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NUMERICAL ANALYSIS OF CONTROLLED LOW STRENGTH MATERIAL BRIDGE ABUTMENTS: STEADY STATE ELASTODYNAMIC ANALYSIS

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This paper presents the steady-steady elasto-dynamic analysis of bridge abutment constructed using sustainable material, a controlled low-strength material (CLSM), using finite element (FE) and boundary element (BE) methods. 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. Two-dimensional planar strain is employed in the FE and BE formulation of elasto-dynamic analyses. Typical examples will be employed for comparison study of backfill material using CLSM abutment and traditional piling support system with compacted soil. Emphasis is put on the comparison of different numerically computed natural frequencies and mode shapes of the conventional and CLSM abutment. Results show that CLSM abutment depicts higher natural frequencies as compared with conventional abutment and can be a suitable sustainable material employed for bridge abutment design and construction in highway and geotechnical engineering.

Keywords: Controlled low-strength material (CLSM), Finite element method (FEM), Boundary element method (BEM), Bridge abutments, Elasto-dynamic analysis.

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; Alizadeh, *et al.* 2014). 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 labor and equipment, etc. 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) and the numerical analyses on static and steady-state elasto-dynamic problems of retaining wall with backfilled CLSMs (Huang *et al.* 2014a, 2014b).

The paper is aimed at the comparison of elasto-dynamic analysis of bridge abutment filled with CLSMs of binder mixtures B130/30% and conventional piling support system with compacted soil using boundary element method (BEM) and finite element method (FEM). Emphasis is put on the different computed natural frequencies and mode shapes of these two types of abutments.

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) Conventional Abutment (Compacted Soil): $E = 0.1\,GPa, \nu = 0.28, \rho = 1745\,kg/m^3$;

(2) CLSM Abutment (B130/30%): $E = 0.87\,GPa, \nu = 0.25, \rho = 1695\,kg/m^3$;

The material constants in (2) 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. However in the static analysis of CLSM abutment using these two mixture series (Part-I) we found that B130/30% is better than B80/30%, thus in this part we only investigate CLSM abutment using B130/30%.

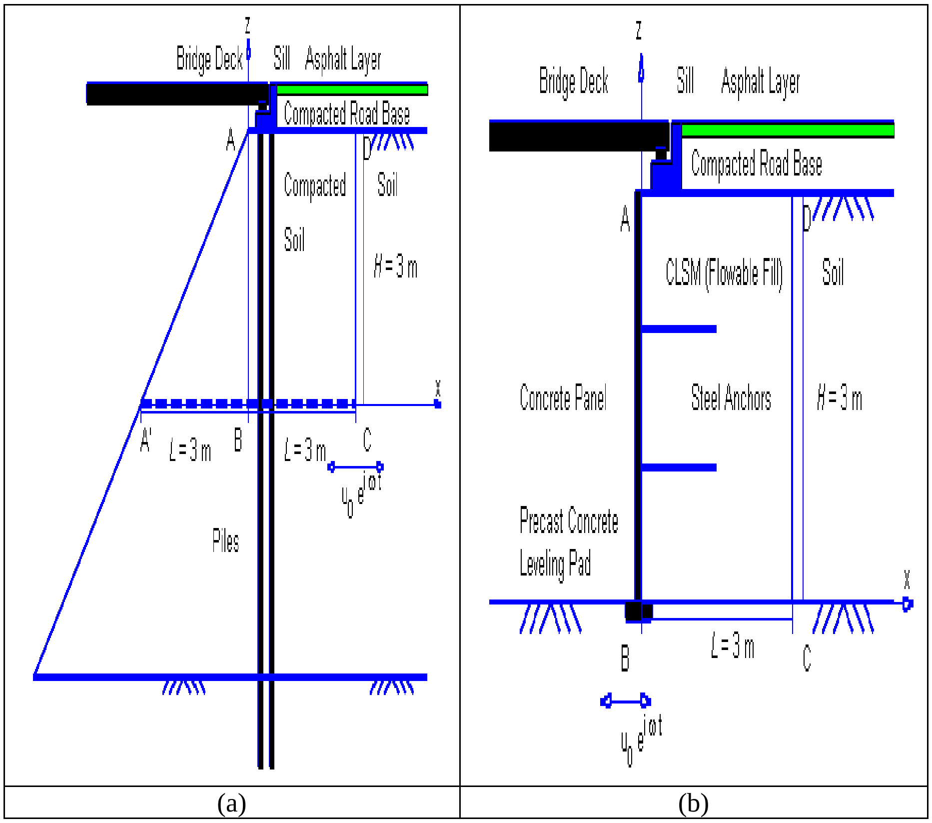
To simulating the steady-state elasto-dynamic response of the backfilled zone subjected to cyclic ground motion, we consider the boundary conditions are $u(0,z) = u_0 \bullet e^{i\omega t}$ on $\overline{CD}$ for conventional abutment (Figure 1a) while on $\overline{AB}$ for CLSM abutment (Figure 1b) where $u_0 = 0.01\,m$ is the presumed amplitude of exciting displacement induced by cyclic earthquake motion with exciting frequency ω .

2.2 Finite Element Formulation

We can deduce the general finite element equations of eigen-value problem in the matrix form as formulated in Rao (1982) and Huang *et al.* (2014b).

2.3 Boundary Element Formulation

The boundary element formulation for the problem can be expressed in matrix form as described in Brebbia and Walker (1980) and Huang *et al.* (2014b).



(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.

3 NUMERICAL RESULTS AND DISCUSSION

3.1 Conventional Abutments

Table 1 shows the first leading natural frequencies of the conventional abutment obtained from various finite elements and boundary elements. Figure 2 shows the numerical results of responses versus exciting frequencies obtained from three BE meshes. Figure 3 depicts the first leading vibration modes of the conventional abutment.

Table 1. Natural frequencies of conventional abutment obtained from FEMs and BEMs $(rad/\sec)$.

Mode	FEM (75 CST, 51 Nodes)	FEM (300 CST, 176 Nodes)	BEM (25 Constant Elements, 75 Cells)	BEM (50 Constant Elements, 300 Cells)	BEM (100 Constant Elements, 300 Cells)
1	78.7107	78.4993	79	79	79
2	143.7532	140.1235	143	141	141
3	152.9524	156.4393	157	156	155
4	183.615	180.0363	180	179	179
5	246.1221	228.5872	226	223	223
6	280.1062	275.8704	275	272	271

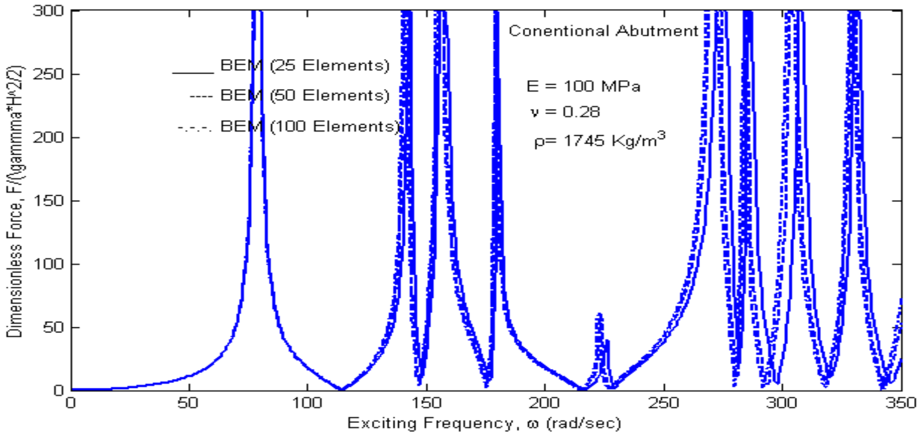
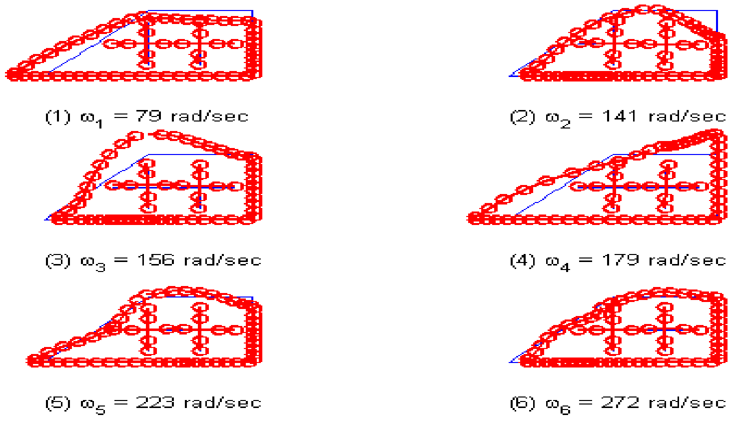


Figure 2. Eigenvalues of conventional abutment using 25, 50 and 100 constant elements.



(1) ω_1 = 79 rad/sec

(2) ω_2 = 141 rad/sec

(3) ω_3 = 156 rad/sec

(4) ω_4 = 179 rad/sec

(5) ω_5 = 223 rad/sec

(6) ω_6 = 272 rad/sec

Figure 3. Mode shapes of the first six natural frequencies of conventional abutment (50 BEs).

3.2 CLSM Abutments

Table 2 shows the first leading natural frequencies of the CLSM abutment obtained from various finite elements and boundary elements. Figure 4 shows the numerical results of responses versus exciting frequencies obtained from three BE meshes. Figure 5 depicts the first leading vibration modes of the CLSM abutment.

Table 2. Comparison of natural frequencies of CLSM abutment obtained from FEMs and BEMs $(rad/\sec)$.

Mode	FEM (50 CST, 36 Nodes)	FEM (200 CST, 121 Nodes)	BEM (20 Constant Elements, 50 Cells)	BEM (40 Constant Elements, 200 Cells)	BEM (80 Constant Elements, Cells)
1	386.5304	396.1129	406	402	400
2	488.6686	472.1451	476	467	466
3	782.8412	773.2629	783	772	769
4	913.3739	876.0930	876	868	865
5	976.2245	896.4259	1086	1069	1066
6	1074.6773	1080.9783	1148	1144	1143

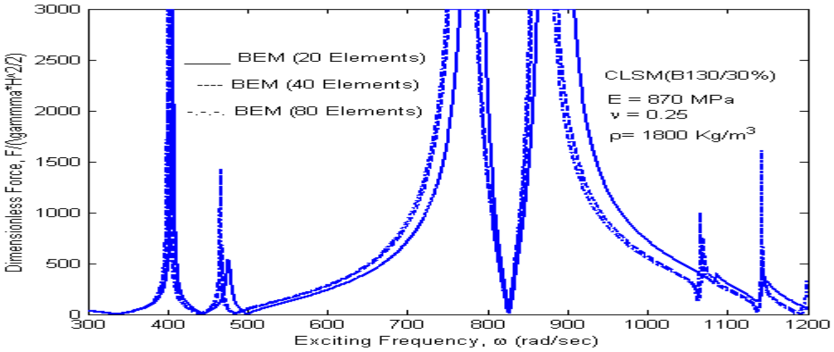


Figure 4. Eigenvalues of CLSM abutment using 20, 40 and 80 constant elements.

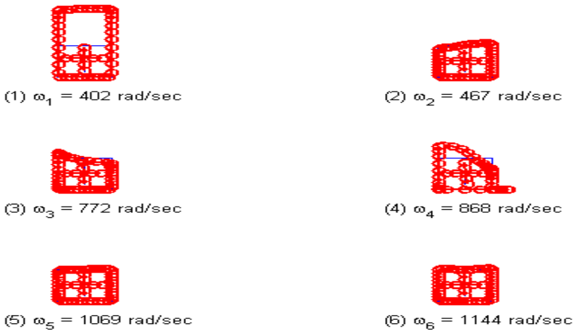

(1) ω_1 = 402 rad/sec
(2) ω_2 = 467 rad/sec
(3) ω_3 = 772 rad/sec
(4) ω_4 = 868 rad/sec
(5) ω_5 = 1069 rad/sec
(6) ω_6 = 1144 rad/sec

Figure 5. Mode shapes of the first six natural frequencies of CLSM abutment (40 BEs).

4 CONCLUSIONS

Consideration of the numerically predicted steady-state elasto-dynamic responses obtained from finite and boundary elements, the CLSM abutment made of binder mixture B130/30% ($E = 0.87\,GPa, \quad \nu = 0.25, \rho = 1800\,kg/m^3$) shows to have higher natural frequencies as compared to conventional abutment with piling supports and compacted soil construction. CLSM abutment can be a good material for bridge abutment design for bridge support system subjected to harmonic vibration.

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