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Hybrid of Natural Element Method (NEM) with Genetic Algorithm (GA) to find critical slip surface

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Abstract One of the most important issues in geotechnical engineering is the slope stability analysis for determination of the factor of safety and the probable slip surface. Finite Element Method (FEM) is well suited for numerical study of advanced geotechnical problems. However, mesh requirements of FEM creates some difficulties for solution processing in certain problems. Recently, motivated by these limitations, several new Meshfree methods such as Natural Element Method (NEM) have been used to analyze engineering problems. This paper presents advantages of using NEM in 2D slope stability analysis and Genetic Algorithm (GA) optimization to determine the probable slip surface and the related factor of safety. The stress field is produced under plane strain condition using natural element formulation to simulate material behavior analysis utilized in conjunction with a conventional limit equilibrium method. In order to justify the preciseness and convergence of the proposed method, two kinds of examples, homogenous and non-homogenous, are conducted and results are compared with FEM and conventional limit equilibrium methods. The results show the robustness of the NEM in slope stability analysis.

1. Introduction

Failure in slopes is a common problem in geotechnical engineering. Collapse in these cases, most times, causes serious damage to both life and property of human beings. Therefore, realistic assessments for the factor of safety and the probable slip surface are highly needed.

Engineering approach to slope stability primarily uses factor of safety values to determine whether slopes areaway from failure. The principal traditional limit equilibrium methods have been the most commonly-used techniques in evaluation of the stability of slopes. Although many other excellent methods were proposed over the past few decades, due to simplicity, limit equilibrium methods are still the common methods used for stability analysis. The most important outputs of limit equilibrium analysis methods are the factor of safety and the probable slip surface. In these methods, a potential sliding is

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assumed prior to the analysis and a limit equilibrium analysis is then performed with regard to the soil mass and/or other loads above the presumed slip surface. Many limit equilibrium methods are available with different degrees of acceptability.

Since these methods are simple, they would not consider the stress-strain distribution in the soil mass before failure, and stress calculations are performed only at the moment of failure.

It is possible to use FEM and obtain both the factor of safety and adequate information on the collapse mechanism. However, it is not easy to achieve a precise factor of safety within the confidence limits achievable by limit equilibrium methods [1]. In order to obtain an accurate factor of safety by FEM, highly refined mesh is required. Furthermore, computer software capable of giving trustworthy results with the Mohr-Coulomb elasto-plastic model for loading states near to failure is needed. It is also necessary to perform a set of analyses with increment c and $\tan\phi$ reduction. These analyses become progressively more costly as factor is increased [2].

In the process of slope stability analysis, finite element stress filed prediction is usually needed in both the factor of safety prediction and the probable slip surface estimation technique, like the limit equilibrium methods. Unfortunately, only an approximate factor of safety can be estimated through finite element analysis and also no rigorous mathematical model for prediction of the probable slip surface has become thus far.

Usually, through some technical measures, a group of potential sliding surfaces through empirical means is determined prior to analysis, consisting of a series of arcs. Then, the probable slip surface is defined as the surface along which the minimum ratio of resisting force to driving force is achieved. Some researchers [1,3] suggested algorithms for locating the potential slip surfaces in which factor of safety is defined as the ratio of the resisting force to the driving force along a potential slip surface. The above definition of factor of safety is different from its definition based on strength reduction [4], and it is closer to the conventional limit equilibrium methods. The disadvantages of this technique can be summarized as: (a) identification of the element which contains a nodal point on the slip surface; (b) determination of the local co-ordinates of this point; and (c) determination of the element nodal stress values to compute the stress field at the chosen point by interpolating the nodal stresses. The difficulty in Finite Element Method (FEM) is the generation of meshes with elements that are connected together by nodes in a properly predefined manner. The limitations of the FEM with predetermined mesh have the motivation for using Meshfree technique, in particular NEM which is the main scope of present work.

Usually, Meshfree methods are based on Radial Basis Function (RBF) interpolation. Since in domain formulation, any single RBF cannot satisfy the governing equations, obtaining a viable solution would require a large number of collocation points for both domain and boundary of the problem [5]. NEM is local compact support and possess delta kroneker, which would introduce the simplicity usage of the method. Generally, in Meshfree methods, two conditions must be observed:

1. Definition of shape functions is literally based on nodes' position.
2. The assessment of the nodal connectivity depends on the number of nodes [6].

The difference among Meshfree methods is based on interpolation scattered data techniques [7]. There are some Meshfree methods; Smooth Particle Hydrodynamic (SPH), Partition of Unity Method (PUM), and Diffuse Element Method (DEM) [8]. Some methods were formed by Moving Least Square technique (MLS) that shape functions do not possess kronecker delta property [9].

Most of Meshfree methods need background cells for the definition of numerical integration on domain problem [10]. These methods need to background cells, causing not to define Meshfree methods completely [11]. Another type of Meshfree methods for interpolation scatter data is Element Free Galerkin (EFG); two points are noticeable in EFG:

- Non-element interpolation of field variable.
- Non-mesh integration of weak form [9].

EFG has no kcronocker delta property, hence, in the implementation of essential boundary conditions faces problems [12]. One way to overcome this shortfall is Point Interpolation Method (PIM). Although PIM is more accurate than MLS, it may cause to singularity matrix for momentum matrix [9]. Matrix Triangularization Algorithm (MTA) is introduced to solve this problem which is an automatic process to make sure whether the effect of selected node in interpolation is applied [9]. According to what was mentioned, some of the shortfalls of most Meshfree methods are as follow:

1. In some methods, imposition of essential boundary conditions is complicated.
2. Many Gouse points are needed to assess weak form of the problem.
3. Some methods have no performance for scattered data [6].

In this research, Natural Element Method (NEM) is used. This method is based on Voronoi diagram and Delaunay tessellation that have been used as weak form for some mechanical problems NEM possesses kronecker delta, a positive point which is rarely found in other Meshfree methods and covers the mentioned shortfalls. NEM shape functions are C^0 at node interpolation and C^∞ elsewhere [13].

The current study uses natural element based method for estimating the probable slip surface and factor of safety described in the following steps.

(1) The natural element method is explained and it is formulated for linear elasto-plastic stress analysis under plane strain assumption. (2) The procedure through which factors of safety are calculated on the potential slip surfaces is described. (3) Genetic Algorithm (GA) is briefly described and it is used to generate and optimize potential slip surfaces (individuals). (4) Examples are provided to justify convergence and robustness of the proposed method, and the results are compared with FEM and conventional limit equilibrium methods.

2. Natural element method

Natural element method is a mesh-less approach which has been developed to solve the partial differential equations (PDEs). Discrete model of a domain Ω consists of a set of distinct nodes N, and a polygonal description of the boundary $\partial\Omega$. The interpolation scheme used in NEM is known as