

CHAPTER 7 – CONCLUSIONS AND RECOMMENDATIONS

This research project investigated the complex interactions that take place between the structural components of the integral bridge and the soil through experimental and analytical studies. A literature review was conducted to gain insight into the integral bridge/soil interactions, and to synthesize the information available about the cyclic loading damage to piles of integral bridges. The ability of the piles and the abutments to withstand cyclic loads was investigated by conducting large-scale cyclic load tests. Three pile types and three semi-integral abutments were tested in the laboratory. Experiments simulated 75 years of bridge life for each specimen by applying over 27,000 displacement cycles. Numerical analyses were conducted to investigate the interactions among the abutment, the approach fill, the foundation soil, and the piles.

7.1. Conclusions

Based on the findings of a literature review, field inspections, experimental investigations, and finite element analyses, the following major conclusions are drawn:

- Integral abutment bridges perform well with fewer maintenance problems than conventional bridges. Without joints in the bridge deck, the usual damage to the girders and piers caused by water and contaminants from the roadway is not observed.
- With integral bridges, all of the movement due to temperature changes takes place at the abutments and this approach system area requires special attention to avoid development of a severe “bump at the end of the bridge.”
- Maximum lengths of integral bridges have not been reached in Virginia. Jointless bridges over 180 meters (590 ft) in total length have been built in other states and have performed satisfactorily.
- The equivalent cantilever method appears to be overly conservative, as it does not consider the effects of abutment/approach fill interactions.
- The published literature concerning the damage to piles supporting integral bridges is scarce. Only five published documents were found in the subject area. All documents reported the use of H-piles oriented in weak-axis bending. The H-piles were able to tolerate the loads including those induced by thermal displacements.
- The VDOT semi-integral abutment with a concrete shear key experienced failure at the shear key as indicated by two large-scale laboratory tests. Despite the shear key failure, the abutment was able to tolerate over 27,000 displacement cycles without any appreciable change in its behavior. The behavior of the revised semi-integral abutment was superior, as it showed no sign of damage after applying over 27,000 displacement cycles.
- Rotational stiffness of the semi-integral abutments appears to be a function of the rotation of the abutment, and converges to a constant low number with a small amount of rotation. Thus, semi-integral abutments can significantly reduce the moments transferred from the superstructure down to the foundation piles.

- It appears that steel H-piles oriented in weak-axis bending are the best pile type for support of integral abutment bridges. Experiments simulated 75 years of bridge life by applying over 27,000 displacement cycles, and indicated no sign of distress for this pile type.
- Pipe piles have significantly higher flexural stiffness than do steel H-piles in weak axis bending, for a given pile width. This creates an undesired condition for the shear stresses in the abutment. For a given displacement, stresses in an abutment supported by pipe piles will be higher than stresses in an abutment supported by steel H-Piles in weak axis bending.
- Experiments indicate that seasonal temperature variations are more important for concrete piles. The total number of daily temperature cycles appears to be more important for the H-pile.
- It appears that stiff piles increase the likelihood of abutment distress. A choice has to be made by the designer whether the pile or the abutment should fail first if one of the two were to fail. Less stiff piles would serve well if the integrity of the abutment is more important.
- Experiments also indicate that piles are not fully fixed at the pile/pile cap interface. In the H-pile and pipe pile tests, measured stresses were about half of the theoretical stresses of the fully fixed-head piles.
- Cyclic loading damage to steel piles of integral bridges is not expected as long as the total stress induced in the pile does not exceed the yield strength of the steel.
- The finite element analyses indicate appreciable rotations occur in integral abutments, resulting in the shear and moment reductions in the piles. Interactions between the approach fill and the foundation soil create further favorable conditions with respect to pile stresses because the foundation soil behaves as if it were softer when it is displaced by the movement of the approach fill.
- The p-multiplier concept can be used to allow for the beneficial approach fill effect when computer programs such as LPILE are used for analysis and design of piles for integral bridges. Appropriate values of p-multiplier range from about 0.1 for stiff soil conditions to about 0.5 for soft soil conditions.

- The finite element analyses indicate that semi-integral abutments offer benefits over fully integral abutments. The benefits of using semi-integral abutments in reducing the pile stresses are more pronounced in the contraction mode of the bridges than the expansion mode.

7.2. Recommendations for design of Integral Abutment Bridges

Semi-integral abutments are recommended for longer integral bridges because they can reduce pile stresses. As the need to build longer integral bridges grows, the role of the semi-integral abutments is expected to become more important.

Steel H-piles oriented in weak-axis bending are recommended for support of integral abutment bridges. Stiff pipe piles are not recommended, as the likelihood of abutment distress will increase. Concrete piles are not recommended for integral bridge support because under lateral loads, tension cracks progressively worsen and significantly reduce the vertical load carrying capacity of these piles.

Interactions among the abutment, the approach fill, the foundation soil and piles should be considered in design because these interactions create favorable conditions with respect to pile stresses.

7.3. Recommendations for Future Work

It would be desirable to instrument abutments of integral bridges and piles supporting integral bridges to investigate the rotation behavior of semi-integral abutments, and to investigate pile stresses. Data from such tests would be very useful in validating the findings of this study.

Research is recommended to evaluate the effects of water on the dowels and joint filler materials of semi-integral abutments during their expected life.

Research is also recommended to investigate the dynamic soil/bridge interactions resulting from temperature variations.