Design of Deep Excavations - Methods and Software Application

Presentation: Dimitrios Mamoglou, Senior Engineer, Deep Excavation LLC
mamoglou@deepexcavation.com - T: +1-206-279-3300
• Software solutions for excavation and foundation professionals

• Consulting Services - Design of deep excavations and pile foundations

• Virtual Reality applications for geotechnical engineers and contractors
PART 1: DeepEX Software Features and Analysis Methods

More information: Click here to learn more: DeepEX – Software Features and Capabilities
DeepEx - Shoring Design Software

Full Structural and Geotechnical Design of any Deep Excavation Model

Wall Types in DeepEX
✓ Soldier Pile and Lagging Walls
✓ Sheet Pile Walls
✓ Secant / Tangent Pile Walls
✓ Concrete Diaphragm Walls (Slurry Walls)
✓ Soldier Pile and Trenched Concrete Walls
✓ Combined Sheet Pile Walls (King Piles)
✓ Box Sheet Pile Walls
✓ Custom Walls

Support Systems in DeepEX
✓ Anchored Walls (Tiebacks and Helical Anchors)
✓ Braced Excavations (Steel Struts and Rakers)
✓ Top/Down Excavations with Concrete Slabs
✓ Dead-man Walls
✓ Bin-Type Walls
✓ Cofferdams
✓ Circular Shafts
✓ Cantilever Walls

ANALYSIS METHODS: LIMIT EQUILIBRIUM ANALYSIS
Soil Pressures: Active/Passive, At-rest, Apparent Pressures (FHWA, Peck, Adaptive, Custom Trapezoidal +more)
Beam Analysis: Blum’s, FHWA Simple Span, CALTRANS +more

NON-LINEAR ANALYSIS (SOIL SPRINGS)
Moments and Reactions from Spring Analysis
Cumulative Results from Stages
Realistic Displacements

FINITE ELEMENT ANALYSIS
Moments and Reactions from Finite Elements
Full Soil-Structure Interaction
Calculate Surface Settlements

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<table>
<thead>
<tr>
<th>Wall Types</th>
<th>Diagrams</th>
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<tbody>
<tr>
<td>Soldier pile and lagging walls</td>
<td><img src="image1" alt="Soldier pile and lagging walls" /></td>
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<tr>
<td>Secant pile walls</td>
<td><img src="image2" alt="Secant pile walls" /></td>
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<tr>
<td>Tangent pile walls</td>
<td><img src="image3" alt="Tangent pile walls" /></td>
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<tr>
<td>SPTC walls</td>
<td><img src="image4" alt="SPTC walls" /></td>
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<tr>
<td>Diaphragm (slurry) walls</td>
<td><img src="image5" alt="Diaphragm (slurry) walls" /></td>
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<tr>
<td>Sheet pile walls</td>
<td><img src="image6" alt="Sheet pile walls" /></td>
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<tr>
<td>Combined sheet pile walls</td>
<td><img src="image7" alt="Combined sheet pile walls" /></td>
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<tr>
<td>Box sheet pile walls</td>
<td><img src="image8" alt="Box sheet pile walls" /></td>
</tr>
<tr>
<td>Custom walls</td>
<td><img src="image9" alt="Custom walls" /></td>
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DeepEx Software - Wall Types

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DeepEx Software - Support Systems

Anchored Walls (Tiebacks)

Braced Excavations (Struts and Rakers)

Circular Shafts (Ring Beams)

Dead-man Walls (Tierods)

Top-Down Excavations (Concrete Slabs)

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Soils and Stratigraphy in DeepEX

- Create multiply soil types and define soil properties
- Soil properties estimation tools (NSPT values - test data)
- Create multiple borings and define the horizontal stratigraphy
- Add CPT logs and SPT Records - Estimate properties from records
- Custom Layer mode: Create inclined soil layers
- Soil Change Commands: Change soil properties through stages
Analysis Methods and Design Standards in DeepEX

Limit Equilibrium Analysis (LEM)

Non-Linear Analysis (NL)
(Elastoplastic Springs)

Finite Element Analysis (FEM)

Structural Codes: Eurocodes 1, 2 & 8, ACI, LRFD, AISC, AS 3600 & 4100, CN (China) + more

Design Standards: Eurocode 7, DIN, BS, XP, AASHTO LRFD, CALTRANS, CN (China) + more
✓ Assume lateral earth pressures.
✓ Determine fixity locations for forces at subgrade.
✓ Analyze wall beam with assumed loads.
✓ Advantages: Easy method to verify. Gives a back check for more rigorous methods.
✓ Disadvantages: Soil-structure interaction ignored.
Earth Coefficients in DeepEX Software

DeepEX Automatic Method Selection According to Project Parameters

<table>
<thead>
<tr>
<th>Active Coefficient Ka</th>
<th>Parameters</th>
<th>Horizontal Surface</th>
<th>Inclined Surface</th>
<th>Wall Friction Considered</th>
<th>Seismic Effects Applied</th>
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<tbody>
<tr>
<td>Method</td>
<td>Rankine</td>
<td>Coulomb</td>
<td>Coulomb</td>
<td>No Effect</td>
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<table>
<thead>
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<th>Passive Coefficient Kp</th>
<th>Parameters</th>
<th>Horizontal Surface</th>
<th>Inclined Surface</th>
<th>Wall Friction Considered</th>
<th>Seismic Effects Applied</th>
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<tr>
<td>Method</td>
<td>Rankine</td>
<td>Coulomb</td>
<td>Caquot-Kerisel</td>
<td>Lancelotta</td>
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<tr>
<td>Method</td>
<td>Description</td>
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<td>------------------------</td>
<td>-----------------------------------------------------------------------------</td>
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<tr>
<td>At-Rest Pressures</td>
<td>Static soil pressure at rest stage.</td>
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<tr>
<td>FHWA Apparent Pressures</td>
<td>Soil pressure calculated using FHWA apparent method.</td>
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<tr>
<td>Custom Trapezoidal</td>
<td>Soil pressure calculated using custom trapezoidal method.</td>
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<tr>
<td>Active - Passive</td>
<td>Combination of active and passive pressures.</td>
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<tr>
<td>Two-Step Rectangular</td>
<td>Soil pressure calculated using two-step rectangular method.</td>
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<tr>
<td>WMATA Pressures</td>
<td>Soil pressure calculated using WMATA method.</td>
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<tr>
<td>New York City DEP</td>
<td>Soil pressure calculated using New York City DEP method.</td>
<td></td>
<td></td>
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</tbody>
</table>

Cantilever Excavations

Construction Stages with multiple support levels

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Water Pressure Methods in DeepEX Software

- **Simplified Flow**
- **Hydrostatic**
- **Full Flownet Analysis**
External Loads in DeepEX: Types and Pressure Methods

**Loads on ground surface:**
- Strip surcharges
- Linear loads
- 3D loads (buildings, footings, 3D surface loads)

**Loads on the wall:**
- Strip surcharges
- Linear loads
- External moments
- Prescribed displacements

**Load modeling options:**
- Elasticity equations
- Two-way distribution angle
- One-way distribution angle
- One-way distribution angle from soil friction
- Elasticity to vertical stress x Ka (or Ko)
- CIRIA Special Pub 95 - 1993
Seismic Pressure Methods in DeepEX Software

Procedure in DeepEX
- Define Seismic Accelerations $A_x$ and $A_z$
- Select Seismic Pressures Calculation Method
- Select a Seismic Design Standard

Seismic Pressure Methods
- Semirigid
- Mononobe-Okabe (frictional soils)
- Wood Automatic
- Wood Manual

Semirigid Method
- Total Vertical Stress at Bottom of Wall $x B$
- $B = 0.75$ in DeepEX
- Rectangular Pressure Diagram

Mononobe-Okabe Method (Frictional Soils)
- Extension of the Coulomb Static Theory
- Accelerations added to a Coulomb Wedge
- Seed & Whitman (1970) Seismic Thrust Redistribution
- Inverse Trapezoid Pressure Diagram
Cantilever Wall Analysis Concept

**Fixed earth method**
Balances out Moment and Shear

**Free earth method**
Balances out moment
Shear not balanced
Increase length by 1.2 to get FS 1.0
Then apply additional safety factors
Beam Analysis - Blum’s Method

Pinned supports - continuous beam

Point of zero net soil shear below subgrade.

Use point of zero shear as a virtual support.

Shear

Moments

Net loading

Reaction for embedment $F_{xb}$

Virtual support

Available resistance $R_x$

$FS_{passive} = \frac{R_x}{F_{xb}}$
Pin support at excavation base, simple spans

**Shear**

- Reaction for embedment $F_{xb}$

**Moments**

- Virtual support
- Available resistance $R_x$

**Net loading**

- $F_{passive} = \frac{R_x}{F_{xb}}$
Beam Analysis - CALTRANS Approach

Pinned supports - simple span
Base at point of zero moment below bottom support
Shears and moments balance out

Shear | Moments | Net loading

No Embedment Reaction | Virtual support | FS.rotation = \frac{F_{\text{resist}}}{F_{\text{drive}}}

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Non-Linear Analysis Concept (Soil Springs)

**Soil Models**
- Linear elastic perfectly plastic
- Exponential
  - \( E = E_0 \left[ \sigma_v + a_H \sigma_h \right]^n \) for subgrade modulus
- Small strain hardening
- Reloading stiffness linear 3 to 5 x loading \( E \)
Finite Element Analysis in DeepEX (Additional Module)

- Moments and reactions calculated with Finite Elements
- Consider full soil-structure interaction
- Calculate surface settlements
- Design Tiedowns, Foundation Piles and Steel Columns

Soil Models:
- Elastoplastic Model
- Exponential (Hyperbolic) Model (approximate solution)
- Exponential (Hyperbolic) Model (complete solution): Soil hardening model

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Finite Element Analysis in DeepEX (Additional Module)

Tunnel Options:
✓ Tunnel Analysis with FEM
✓ TBM Tunnels
✓ NATM - SEM Tunnels
✓ Oval and Complex Tunnel Shapes
✓ Tunnel Model Wizard
✓ Cut-and-Cover Tunnels

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✓ Bishop Method
✓ Morgenstern Price Method (G.L.E.)
✓ Spencer Method
✓ Ordinary (Swedish) Method
✓ Automatic Slope Search Method
✓ Single Point Slope Center
✓ Rectangular Slope Center
✓ Define Radius Search Limits
✓ Clouterre Standards for Soil Nails
PART 2: Projects Designed with DeepEX

More information: Click here to learn more: DeepEX – Project Gallery

2000+ users – more than 10000 projects worldwide!
DeepEX Software - Project - Braced Excavation

LaBrea Metro Station, Los Angeles, California, USA

✓ 100 ft (30.5 m) Excavation
✓ Soldier Piles and Lagging
✓ Lateral Bracing (Struts)
✓ Full Design with DeepEX
✓ 5 Stations designed and under construction
DeepEX Software - Project - Cofferdam

New Tapan Zee Bridge Cofferdams, New York, USA

- $3.9 billion project
- 90x45ft (27.5x13.7m) Cofferdams
- Lateral Bracing (Struts)
- Full Design with DeepEX

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Soldier Pile Excavation Pits with Diagonal Struts and Tiebacks, Arkansas, USA

- 90 ft (27.5m) Excavation
- Soldier Piles and Lagging
- Pipe Struts
- 9 rows of Tiebacks
DeepEX Software - Project - Braced Excavation

Soldier Pile Excavation Pits with Diagonal Struts, Arkansas, USA

- 24 ft (7.3m) Excavation
- Soldier Piles and Lagging
- Pipe Struts
- Full Design with DeepEX

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DeepEX Software - Project - Cofferdam

All American Canal, Imperial Irrigation District, Yuma, Arizona

✓ Cofferdam
✓ Water Wall Design
✓ Water Depth up to 20’ (6m)
✓ Sheet Pile System
✓ Post Tension cable Ties
✓ Full Design with DeepEX
PART 3: DeepEX Additional Modules and Standard Packages

More information: 

Click here to learn more: DeepEX – Software Versions
2D Sections and 3D Models Design - Export Holograms

- Full Design - 2D Sections and 3D Model
- Structural & Geotechnical design of Tiebacks and Struts
- 3D Building Loads
- Full Model Optimization (Walls and Supports)
- Virtual Reality Model Visualization - Export Model to HoloDeepEX

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Building Damage Assessment - Additional Module to DeepEX 3D

✓ Perform Damage Assessment of all Buildings close to an excavation site
✓ Review Crack widths, Damage Categories, Strains etc. for all building walls.

Building Damage Results

<table>
<thead>
<tr>
<th>Maximum values</th>
<th>All elements</th>
<th>Individual elements</th>
<th>Horizontal movement</th>
<th>Settlement</th>
<th>Boscardin=Costing Chart</th>
<th>Hoggins Chart (Burland 1979)</th>
<th>Damage Cat</th>
<th>Dam. Crack width</th>
</tr>
</thead>
<tbody>
<tr>
<td>B Max</td>
<td>203</td>
<td>0.00703</td>
<td>0.00850</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>Moderate</td>
<td>Moderate</td>
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<tr>
<td>y Max</td>
<td>0.005103</td>
<td>0.002551</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>Negligible</td>
<td>Negligible</td>
</tr>
<tr>
<td>y Ave</td>
<td>0.000752</td>
<td>0.000376</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>Negligible</td>
<td>Negligible</td>
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<tr>
<td>C(p) in</td>
<td>526</td>
<td>0.002511</td>
<td>0.061356</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>Negligible</td>
<td>Negligible</td>
</tr>
<tr>
<td>C(l) in</td>
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<td>Damage Cat</td>
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<tr>
<td>Dam. Crack with</td>
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Export All Project Sketches to DXF

2D Sections:
- Export all 2D Sections Sketches for each Construction Stage
- Export Wall Section Details
- Export 2D Sections with Result Diagrams

3D Models:
- Export all 2D Sections and Wall Details
- Export Full Project Plan Sketches
- Export Elevation Sketches for each Project Wall
Gravity Walls and Pile Supported Abutments

- Design gravity walls (any shape)
- Design pile supported abutments
- Use footings (3D loads) and design the foundation piles
Sea Walls - Quay Walls - Wave Pressures - Overtopping

- Load combinations for British Standards 6349 Parts 1-2 (Marine Structures-Quay Walls)
- Wave pressures with Sainflou, McConnel, Proverbs
- Average overtopping volume calculations
- Block/segmental walls with individual shear resistances and densities
- Quay caisson walls (3D) with infill zones. The program can calculate the 3D weight
- Quay wall wizard - Create a model in minutes

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Steel Connections

✓ Generate all steel connections
✓ Check Steel Connections (Struts and Walers)
✓ Optimize Steel Connections with a Click
✓ Adjust weld sizes and apply plate stiffeners
Soil Estimation - Statistical Analysis

- Estimate Soil Properties with different methods
- Review a statistical analysis of the estimated properties
- Select the project values with a high level of certainty

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# DeepEX - Standard Packages and Additional Modules

## Standard DeepEX Software Packages

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<tr>
<th>Package</th>
<th>Description</th>
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<tbody>
<tr>
<td>DeepEX 2D Basic Version</td>
<td>Design 2D Sections with LEM and NL Methods</td>
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<tr>
<td>DeepEX 2D + FEM</td>
<td>DeepEX 2D + Finite Element Analysis</td>
</tr>
<tr>
<td>DeepEX Marine Walls</td>
<td>DeepEX 2D + Gravity Walls + Sea Walls/Quay Walls + Soil Estimation</td>
</tr>
<tr>
<td>DeepEX 3D</td>
<td>DeepEX 2D + 3D Frame Analysis + Project Cost Estimation + Export 3D Holograms + Steel Connections</td>
</tr>
<tr>
<td>DeepEX 3D + FEM</td>
<td>DeepEX 3D + Finite Element Analysis</td>
</tr>
<tr>
<td>DeepEX 3D Advanced</td>
<td>DeepEX 3D + Finite Element Analysis + Building Damage Assessment</td>
</tr>
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## Available Additional Optional Modules – Expand the Standard Version Capabilities

<table>
<thead>
<tr>
<th>Module</th>
<th>Description</th>
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<tbody>
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<td>Finite Element Analysis</td>
<td>Available Add on</td>
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<tr>
<td>Gravity Walls &amp; Pile Abutments</td>
<td>Available Add on</td>
</tr>
<tr>
<td>Gravity Walls &amp; Sea Walls/Quay Walls</td>
<td>Available Add on</td>
</tr>
<tr>
<td>Soil Estimation &amp; Statistical Analysis</td>
<td>Available Add on</td>
</tr>
<tr>
<td>Export Sketches to DXF</td>
<td>Available Add on</td>
</tr>
</tbody>
</table>

## DeepEX Licensing Options

- Single Licenses (activated in specific devices), Single USB Keys, Network USB Key Solutions
- 1 Year of full Technical Support (training, questions, file reviews) is included in any software purchase
- Optional Annual Maintenance options (after the first year)
- Discounts for Additional Licenses
- Additional Modules can be purchased and activated at any point in any software package
THANK YOU!

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