Design Practice of Transverse Spiral Reinforcement of Piles in Accordance with AASHTO LRFD Bridge Design Specification

Kim, Yeong Seon* Song, Jong Young** Park, Kyoung Lae***
Choi, In-Ki**** Yang, Byung Hong***** Innes D. Flett******

ABSTRACT

The purpose of this study is to introduce design practice for transverse reinforcement in piles where the top of the pile is free-standing above the ground in accordance with AASHTO LRFD Design Specification. Based on the relevant requirements, the amount and spacing of transverse spiral reinforcement is given for the two different pile types, namely piles with pile cap and pile bents. In addition, a recommended design procedure is introduced depending on the predicted behaviour of the piles from the analysis.

1. Introduction

The transverse reinforcement in piles plays the dual roles of maintaining longitudinal reinforcements rigidly in position and also preventing piles from bursting due to bending and/or compressive forces. There are two types of transverse reinforcement, namely ties and spirals. They carry out the same function but have some differences in detail. In general, the amount and spacing of transverse reinforcement is determined in accordance with specifications. However, it is necessary to apply appropriate requirements to the design of piles. Requirements for transverse spiral reinforcement, according to AASHTO LRFD BRIDGE SPECIFICATION, is addressed and the design practice that was applied to large diameter drilled piles on the Incheon Bridge Project is presented in this study.

2. Requriements of transverse reinforcements

Requirements for transverse reinforcement that are specified in AASHTO LRFD Bridge Design Specification(Second Edition, 1998, as revised by 1999, 2000, 2001, 2002 and 2003 Interim Revisions) are divided for design purposes into 'compression members' and 'piles' as shown in the Table1 and Table2.

*Member, Deputy Design Manager, Incheon Bridge Project, Samsung Construction
**Member, Manager, Design Team, Incheon Bridge Project, Samsung Construction
***Member, Manager, Design Team, Incheon Bridge Project, Samsung Construction
****Member, Manager, Incheon Bridge Project, Seoyeong Engineering
*****Member, Design Manager, Incheon Bridge Project, Seoyeong Engineering
******Project Manager, Incheon Bridge Independent Design Checker, Halcrow Group Ltd.

Table 1. Compression Members

Division	Relevant Article	Remarks
Spirals and Ties	5.7.4.6 $\rho_s \geq 0.45*(Ag/Ac-1)*(fc'/fyh)$	Where the area of spiral and tie reinforcement is not controlled by: -Seismic requirements -Shear or torsion as specified in Article 5.8, or -Minimum requirements as specified in Article 5.10.6, the ratio of spiral reinforcement to total volume of concrete core, measured out-to-out of spirals, shall satisfy the equation shown to the left.
Spirals	5.10.6.2	The clear spacing between the bars of the spiral shall not be less than either 25mm or 1.33 times the maximum size of the aggregate. The c.t.c spacing shall not exceed 6.0 times the diameter of the longitudinal bars or 150mm.
Transverse Reinforcement for Confinement at Plastic Hinges	5.10.11.4.1d $\rho_s \geq 0.12*(fc'/fy)$	For a circular column, the volumetric ratio of spiral reinforcement, ρ_s, shall satisfy either that required in Article 5.7.4.6 or 5.10.11.4.1d.
Spacing of Transverse Reinforcement for Confinement	5.10.11.4.1e 5.10.11.4.3 5.10.11.4.1e	<u>The top and bottom of the column</u> Transverse reinforcement for confinement shall be provided at the top and bottom of the column over a length not less than the greatest of the maximum cross-sectional column dimensions, one-sixth of the clear height of the column, or 450mm. <u>Column Connections</u> Column transverse reinforcement, as specified in Article 5.10.11.4.1d, shall be continued for a distance not less than one-half the maximum column dimension or 380mm from the face of the column connection into the adjoining member. <u>Pile bent</u> Transverse reinforcement for confinement shall be: o Provided at the top of piles in pile bents over the same length as specified for columns, o Provided within piles in pile bents over a length extending from 3.0 times the maximum cross-sectional dimension below the calculated point of moment fixity to a distance not less than the maximum corss-sectional dimension or 450mm above the mud line. <u>maximum spacing of reinforcement</u> Transverse reinforcement for confinement shall be spaced not to exceed one-quarter of the minimum member dimension or 100mm center-to-center.

Table 2. Piles

Division	Relevant Article	Remarks
Concrete Piles	5.13.4.1 C5.13.4.1	Any portion of a pile where lateral support adequate to prevent buckling may not exist at all times, shall be designed as a column. Locations where such lateral support does not exist include any portion of a pile above the anticipated level of scour or future excavation as well as portions that extend above ground, as in pile bents.
Cast-in-Place Piles	5.13.4.5.2 General Requirements 5.13.4.6.2b Seismic Requirements	The area of longitudinal reinforcement shall not be less than 0.8 percent of Ag, with spiral reinforcement not less than MW25 at a pitch of 150mm. The reinforcing steel shall be extended 3000mm below the plane where the soil provides adequate lateral restraint. Spiral reinforcement or equivalent ties of not less than No. 10 bars shall be provided at pitch not exceeding 225mm, except that the pitch shall not exceed 75mm within a length not less than 600mm or 1.5 pile diameter below the pile cap reinforcement.
Drilled Shaft	10.8.5.3	Transverse reinforcement shall be designed to resist loads due to fresh concrete flowing from inside the cage to the side of the excavated hole.

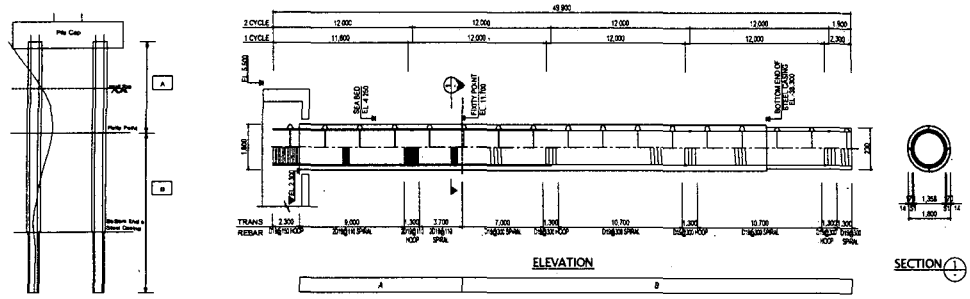
3. Practices of application according to types of piles

3.1 Piles with Pile Cap

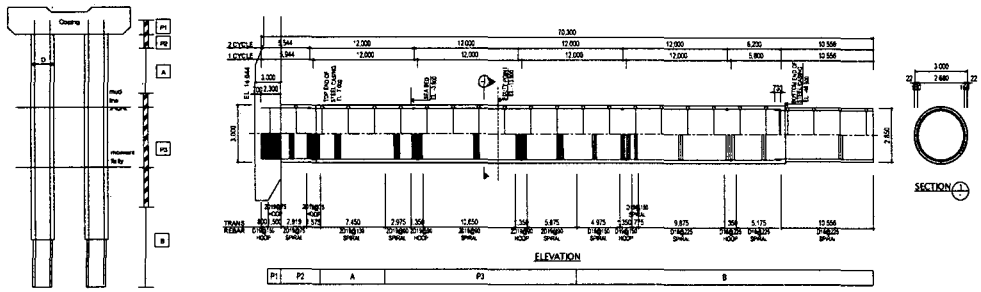
Piles that form part of a pile group supporting a pile cap are generally designed using plastic methods of analysis in order to dissipate large seismic loads efficiently through the structure. For large diameter piles an excessive quantity of transverse reinforcement is required in the piles near the effective point of fixity and the connection between piles and the pile cap to comply with the Article 5.10.11.3. However, it was recognized that the piles exhibited elastic behaviour through out from the results of Moment-Curvature theory, and hence plastic hinges were not forming. Therefore general detailing was applied instead of plastic detailing accordingly. Figure1.(a) shows piles with a pile cap. The piles are divided into a column section and a pile section according to the location of the point of effective fixity where the biggest moment in the pile occurs. It is also considered that at this location lateral restraint is effective. The minimum transverse reinforcement in the column section of the pile was calculated in accordance with the Article 5.7.4.6 as the requirement for compression members. However, in the pile section of the pile, Articles 5.13.4.5.2, 10.8.5.3 and the requirements for the spacing of transverse reinforcement in the report of FHWA-IF-99-025 (that was published by Federal Highway Administration) were compared with requirements for a shear check. Figure1.(b) shows an example of reinforcement layout in a pile cap type foundation.

3.2 Pile Bents

A Pile bent is the case where the pier cap is supported by piles directly and plastic design was therefore applied. When plastic design methods are applied, sectional forces can be reduced because they are multiplied by response modification factor and therefore an economic design can be adopted. However, construction of the reinforcement cage can be difficult due to the excessive amounts of transverse reinforcement required in the plastic hinge zones. Figure1.(c) shows a pile bent and it is divided into a plastic hinge zone, a column zone and a pile zone. The plastic hinge zone is the connection between a pile and a pile cap (P1,P2) and the portion in the ground(P3). The column section is Zone A and the pile is Zone B. The plastic hinge zone P1 was defined in accordance with Article 5.10.11.4.3 and P2,P3 were defined according to Article 5.10.11.4.1e. The amount and spacing of transverse reinforcement was calculated by the seismic requirements defined in Article 5.10.11.4.1d. The provision of transverse reinforcement was identical to that used in the pile cap type foundation for the column portion A and pile portion B . Figure1.(d) shows an example of reinforcement in a pile bent type foundation.



(a) Pile Cap (b) Reinforcement layout in a pile with pile cap



(c) Pile Bent (d) Reinforcement layout in Pile Bent

Figure 1. Division of transverse reinforcement arrangement

4. Conclusion

Where piles are free-standing above the ground, they are divided into two portions, a column portion and a pile portion, depending on where lateral restraint is provided. Transverse reinforcement is provided accordingly. Lateral restraint is considered to be effective at the point of effective fixity in the pile where the maximum moments occur. For the case of a pile cap type of foundation where the piles exhibited elastic behaviour, it is reasonable to apply the general detailing requirements instead of plastic requirements of the code even though the piles are located in a seismic zone(Incheon Bridge belongs to Zone 2 in accordance with AASHTO LRFD Specification).

The spacing of transverse reinforcement must be reduced if concrete cover is provided greater than the design cover(see Article 5.7.4.6). However, this can lead to construction difficulties and it is therefore desirable to maintain the minimum design cover depth for durability purposes.

References

1. AASHTO LRFD Bridge Design Specifications, SI Units, Second Edition, 1998, (published by the American Association of State Highway and Transportation Officials, Washington DC) as revised by 1999, 2000, 2001, 2002 and 2003 Interim Revisions.
2. Publication No. FHWA-IF-99-025(published by U.S Department of Transportation, Federal Highway Administration), Drilled Shafts: Construction Procedures and Design Methods, P366~367.