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Finite element analysis on earth reinforcement – Current and future

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ABSTRACT: The Japanese Local Task Force Committee of Asian Technical Committee for Earth Reinforcement carried out extensive survey of technical papers related to the numerical analysis on earth reinforcement which were appeared in Journals and Proceedings for last 12 years. In this paper, current state and future trend of the Finite Element Analysis on earth reinforcement will be discussed based on this survey.

1 STATISTIC ON NUMERICAL ANALYSIS FOR EARTH REINFORCEMENT

Statistics on current state of the numerical analysis is summarized based on the survey of technical papers related to the numerical analysis on earth reinforcement which were published in Journals and Proceedings for last 12 years (1985 - 1996). The details of this survey are introduced in another report written by the Japanese Local Task Force Committee of Asian Technical Committee for Earth Reinforcement in this proceeding volume.

More than 160 technical papers in which there is a keyword "analysis" were selected and reviewed from the following journals and proceedings;

- ASCE Journal of Geotechnical Engineering
- Géotechnique
- Canadian Geotechnical Journal
- Soils and Foundations
- Geotextiles and Geomembranes
- Computers and Geotechnics
- Int. J. Num. Anal. Meth. in Geomechnics.
- Proc. JSCE
- Proc. IS-Kyushu ('88, '92 and '96)

Half of the selected papers treated the deforma-

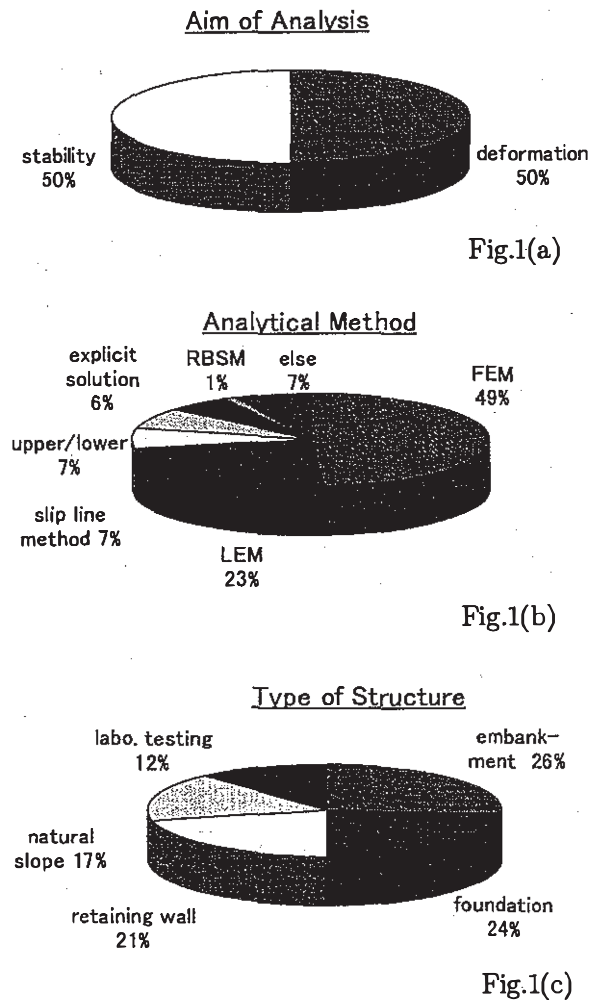

Fig.1 Statistics on numerical analysis for earth reinforcement

tion problem and another half treated the stability problem (Fig.1(a)). It is found from Fig.1(b) that the finite element method (FEM) was used for the prediction of the deformation of the ground with earth reinforcement. On the other hand, the limit equilibrium method (LEM), slip line method, upper/lower bound theorem, RBSM, etc. were used for the assessment of the stability of the ground with earth reinforcement. Fig.1(c) summarizes the type of structure treated in the technical papers. Deformation/stability problems on embankment and foundation subsoil were mainly investigated by the numerical analysis. From this statistic, the finite element analysis on embankment and foundation subsoil with earth reinforcement is found to have been studied intensively for last 12 years. In this report, therefore, the finite element analysis will be discussed as a main subject.

2 CONTRAST BETWEEN LEM AND FEM

For the analysis by the limit equilibrium method (LEM) which is commonly used for the assessment of the stability of the ground with earth reinforcement, the design strength parameters are only needed. The construction process should be reflected in determining design strength parameters. We have to choose undrained, partially drained or fully drained strength of subsoil materials based on the construction process and permeabilities of subsoils. The compressive, extensive or simple shear strength should be carefully used based on the stress condition of the subsoil near the failure state.

For the analysis by the finite element method (FEM) which is used for the prediction of the deformation of the ground with earth reinforcement, on the other hand, we have to predict the elastic behavior, plastic (viscoplastic) behavior and failure (ultimate limit state) based on a correct initial condition (Fig.2). For this purpose, the correct initial condition, constitutive model and stable numerical algorithm must be prepared before the analysis.

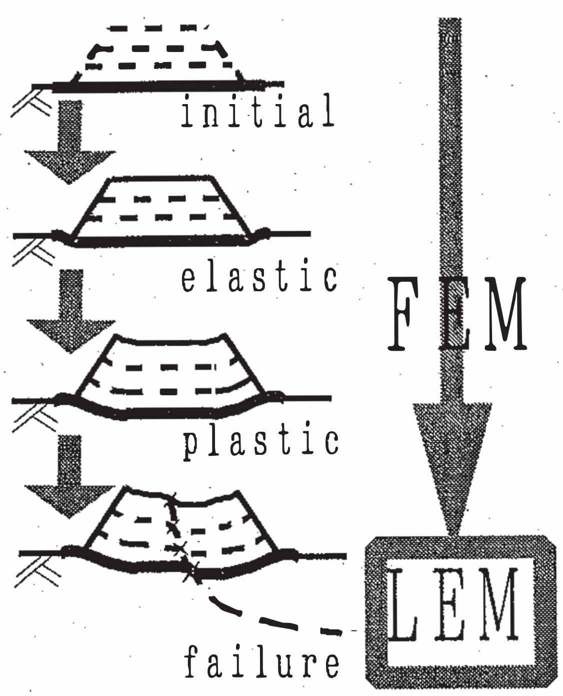

Fig.2 Contrast between LEM and FEM

3 CURRENT STATE OF FE ANALYSIS

3.1 *Merit of FEM in earth reinforcement design*

The finite element analysis is a more powerful analytical tool for solving boundary value problems than the limit equilibrium method.

The finite element analysis

- offers deformation, stress-strain distribution which informations are highly required in designing some of the important civil engineering structures,
- helps engineers to understand real mechanism in earth reinforcement,
- provides additional information to fully understand the complex interaction behavior which will be reflected in easy-to-use design method (refines the current design chart),
- validates a simplified design method,
- takes account of construction process which is one of the most dominant factors in determining reinforced soil behavior,
- identifies potential failure planes,
- is easily applied in observational method,
- etc.

3.2 *Difficulty in FEM based earth reinforcement design*

Why is the finite element method still far from being a practical tool for designing the earth reinforcement? The answers for this questions are;

- The correct initial condition is difficult to be postulated.

- The finite element analysis is poor at predicting failure (ultimate limit state).
- The finite element analysis is rather expensive and is usually limited to the mainframe computer.
- The mechanism of complex interaction is needed before analysis (It is impossible to obtain new mechanism which was not implemented a pri-o-ri in the modeling).
- How the complex system is going to fail is needed to know before modeling that failure.
- The finite element analysis is often thought to be a black box (refuses engineers to participate in the whole design process).
- The soil, reinforcement, and interaction properties under operational conditions are difficult to determine from the results of standard laboratory tests on component materials.
- Sophisticated constitutive model proposed has been not implemented for earth reinforcement analysis.

3.3 *Recent progress in FE analysis on earth reinforcement*

In 1980, Ohta et al. (1980) published the paper entitled "Investigation of Soft Foundations with Surface Reinforcement". In their paper, they discussed many important subjects on the prediction of the deformation of the embankment constructed on the clay foundation with surface reinforcement by the finite element analysis. In this chapter, we will understand the current state of the finite element analysis by answering the question "what is the progress from the paper by Ohta et al. (1980)?".

Soil modeling

In the paper by Ohta et al., the Cam-clay type elasto-plastic model with stress induced anisotropy (Sekiguchi and Ohta 1977) was used for the clayey foundation. For the analysis of the earth reinforcement, Mohr-Coulomb yield surface, Drucker-Prager yield surface, Modified Cam-clay model (Hird et al. 1990), elasto-viscoplastic model, nonlinear elastic model, etc. have been proposed and used for the foundation material. From now on, we should use a sophisticated constitutive model for foundation and embankment material.

Reinforcement modeling

In the paper by Ohta et al., an elastic thin layer element was used to model the behavior of reinforcement material. Based on the laboratory/insitu tests for reinforcement materials, many constitutive models considering elastic, visco-elastic or plastic properties have been proposed. To model the reinforcement itself, the bar element, truss element or thin layer element has been used.

To obtain the reasonable prediction of the behavior of reinforced ground, the interaction behavior between soil and reinforcement material should be modeled appropriately. The special elements which simulate the interaction behavior have been proposed. A simple thin-layer element to model soil-geotextile interaction was proposed by Handel et al. (1990). The anisotropic element was designed by the homogenization technique. The joint (Kutara et al. 1986; Ochiai et al. 1988; Matsui and San 1989) or linkage elements has been used to reproduce the slippage between soil and reinforcement material. The nodal compatibility-slip model was proposed by Rowe (1984). Rowe has succeeded in predicting the deformation of the reinforced embankment with this special treatment in many case studies. Otani and Ochiai (1993) introduced a special rectangular element with high cohesion to model the interaction between soil and reinforcement.

Soil-water coupling

In the paper by Ohta et al., the soil-water coupling behavior was treated by introducing the variable of pore water pressure in the finite element formulation. In most papers appeared in journals and proceedings, fully undrained behavior has been considered for clayey foundation and fully drained behavior has been considered for sandy foundation. During the construction process, the generation and dissipation of the pore water pressure takes place at the same time at different places in the analyzed region. The soil-water coupled analysis is therefore recommended in the application to the reinforcement soft foundation.

Hardware

In the paper by Ohta et al., the parametric study on imaginary reinforced embankment and application to trial embankment were carried out using the mainframe computer. In most technical papers, mainframe computer has also been used for the numerical analysis. For the last decade, we have experienced a great progress in hardware of the personal computer (PC) and rapid development of pre- and post-processor. Now, the two-dimensional soil-water coupled analysis on earth reinforcement can be carried out in PC.

Static or dynamic

In the paper by Ohta et al., the static problem was only treated. Many reinforced earth structures have been reported to confirm their high seismic stability during recent large earthquake disaster. The reinforced soil is found to have high ductility during earthquakes. For the assessment of the stability of the reinforced soil during earthquake, the limit equilibrium method is commonly used. Only few papers dealt with deformation problems of the reinforced soil during earthquake by the finite element method. Uzuoka et al. (1996) tried to analyze the dynamic response of the embankment with/without reinforcement on liquefiable ground (Fig.3). They used effective stress based dynamic finite element method with beam element for reinforcement material.

Initial condition

To predict the deformation of the reinforced soil, the correct initial condition should be postulated. In the paper by Ohta et al., normally consolidated as well as overconsolidated stress state were assumed as the initial stress condition for the clayey foundation. The effect of the anisotropic consolidation was also taken into account. In most papers, on the other hand, much attention has not been paid to postulate the initial stress condition. In the finite element analysis, the correct initial stress condition must be established before the analysis.

Infinitesimal or finite strain

It is well known that the restriction of the lateral movements of the ground surface beneath the embankment load can be effective in increasing the bearing capacity of the foundation and decreasing

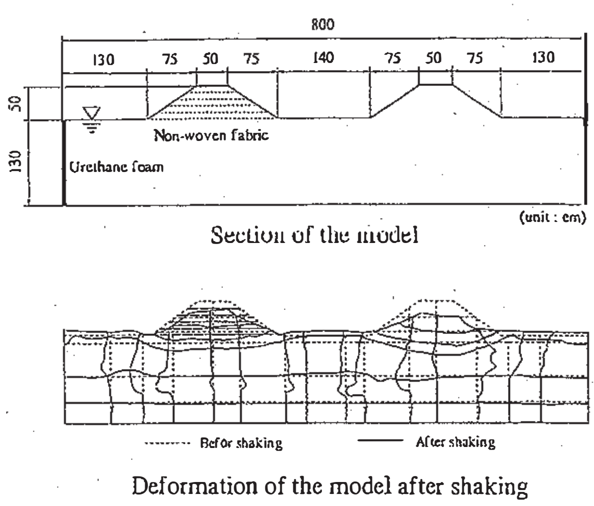

Fig.3 Dynamic response of the embankment with/without reinforcement on liquefiable ground (Uzuoka et al. 1996)

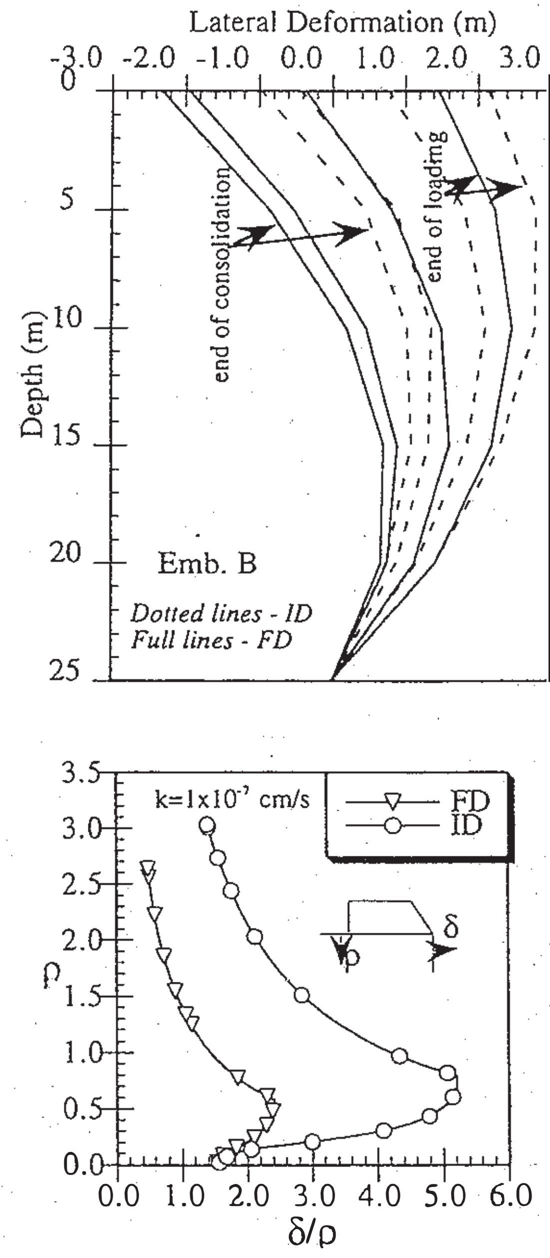

Fig.4 Infinitesimal strain theory vs. finite strain theory in predicting lateral deformation of embankment (Fernando 1996)

the undrained settlement. In the finite element analysis of the reinforced embankment, therefore, the prediction of the lateral displacement of the foundation is a very important subject. In the paper by Ohta et al., the infinitesimal strain was assumed. Fernando (1996) carried out a comparative study on infinitesimal strain theory vs. finite strain theory in predicting lateral deformation of embankment. It is found from Fig.4 that the infinitesimal strain theory fails to predict acceptable lateral deformation when significant geometry changes occur. To assess the stability of the reinforced soil which is close to the failure state by the finite element method, we have to study

- finite strain theory,
- strain localization,
- progressive failure,
- stable numerical algorithm,
- etc.

4 EXPECTED DIRECTION FOR FE ANALYSIS

4.1 *Purpose of FE analysis*

The purposes of the finite element analysis on earth reinforcement are summarized as;

- Qualitatively predict all features of composite structures (complex earth reinforcement) by using **only** the results of standard laboratory testing carried out on **component** materials.
- Provide a back analysis tool in observational method.
- Validate a simplified design method and refine the current design chart.
- Help engineers to understand real mechanism in earth reinforcement.
- Offer detailed informations to engineers in designing some of the important civil engineering structures.

4.2 *Acceptable Modeling (at least)*

- Composite modeling (e.g. by homogenization) is acceptable if there are numerous reinforcement elements. On the other hand, the interface elements are recommended to model a few reinforcement elements in the structure.
- Soil-water coupled analysis is recommended in the application to the reinforced soft ground.
- A linear or nonlinear elastic constitutive model is still acceptable for predicting a small strain distribution (e.g. less than 0.5~1%). To predict larger deformation up to failure, on the other hand, elasto-(visco)plastic constitutive model should be used.
- Two-dimensional idealization is acceptable in the form of a sheet or grid. Where strip or anchor reinforcement is used, the equivalent stiffness and equivalent interaction model in 2-D should be proposed based on a real 3-D behavior.

4.3 *Future Trend for FE Analysis*

Based on the previous discussions, the future trend for the finite element analysis on earth reinforcement is summarized as;

- PC-based finite element code as well as PC-based pre- and post-processor should be developed **(practical design tool, Computer Aided Design)**.
- Dynamic analysis is necessary.
- Three-dimensional analysis is necessary (e.g. for strip or anchor).
- The finite element analysis qualitatively evaluates new applications (new materials, new structures).
- To predict failure, finite strain theory, strain localization (shear banding), progressive failure, post peak behavior, stable numerical algorithm, etc. should be studied and implemented into the analytical tool.
- Sophisticated constitutive model should be used. At the same time, the optimum procedure for obtaining correct material parameters in the constitutive model from laboratory tests should be proposed.
- More attention should be paid to postulate the initial condition of the analysis.
- At least, deformation analysis should be carried out prior to a practical design in the case of the reinforced soft ground.

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