Steel Pipe Pile/Concrete Pile Cap Bridge Support Systems: Confirmation of Connection Performance

Amendment

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1 Overview

The existing contract between the Western Transportation Institute (WTI) and the Montana Department of Transportation (MDT) is to investigate the performance of a commonly used and critical connection in Montana bridges: steel pipe pile to concrete pile cap connections. This connection must provide acceptable performance under both gravity and lateral loads (e.g., wind and seismic). While the gravity load performance of these systems is well understood, their strength and ductility under extreme lateral loads is more difficult to reliably predict using conventional design procedures. Under the scope of the existing contract, WTI has tested four half-scale connection models to evaluate their performance relative to MDTs design guide, and considerable insight has been gained on connection response. These tests have particularly focused on fundamental connection strength under monotonic load to failure. During a seismic event, these connections may well experience several cycles of fully reversed load, and thus it is suggested that this phase of the test program conclude with two additional tests designed more specifically to look at connection response under cyclic loads. This document provides a brief summary of the results obtained from the current test effort and a description of the proposed two additional tests.

2 Summary of Completed Tests

Under the existing contract between MDT and WTI, four connection specimens have been tested under a unidirectional monotonic load until failure. The first of these tests (VT1) resulted in the formation of a plastic hinge in the pile (desired failure mechanism). The remaining three tests (i.e., VT2, VT2.5 and VT3) were subsequently and specifically configured to force the failure into the pile cap by using an overstrength pile relative to the expected cap capacity. Following this approach, comparisons could be made between observed cap capacities and the capacities predicted by the MDT design guide. The moments at which initial crushing occurred as well as the ultimate moment capacities observed in these tests are plotted in Figure 1, along with the crushing capacities predicted via the MDT design guide. That is, the design guide addresses compression failure of the concrete in the cap, and the pertinent equations in the guide can be reformulated to effectively calculate the applied moment from the pipe pile at which crushing of the cap concrete will occur. The equation for this moment capacity is:

$$M_{calc\_crush} = \frac{\beta_1 \left(\frac{L_{emb}{}^2}{2}\right) D \left(1 - \frac{1}{2}\beta_1\right) \alpha f'_c}{1000 \cdot 12} \tag{2.1}$$

This equation is plotted in Figure 1 as a function of embedment length for two different concrete strengths, 4,000 psi and 6,250 psi (the strength of the concrete in VT2, and the strength in VT2.5 and VT3, respectively). Note that for the graphed equations, the strength reduction factor, ϕ, has not been used, as this factor is typically included (in part) to account for uncertainties in as built dimensions and material properties, and in this controlled situation the exact dimensions and material properties are known. In test VT2, ($f'_c =$ 4,000 *psi*) initial crushing was observed in the cap at a moment of 131 *ft-kips*, prior to reaching the predicted capacity of 174.6 *ft-kips* ($\approx 75\%$ of the predicted capacity), and although the observed ultimate capacity of this cap of 173.7 *ft-kips* closely approached the predicted capacity, the cap was severely damaged prior to reaching this point, and the cyclic response of this connection would have been significantly degraded. With regards to VT2.5, initial crushing was observed at 124 *ft-kips*, which again is below the predicted capacity, more precisely being 81.3% of the predicted capacity of 152.5 *ft-kips*. Initial concrete crushing was observed in VT3 at a moment of 89.9 *ft-kips* which is approximately 66% of the predicted capacity of 136.1 *ft-kips*. However, the ultimate capacity of this specimen of 152.0 *ft-kips* did exceed the predicted capacity by 12%.

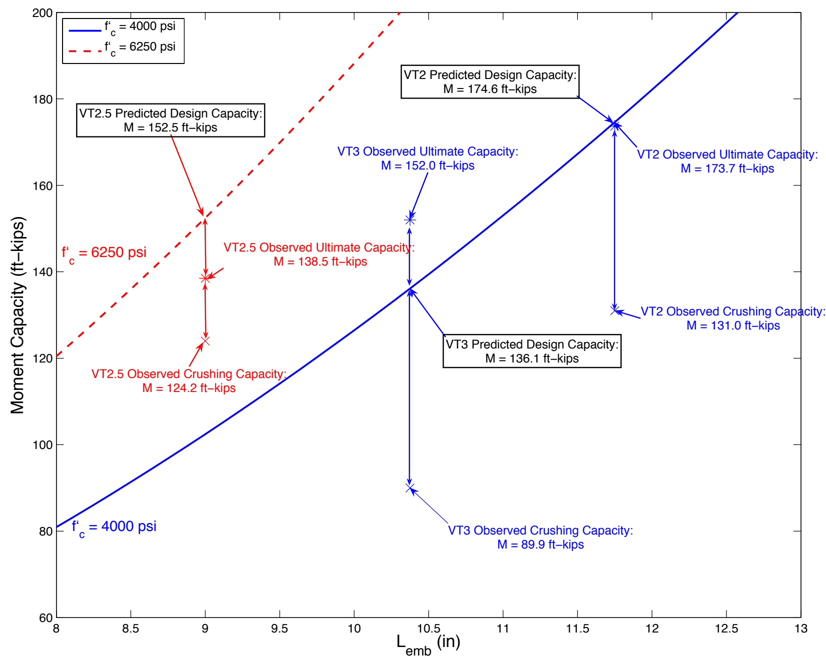

Figure 1: MDT Design Guide Predicted Capacities vs. Measured Capacities

These data and analyses suggest that when the ϕ factor is removed and the respective concrete strengths from the tests are considered, the design guide is overestimating the crushing capacity of the pile cap. It is worth noting that if the ϕ factors are included, the design guide values are below the observed capacities. However, although the ϕ factors are intended to in part account for uncertainties in modeling techniques, some margin should be reserved for uncertainties in other aspects of the design. Further, the initial crushing of concrete observed in these tests occurred on both the exterior and interior compression regions of the pile cap (Figure 2). While this initial crushing of the concrete did not directly govern the ultimate capacity of the cap under monotonic loading, this crushing could lead to the degradation of the cyclic response of the connection. Seismic loading is inherently cyclic, and structural systems count on ductile, nondegrading responses for energy dissipation. Thus, to ensure a robust response under cyclic loads, the design strength of the concrete cap may have to be limited to its crushing capacity, rather than its ultimate capacity (which is the capacity estimated in the current design methodology). This issue can be resolved by observing the hysteresis response of a test specimen cycled at a lateral load level below the predicted design capacity using the current design methodology, but in excess of the expected crushing load (where this load level has been estimated based on the results of earlier tests).

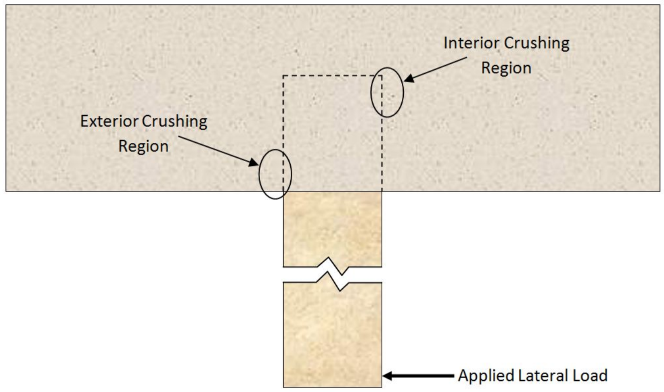

Figure 2: Location of interior and exterior crushing regions

3 Proposed Additional Tests

Thus, the research team is proposing two additional tests to further evaluate/improve the current MDT design methodology. These tests will be designed to evaluate: (1) the cyclic response of the connection at various load levels including levels below, at, and above the initial crushing load, and (2) the effect of including additional U-bars in the interior of the cap encircling the embedded tip of the pipe pile, with the intention of increasing the load at which initial crushing occurs as well as the ultimate capacity of the cap. The effects of concrete crushing on the overall cyclic response of the test specimens will be determined by loading these additional specimens under cyclic lateral loads with increasing magnitude (similar to the effect from actual seismic events). This in contrast to the monotonic loading used in the original tests. One of these additional tests will use a reinforcing scheme similar to the original tests in the current contract. That is, this specimen will have U-bars located at the exterior of the cap as shown in Figure 3a. The second specimen will have an identical reinforcing scheme, with the exception of additional U-bars located at the interior crushing region of the cap (Figure 3b). The additional U-bars are expected to help reduce the concrete crushing at the interior of the pile cap, and thus improve overall performance of this connection with respect to initial crushing, ultimate load, and cyclic degradation. These additional tests would provide valuable data points for validating/improving recently developed design equations for predicting the onset of concrete crushing.

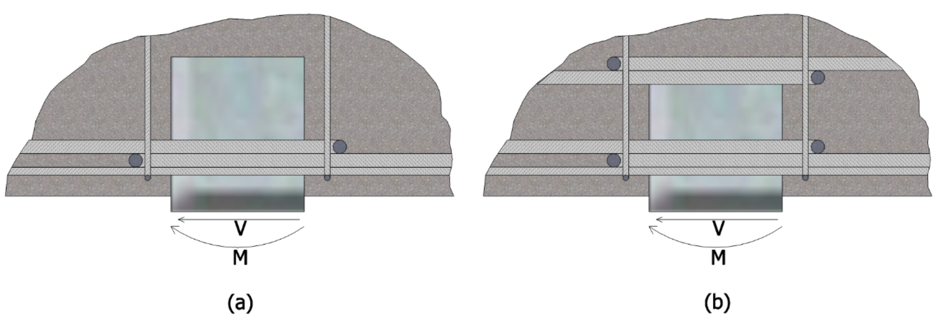

Figure 3: (a) exterior U-bar only, (b) exterior and interior U-bar

4 Budget

These additional tests and the subsequent analysis and reporting are expected to take approximately 12 months to complete, with an anticipated start date of August 15, 2011 and an estimated completion date of July 31, 2012. The total cost for this amendment is $31,818, as can be seen in the budget provided in Table 1. Table 2 provides a breakdown of the *Expendable Supplies and Minor Equipment* line item.

Table 1: Expenditures by Item

Employee/Item	Cost
Michael Berry	$3,900
Jerry Stephens	$2,955
Graduate Student (Salary and Support)	$16,341
In-State Travel	$240
Expendable Supplies and Minor Equipment	$3,600
Total Direct Costs	$27,036
Overhead (20%)	$4,537
Total Project Cost	**$31,572**

Table 2: Breakdown of Expendable Supplies and Minor Equipment

Item	Cost
Recurring items for each model:	
Reinforcing steel	$250
Concrete	$250
Pipe Pile	$200
Embedments	$110
Strain gauges and accessories	$250
Concrete specimen molds	$40
Miscellaneous	$200
Total for one model	$1,300
Total for two models	**$2,600**
Structures Lab Fee	$1,000
Grand Total	**$3,600**