.). To additionally complicate the analysis, the response of a structure to a given set of external forces is very dependant on the geometry, materials, configuration, soil interaction, and construction details of the individual system.

In order to avoid dealing with this complicated analysis, Integral Abutment Bridges are typically designed almost empirically, using conservative methods and building on field experience. While this strategy provides safe and reliable structures, it does not forward the knowledge base on how and why Integral Abutment Bridges actually work. To that end, there is a great deal of research on the topic of Integral Abutment Bridges. The published research typically measures how a given structure reacts to applied forces and environmental conditions. From this information, computer models are created to precisely predict the in-service response of the structure to a given load.

While precise computer models are interesting from a research point of view, they present a problem for the practicing design engineer. In a research project, the structure is heavily instrumented so that all the variables are known and the computer model can be calibrated to the actual field conditions. In contrast, an engineer attempting to design a typical Integral Abutment Bridge structure must make numerous interrelated assumptions.
that may be significantly different from what is experienced in the field. Driven piles may not be perfectly straight, significantly increasing the lateral resistance of the pile group and thus transferring larger forces into the superstructure. The retained soil, after many years of expansion and compression due to bridge movements, may be quite stiffer than what was originally assumed inducing greater lateral soil pressure on the abutments. The amount of beam end restraint, after many years of service, may be less than was assumed and, therefore, increases beam mid-span moments. It is unrealistic to expect that a constructed structure will behave exactly as predicted by a computer simulation that is based on assumed values. Computer modeling is a useful tool, but it must be based on conservative assumptions and field experience to determine a safe and economical Integral Abutment Bridge design.

Given the above information, it seems unlikely that there will come a time when every agency across the globe will agree on every detail of what makes the best Integral Abutment Bridge. In the meantime, the differences in design philosophies between agencies are less important than the fact that Integral Abutment Bridges have proven to be more economical to build and own than traditional bridge types. As long as agencies continue to share their experiences, both successes and failures, Integral Abutment Bridges will continue to improve, providing an even more durable and cost effective solution for the future.
Appendix
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SURVEY OF INTEGRAL ABUTMENT BRIDGE (IAB) DESIGN CRITERIA
January 2007

Name: _________________________________________________________________
Organization: ___________________________________________________________
Position/Job Title: ____________________________
Postal Address: __________________________________________________________
Country: _______________________________________________________________
E-mail Address: _________________________________________________________

Fully Integral Abutment Bridges (FIAB)

1. Does your agency allow the use of FIAB? _____
2. Are piles always required? _____
   If you answered No to 2 above, skip to question 9.
3. What is the minimum pile length below the bottom of the abutment stem? _____
4. Are steel piles used? Yes No What type? __________
   Minimum embedment into the abutment stem? _____
5. How are they oriented? ______________________________________________
6. Are cast in place concrete piles used? _____
7. Are precast/prestressed concrete piles used? _____
   Minimum embedment into the abutment stem? _____
8. Do you account for the bend forces in the pile? _____ If yes, how? __________
   ___________________________________________________________________
9. What type of backfill material is required? ______________
10. Does your agency require that the substructure be backfilled evenly on both sides
    of the structure? _____
11. Does your agency require an elastic material be placed between the abutment
    stem and the retained soil? _____
12. Do you require the use of approach slabs? ____ If so, what is the minimum
    length? _____
13. Do you design the abutment stems for full passive soil pressure? _____
14. Do you permit the wingwalls to be cast rigidly with the abutment stem? _____
15. Is there a maximum length of wingwall before they are put on their own
    foundation? _____
16. Does your agency permit the wingwalls to have piles placed beneath them? _____
17. Does your agency permit use of U-wingwalls (wingwalls placed perpendicular to
    the roadway)? _____
18. When analyzing the superstructure beams, do you use traditional line girder
    techniques, or do you create a 3-Dimensional computer model of each structure?
    _____
19. Do you consider the beam ends to be simply supported, fully fixed, or something
    in-between (please explain)? __________________________________________
   ___________________________________________________________________
20. Does your agency use steel beams with FIAB? _____
   If you answered No to 20 above, skip to question 27.
21. The minimum number of beams in the cross section is: _____
22. The limit for an individual span length is: __________
23. The limit for overall span length is: __________
24. The maximum permitted skew angle is: __________
25. The maximum grade of the roadway is: _________
26. The maximum bridge width is: __________
27. Does your agency use reinforced concrete beams with FIAB? _____
   If you answered No to 27 above, skip to question 35.
28. The minimum number of beams in the cross section is: _____
29. The limit for an individual span length is: __________
30. The limit for overall span length is: __________
31. The maximum permitted skew angle is: __________
32. The maximum grade of the roadway is: __________
33. The maximum bridge width is: __________
34. Does your agency account for shrinkage of the beams in the FIAB design? _____
35. Does your agency use precast/prestressed concrete beams with FIAB? _____
   If you answered No to 35 above, skip to question 43.
36. The minimum number of beams in the cross section is: _____
37. The limit for an individual span length is: __________
38. The limit for overall span length is: __________
39. The maximum permitted skew angle is: __________
40. The maximum grade of the roadway is: __________
41. The maximum bridge width is: __________
42. Does your agency account for creep and shrinkage of the beams in the FIAB design? _____

Semi Integral Abutment Bridges (SIAB)

43. Does your agency allow the use of SIAB? _____
44. Are piles always required? _____
   If you answered No to 44 above, skip to question 51.
45. What is the minimum pile length below the bottom of the abutment stem? _____
46. Are steel piles used? ______ If so, what type? __________
47. How are they oriented? ______________________________________________________
48. Are cast in place concrete piles used? _____
49. Are precast/prestressed concrete piles used? _____
50. Do you account for the bend forces in the pile? _____ If yes, how? __________
51. What type of backfill material is required? ______________________________________
52. Does your agency require that the substructure be backfilled evenly on both sides of the structure? _____
53. Does your agency require an elastic material be placed between the moving upper portion of the abutment stem and the retained soil? _____
54. Do you require the use of approach slabs? ____ If so, what is the minimum length? _____
55. Do you design the top portion of the abutment stem for full passive soil pressure? _____
56. Do you require the wingwalls to be cast with the non-moving lower abutment stem? _____
57. Does your agency permit use of U-wingwalls (wingwalls placed perpendicular to the roadway)? _____
58. When analyzing the superstructure beams, do you use traditional line girder techniques, or do you create a 3-Dimensional computer model of each structure? _____
59. Do you consider the beam ends to be simply supported, fully fixed, or something in-between (please explain)? ____________________________________________________________
60. Does your agency use Steel beams with SIAB? _____
   If you answered No to 60 above, skip to question 67.
61. The minimum number of beams in the cross section is: _____
62. The limit for an individual span length is: __________
63. The limit for overall span length is: __________
64. The maximum permitted skew angle is: __________
65. The maximum grade of the roadway is: __________
66. The maximum bridge width is: __________
67. Does your agency use reinforced concrete beams with SIAB? _____
   If you answered No to 67 above, skip to question 75.
68. The minimum number of beams in the cross section is: _____
69. The limit for an individual span length is: __________
70. The limit for overall span length is: __________
71. The maximum permitted skew angle is: __________
72. The maximum grade of the roadway is: __________
73. The maximum bridge width is: __________
74. Does your agency account for shrinkage of the beams in the SIAB design? _____
75. Does your agency use precast/prestressed concrete beams with SIAB? _____
   If you answered No to 75 above, skip to question 83.
76. The minimum number of beams in the cross section is: _____
77. The limit for an individual span length is: __________
78. The limit for overall span length is: __________
79. The maximum permitted skew angle is: __________
80. The maximum grade of the roadway is: __________
81. The maximum bridge width is: __________
82. Does your agency account for creep and shrinkage of the beams in the SIAB design? _____
83. What is the temperature range you design for? __________________________
84. Please list the governing code for the design and detailing of FIAB and SIAB: __________________________
85. Please list any additional information you believe would be helpful to this survey:
Acknowledgements

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