

論文

[2220] Nonlinear Response of RC In-Plane Structures Surrounded by Soil Continuum under Shear

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1. INTRODUCTION

In the design of underground RC structures, soil and RC structures are basically treated as independent systems. This is due to the insufficient knowledge about the interaction between the soil and RC structures especially in the elasto-plastic stages. Several researches were undergone on underground structures subjected to seismic loading[1]. These researches considered low stress levels which are close to the elastic range. As a result, underground structures have high structural stiffness and high factor of safety which would bring uneconomical decision and lower ductility of structures in some cases. This paper treats underground RC structures subjected to high shear deformation through surrounding soil medium.

In present design practice, the earth pressure is generally specified independent on the structural deformations and types. But, it was clearly proved through experiments that the induced force from surrounding soil varies according to the structural nonlinearity of RC[2]. For rationale design of underground structures, the possible mode of failure of RC underground should be known. In this paper, numerical parametric FEM analysis is carried out to investigate the change in the response due to the nonlinearity of RC shell type structures (tanks, ducts, cason...) surrounded by soil medium under high shear transferred through the surrounding soil. Due to these loads, the nonlinearity of the RC structure is induced by cracking of concrete and yield of reinforcement. From this analysis, failure mode, residual deformation and nonlinearity of underground structures are investigated to obtain rationalized guidelines for the future improvement of underground structural design.

2. DEFINITION OF THE PROBLEM

In this study, RC under-ground duct with height ($H = 15.0$ m) and box cross section ($L \times L = 5.0 \times 5.0$ m) with thickness (d) and surrounded by soil continuum is studied. The RC duct coupled with surrounding medium is analyzed under the shear mode denoted by (δ) acting on the soil as shown in Fig(1). In the analysis, the soil is considered as linear elastic material with Young's Modules E_{soil} to clearly know the possible failure condition of RC structure. Assumption of elastic soil medium is severe to the failure condition of RC since no damage is made in soil. Various parameters are considered in the analysis in order to study the deformation mode of the RC structure in the nonlinear stage.

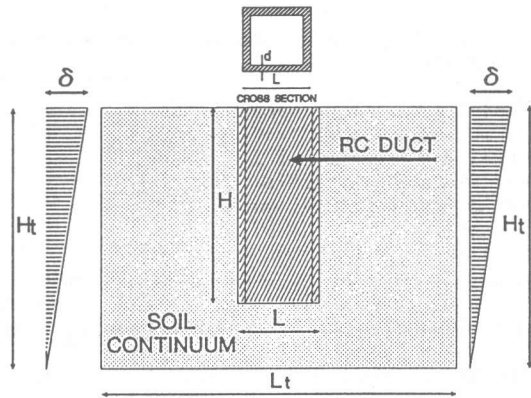


FIG.(1) ENTIRE SYSTEM

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3. DESCRIPTION OF THE ANALYSIS

The Computer Program "WCOMR"[3] is used in this study. It is based on the finite element method with two-dimensional quadrilateral 8-nodes isoparametric elements. Nonlinear solution technique enables a step by step loading of a structure. An iterative procedure is performed at each load step until equilibrium requirement is satisfied. It provides the information about deformations, stresses, crack development and failure modes (crushing of concrete and reinforcement yielding) at each load step. The post-peak behavior of the structure is obtainable under reversed cyclic loads.

In "WCOMR", the nonlinearity of reinforced concrete depends on the bond between reinforcement and concrete, compressive characteristics of concrete between cracks and shear transfer behavior of cracks. The reinforced concrete plate element model was constructed by combining the constitutive law of both concrete and reinforcing bars. The constitutive law adopted for the smeared crack concrete is composed of the tension stiffening model, the compression model and shear transfer model [3]. The constitutive laws for smeared crack RC model was systematically verified, as a result of which laboratory experimentation for in-plane members and structure can be replaced by numerical simulation.

The finite element mesh, composed of eight node quadrilateral elements is used as shown in Fig(2). In the analysis, the mean shear displacement ($\gamma = \delta/H_0$) is applied incrementally up to a maximum of 2.0 % (severe earthquake) or failure. The mechanical properties of surrounding Soil[4] are represented by Young's Modules (E_{soil}) which varies from very weak soil (250 kgf/cm^2) to very stiff soil (5000 kgf/cm^2). The RC structural rigidity, as represented by the ratio of the thickness to the length of the wall (d/L), is changed from 0.025 to 0.3. The reinforcement ratio of the RC structure is considered isotropic ($P_x = P_y$) and ranges from 0.3 to 2.0%. The interface between the soil elements and RC elements is assumed totally fixed (no separation and no sliding), which is also a severe condition concerning RC failure.

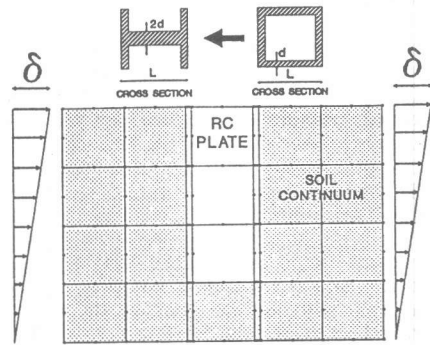


FIG.(2) FINITE ELEMENT MESH

4. NONLINEAR RC RESPONSE UNDER CONTINUUM MEDIA

4.1. STRUCTURAL INDICATORS OF STRESS, STRAIN AND DAMAGES

Stress and strain tensors invariants[5] are used as indicators to identify the response mode and cracking condition.

The first strain tensor invariant denoted by (I_1') is closely associated with the crack occurrence and expansion of the in-plane element (volumetric change of the element). *Spatially average first strain invariant* (I') is the average of (I_1') for all the RC elements. This average is used as an indicator for the

volumetric change of the RC structure within 2D plane. This value is equal zero in case of elastic shear (no volumetric change). The authors accepted the volumetric averaging (I') of the local intensity of expansive deformation which has much to do with leakage resistance and structural soundness.

The second strain deviator invariant denoted by (J_2') is used as indicator of shear mode of the deformation of the in-plane element which is closely connected with induced shear force. The authors used the ratio of *spatially averaged second strain deviator* (J') of RC structure with respect to

$$I_1' = e_1 + e_2 = \Delta V / V \quad (\text{local})$$

$$I' = \int_{\text{elements}} I_1'(x,y) dx dy / A \quad \dots \quad (1)$$

.... (structure based average)

$$J_2' = |e_1 - e_2| \quad (\text{local intensity of shear})$$

$$J' = \int_{\text{elements}} J_2'(x,y) dx dy / A \quad \dots \quad (2)$$

.... (structure based average)