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NUMERICAL ANALYSIS OF CONTROLLED LOW STRENGTH MATERIAL BRIDGE ABUTMENTS: STATIC ANALYSIS

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This paper presents static analysis of bridge abutment constructed using sustainable material, a controlled low-strength material (CLSM), using boundary element (BE) method. The structure is constructed using full-height precast concrete panels that are attached to a CLSM backfill via steel anchors and can be employed as a replacement of traditional piling support systems. The Young's moduli of CLSM are obtained from laboratory tests for two different binder mixtures. Two-dimensional planar strain is employed in the BE formulation of static analysis and comparison study of load-bearing systems using CLSM abutment and conventional piling support system with compacted soil. Emphasis is put on the settlement at the upper road base as well as the lateral pressures on the side wall induced by three wheel surcharges: concentrated, strip and uniform lane loads on the CLSM abutments with different binder mixtures. Convergence studies obtained from programs coded in MATLAB were first assured. Numerical results show that the settlement and lateral pressure of CLSM abutments are acceptable to assure the applicability of CLSM as a suitable sustainable material employed for bridge abutment design and construction.

Keywords: Backfill analysis, Boundary element method (BEM), Bridge abutments, Controlled low-strength material (CLSM), Sustainable materials.

1 INTRODUCTION

Highly developed city and urban with growing traffic demands lead to an increasing need of rapid construction and/or replacement of bridge systems to accommodate passengers transportation and maintain fright movement with least economic impact and under acceptable cost. Most bridge systems using conventional construction with superstructural, substructural components and pile foundations which usually demands a substantial period of construction and labors during the forming, placing and curing processes. Recently an effective rapid bridge construction had been achieved by using the controlled low strength materials (CLSM) bridge abutment (Helwany *et al.* 2012). CLSM is a kind of flowable fill defined as self-compacting cementitious material that is in a flowable state at the initial period of placement and has a specified compressive strength of 1200 psi or less at 28 days or is defined as excavatable if the compressive strength is 300 psi or less at 28 days (ACI 2005). The special features of CLSM include: durable, excavatable, erosion-resistant, self-leveling, rapid curing, flowable around confined spacing, wasting material usage and elimination of compaction labors and equipments, etc. Literature reviews showed that on-site residual soil after pipeline excavation may be an alternative source for fine constituent in production of soil-based CLSM, effectively used as backfill around buried pipelines (Howard *et al.* 2012). Experimental and computational works have been done on the use of CLSM as abutment backfill (Schmitz *et al.* 2004). The authors also conducted some preliminary studies on engineering properties of CLSM (Sheen *et al.* 2014, Huang *et al.* 2014).

The paper is aimed at the comparison of static analysis of bridge abutment filled with CLSMs of two different binder mixtures (B130/30% and B80/30%) and conventional piling support systems with compacted soil using boundary element (BE) method. Three loading cases will be considered.

2 NUMERICAL ANALYSIS OF THE ABUTMENT ZONE

2.1 Problem Description

Conventional support system with piles and compacted soil is shown in Figure 1(a), while the CLSM abutment supported with concrete panels and steel anchors depicted in Figure 1(b). Comparison study is considered in the backfilled zone with length $L = 3\,m$, height $H = 3\,m$. Different materials will be investigated as follows:

(1) Compacted Soil: $E = 0.1\,GPa, \nu = 0.28$;

(2) CLSM (B80/30%): $E = 0.27\,GPa, \nu = 0.25$;

(3) CLSM (B130/30%): $E = 0.87\,GPa, \nu = 0.25$;

The material constants in (2) and (3) are obtained from experimental works as explained in Sheen *et al.* (2014). Selection of materials for the CLSM mixture in this study consisted of fine aggregate, type I Portland cement, stainless steel reducing slag (SSRS), and water. The experimental work was conducted on two binder content levels in mixtures (i.e. 80- and 130 *kg/m3*). The B80 and B130 denote for mixture series containing 80 and 130 *kg/m3*, respectively.

2.2 Loading Conditions

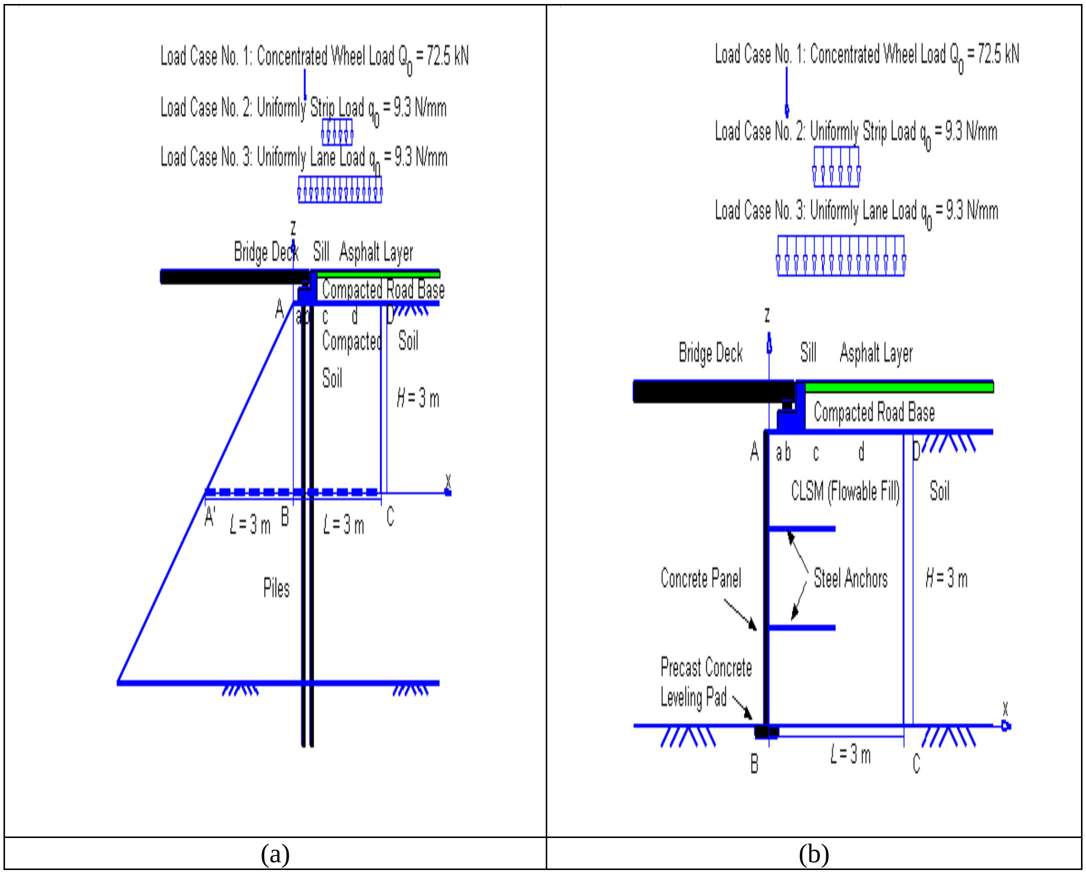
We consider three loading conditions:

(a) Load Case No. 1: the vertical concentrated wheel load, $Q_0 = 72.5\ kN$, acting on the roller of bridge deck which is located away from the retaining wall by *Ab = 0.133 H..*

(b) Load Case No. 2: vertical uniform strip load: $q_0 = 9.3\ kN/m$ distributed from *c = H/3* to *d = 2H/3 (cd=H/3)..*

(c) Load Case No. 3: vertical uniform lane Load: $q_0 = 9.3\ kN/m$ distributed on *aD= 0.9 H.*

Load Case No. 1 and 3 are based on AASHTO LRFD Bridge Design Specifications (1998). Load Case No. 1 is equivalent to the single heaviest wheel load of a common AASHTO HS20 truck (or HL-93 truck in the AASHTO LRFD version).



(a) (b)

Figure 1 Schematic of bridge abutments: (a) conventional bridge abutment using compacted soil with pile foundations (b) CLSM abutment with concrete panel and steel anchors.

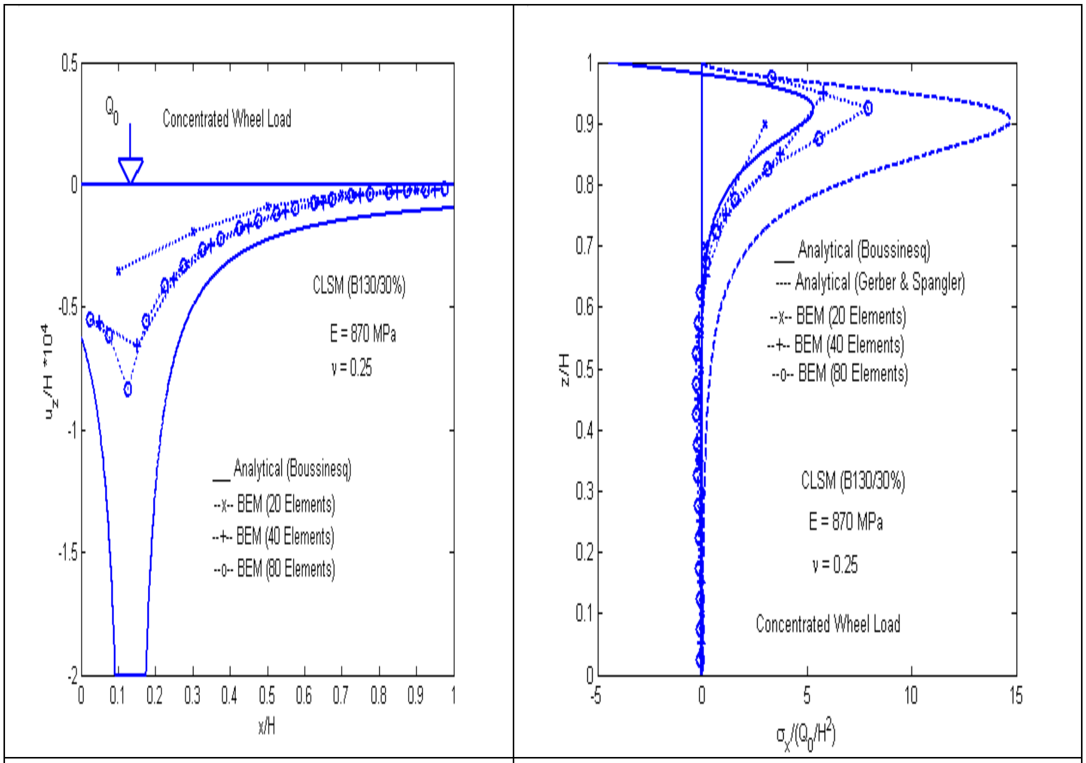
2.3 Boundary Element Formulation

The boundary element formulation for the problem can be expressed in matrix form as Brebbia and Walker (1980).

3 NUMERICAL RESULTS AND DISCUSSION

3.1 Convergence Tests

Figure 2 shows the numerical prediction of surface settlement and variation of lateral wall pressure as depth, respectively, of backfilled CLSM (B130/30%) due to concentrated wheel loads calculated by different boundary element meshes and analytical formula. Convergent results can be obtained using 20, 40 and 80 boundary elements (corresponding mesh sizes are $\Delta x = \Delta y = 0.6\,m, 0.3\,m, 0.15\,m$, respectively). Analytical solution from Boussinesq (1883) for semi-infinite solids (no retaining wall exists) and modified equations proposed by Gerber (1929) and Spangler (1938) (under assumption of $\nu = 0.5$) are also shown.



(a) surface settlement

(b) lateral pressure

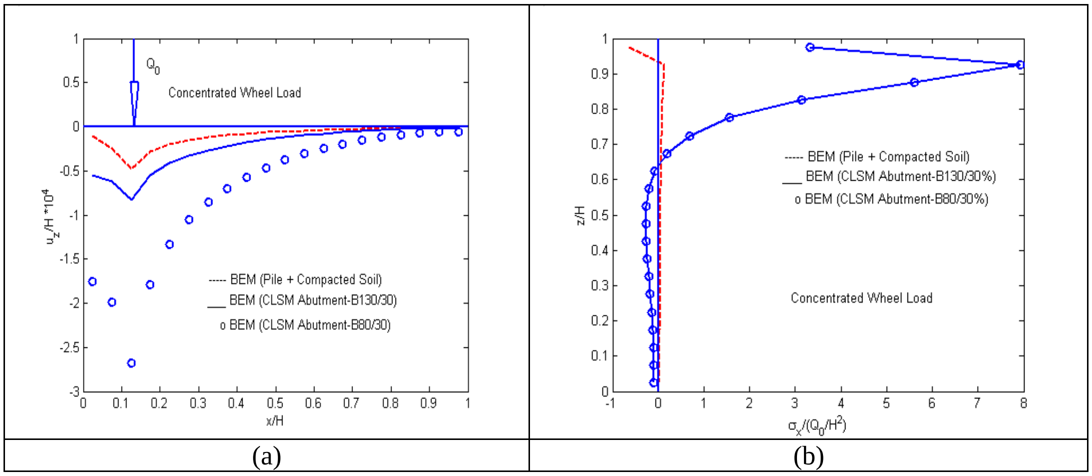
Figure 2 Analytical and BEM results of CLSM abutment under concentrated wheel loads using 20, 40 and 80 constant elements (a) surface settlement (b) lateral pressure

3.2 Comparison Study of CLSM Abutments with Conventional Abutment of Piling Support with Compacted Soil

Two different binder mixtures for CLSM abutments are considered: CLSM-B130/30% and CLSM-B80/30%. In the BEM analyses, 80 constant elements are adopted for CLSM abutments while 100 constant elements for conventional abutment. Mesh sizes are the same with $\Delta x = \Delta y = H/20 = 0.15\,m$.

3.2.1 *Load case No. 1 (concentrated wheel load)*

Figure 3 shows that the surface settlements are influenced significantly by the modulus of elasticity (E). In conventional piling system we considered only 10% vertical load transferred from piling system to compacted soil. In this loading case conventional pile supporting system depicts smaller settlements than CLSM abutments but CLSM-B 130/30% provides acceptable settlement resistance. Lateral pressure is huge in the upper region but deceases rapidly in depth.

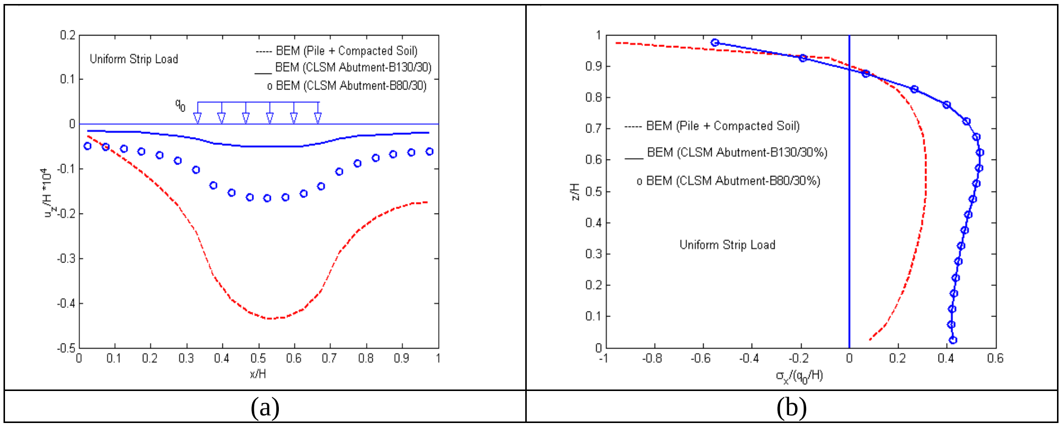


(a) (b)

Figure 3. Comparison of CLSM abutment and conventional abutment with pile and compacted soil under concentrated wheel load (a) settlement (b) lateral pressure.

3.2.2 *Load case No. 2 (uniform strip load)*

Figure 4 shows the boundary element predictions on the surface settlements and lateral pressure under uniform strip load acting on the compacted road base transferred from Asphalt layer. In this situation both two CLSM abutments yield smaller settlement and lateral pressure than conventional abutment with piling and compacted soil.

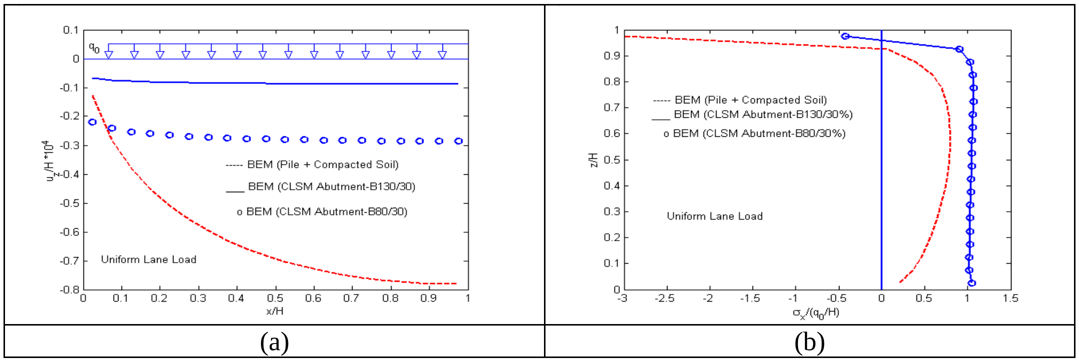


(a) (b)

Figure 4. Comparison of CLSM abutment and conventional abutment with pile and compacted soil under uniform strip load (a) settlement (b) lateral pressure.

3.2.3 *Load case No. 3 (uniform lane load)*

The results shown in Figure 5 explain that the CLSM abutments yield smaller settlement and lateral pressure as compared to the conventional abutment when uniform lane load acts on the asphalt layer.



(a) (b)

Figure 5. Comparison of CLSM abutment and conventional abutment with pile and compacted soil under uniform lane load (a) settlement (b) lateral pressure.

4 CONCLUDING REMARKS

Consideration of both lateral pressure on the wall and surface settlement from the numerical analyses using BEM, CLSM(B130/30%)($E = 0.87\ GPa, \quad \nu = 0.25$) shows to be a good material for bridge abutment construction that can be employed as an alternate design for conventional compact soil with pile foundation.

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