BACKGROUND OF **SLOPE-ffdm 2.0**

To transcend the limitations of traditional limit-equilibrium-based slope stability analysis methods, the **Force-equilibrium-based Finite Displacement Method** (FFDM) was developed in 2012 by Dr. C.-C. Huang at the Department of Civil Engineering, National Cheng Kung University in Tainan, Taiwan. FFDM transforms conventional slope stability analysis into a displacement-based approach by integrating a stress-displacement constitutive law into the force equilibrium of sliced soil masses.

FFDM serves as the core of the previous iteration of **SLICE-DISP** program, which has been employed in preliminary studies on groundwater-table-induced slope displacements. Follow-up experimental studies, including direct shear tests and back-analyses of slope failures, have further validated FFDM's effectiveness in predicting slope displacements caused by internal and external factors.

A significant enhancement in FFDM involves its treatment of the transition from pre-peak to post-peak states along the displaced slip surface, incorporating the classic **Versoria** curve, also known as the **Witch of Agnesi**. This integration provides a refined approach to analyzing progressive failure mechanisms in soil slopes.

With the support of these studies and the inclusion of a user-friendly, window-based interface, the latest iteration—**SLOPE-ffdm 2.0**—offers an advanced analytical tool for slope stability assessment and displacement prediction.

WHY USE **SLOPE-ffdm 2.0**

Built upon the core principles of FFDM, the program SLOPE-ffdm 2.0 introduces several features that set it apart from conventional slope stability analysis methods, including the limit equilibrium method (LEM), finite element method (FEM), and discrete element method (DEM):

1. **Accurate Displacement Prediction:**
   - FFDM provides precise and practically significant slope displacement estimates, ranging from 10^{-4} to 10^{-1} meters, spanning four logarithmic cycles.
   - Unlike LEM-based analyses, which rely on empirical safety factors for decision-making, FFDM offers a direct and quantifiable displacement prediction approach.
   - Compared to FEM analysis using strength reduction techniques, FFDM simplifies verification and problem-solving processes, enhancing efficiency.
2. **Streamlined Input Requirements and Computational Speed:**
   - FFDM requires only three input soil parameters to capture nonlinear displacement responses to slope condition changes.
   - The computational time for FFDM displacement analysis is comparable to conventional LEM-based safety factor assessments yet significantly faster than FEM and DEM, which often require hours—or even tens of hours—per case, especially when incorporating nonlinear soil stress-strain behavior.
3. **Reduced Input Data for Failure Surface Analysis:**
   - By focusing on the stress-displacement response along the potential failure surface, FFDM minimizes required input parameters compared to FEM and DEM.
   - In back-analysis cases, where soil parameters are derived from observed slope displacements, FFDM offers a substantial advantage over FEM and DEM by providing a more direct and efficient approach.
4. **Efficient Validation Process:**
   - FFDM significantly reduces the time required for validating analytical outputs compared to FEM and DEM.
   - The streamlined input requirements allow faster assessments of critical failure zones, improving practical applicability.
5. **Versatile Batch Simulation Capabilities:**
   - Engineers and researchers often need to simulate multiple cases to explore optimal solutions. **SLOPE-ffdm 2.0** supports this need in two keyways:
     - **Batch Job Modes:** Systematic parameter adjustments allow multiple cases to be analyzed efficiently. These automated simulations can run for hours or days, with results stored systematically, broadening research perspectives.
     - **Multi-Method Comparison:** Each trial-and-error or designated failure surface undergoes analysis using two to three different methods, including Fellenius,

Bishop, Janbu, Spencer, and multi-wedge techniques. This eliminates biases in method selection and reveals the strengths of various approaches under specific geological and loading conditions, leading to more informed final decisions.

6. **Displacement-Based Evaluation of Retaining Structures:**
   - For projects using soil-retaining structures for slope stabilization, FFDM enables displacement-based assessments of structural contributions to overall stability.
   - Three types of facing structures- gravity walls, stacked modular blocks, and stacked gabions- can be analyzed for inter-block, along-the-base, and above-facing failure mechanisms using displacement modeling.
7. **Reinforcement Interaction Analysis for Geosynthetic and Steel-Strip Walls:**
   - FFDM incorporates a displacement-based pullout model to evaluate the interaction between reinforcement materials and facing structures**.**
   - The methodology assesses pullout behavior from both the facing blocks and the backfill soil using a comprehensive database of reinforcement materials, optimizing slope stabilization analysis.
8. **Anchored Slope Stability Analysis:** For slopes stabilized with a pre-stressed ground anchor and RC girder facing system**,** SLOPE-ffdm 2.0 introduces three analytical approaches to assess potential failure mechanisms induced by anchor pre-stress. This advanced methodology offers a displacement-based perspective for evaluating anchored slopes, enhancing accuracy in stability predictions and structural assessments.
9. **Stress-Displacement Evolution Along Failure Surfaces:** The entire evolutionary process **of** stress-displacement in soils along a failure surface can be captured using a hyperbolic stress-displacement curve for pre-peak and peak states**,** and a Versoria curve **for** post-peak conditions**.** This analytical framework allows deeper exploration into soil strength deterioration along the sliding path, helping to identify the dominant factors influencing slope failures**.**
10. **Analysis of Slope Anti-Sliding Piles Based on Displacement Criteria:** Slope anti-sliding piles are displacement-sensitive structures that involve interaction between the slope and the pile body. Traditional design methods for slope anti-sliding piles are based on empirical assumptions regarding earth pressure distribution, often neglecting the development of pile resistance following displacement. Using SLOPE-ffdm 2.0, under conditions ensuring displacement compatibility between the slope and pile body, the model accounts for both earth pressure and the internal stress development within the pile, making it an effective analytical tool. This analysis module will be included in the next version of SLOPE-ffdm.

Applications of **SLOPE-ffdm 2.0**

1. **Predicting Slope Displacements & Settlements**
   - SLOPE-ffdm 2.0 enables accurate calculations of potential slope displacements and settlements, considering geological conditions, groundwater table variations, internal and external loadings, and seismic influences.
2. **Evaluating the Performance of Different Soil Retaining Systems**
   - The effectiveness of various facing types—including gravity walls, modular blocks, and gabions—can be assessed through displacement-based performance analysis, ensuring stability optimization.
3. **Estimating Mobilized Reinforcement Forces**
   - For reinforced and nailed soil structures, FFDM estimates mobilized reinforcement forces as part of the analytical output, replacing empirical input-based reinforcement forces used in conventional limit equilibrium analysis.
4. **Optimizing Reinforcement Configurations**
   - The system assists in optimizing reinforcement configurations, determining the ideal number of layers, reinforcement locations, and orientations for enhanced structural integrity.
5. **Identifying Critical Failure Mechanisms in Anchored Slopes**
   - FFDM enables detailed failure mechanism analysis in slopes stabilized with ground anchors and RC girder systems, providing a deeper understanding of slope stability control factors.
6. **Determining Optimal Ground Anchor Configurations**
   - The methodology supports precise ground anchor configuration design, optimizing anchor quantity, tendon length, pre-stress intensity, and dip angles to maximize slope stability.
7. **Assessing Seismic Resistance Through Displacement Response Curves**
   - Displacement response curves generated via FFDM displacement analysis allow for evaluating the seismic resistance of slopes and soil-retaining structures, enhancing earthquake resilience planning.
8. Back-Calculating Material Properties for Landslide Analysis
   - FFDM facilitates back-calculation of material properties in slopes composed of disintegrated rock materials, offering valuable insights into potential future landslide occurrences.
   - This approach **eliminates the technical challenges** associated with undisturbed soil sampling.