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Free Vibration and Seismic Response Analysis of Trench Ducts Backfilled with Controlled Low-Strength Materials

*Li-Jeng Huang[1)], Her-Yung Wang[2)], and Yen-Chu Liang[3)]

[1), 2)] Department of Civil Engineering, NKUST, Kaohsiung 807, Taiwan, ROC.
[3)] Department of Aeronautics and Astronautics, CAFA, Kaohsiung 820, Taiwan, ROC
[1)] ljhuang@nkust.edu.tw

ABSTRACT

Controlled low-strength material (CLSM) has been proposed as a suitable substitute for conventional excavation and backfill materials. Reliable analysis is required to assure the safety of overall structural system including the backfill especially dynamic behavior due to earthquake. This paper presents seismic analysis of trench duct backfilled with sustainable materials and conventional materials using finite element method (FEM) based on 2D planar strain assumption. Emphasis are put on the comparison of natural frequencies, natural modes and seismic responses (maximal and averaged displacements, velocities and accelerations) of three kinds of backfilled materials, including conventional compacted soil and two kinds of CLSM with different binders (CLSM-B80/30% and CLSM-B130/30%). Both 1940 El-Centro and 1995 Kobe ground accelerations are employed and dynamic systems without and with damping are discussed. Numerical results show that dynamic responses of CLSM backfills are smaller than those using compacted soil and acceptable to assure the applicability of CLSM as a suitable sustainable material employed for trench duct backfill construction.

KEYWORDS: *Trench Duct Backfill, Controlled Low - Strength Materials, Modal Analysis, Seismic Response*

1. INTRODUCTION

[1,2)] Professor
[3)] Associate Professor

Recently in rapidly developed city and urban, growing life and communication demands lead to an increasing need of rapid construction (excavation and backfill) of trench duct and pipe systems to provide water supply, electric power lines, control cables, etc. Trench duct is an ideal design for projects requiring underground wiring distribution (Earle & Victor, 2011). Excavation and backfilling techniques are also developed rapidly. Backfill performs the following important functions: (a) serves as wall support and slope stabilization, (b) provides an artificial roof for underground construction, (c) fills the excavated space and voids, (d) disposes of waste soils, (e) serves as subsidence and rock-burst control, etc. However, analytical solutions of the backfill problems are not so easy due to complicated domain shape and boundary conditions and thus experimental techniques (Shakhzod, et al., 2014) as well as numerical approaches such as finite element methods (FEM) (Deng et al., 1999; Karimi, et al., 2009) are usually employed for stress and displacement analysis in geotechnical applications.
On the other hand, an effective rapid backfill technique of excavated trench ducts had been achieved by using the controlled low strength materials (CLSM). 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 (ACI229R, 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). Some researchers had applied to pavements (Lin et al., 2007). The authors also conducted some preliminary experimental studies on engineering properties of CLSM (Sheen et al, 2014a) and stress-strain relationship of CLSM (Sheen et al, 2014b). The authors further investigate the static and elasto-dynamic analyses of excavation zone backfilled with CLSM for retaining walls (Huanget al, 2014a, b), bridge abutments (Huang 2015a, b) and flexible pavements (Huang et al, 2017a, b).
Static and dynamic stability of trench duct are important problems in the geotechnical and construction engineering. Taiwan is located at the Circum-Pacific Seismic Belt and thus many earthquakes occur each year. The horizontal and vertical accelerations induced by earthquakes usually leads to liquefaction of perfectly and/or partially saturated stratum as well as softening, peel-off, separation and deposit of backfilled zone. However, in practice sudden ground acceleration during earthquakes induces large inertia forces in underground structures. The oscillatory amplitudes and cyclic dynamic stresses usually cause severe damage or collapse of trench duct which might directly lead to hydraulic pipe leakage or electric power supply interruption.

The authors had conducted numerical analysis of earth pressure and settlement of trench duct backfilled with CLSM (Huang et al., 2016). This paper is aimed at the comparison of seismic analysis of trench duct backfilled with CLSMs of two different binder mixtures (B-80/30% and B-130/30%), and compacted soil using FEM. The 1940 El-Centro NS component of ground acceleration and 1995 Kobe ground acceleration will be employed for dynamic response analysis of the trench duct without and with damping, respectively. Emphasis is put on the comparison on the seismic responses (displacements, velocities and accelerations) of trench duct using three kinds of backfill materials.

2. FINITE ELEMENT ANALYSIS OF THE BACKFILLED TRENCH DUCT

2.1 Problem Description

A typical trench duct backfilled with graded sand or CLSM is shown in Fig. 1(a). Different backfill materials will be investigated as follows:

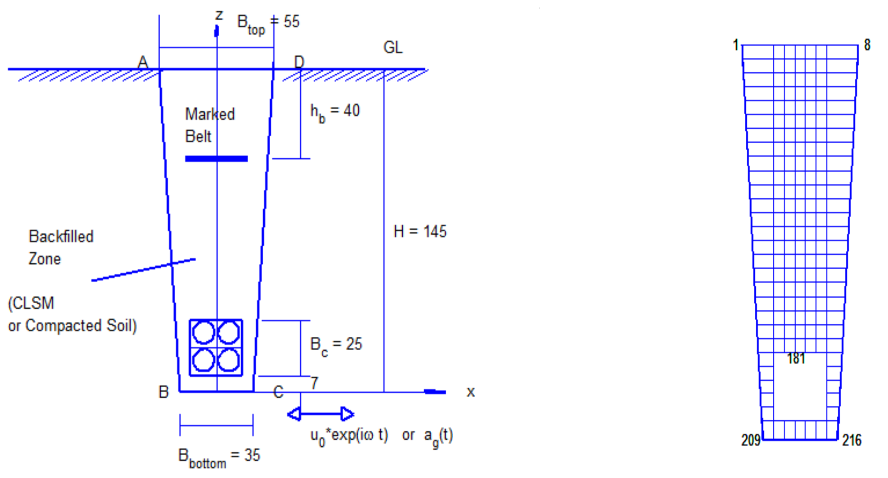
(1) Compacted Soil: $E = 0.1\,GPa, \nu = 0.3,\ \rho = 1745\ kg/m^3$;

(2) CLSM-B80/30%: $E = 0.27\ GPa,\ \nu = 0.25,\ \rho = 1695\ kg/m^3$;

(3) CLSM -B130/30%: $E = 0.87\ GPa,\ \nu = 0.25,\ \rho = 1800\ kg/m^3$;

The material constants in (2) and (3) are obtained from experimental works (Sheen et al., 2014). Selection of materials for the CLSM mixture in this study consistes 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.

The boundary conditions on $\overline{AB}$, $\overline{BC}$ and $\overline{CD}$ are assumed to be fixed. In free vibration analysis, we consider the excitations are in the form $u(x,z) = u_0(x,z) \bullet e^{i\omega t}$; while in seismic analysis we assume the excitations resulting from the ground acceleration in the form $a_g(t)$ (Figure 1(a)). In this study two record of typical ground acceleration will be employed for numerical experiments: (1) 1940 N-S component of El-Centro ground acceleration; and (2) 1995 Kobe ground acceleration.



(a) (b)

Fig. 1 (a) Schematic of a trench duct with backfill (length unit:cm); (b) finite element mesh of a trench duct (171 quadrilateral elements with 216 nodes)

2.2 Basic assumptions

The basic assumptions of numerical analysis are:
(1) All the dynamic displacements remain in small amplitude;
(2) Backfilled materials are linearly elastic and backfilled zone is homogeneous and isotropic;
(3) The trench duct is infinitely long therefore the deformation is in the state of plane strain;
(4) The surrounding boundaries except the top free surface zone are assumed to be rigid without considering the structure-foundation interaction effect;
(5) Damping of the backfill materials are very small and will be considered to be without damping or with a small damping (2%).

2.3 Finite Element Formulation

We can deduce the general finite element equations of equilibrium in the matrix form as (Rao, 1982):

$$[M]\{\ddot{x}\}+[K]\{x\}=\{f\} \tag{1}$$

where $[M],[K]$ denotes the global inertia and stiffness matrix, $\{x\}$ and $\{f\}$ denotes the nodal degrees of freedom ad nodal loads of the finite element system.

In free vibration analysis, we solve the eigen-value problem:

$$(-\omega^2[M]+[K])\,\{X\}=\{0\} \tag{2}$$

and obtain the circulatory natural frequencies, ω_k, and associated natural modes, $\{X\}_k, k=1,2,\cdots,n$.

If we want to consider the damping of materials, method of including Rayleigh damping can be considered as follows (Chopra 1995):

$$[C]=a_0[M]+a_1[K] \tag{3}$$

where the coefficients a_0 and a_1 can be determined from specified damping ratios ζ_1 and ζ_2 for the 1st and the 2nd modes (with assumption that $\zeta_1=\zeta_2=\zeta$):

$$a_0=\frac{2\omega_1\omega_2}{\omega_1+\omega_2}\zeta, \quad a_1=\frac{2}{\omega_1+\omega_2}\zeta \tag{4}$$

Then the damping ratio for the k-th mode is

$$\zeta_k=\frac{a_0}{2}\frac{1}{\omega_k}+\frac{a_1}{2}\omega_k \tag{5}$$

If the dynamic system is subjected to ground acceleration, $a_g(t)$, Eq. (1) becomes

$$[M]\{\ddot{x}\}+[C]\{\dot{x}\}+[K]\{x\}=-[M]\{L\}a_g(t) \tag{6}$$

where $\{L\}=[1 \quad 1 \quad \cdots \quad 1]^T$ is a *nx1* column vector.

A continuous system modelled using finite elements might involve a large number of degrees of freedom. However, using model reduction technique we can treat transformed system with smaller number of system variables. Selecting the first M leading natural modes:

$$[\Phi]=[\{X\}_1,\{X\}_2,\cdots,\{X\}_M]_{n\times M} \tag{7}$$

and introduce a new modal displacement vector $\{\xi(t)\}$ such that:

$$\{x(t)\}=[\Phi]\{\xi(t)\} \tag{8}$$

Then the equations of motion in natural coordinates become:

$$[\tilde{M}]\{\ddot{\xi}\}+[\tilde{C}]\{\dot{\xi}\}+[\tilde{K}]\{\xi\}=-[\Phi]^T[M]\{L\}a_g(t) \tag{9}$$

Where

$$\begin{aligned}[\tilde{M}]&=[\Phi]^T[M][\Phi]\\ [\tilde{C}]&=[\Phi]^T[C][\Phi]\\ [\tilde{K}]&=[\Phi]^T[K][\Phi]\end{aligned} \tag{10}$$

Introducing state vector

$$\{Z(t)\}=\begin{Bmatrix}\{\xi(t)\}\\ \{\dot{\xi}(t)\}\end{Bmatrix} \tag{11}$$

Eq. (2) can be expressed in a form as the state equation (Hart and Wang, 2000)

$$\frac{d}{dt}\{Z(t)\}=[A]\{Z(t)\}+[B]\{u(t)\} \tag{12}$$

where the state matrix *[A]* , input matrix *[B]*, and input vector *{u(t)}*, are defined as

$$\begin{aligned}[A]&=\begin{bmatrix}[0] & [I]\\ -[\tilde{M}]^{-1}[\tilde{K}] & -[\tilde{M}]^{-1}[\tilde{C}]\end{bmatrix}\\ [B]&=\begin{bmatrix}[0]\\ -[\tilde{M}]^{-1}\end{bmatrix}\\ \{u(t)\}&=[\Phi]^T[M]\{L\}a_g(t)\end{aligned} \tag{13}$$

Eq. (12) is linear first-order simultaneous ordinary differential equations of order $(2M \times 2M)$ and can be solved by fourth-order Runge-Kutta scheme when the initial conditions $\{z(0)\}^T = \{\{\xi(0\}, \{\dot{\xi}(0)\}^T$ are specified. In the seismic response analysis we usually assume zero initial conditions, i.e., the system is at rest before ground excitation. After the state vector solved, the original displacement vector (and velocities and accelerations) can be evaluated from Eq. (8) and its derivatives. If absolute accelerations are required the following relationship can be employed:

$$\{a_{abs}(t)\} = \{a(t)\} + \{a_g(t)\} \tag{14}$$

Sometimes we want to evaluate the overall behaviour of the dynamic system, via the maximal responses:

$$[u, v, a]_{\max} = \max[u, v, a] \tag{15}$$

Or the averaged responses defined as:

$$[u, v, a]_{AVE} = \frac{1}{T}\int_0^T abs[u(t), v(t), a(t)] \bullet dt \tag{16}$$

3. NUMERICAL RESULTS OF FREE VIBRATION ANALYSIS

3.1 Finite Element Discretization

The trench duct backfilled by three kinds of materials as shown in Fig.1(a) had been discretized using 171 quadrilateral elements with totally 216 nodes, as depicted in Fig.1(b). At each nodes there are two displacements (u_x, u_z) in the horizontal and vertical direction, respectively.

3.2 Natural Frequencies and Natural Modes

From the Eq. (2), the FEM gives all the natural frequencies and natural modes from which we summarize the first 6 natural frequencies for three backfill materials (Compacted Soil,CLSM-B80/30% and CLSM-B130/30%) in the Table 1. On the other hand, the associated 6 natural modes of CLSM-B130/30% are shown in Fig. 2. (Natural mode shapes are the same for another two backfill materials, only the natural frequencies are different).

Table 1 Natural frequencies of trench ducts backfilled with different materials obtained from FEM $(rad/\sec)$

Mode #	Mode Type	Backfill Materials		
		Compacted Soil	CLSM-B80/30%	CLSM-B130/30%
1	1^{st} bending	990.0896	1656.9344	2886.2348
2	1^{st} stretching	1309.0439	2173.7252	3786.4402
3	1^{st} twisting	1595.2688	2600.7514	4530.3018
4	2^{nd} twisting	1733.2807	2865.5127	4991.4725
5	2^{nd} bending	1770.9220	2903.1985	5057.1189
6	3^{rd} twisting	1927.7219	3164.0289	5511.4644

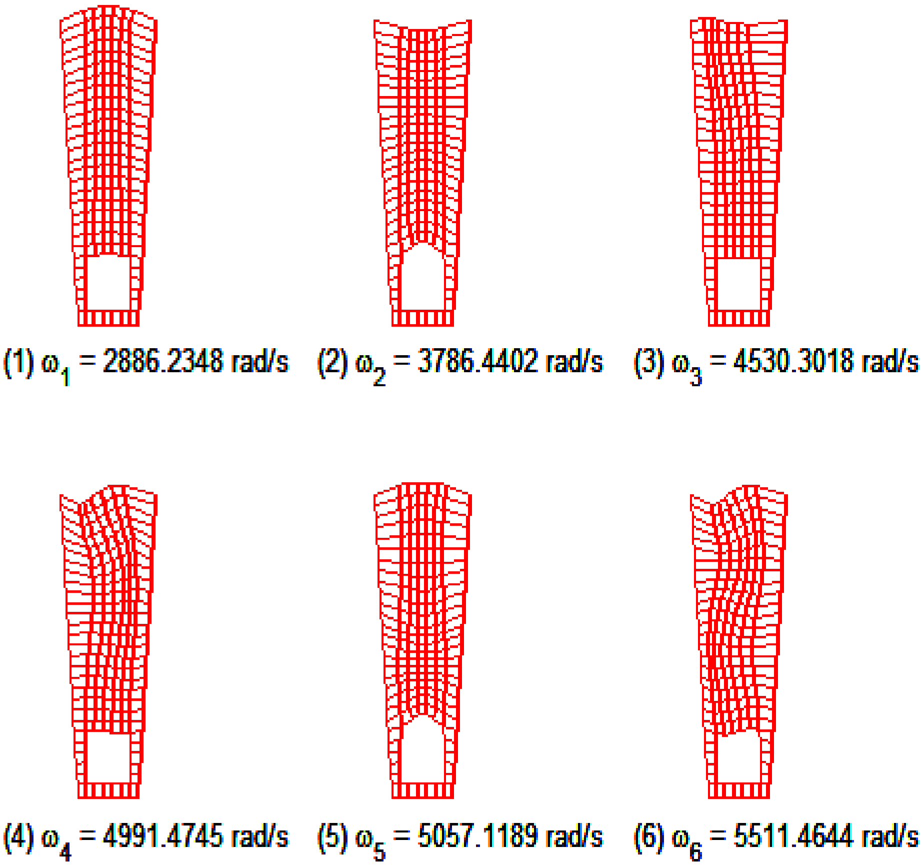


Fig. 2 Natural modes of trench ducts backfilled with CLSM-B130/30%

3.3 Determination of Coefficients of Rayleigh Damping

From Eq. (4) and Eq. (5) and we assume that $\zeta_1 = \zeta_2 = 0.02$. Damping ratio 2% is a reasonable and conservable assumption in civil engineering. The associated Rayleigh coefficients and damping ratio for the first 6 leading modes are list in Table 2. It can be observed that all the damping ratios are nearly equal to 0.02. We then use these coefficient a_0 and a_1 to estimate the damping matrix for three different backfill materials.

Table 2 Coefficients of Rayleigh damping and damping ratios for the first 6 leading modes.

Backfilled Materials	Coefficients		Damping ratios for the first 6 leading modes					
	a_0	a_1	ζ_1	ζ_2	ζ_3	ζ_4	ζ_5	ζ_6
Compacted Soil	0.2255	0.0017	0.0200	0.0200	0.0209	0.0216	0.0218	0.0226
CLSM-B80/30%	0.3760	0.0010	0.0200	0.0200	0.0208	0.0215	0.0216	0.0225
CLSM-B130/30%	0.6551	0.0006	0.0200	0.0200	0.0208	0.0215	0.0216	0.0225

4. NUMERICAL RESULTS OF SEISMIC RESPONSES ANALYSIS

4.1 Convergence Study on the Number of Modes Employed in Model Reduction

At first we should check the convergence for dynamic response calculation using state space description with Runge-Kutta scheme obtained from model reduction technique where some leading natural modes are selected, as depicted in Eq. (7). Here we select backfill material to be CLSM-B10/30% and the trench duct subjected to 1940 El-Centro NS ground acceleration. Vertical responses (displacement, velocity, acceleration and absolute acceleration) of nodal number 181, which is located at the top surface of the duct as marked in Fig. 1(b), will be investigated.

Figure 3 and 4 shows the seismic responses of the reduced model using different number of natural modes for $M = 1,2,3,6$ for system without and with damping, respectively. It can be observed that the curves for $M = 2,3,6$ are all nearly merged to be the same curves, except those for $M = 1$. The results converge rapidly. Table 3 and 4 show further the maximal responses and averaged responses for these cases in which percentage errors are calculated based on those obtained using $M = 9$. It can be realized and confirmed that reduced model using $M = 6$ can be considered to be capable of representing original dynamic system with percentage errors are smaller than 5%. Therefore, in the following seismic analysis we employ the first leading 6 modes to obtain reduced finite dimensional system.

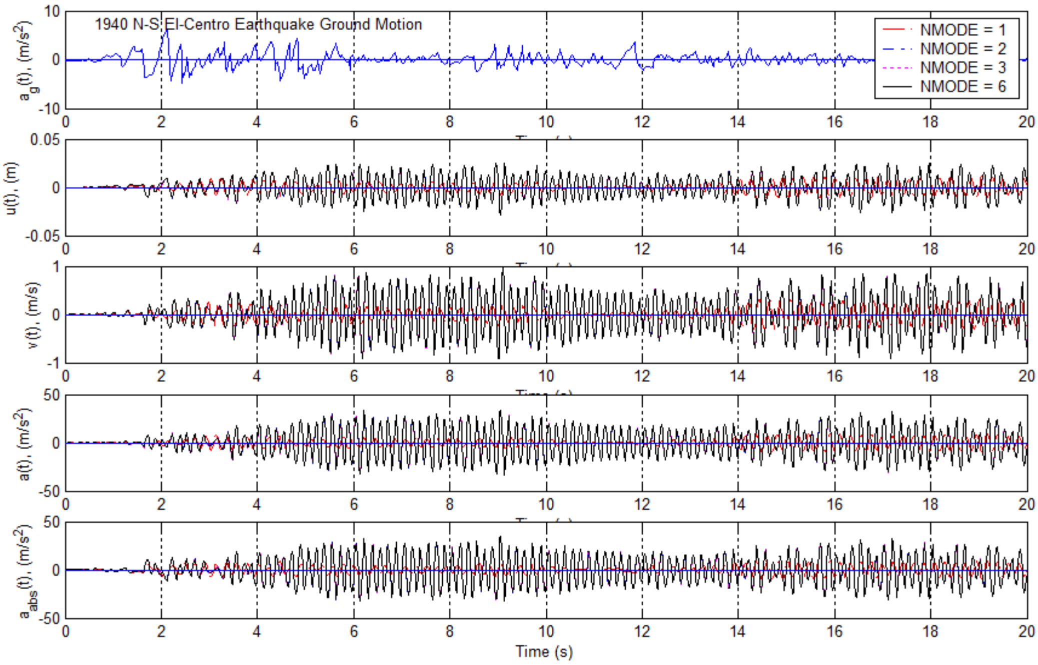


Fig. 3 Calculated vertical responses of node 181 of trench duct backfilled with CLSM-B130/30% without damping subjected to 1940 El-Centro NS ground acceleration.

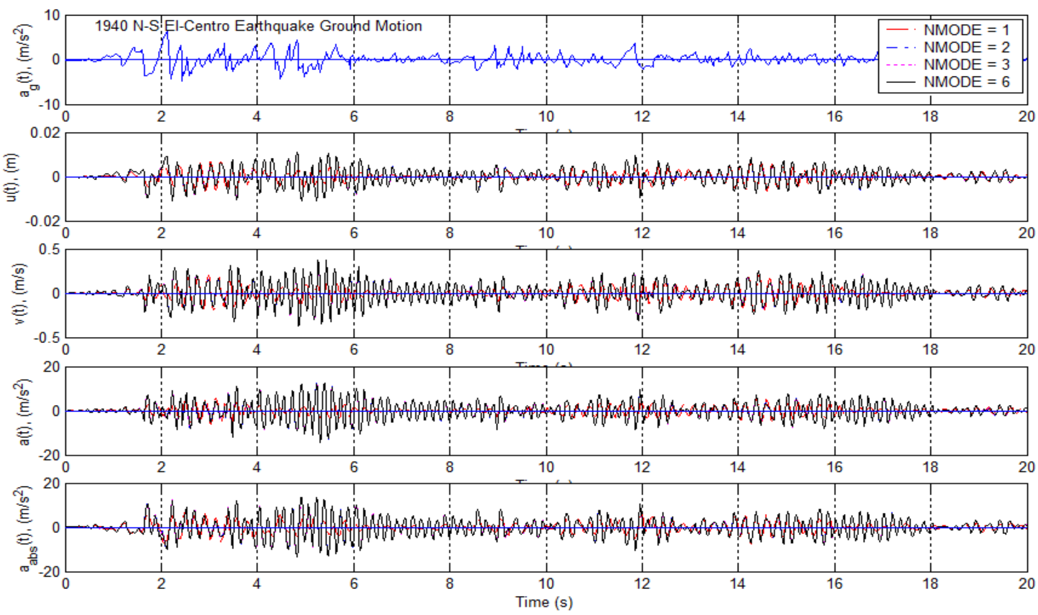


Fig. 4 Calculated vertical responses of node 181 of trench duct backfilled with CLSM-B130/30% with damping subjected to 1940 El-Centro NS ground acceleration.

Table 3 Maximal vertical responses of node 181 of trench duct backfilled with CLSM-B130/30% subjected to 1940 El-Centro NS ground acceleration with reduced model using different number of natural modes

El-Centro CLSM-B130/30%	Maximal Displacements (m)		Maximal Velocities (m/s)		Maximal Accelerations (m/s^2)	
NMODE (*M*)	Undamped	Damped	Undamped	Damped	Undamped	Damped
1	0.0112 (60.23%)	0.0073 (32.95%)	0.3180 (66.91%)	0.2032 (45.67%)	10.11 (71.26%)	7.35 (46.78%)
2	0.0281 (0.22%)	0.0110 (-0.05%)	0.9542 (0.72%)	0.3764 (-0.64%)	34.98 (0.54%)	13.59 (1.58%)
3	0.0281 (0.24%)	0.0109 (0.04%)	0.9540 (0.74%)	0.3765 (-0.66%)	34.97 (0.56%)	13.60 (1.56%)
6	0.0282 (-0.08%)	0.0109 (0.20%)	0.9597 (0.14%)	0.3744 (-0.11%)	35.36 (-0.52%)	13.52 (2.09%)
9	0.0282	0.0109	0.9611	0.3740	35.17	13.81

Table 4 Averaged vertical responses of node 181 of trench duct backfilled with CLSM-B130/30% subjected to 1940 El-Centro NS ground acceleration with reduced model using different number of natural modes

El-Centro CLSM-B130/30%	Averaged Displacements (m)		Averaged Velocities (m/s)		Averaged Accelerations (m/s^2)	
NMODE (*M*)	Undamped	Damped	Undamped	Damped	Undamped	Damped
1	0.0038 (56.57%)	0.0017 (39.12%)	0.1083 (65.84%)	0.0456 (47.45%)	3.1236 (73.27%)	1.2993 (56.18%)
2	0.0088 (-0.013%)	0.0027 (-0.001%)	0.3169 (0.009%)	0.0867 (0.034%)	11.867 (-0.000%)	2.9644 (0.027%)
3	0.0088 (-0.012%)	0.0027 (0.016%)	0.3169 (0.008%)	0.0867 (0.039%)	11.6870 (-0.004%)	2.9646 (0.021%)
6	0.0088 (0.038%)	0.0027 (0.214%)	0.3169 (0.008%)	0.0867 (0.061%)	11.6895 (-0.025%)	2.9693 (-0.139%)
9	0.0088	0.0027	0.3169	0.0867	11.6866	2.9652

4.2 Seismic responses to 1940 El-Centro NS ground acceleration

We then investigate seismic responses of the trench duct backfilled with three kinds of materials (Compacted soil, CLSM-B80/30% and CLSM-B130/30%) subjected to 1940 N-S component of El-Centro ground accelerations. The ground acceleration record, displacement, velocity, acceleration and absolute acceleration responses are plotted in Fig. 5 for undamped case and in Fig 6 for damped case ($\zeta_1 = \zeta_2 = 0.02$), respectively. We employ $\Delta t = 0.02\sec$ and 1000 records of ground motion to compute the FEM solutions using Runge-Kutta scheme on 1st-order state space model. Maximal responses, calculated from Eq. (15), and averaged responses, calculated from Eq. (16), are shown in Table 5 and Table 6, respectively.

From the figures and tables we can find that among these three backfilled materials CLSM-B130/30% provides relative higher rigidity to reduce the displacement and velocity responses while larger acceleration responses for cases without and with damping. Both two kinds of CLSM backfill materials perform better than the compacted soil.

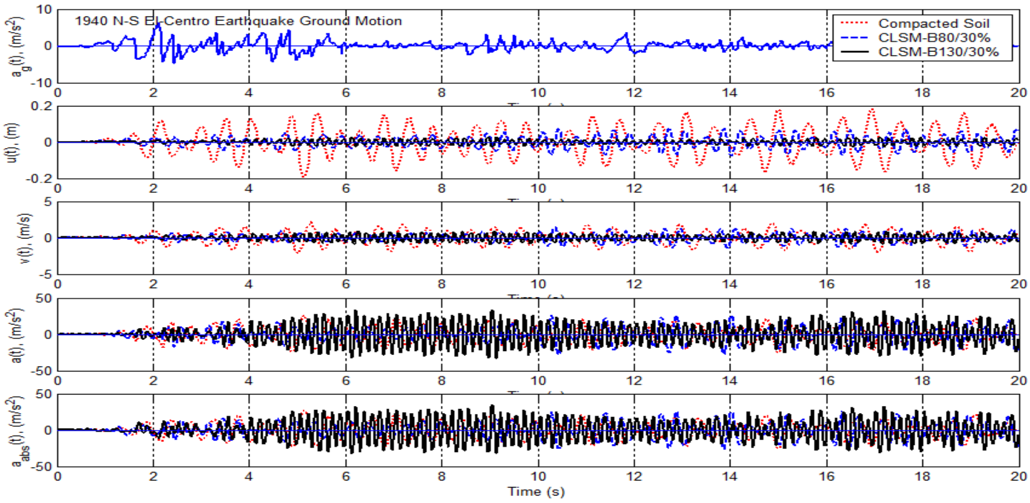


Fig. 5 Calculated vertical responses of node 181 of trench duct backfilled with three different backfill materials without damping subjected to 1940 El-Centro NS ground acceleration.

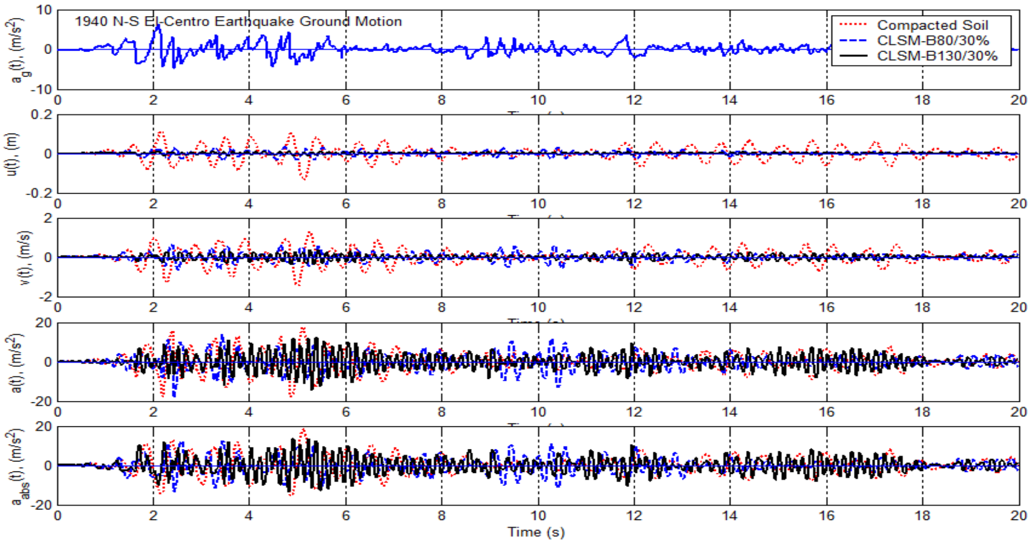


Fig. 6 Calculated vertical responses of node 181 of trench duct backfilled with three different backfill materials with damping subjected to 1940 El-Centro NS ground acceleration.

Table 5 Maximal vertical responses of node 181 of trench duct backfilled with three different backfill materials subjected to 1940 El-Centro NS ground acceleration

El-Centro	Maximal Displacements (m)		Maximal Velocities (m/s)		Maximal Accelerations (m/s^2)	
Materials	Undamped	Damped	Undamped	Damped	Undamped	Damped
Compacted Soil	0.1992	0.1325	2.1405	1.4489	27.3598	18.5684
CLSM-B80/30%	0.0737 (-62.99%)	0.0342 (-74.19%)	1.4071 (-34.26%)	0.6572 (-54.64%)	25.8957 (-5.35%)	13.3984 (-27.84%)
CLSM-B130/30%	0.0282 (-85.84%)	0.0109 (-91.75%)	0.9597 (-55.16%)	0.3744 (-74.16%)	35.3558 (29.23%)	13.5221 (-27.17%)

Table 6 Averaged vertical responses of node 181 of trench duct backfilled with three different backfill materials subjected to 1940 El-Centro NS ground acceleration

El-Centro	Averaged Displacements (m)		Averaged Velocities (m/s)		Averaged Accelerations (m/s^2)	
Materials	Undamped	Damped	Undamped	Damped	Undamped	Damped
Compacted Soil	0.0638	0.0277	0.7200	0.3061	8.6302	3.6165
CLSM-B80/30%	0.0245 (-61.55%)	0.0078 (-71.81%)	0.4220 (-41.38%)	0.1417 (-53.69%)	7.6308 (-11.58%)	2.8379 (-21.53%)
CLSM-B130/30%	0.0088 (-86.24%)	0.0027 (-90.17%)	0.3169 (-55.99%)	0.0867 (-71.68%)	11.6894 (35.45%)	2.9693 (-17.89%)

4.3 Seismic responses to 1995 Kobe ground acceleration

We then investigate seismic responses of the trench duct backfilled with three kinds of materials (Compacted soil, CLSM-B80/30% and CLSM-B130/30%) subjected to 1995 component of Kobe ground accelerations. The ground acceleration record, displacement, velocity, acceleration and absolute acceleration responses can be observed in Fig. 7 for undamped case and in Fig. 8 for damped case ($\zeta_1 = \zeta_2 = 0.02$), respectively. In this case we employ $\Delta t = 0.005\sec$ and 4000 records of ground motion to compute the FEM solutions using Runge-Kutta scheme on 1st-order state space model. Table 7 and Table 8 show the maximal responses, calculated from Eq. (15), and averaged responses, calculated from Eq. (16), respectively.

In this case study figures 7 and 8 as well as tables 7 and 8 all depict that, among these three backfilled materials, CLSM-B130/30% provides relative higher rigidity to reduce the responses for cases without and with damping. Both two kinds of CLSM backfill materials perform better than the compacted soil.

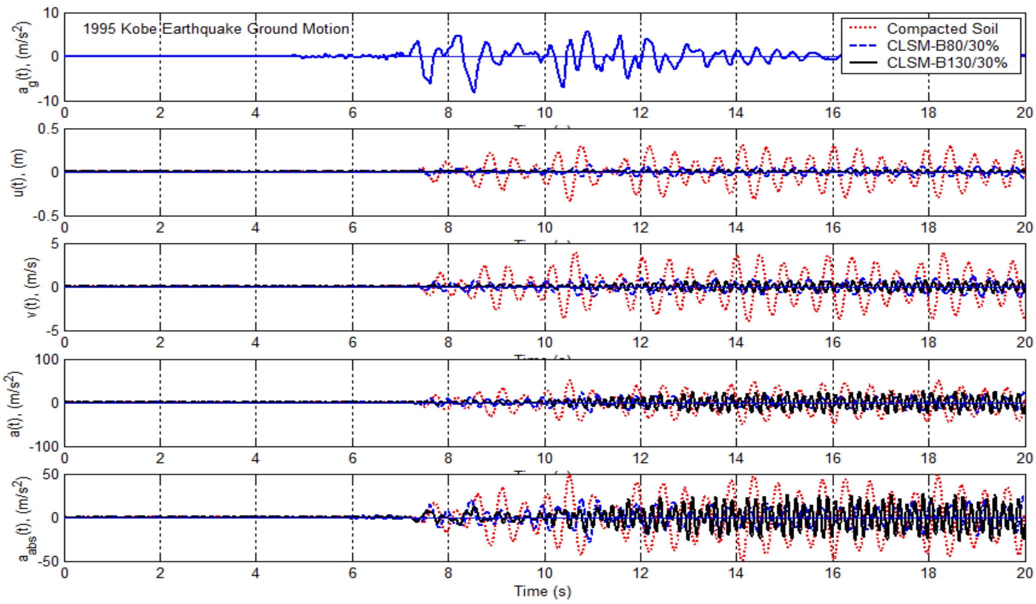


Fig. 7 Calculated vertical responses of node 181 of trench duct backfilled with three different backfill materials without damping subjected to 1995 Kobe ground acceleration.

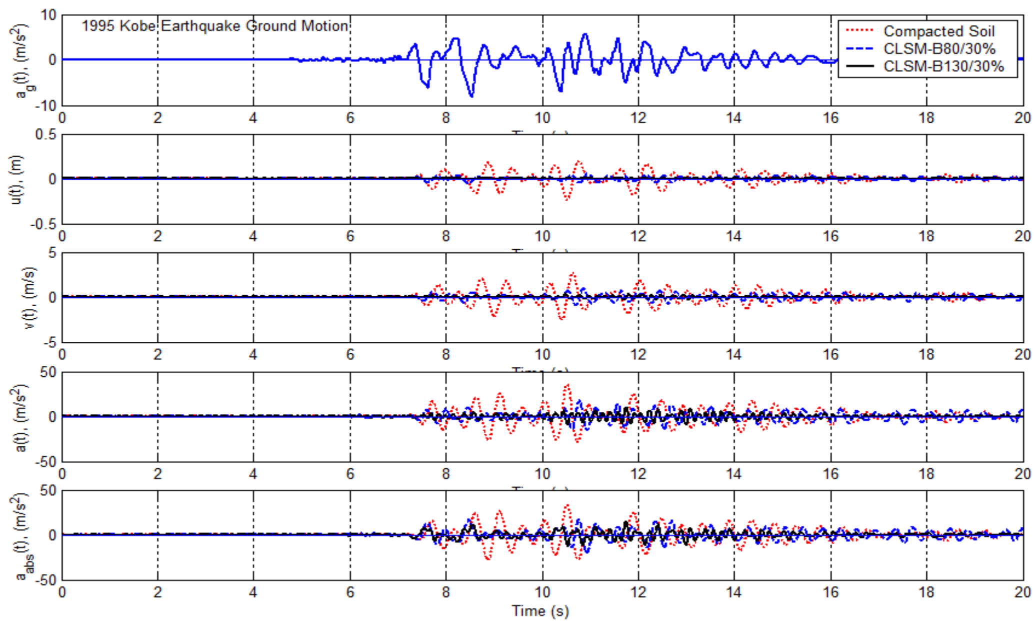


Fig. 8 Calculated vertical responses of node 181 of trench duct backfilled with three different backfill materials with damping subjected to 1995 Kobe ground acceleration.

Table 7 Maximal vertical responses of node 181 of trench duct backfilled with three different backfill materials subjected to 1995 Kobe ground acceleration

Kobe	Maximal Displacements (m)		Maximal Velocities (m/s)		Maximal Accelerations (m/s^2)	
Materials	Undamped	Damped	Undamped	Damped	Undamped	Damped
Compacted Soil	0.3333	0.2332	3.9857	2.7346	49.7428	33.2587
CLSM-B80/30%	0.0803 (-75.65%)	0.0579 (-75.20%)	1.3116 (-67.09%)	0.9502 (-65.25%)	28.8570 (-41.99%)	20.3267 (-38.88%)
CLSM-B130/30%	0.0234 (-92.91%)	0.0136 (-94.16%)	0.7634 (-80.85%)	0.3096 (-88.68%)	27.5986 (-44.52%)	14.9377 (-55.09%)

Table 8 Averaged vertical responses of node 181 of trench duct backfilled with three different backfill materials subjected to 1995 Kobe ground acceleration

Kobe	Averaged Displacements (m)		Averaged Velocities (m/s)		Averaged Accelerations (m/s^2)	
Materials	Undamped	Damped	Undamped	Damped	Undamped	Damped
Compacted Soil	3.094e-5	3.0320e-5	2.7518e-4	2.7121e-4	0.0064	0.0063
CLSM-B80/30%	1.8232e-5 (-41.07%)	1.7248e-5 (-43.11%)	4.1099e-4 (49.35%)	3.8705e-4 (42.72%)	0.0080 (25.64%)	0.0076 (20.30%)
CLSM-B130/30%	0.8531e-5 (-72.42%)	0.7842e-5 (-74.14%)	2.2733e-4 (-17.39%)	1.9819e-4 (-26.92%)	0.0089 (38.31%)	0.0078 (23.93%)

4. CONCLUSIONS

Numerical experiments of seismic responses (displacement, velocity and acceleration) of trench duct using two kinds of CLSM backfill materials (CLSM-B80/30% and CLSM-B130/30%) and conventional compacted soil show that finite element can provide satisfactory results. The numerical analysis using FEM for trench duct backfilled with CLSM forms a basis for future of spectra analysis of seismic response for the structure. Numerical test studies also show that:

(a) seismic responses of trench duct backfilled with CLSMs depict smaller displacement responses than compacted soil. This reveals that CLSM is a good backfill since it can sustain higher seismic excitation than compacted soil and possess the same ease of excavation and backfill operations.

(b) Consideration of dynamic characteristics of trench ducts backfilled with CLSM, CLSM-B130/30% ($E = 0.87\ GPa,\ \nu = 0.25,\quad \rho = 1800\ kg/m^3$) shows to be a good selection for backfill material providing as hydraulic pipes and electric transmission lines for construction engineering applications.

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