
EVERGREEN® WALLS
THE NATURAL ALTERNATIVE

EVERGREEN® **EVERGREEN WALLS, INC.**

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Ennetbaden, 21-Jan-14

Evergreen Macro Retaining Walls

This reference book summarizes Evergreen development, product lines, and references worldwide with emphasis on American and Canadian projects.

1. **Introduction**

2. **Company Background**
   - Evergreen Company
   - Dr. Felix P. Jaecklin

3. **Evergreen Walls**
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   - General description of the components
   - List of completed projects throughout the world
   - Pictures of projects including Evergreen Macro, Everwall and Evergreen Maxi.

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5. **Software and some printouts**

6. **International List of Evergreen Walls**

Respectfully submitted:

Evergreen Walls, Inc. Dr. Felix P. Jaecklin, Geotechnical Consultant

1. Evergreen Companies

Organization and Background

The Evergreen companies consist of the following structure:

• **Evergreen Walls, Inc., Norcross**	Activities in USA and Canada
• **Geotech Lizenz AG, Lugano**	European and Asian Activities
• **Geotech Systems AG, Lugano**	Office building, facilities
• **System Evergreen AG, Lugano**	Transatlantic and Design Activities

- Clay Warner, PE, Manager of American Activities.
- Dr. Felix P. Jaecklin, Expert, Geotechnical Consultant for soil investigation, foundation designs, conceptual work, special designs for standard fee.
  Geissbergstrasse 46, CH-5408 Ennetbaden, Switzerland.
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1. Evergreen Company - Organization and Background

The Evergreen retaining wall started under the umbrella of: **Geotech Lizenz AG**, Lugano, Switzerland with the head office in Lugano Castagnola overlooking the lake of Lugano.

- **President, CEO, owner Giuseppe Macario** who visited Saudi Arabia and Binladin Group.
- **New Partner Dr. Emilio Brovelli**, structural engineer, with an engineering company in Alassio near Genova, Italy; co-developer of Evergreen Maxi.
- **New Partner Didier Damseaux**, international business development for Besix, a very large international contractor, presently building the 300m high tower in Dubai.
- **Past owner** and past president for 30 years **Ladina Jaecklin**.

However Geotech Lizenz AG no longer does any business in USA and Canada.
These activities are followed up exclusively under Evergreen Walls, Inc.

The entire organization is privately owned, no bank involved, with emphasis on innovative technology, know-how, and cooperation.

Goals

Evergreen walls are on the market since 1976. The first wall was built along the seven-lane highway exit to the North of Zurich, Switzerland. Ever since the concept and units have constantly been upgraded and additional wall types developed. These wall systems include engineering design, production drawings, design software, know-how trademarks, and patents.

- The main principle of the Evergreen success is innovative engineering and technical support.

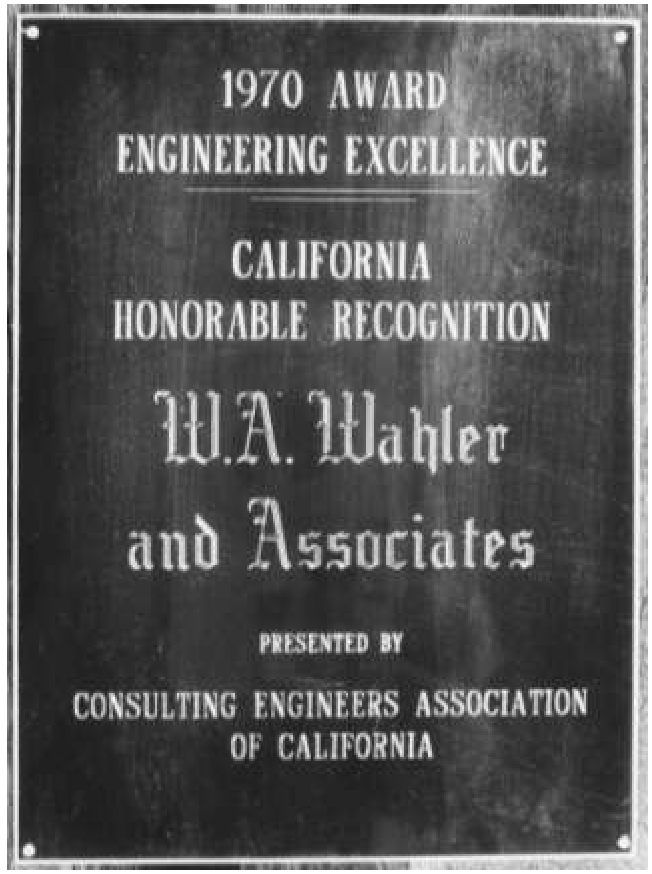
- The walls are implemented in cooperation with local engineers, precasters, and contractors on a franchise, cooperation and licensing.

- These principles were applied to build walls in the following countries:
  - Europe: Switzerland, Germany, France, Belgium, Spain, Italy, Austria, Sweden, and Slovenia.
  - Asia: Japan, Saudi Arabia, Yemen.
  - Africa: South Africa
  - North America: Vancouver, Canada; USA: States of New York, New Jersey, Connecticut, Massachusetts, New Hampshire, Pennsylvania, Virginia, Tennessee, North Carolina, Kentucky, Kansas, California, Oregon.

- Each new locations and each new project means an effort to convince the authority purchasing the wall, the consulting engineers approving the principles, and teaching contractors the special skills for achieving the technical requirements.

2. Felix P. Jaecklin

Evergreen inventor, developer



Excellence in Technology,
Award, year 2000

"Honoring Excellence in the Application of a new practice and design approach for combined technology and environmental considerations from IECA, the International Erosion Control Association."

Received for the highest retaining wall ever built in Europe, the 4 x 7m = 28m high wall under the motorway from Madrid to Coruña, in Ponferrada, Spain.

Engineering Excellence
rd, year 1970

"California honorable recognition from the Consulting Engineering Association of California. "

Received for developing a design and construction method for the earth fill dam, the Auld Valley Dam built for the Metropolitan Water District of Los Angeles, to safely withstand earthquakes.

Felix P. Jaecklin Curriculum Vitae

Dr. sc. tech (Ph.D.), Dipl. Ing. (M. Sc.),
both at the Federal Institute of Technology, Zurich, Switzerland
P. E., Reg. Civil Eng. CA 20133, Euring, MASCE, Ing. SIA

Felix P. Jaecklin - Work Experience

2000 – **Consultant** working out of Switzerland for court cases: consultant to the judges of public courts in Switzerland, Consultant for retaining walls for the Evergreen Group for projects in the Middle East, Europe, and USA.

1974 – 2000 **Owner and president of the geotechnical consulting company 'Dr. Felix P. Jaecklin, Geotechnical Engineering'**, for geotechnical design in deep excavations, shoring, piling, retaining walls. Developing numerous types of retaining wall systems made in precast concrete, made in wire mesh built on site and built in large series in a field factory.
- President of the Swiss committee for a code on deep excavations.
- Results: Swiss code on Deep Excavations, numerous papers and about 30 patents on retaining walls.
- Passing exam for professional engineer (Registered Civil Engineer) in California, RCE 20'133.

1972 – 1974 **Member of the management of 'Emch und Berger AG'**, the largest engineering company in Bern, Switzerland with 15 subsidiaries in numerous Swiss towns, responsible for research and development, for coordinating the structural, geotechnical, and geophysics of structures group for larger projects, member of the board of companies belonging to the group, such as 'Geotechnical Institute AG' and 'Geophysical Institute AG'.

1968 – 1972 **Associate of 'W. A. Wahler and Associates Corp.**'
A 60 persons consulting group in Palo Alto, California, responsible for the (first) seismic design of earth fill dam in California, the 'Auld Valley Dam', for the Metropolitan Water District in Los Angeles and several other dams for the Mescalero Apache Tribe in New Mexico and for Chile Copper Tailing Dams. Result: a paper presented at the International Society for Soil Mechanics and Foundation Engineering at the International Conference in Mexico 1970.

1965 – 1968 **Assistant manager of the 'Hollinger Engineering AG'**
a 25 person engineering company in Zurich, Switzerland, responsible for the design, project management, and construction supervision of the first drilled tunnel in Switzerland, for design, project management, and construction supervision of several waste water treatment plants in Dietikon (Zurich), Baden, and Lenzburg, Switzerland. Result: A paper published in the Swiss 'Engineering News Record' on the first drilled tunnel in Switzerland.

1960 – 1965 **Research Engineer at the Geotechnical Laboratory and Research Facility of the Federal Institute of Technology in Zurich** for field testing and consulting for delicate parts of the Swiss Highway Departments and other public organizations, field testing and research on rock mechanics for Verzasca dam, a large concrete arch dam, 220 m 722 ft. tall and research for the principles and application of physical and chemical alterations with Electro-Osmosis for stabilizing landslides in clays. Results: A paper on the sub-foundation behavior of Verzasca granite gneiss behavior and a book on the combined application of electro-osmosis in clay.

Education

1960 Diploma as a Civil and Structural Engineer (Master of Science) at the Federal Institute of Technology in Zurich, Switzerland

1968 Dr. sc. tech. (Ph. D) at the Federal Institute of Technology in Zurich, Switzerland with a thesis on slope stabilization using electricity

Registrations

1970 RCE 20'133, Registered Civil Engineer in California

1990 Euring, registered civil engineer in Europe

1971 Member of the American Society of Civil Engineers, ASCE

Awards

Excellence in Technology, Award, year 2000

From IECA, the International Erosion Control Association.
Received for the highest retaining wall ever built in Europe, the 4 x 7m = 28m high wall under the motorway from Madrid to Coruña, in Ponferrada, Spain:
"Honoring Excellence in the Application of a new practice and design approach… for combined technology and environmental considerations…"

Engineering Excellence Award, year 1970

From the Consulting Engineering Association of California for the company W.A. Wahler and Associates for the team with Felix P. Jaecklin developing a design and construction method for the earth fill dam, the Auld Valley Dam built for the Metropolitan Water District of Los Angeles, to safely withstand earthquakes.

Author of Books

1968 Electrochemical Soil Stabilization (by Electro Osmosis) published by the Swiss Association for Foundation Engineering, 1968.

1985 Co-author of the 'Manual for Geotextile Applications' published by the Swiss Geotextile Association, 1985

Publications (very few recent papers only)

1. Felix P. Jaecklin: **Innovative design for repairing Gondo mudslide by 20m high geogrid wall**, International Geosynthetic Society, International Conference on Geosynthetics in Yokohama, Japan, Sep. 2006.

2. Felix P. Jaecklin and Ahmad B. Tal: **Seismic design of retaining walls, design trends, theories and engineering practice**, International Earthquake Engineering Conference at the Dead Sea Conference Center near Amman, Jordan, November 2005.

3. R. Ruegger, D. Flum, Felix P. Jaecklin, A. Brinkmann, P. Zeiter, I. Sterba: **Requirements for Geosynthetics for Reinforcement, and Protection**, research funds project VSS 1999/124, granted by the Federal Ministry for the Environment, Energy, Communication and Highways, Bern, Switzerland, Mai 2002.

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Mitarbeiter VAWE, Strasse und Verkehr No. 8 - 1962

[2] 1965 Jaecklin, Felix P. : "Beitrag zur Felsmechanik"
Schweizerische Bauzeitung Heft 15 und 27, 1965

[3] 1966 Jaecklin, Felix P. :"Tunnelform und Felsmechanik"
1.intern. Kongress für Felsmechanik, Febr. 1966

[4] 1968 Jaecklin, Felix P. :"Elektrische Bodenstabilisierung"
Dissertation, Institut für Geotechnik, ETH Zürich, Juni 1968
Schweiz. Gesellschaft für Boden- und Felsmechanik No 72

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Intern. Conference in Soil Mechanics + Foundation Engineering, Mexico City 1969

[6] 1970 Jaecklin, Felix P. + Wahler, W.A. : "Dynamische Berechnung v. Dämmen gegen Erdbeben" Separata Neue Zürcher Zeitung No.247, 1. Juni 1970

[7] 1971 Jaecklin, Felix P. + Wahler, W.A. : "Dynamische Berechnung v. Dämmen gegen Erdbeben" Schweizerische Bauzeitung, Heft 9, März 1971

[8] 1980 Jaecklin, Felix P. : "Verhalten von unterirdischen Leitungen"
Schweiz. Ingenieur + Architekt, Docu 43 und
Conference ETH Lausanne, 24.9.1980

[9] 1981 Jaecklin, Felix P. : "Selective Nutzung von Grundwasser für Wärmegewinnung"
Schweiz. Ingenieur + Architekt, Heft 20, 1981

[10] 1981 Jaecklin, Felix P. : "Begrünte Stützmauern + Lärmschutzwände b. Fruence und Prayoud"
Strasse und Verkehr, No 10, 1981

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Schweizer Baublatt Nr. 45, Juni 1982

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2. Geotextiltagung, März, 1983

[13] 1984 Zeeleder-Jaecklin-Adamina : "Neuartige Pfeilermauer"
Strasse + Verkehr No 9, Sept. 1984 (S.313)

[14] 1985 Rüegger, R., Amman, J.F., Jaecklin, F.P. :"Geotextil-Handbuch"
Schweiz. Verband der Geotextilfachleute, EMPA, St.Gallen,
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TK-Dokument des SVG, EMPA St. Gallen, Januar 1985

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Proceedings, 1. Kongress Kunststoffe in der Geotechnik K-Geo88, Hamburg, Sept. 1988

[22] 1989 Jaecklin, Felix P. : "Geotextileinlagen in bituminösen Belägen"
Schweizer Baublatt, Nr. 90, Nov, 1989 und GeoTex No.3, 1989

[23] 1991 Jaecklin, Felix P. : "Risse-Entstehung und Wirkungsweise der Geotextileinlagen im Belag" 7. Geotextil-Tagung, Bern

[24] 1991 Jaecklin, Felix P. : "Development of Fissures and Cracks in Asphalt and Procedures and Design, Steps for Design and Construction for Retrofitting Conservation"
Vorträge, Techn. University of Krakau / Polen Okt. 1991

[25] 1991/92 Jaecklin, Felix P. :"Unsurfaced Road Base Design on Soft Ground using Geotextiles"
Vortrag, Schulungszentrum für Ingenieure Horw/Luzern 1991/92

[26] 1991/92 Jaecklin, Felix P. :"Geotextile Design and use in rail road construction"
Vortrag, Schulungszentrum für Ingenieure Horw/Luzern 1991/92

[27] 1991/92 Jaecklin, Felix P. :"Geotextile reinforcing for fill on very soft ground"
Vortrag, Schulungszentrum für Ingenieure Horw/Luzern 1991/92

[28] 1991/92 Jaecklin, Felix P. :"Design of reinforced geotextile retaining walls"
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Vortrag, Schulungszentrum für Ingenieure Horw/Luzern 1991/92

[30] 1991/92 Jaecklin, Felix P. :"Engineering Biology and using Geotextiles"
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Vestra Fachtagung, Regensdorf, Jan. 1997

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Strasse und Verkehr, Nr.2, 1997

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Geosynthetic Conference, Denver/USA, Febr. 1997

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NPCA - USA, Denver/USA, Febr, 1997

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Grundlagen für Geotextilien (Trennen, Filtern, Drainieren, Armieren)
Gebäudedrainagen konzipieren, bemessen
Strassenbau, Geotextilien Auswählen und Bemessen im Strassen- und Pistenbau
Asphalteinlagen: Geotextilien zur Verstärkung von bituminösen Belägen
Fundationen und Baugruben: Geotextil zur Sicherung von Fundationen und Baugruben
Versickerungsanlagen: Geotextil für Dach- und Oberflächenwasser-Versickerung
Geotextilien im Bahnbau; Geotextilien zum Trennen, Filtern und Draineren im Bahnkörper
Hangsicherungen: Geotextilarmierte Stützmauern
Sportplätze und Wegebau mit Geotextilien
Wasserbau mit Geotextilien

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[60] 2003 Jaecklin F. P + Paolo Casartelli: "Evergreen opere a scomparsa per inerbimento", Consolidamento Terreni; Lavori Pubblici No 5, Nov-Dez 2003

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- o collapse of retaining walls - learn from bad experiences
- o highest wall in Ponferrada, Espagna
- o disaster repair of wall failure in Gondo/Switzerland

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[62] 2004 Felix P. Jaecklin: "Retaining Wall Failures - Learn from Bad Experiences", Geosynthetics Conference, Schloss Pilnitz, Dresden, Germany, Sept 2004

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[65] 2006 Felix P.Jaecklin:"Hangsicherungen aus Fertigbetonelementen", Fachtagung Creabeton "Hangsicherungen" im AAL Murmattweg 4, 6005 Luzern am 28. März 2006

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3. Evergreen Walls   Evergreen Concepts

Felix P. Jaecklin started developing the Evergreen Walls in 1976.
The first concepts had to resolve the following task:

- Design precast modules to order from a precast plant to stop a landslide.

The conceptual answer was:

- build reinforced precast concrete modules of variable size,
- excavate just outside of one end of the earth slide,
- Build a stack of units filled with earth to resist the mountainside forces.
- Continue excavating into the landslide and build the next stack.
- That way the landslide is gradually stopped from moving, without the need of temporary shoring.

One of the first Evergreen walls was built in this sequence in an active earth slide and it worked.
The additional engineering task to be successful were:

- Design the frame in an aesthetical manner.
- Provide ample room for plants to grow between beams.
- Optimize the simple frame for economical use of reinforced concrete.

The technical solution is:
Cast simple concrete frames taking special care for the various tasks.

Historical Development

The first wall was built 1976 in Zurich - a crude way – compared to today's measures.

Ever since the concept was further developed for increased requirements in aesthetics, plant performance, structural performance, and maximum wall height.

Then the first marketing company was formed 'System Evergreen AG' separately owned by Ladina Jaecklin for clearly separate Marketing and Licensing from engineering and design, each one requiring separate insurance and skills.

Then followed the expansion to western European countries: Germany, Austria, France, Italy, and Spain, later to Belgium, Slovenia, and Sweden.

The next expansion was to USA, Canada, Japan, and South Africa, later to Yemen, Saudi Arabia, and Pakistan.

This expansion required an intense study of languages and culture for each area, then study local construction codes and requirements and fulfill any task needed locally.

This expansion also required developing additional wall systems, such as Everwall, closed face Evergreen walls, Evergreen Geo, Geogreen-Gabion, Geogreen-Situ, and Geogreen-Rock, finally Evergreen Maxi.

The results are:

- Some six wall systems, each one for different tasks.
- There are some 20 licensees, operating in very different environments.
- There are some 15 countries on four continents.

The goal is to continue developing the concepts, the markets, and bring fascinating technology to many engineering and construction communities around the globe for further enhancing quality of life in a nicer environment.

General Description of Various Types of Evergreen Walls

The Evergreen family of walls includes several wall systems:

3.1 **Evergreen® Macro,** the planted wall.

3.2 **Evergreen® Geo**, the super cost effective planted wall.

3.3 **Everwall®,** the closed face, drawer like wall.

3.4 **Closed Face Evergreen Macro** walls

3.5 **Geogreen®** walls (non-concrete technology) made from mesh wire **Geogreen-Gabion, Geogreen-Situ and Geogreen-Rock.**

3.6 **Evergreen® MAXI** - the newest, big size wall units for heavily loaded railroads and highways. - see section 4

- All wall systems are fully developed and in use in many countries and many places.
- These wall systems have been used, tested, and approved worldwide.
- They are protected by trademarks, patents in USA, Canada, European countries, and overseas.
- Key roles play long lasting experience, special know-how on soil-structure-interaction, technical know-how, soil mechanics, and geotechnical engineering. Special tools and specialty structural design methods are needed for the design against silo pressure characteristics and slanted irregular sections under slanted loadings on highly irregular sections of inhomogeneous material.
- Experience demonstrated how effectively a producer can change his position for sales of one product, of a 'one-type-of-a-wall-manufacturer' to an 'expert-specialist-on-walls' by having several wall systems in his production line. That way he can readily select the best solution and the best type of product for each application using marketing tools, brochures, and technical data compiled.
- The walls are well proven and have set the high standards of quality and engineering in many countries.

List of completed projects throughout the world

There are about 1200 walls completed worldwide.
Please find such list at the end of this package.

3.1 Evergreen Macro Walls **the fancy planted wall**

San Diego – Spring Street – for San Diego Metro Rail Parking, USA

Smithtown Development, Long Island, NY, USA

Evergreen Walls Madinah

Cape town, South Africa

International Airport of Bilbao, Spain, Access Road, Wall about 10 m high

Motorway A 51, near Grenoble, France, high wall, about 6000m2

Brussels International Aiport Evergreen Wall 16m high

Home Depot Shopping Center in Connecticut, USA

3.2 Evergreen GEO Walls **the low cost planted wall**

Evergreen GEO wall built in Port Jefferson, Long Island, New York

Similar Evergreen GEO Wall built in Port Jefferson

Evergreen Geo Wall built in Japan under a new Motorway

3.3 Everwall **the closed face, drawer like wall**

Everwall in Connecticut

Everwall on Long Island, Beechwood
Replacing and repairing a damaged Keystone Blockwall

3.4 Evergreen Closed Face Walls

Evergreen Closed Face wall along a Riverbed in San Capistrano, California
Above are an access road and an additional mountainside Evergreen Macro wall.

Everwall for a Seawall
along the Pacific Ocean in Avila Beach near Santa Barbara in California, USA

3.5 Geogreen Walls (non-concrete technology) made from mesh wire

a) Geogreen-Gabion walls, prefabricated, pre-seeded gabions

Geogreen Gabion wall in Ponferrada, Motorway Madrid-Coruña, Spain

Thousands of gabions ready for shipping for installation.

Geogreen Gabions being installed from Truck

Wall in Ponferrada, Spain, shortly after completion.

This wall is 4 x 7m = 28m high, **the highest retaining wall ever built in Europe**

This wall was the first large scale application of the newly developed Geogreen gabion wall, that brings precast concrete technology to the earthwork contractor to produce gabions by the thousands and then build retaining walls fast and easy.

The IECA, International Erosion Control Association recognized the development with an **'Award for Excellence in Technology'** at the closing ceremony of the IECA Congress in Palm Springs, 2000.

b) Geogreen-Situ made in place mesh-wire walls

Geogreen Situ wall, under construction in Gondo, Switzerland.

The 20 m high retaining wall is completed and getting hidden by grass plants.

c) Geogreen-Rock beautifying and protection of rock and gunite

Geogreen Rock facing protects a gunite (shotcrete) excavation face against frost damages, cracking from intense sunshine and beautifies the entrance very nicely.

Details of the Geogreen Rock using galvanized mesh wire and a specially developed, non-inflammable, thus non-geosynthetical vegetation geogrid backfilled with a special non shrink and highly water retaining mix topsoil and seeds to grow dry season resisting plants, at least partially.

4. EVERGREEN® MAXI Retaining Wall System

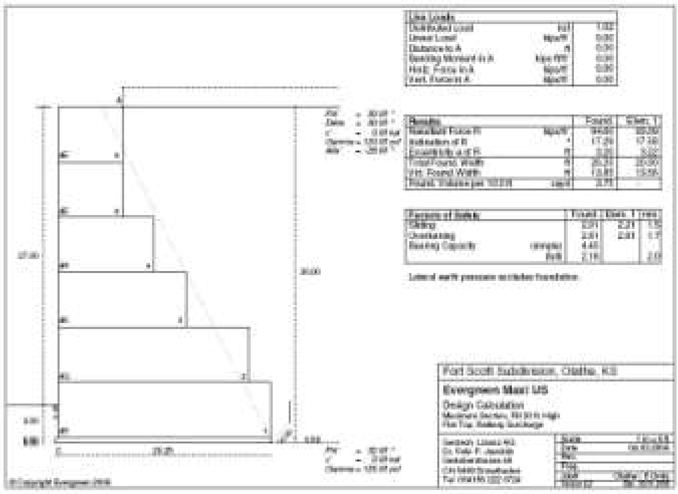
Evergreen® Maxi Retaining and Bridge Abutment Walls

Built for Olathe (Kansas) Railway Super Elevation

Special Features:

1. **Big units covering a face area of 100 sf, $9m^2$ each, weighing 8 to 11 tons.**
2. **This means a super efficient production and a lot of wall built per day.**
3. **Self-aligning keys and dowels provide high precision erection every time.**
4. **Open access on the back allows for big equipment and fast backfilling.**
5. **Sturdy and heavy units mean no shifting during compaction.**

Goal: The most efficient way to build big walls fast.



Evergreen Maxi Design Calculation **Areal View of Wall near Completion**

Erecting a Unit: Final Touch **Ramp Details**

Project: **BNSF Railway** Super Elevation for the **City of Olathe,** Kansas, 2007
Engineers: **TranSystems Corporation,** Kansas City, Missouri 64108
Precaster: **Barbour Concrete Co.,** E-Truman Road, Independence, MO 64056
Contractor: **Ames Construction Inc.,** 18450 E. 28.th Ave, Aurora CO 80011

System: **EVERGREEN WALLS, INC.,** 6069 Oakbrook Parkway, Norcross, GA30094
Clay Warner, Evergreen manager nationwide,
Cell 404 372 5476, phone 770 840 7060, and fax 770 840 7069
www.evergreenwalls.com, www.evergreen.us, www.evergreen.eu

System developers: **Felix P. Jaecklin, Emilio Brovelli, Mauro Cappellin.**

Evergreen® MAXI protected by international trademark, patents pending

20 to 25% more efficient for:
Vertical or battered retaining and <u>bridge abutment</u> walls.

Evergreen MAXI - Special Features: <u>One Page Summary</u>

Evergreen Maxi is the most recent Evergreen retaining wall, especially developed for the BNSF railway in Olathe near Kansas City, USA. The casting and construction of this project went very well. The precaster shipped the last concrete elements in September 2007. Therefore, the wall is now complete and it is a good moment to evaluate results. The railway company already ordered the next wall, which proves they are happy and it was a success. Here are the main points:

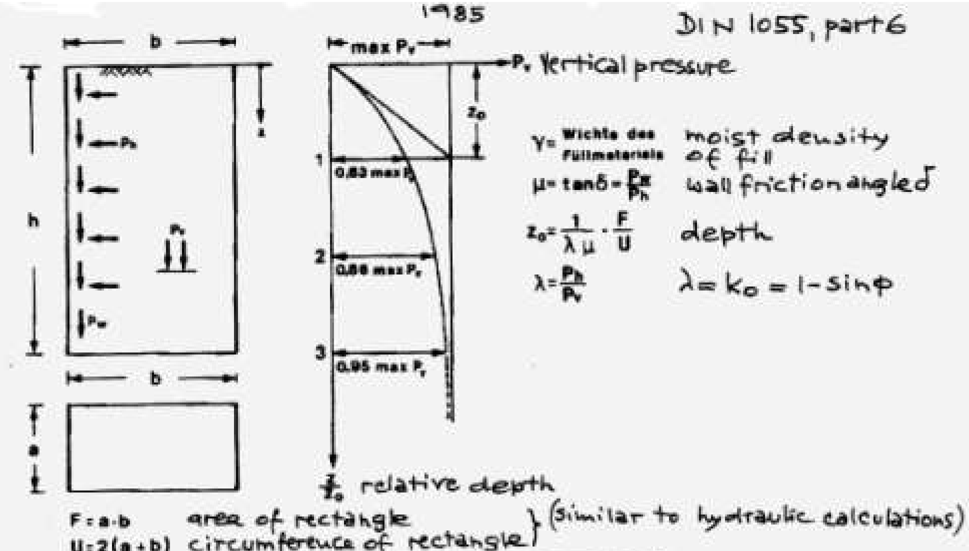
- **Scope:** The wall design accepts heavy loads from railways and motorways.
- **Narrow Footprint:** The heavy units fulfill the gravity wall effect to a maximum, which reflects in a narrow footprint. This means walls are built on a narrower base than other wall may need. This causes less risky excavations into steep hillsides or easier spacing of opposite walls closely together or separate walls in tight places.
- **Huge Units:** The big size units encourage fast production and construction.
- **Independent Stacks:** The simple vertical stacks results in a fast and high precision erection. This allows for vertical foundation steps anywhere as needed. The vertical joints mean free temperature expansion and no long term cracking from temperature effects (that is an issue under extreme desert conditions).
- **Automatic Precision Stacking:** The self-alignment keys guide each unit into the proper place accurately.
- **Stiff and Sturdy Units:** The units are very heavy and extremely sturdy, so they cannot move nor shift during filling and compaction – that means it is easy to work with.
- **Open Access from Behind:** The wall is completely open on the back, which makes it easy to fill from behind with good access for excavator, dozer, and compactor. Fast filling and good compaction results are the logical benefits.
- **Regular Backfill Material is Acceptable:** Unlike mechanically stabilized earth fill, no special requirements ask for high frictional material or low content of fines. As long as the material has acceptable water content for good compaction, any fill is fine (provided the wall was originally designed for that type of material).
- **Contractor Oriented Design:** These features purposely keep the erection procedures in mind for fast and profitable erection, without the hassle for mistakes and misalignment, but consistent precision for top quality.
- **No Foundations:** The wall does NOT need a foundation, a leveling pad is sufficient. - Saving foundations means a lot. This is a relatively new concept, based on mechanically stabilized walls experience: The weight of the wall is the same, whether there is a wall foundation or not, thus even crib walls do not necessarily need a foundation. More than ten years ago Caltrans (California Department of Transportation, the owner of the biggest highway system existing) approved Evergreen walls without requesting a formal foundation.
- **Very Economical:** Evergreen MAXI is about 20% more economical than Evergreen Macro, and more economical than other gravity walls, considering:
- **12- Very Efficient Panels:** The panels are much bigger: 6.0 x 1.50m, thus 9m2 each instead of 4m2, only about half as many units are needed! It means half as many units to cast, to ship, to crane and twice as much volume to backfill every time. This speeds up the work systematically.
- **Now also in Metric:** Originally, the wall based on imperial units, now metric drawings are available.

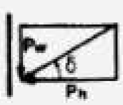
8. Design Theory

Below follow design principles regarding:

- **silo pressure theory, then**
- **Evergreen Macro gravity wall sample calculation, then**
- **details regarding foundation bearing capacity calculations**

Silo Pressures - Definitions for calculating internal fill pressures (from German code)





für $z = \infty$

max $P_v = \gamma \cdot z_0 = \frac{\gamma}{\lambda\mu} \cdot \frac{F}{U}$ max vertical pressure

max $P_h = \lambda \cdot$ max $P_v = \frac{\gamma}{\mu} \cdot \frac{F}{U}$ max horizontal pressure

max $P_w = \mu \cdot$ max $P_h = \gamma \cdot \frac{F}{U}$ max downdrag along side wall for depth $z = \infty$

für $z < \infty$

$P = \max p \cdot (1 - e^{-\frac{z}{z_0}})$

z/z_0	0	0.5	1.0	1.5	2.0	2.5	3
$(1-e^{-\frac{z}{z_0}})$	0	0.39	0.63	0.78	0.86	0.92	0.95

$\} \frac{4.53}{7} \approx 1.65$

Bild 2: Bezeichnung des Silodrucks nach DIN 1055 Teil 6 für die Lastannahmen aus der Verfüllung der Raumgitterkonstruktion Definitions for silo pressure from DIN 1055 German code for soil parameters of fill inside of cribwall

Abweichend von DIN 1055, Teil 6, wird vereinfacht der Wandreibungswinkel im Inneren der Raumgitterzelle zu change wall friction using wall friction angle for cribwalls

δ_s (innen) = ⅔ · φ' (1)

und das Verhältnis von Horizontallast P_h zur Vertikallast P_v zu ratio between horizontal and vertical forces P_h, P_v

$\lambda = P_h : P_v = K_0 = 1 - \sin(\varphi')$ (2)

festgelegt.

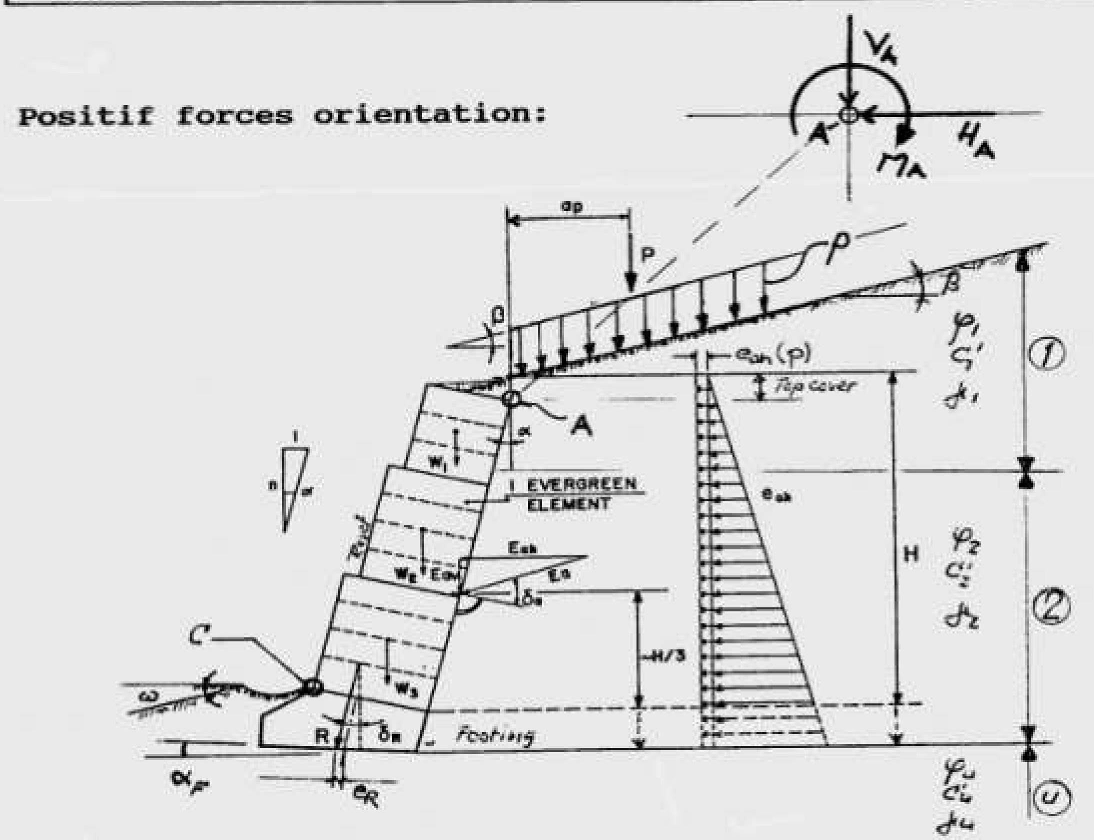
Die Auflasten auf und aus Teilbereichen der Wand müssen im Inneren der Raumgitterzellen verfolgt werden.

Silo pressure theory: In water and in soil the vertical pressure increases with depth linearly, not so inside of silos, because of lateral horizontal side pressures against the walls and subsequent vertical friction along the walls. This wall friction reduces the vertical internal silo pressures to a maximum level, which in turn limits the lateral silo wall pressure to a maximum. Silo pressures largely depend on the silo dimensions, which is explicitly defined here.

Design Parameters and Variables involved in gravity retaining wall design
This sketch defines and illustrates numerous parameters involved

Evergreen Hand Calculations - A 'hand calculation of an Evergreen Macro wall demonstrates details of a gravity wall design and defines safety factor calculations

INPUT PARAMETERS



1. *Soil Parameters*

The following parameter are needed for design analysis :

φ = friction angle
c = cohesion
δ = wall friction angle
γ = moist density of backfill
β = slope angle above wall
α = wall batter (slope)

Subsoil :

φu = friction angle of bearing soil
cu = cohesion
γu = density
ω = slope angle below wall

2. *Design*

Evergreen retaining walls are designed using standard earth pressure theory and gravity wall principles.

In addition each joint between elements is checked against sliding and overturning.

3. *Additional variables*

w = weights of elements
p = distributed live load
P = linear live load
ap = distance from P to wall
Ea = active earth pressure
R = resultant force
δR = slope of resultant force
eR = excentricity

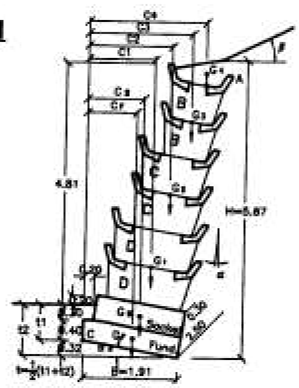
EVERGREEN RETAINING WALL - HAND CALCULATION metric version

1. SOIL COEFFICIENTS

	backfill	subsoil
friction angle	$\varphi = 30°$	$\varphi_u = 35°$
wall friction	$\delta = 3/4\ \varphi' = 22.5°$	
cohesion	$c' = 0$	$c' = 0$
density	$\gamma = 20$ kN/m3	$\gamma_u = 21$kN/m3
slope angle	$\beta = 20°$, $\omega = 0$	
wall batter	$\alpha = 9.46°$ (6:1)	

H = 5.67 m

2. WALL DESIGN



3. EARTH PRESSURES

from α, β, φ and δ result Kah = 0.311, Kav = 0.0721

eah = Kah • γ • H = 0.31 • 20.0 • 5.67 = 35.27 kN/m2

$$\text{Eah} = \text{eah} \cdot \frac{H}{2} = 35.27 \cdot \frac{5.67}{2} = 99.98 \text{ kN/m1}$$

Eav = Eah • tg (δ−α) = 99.98 • tg (22.5 - 9.46°) =

= 23.15 kN/m1

4. WEIGHTS

earth cover $^1/_2$ • 0.30 • 0.86 • cos (9.46) • 20 = 2.54 kN/m1

fill density of units γ = 18 kN/m^3

elements B	2 • 16.2 kN/m1	= 32.4 kN/m1
elements C	2 • 20.9 kN/m1	= 41.8 kN/m1
elements D	2 • 25.3 kN/m1	= 50.6 kN/m1
pier =	0.27 m^3 . 24.5 • $^2/_5$	= 2.65 kN/m1
foundation =	2.09 m3 • 24.5 • $2/_5$	=20.48 kN/m1

soil between piers

= (2.5-0.30) 0.5 • 1.8 • 18 cos(9.46) • $2/_5$ = 14.06 kN/m1

TOTAL Σ G = 164.53 kN/m1

5. POSITION OF RESULTANT FORCE R

distance between foundations

Rh = s • Eah = 2.5 • 99.98 kN/m1

Rv = s • [ΣG+Eav] = 2.5 (164.53+23.15) = 469.20 kN

$R = (Rh^2 + Rv^2)^{1/2} = (249.95^2 + 469.20^2)^{1/2} = 531.62$ kN

angle of load inclination δ R

$$\delta R = \text{arc tg} \frac{Rh}{Rv} = \text{arc tg} \frac{249.95}{469.20} = 28.04°$$

moment around point : C

lever arms			
footing	Cf = 0.95	
pier	Cs = 1.14	h_{Eah} = 1.57
2 D	C1 = 1.34	
2 C	C2 = 1.68	h_{Eav} = 2.22
2 B	C3 = 2.10	
cover	C4 = 2.38	

vertical moment :

Σ Mcv = 2.54 • 2.38 + 32.4 • 2.10 + 41.8 • 1.68 + 50.6 • 1.34 + (2.65 + 14.06) 1.14 + 20.48 • 0.95 + 23.15 • 2.22

Σ Mcv = 302.0 kNm/m1

horizontal moment :

Σ Mch = 1.57 • 99.98 = 156.97 kNm/m1

distance of resultant force from C

$$B' = 2 \cdot \frac{\Sigma(\text{Mcv} - \text{Mch})}{(\text{Rv} + \text{Rh} . \text{tg}\ \alpha u) \cdot \cos \alpha_u} = 2 \cdot \frac{2.5 . (302.0 - 156.97)}{(469.20 + 249.95 . \text{tg}\ 9.46°) \cos 9.46°} =$$

B' = 1.44 m

eccentricity $e = B/_2 - B'/_2 = 1.91/_2 - 0.72 = 0.235$ m

6. OVERTURNING (SAFETY FACTOR Fo)

$$Fo = \frac{\Sigma \text{Mc vert}}{\Sigma \text{Mc hor}} = \frac{302.69}{156.97} = 1.93$$

overturning Fo = 1.93 safety factor

7. SLIDING (SAFETY FACTOR Fs)

$$Fg = \frac{\cos(\delta R - \alpha u)}{\sin(\delta R - \alpha u)} . \text{tg}\ \varphi u = \frac{\cos(28.04 - 9.46)}{\sin(28.04 - 9.46)} \text{ tg } 35° = 2.08$$

sliding Fg = 2.08 safety factor

8. BEARING CAPACITY (safety factor Fb)

$po = c_u \cdot Nc \cdot dc \cdot ic \cdot gc \cdot fc + (\gamma_u \cdot t + q) \cdot Nq \cdot dq \cdot iq \cdot gq \cdot fq + 0.5 B' \cdot \gamma_u \, N\gamma \cdot d\gamma \cdot i\gamma \cdot g\gamma \cdot f\gamma$

$t = 1.02$ m
$B' = 1.44$ m
$\alpha_u = 9.46°$

force normal to base,	N	$= R \cdot \cos(\delta r - \alpha u)$	= 503.91 kN
force parallel to base,	T	$= R \cdot \sin(\delta r - \alpha u)$	= 169.39 kN

bearing capacity factors :

$Nc = (Nq - 1) / tg\,\varphi u$ = 46.12
$Nq = e^{(\pi \cdot tg\,\varphi u)} \cdot tg^2 (45 + \varphi u/_2)$ = 33.30
$N\gamma = 1.8\,(Nq - 1) \cdot tg\,\varphi u$ = 40.71

depth factors :

$dc = 1 + 0.007 \cdot arctg(t / B') = 1 + 0.007 \cdot arctg(1.02 / 1.476)$ = 1.246
$dq = 1 + 0.035 \cdot tg\,\varphi u \cdot (1 - \sin\varphi u)^2 \cdot arctg(t / B')$ = 1. 157
$d\gamma = 1$ = 1.0

load inclination factors :

$ic = iq - (1 - iq) / (Nq - 1)$ = 0.424
$iq = [1 - T / (N + c \cdot B' \cdot L' \; 1/tg\,\varphi u)]^2 = [1 - 169.39 / 503.91]^2$ = 0.441
$i\gamma = (iq)^{3/2}$ = 0.293

ground slope factors :

$gc = gq - (1-gq)/(Nq-1)$ = 1.00
$gq = (1-tg\omega)^2 \quad = (1-tg\,0)^2$ = 1.00
$g\gamma = gq$ = 1.00

foundation tilt factors :

$fc = 1 - \alpha u° /_{147°}$ = 0.936
$fq = e^{(-0.035 \cdot \alpha u° \, tg\,\varphi u)}$ = 0.793
$f\gamma = e^{(-0.047 \cdot \alpha u° \, tg\,\varphi u)}$ = 0.732

$po = 0.0 + 288.61 + 132.02$ = 420.63 kN/m2

virtual foundation width, $B' = B - 2e = 1.91 - 2 \cdot 0.235 =$ $B' = 1.44$ m
virtual foundation length, $L' = L = s = 2.50$ m $L' = 2.50$ m

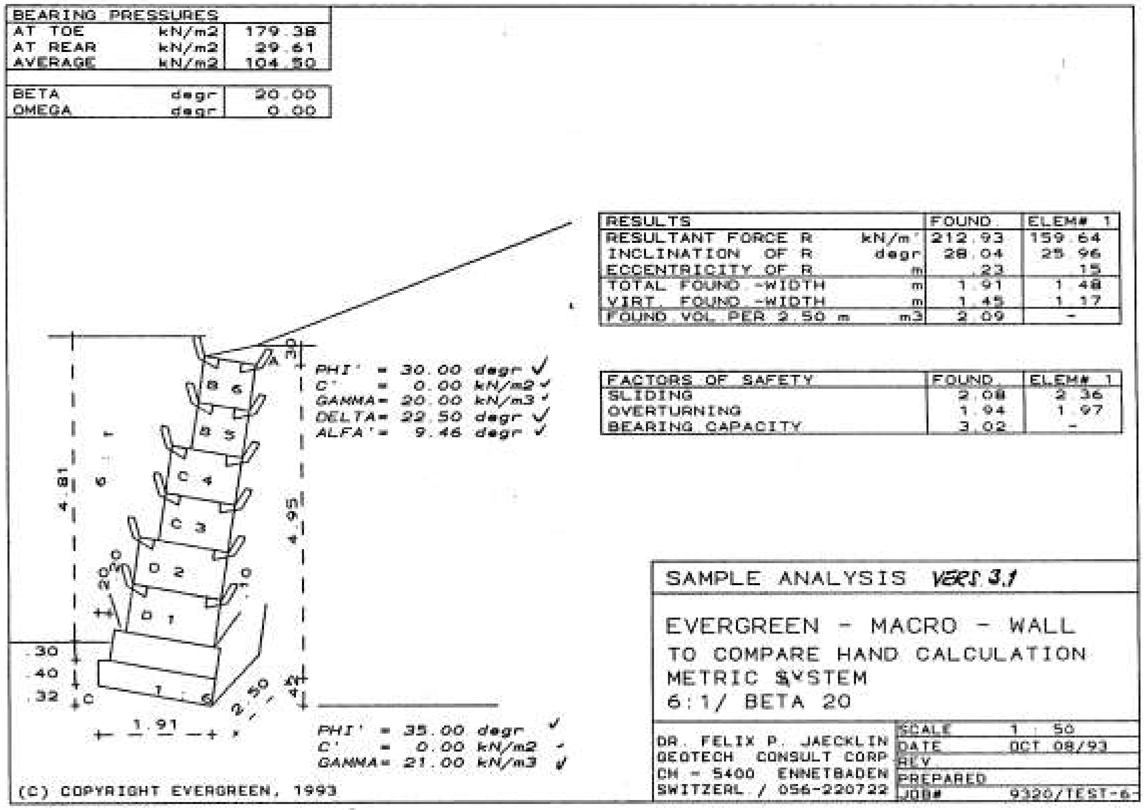
$peff = N / B' \cdot L' = 503.91 / 1.44 \cdot 2.50$ = 139.97 kN/m2 effective bearing pressure

$Fb = po / peff = 420.63 / 139.97 =$

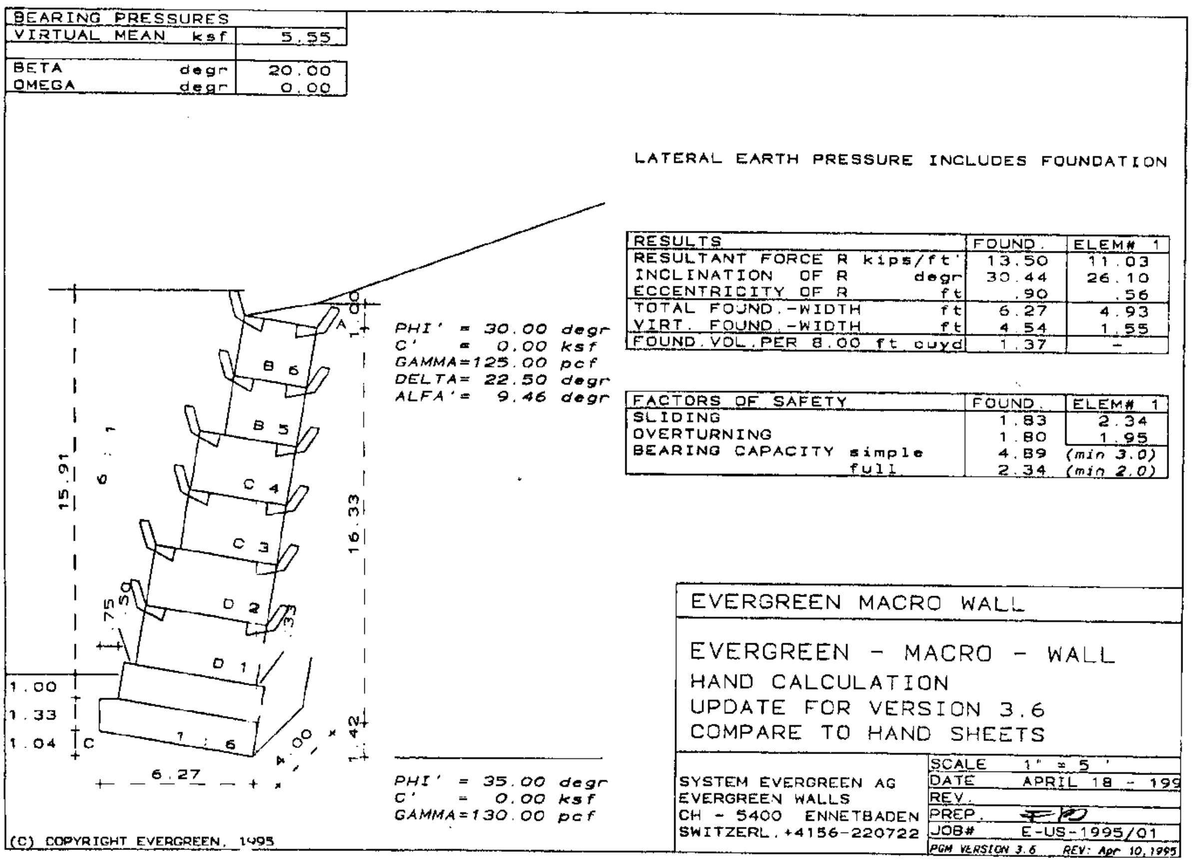
<u>bearing capacity Fb = 3.01 safety factor</u>

SYSTEM EVERGREEN AG Ennetbaden, 11.10.93 HANDMETR WPS metric

Bearing Capacity Design Calculation - This page demonstrates the use of the bearing capacity design calculation for foundation design. The mathematical details of the actual formulas are shown on the next two pages.



So far the **metric** hand calculation, below follows the according **imperial** unit hand calc:



(update
(version 3.6 / USA)

EVERGREEN RETAINING WALL HAND CALCULATION

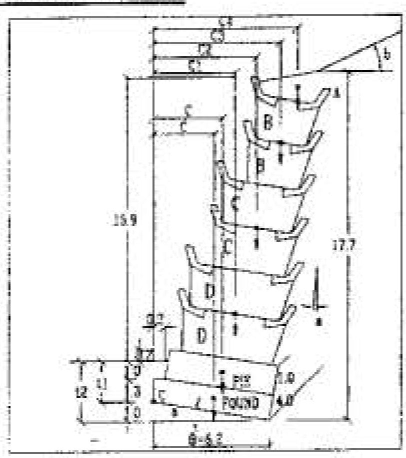
1. SOIL COEFFICIENTS

friction angle	$\varphi = 30°$
wall friction	$\theta = 3/4\ \varphi' = 22.5°$
cohesion	$c' = 0$
density	$\gamma = 125$ pcf
slope angle	$\beta = 20°$
wall batter	$\alpha = 9.46°$ (6:1)

subsoil :

friction angle	$\varphi = 35°$
cohesion	$c = 0$
density	$\gamma = 130$ pcf

2. WALL DESIGN



3. EARTH PRESSURES

from α, β φ and δ results Kah = 0.311
H = 18.75 ft. And results Kah = 0.0721

$$eah = Kah \cdot \gamma \cdot H = 0.311 \cdot 0.125 \cdot 18.75 = 0.729 \text{ ksf}$$

$$Eah = eah \cdot \frac{H}{2} = 0.729 \cdot \frac{18.75}{2} = 6.833 \text{ kips / ft}$$

$$Eav = Eah \cdot \tan(\delta - \alpha) = 6.833 \cdot \tan(22.5 - 9.46°) = 1.583 \text{ kips / ft}$$

4. WEIGHTS

earth cover 1/2 · 1 · 3 · cos(9.46) · 0.125 = 0.185 kips/ft.
fill density of units is B:112.5 pcf, C:114 pcf, D:116 pcf

element B	2 · 1.12 kips/ft.	= 2.24 kips/ft.
element C	2 · 1.43 kips/ft.	= 2.86 kips/ft.
element D	2 · 1.75 kips/ft.	= 3.50 kips/ft.
pier	1 · 1.5 · 5.833 · 0.152 / 8	= 0.167 kips/ft.
foundation	1.37 cu yd · 27 · 0.153 / 8	= 0.707 kips/ft.
Soil between piers	1.5 · 7 · 5.833 · 0.125 / 8 =	= 0.957 kips/ft.
	Total Σ G	= 10.26 kips/ft.

5. POSITION OF RESULTANT FORCE R

distance between foundations s = 8 ft.

$$Rh = s \cdot Eah = 8 \cdot 6.833 \text{kips / ft} = 54.664 \text{ kips}$$

$$Rv = s \cdot [\Sigma G + Eav] = 8(1.583 + 10.26) = 94.78 \text{ kips}$$

$$R = (Rh^2 + Rv^2)^{1/2} = (54.664^2 + 94.78^2)^{1/2} = 109.41 \text{ kips}$$

angle of load inclination δR

$$\delta R = \text{arc } \tan\frac{Rh}{Rv} = \text{arc } \tan\frac{54.66}{94.78} = 30.0°$$

moment around point : C

lever arms	c-footing		=3.00	
	c-pier		=3.45	aEa=4.83
	c1	2D	=3.80	
	c2	2C	=5.40	bEv=7.00
	c3	2B	=6.50	
	c4	cover	=8.10	

vertical moment :
$\Sigma Mcv = 0.185 \cdot 8.1 + 2.24 \cdot 6.5 + 2.86 \cdot 5.4 + 3.5 \cdot 3.8 + 0.16 \cdot 3.4 + 0.957 \cdot 3.4 + 0.707 \cdot 3 + 1.583 \cdot 7.0 = 61.83$ ft.kips
$\Sigma Mcv = 61.83$ kips/ft. · 8 = 494.61 ft./kips

Horizontal moment :
$\Sigma Mch = 54.664 \cdot 4.83 = 264.03$ kips
Mres = Mcv - Mch = 494.61 - 264.03 = 230.58
$V = R \cos(\delta R - \alpha R) = 109.41 \cos(30° - 9.46) = 102.46$

$$Mres = V \cdot \frac{B'}{2}$$

distance of resultant force from C

$$\frac{B'}{2} = Mres / V = 230.58 / 102.46 = 2.251 \text{ ft.}$$

$$\frac{B'}{2} = 6.27 / 2 = 3.135 \text{ ft.}$$

$$\text{eccentricity } e = \frac{B}{2} - \frac{B'}{2} = \frac{6.27}{2} - 2.251 = 0.884$$

6. OVERTURNING (SAFETY FACTOR Fo)

$$Fo = \frac{\Sigma Mc \text{ vert}}{\Sigma Mc \text{ hor}} = \frac{494.609}{264.027} = 1.873$$

overturning Fo = 1.87 safety factor

7. SLIDING (SAFETY FACTOR Fs)

$$Fs = \frac{\cos(\delta R - \alpha u)}{\sin(\delta R - \alpha u)} \cdot \tan \varphi u = \frac{\cos(30 - 9.46)}{\sin(30 - 9.49)} \cdot \tan 35° = 1.869$$

sliding Fs = 1.87 safety factor

8. BEARING CAPACITY (SAFETY FACTOR Fb)

$qu = c' \cdot Nc \cdot dc \cdot ic \cdot gc \cdot fc \cdot sc + (\gamma_u \cdot d + q) \cdot Nq \cdot dq \cdot iq \cdot gq \cdot fq \cdot sq + 0.5\,B' \cdot \gamma_u \cdot N\gamma \cdot d\gamma \cdot i\gamma \cdot g\gamma \cdot f\gamma \cdot s\gamma$

d = 3.37 ft.		e = 0.884 ft.	c = 0	δ = 0.130
B'= 4.50 ft.	because L'>B', reverse:	B'= 4.0 ft.	q = 0	α = 9.462
L = L'= 4		L'= 4.5 ft.	φ = 35°	

simple formula : $qu = c' \cdot Nc + (\delta u \cdot d + q) \cdot Nq + 0.5 \cdot B \cdot \delta u \cdot N\delta$

Bearing capacity factors :

$Nc = (Nq - 1) / \tan\varphi u = \mathbf{46.12}$

$Nq = e(\pi \cdot \tan\varphi u) \cdot \tan^2 \cdot (45 + \frac{\varphi u}{2}) = \mathbf{33.30}$

$N\gamma = 2.0(Nq + 1) \cdot \tan\varphi u = \mathbf{48.03}$

depth factors :

$dc = 1 + 0.007 \cdot \arctan(\frac{d}{B'}) = 1 + 0.007 \cdot \arctan(\frac{3.37}{4.0}) = \mathbf{1.281}$

$dq = 1 + 2(\frac{d}{B'})\tan\varphi(1 - \sin\varphi)^2 = \mathbf{1.0}$

load inclination factors

$ic = iq - (1 - iq) / (Nc \cdot \tan\varphi) = \mathbf{0.474}$

$iq = (1 - \frac{T}{V + c' \cdot B' \cdot L' \cdot \cot an\,\varphi})^n = \mathbf{0.488}$

$i\gamma = (1 - \frac{T}{V + c' \cdot B' \cdot L' \cdot \cot an\,\varphi})^{n+1} = \mathbf{0.305}$

for theta = 0 $\quad n = \frac{2 + \frac{B'}{L'}}{1 + \frac{B'}{L'}} = 1.529$

ground slope factors:

$gc = e(-2\omega \tan\varphi) = \mathbf{1.00}$

$gp = (1 - \tan\omega)^2 = \mathbf{1.00}$

$g\gamma = (1 - \tan\omega)^2 = \mathbf{1.00}$

foundation inclined base factors :

$fc = fq - (1 - fq) / Nc \tan\varphi) = \mathbf{0.775}$

$fq = (1 - alfa \tan\varphi)^2 = \mathbf{0.782}$

$f\gamma = (1 - alfa \tan\varphi)^2 = \mathbf{0.782}$

footing shape factors :

a) for continuous foundations $\quad sc = 1,\ sq = 1,\ s\gamma = 1$

b) for individual foundations

$sc = 1 + (B'/L')(Nq / Nc) = \mathbf{1.642}$

$sq = 1 + (B'/L')\tan\varphi = \mathbf{1.622}$

$s\gamma = 1 - 0.4(B'/L') = \mathbf{0.644}$

$qo = 0.0 + 10.755 + 1.918 = 12.673$ ksf

virtual foundation width, $B' = B - 2e = 6.27 - 2 \cdot 0.884 = B' = 4.50$ ft.

virtual foundation length, $L' = \mathbf{4.0}$ ft.

force normal to base, $V = R \cdot \cos(\delta r - \alpha u) = 102.456$ kips

force parallel to base, $T = R \cdot \sin(\delta r - \alpha u) = 38.384$ kips

effective bearing pressure $qeff = V / B' \cdot L' = 102.456 / 4.0 \cdot 4.5 = 5.692$ ksf

simple :$Fb = qo / qeff = 27.077 / 5.692 = 4.76$

bearing capacity (full) Fb = 12.673 / 5.692 =2.22 safety factor

SYSTEM EVERGREEN AG — Ennetbaden, 20.4.1995 hand-us.doc

BEARING CAPACITY ANALYSIS

Compiled by DR. FELIX P. JAECKLIN - GEOTECHNICAL ENGINEERS

DEFINITIONS

qu = "ultimate load" = stress producing rupture of the subsoil (Terzaghi, Meyerhof)

R = V + T	resultant force
T	transverse component ('horizontal') of R
V	perpendicular component ('vertical')
B' = B - 2 e	virtual width
L' = L + $^h/_2$ tan phi'	virtual or actual length, L' > = B' is a precondition
c'	cohesion
gamma	moist density
d	foundation depth
q	live load next to the foundation, q = 0 in most cases
phi	angle of internal friction of subsoil, also named phi'
omega	downhill slope angle or ground surface inclination
alfa	foundation slant, in radian, alfa = pi $_*$ grad / 180

FORMULA :

The bearing capacity formula consists of three segments : cohesion, depth, and width

a) Conventional Bearing Capacity Calculation (simple formula, 1957) :

qu =c' Nc + (gamma d + q) Nq + 0.5 B' gamma Ng (Terzaghi, Meyerhof 1957)

| | | |
cohesion c' depth d width segment B'

Minimum Factor of Safety **FS = min. 3.0** (AASHTO 1993)

b) Complete Bearing Capacity Calculation (complete or full formula, updated for 1995) :

qu = c' Nc dc ic gc fc sc +	(**cohesion c'** segment)
+ (gamma d + q) Nq dq iq gq fq sq +	(**depth d** segment)
+ 0.5 B' gamma Ng dg ig gg fg sg	(**width B** segment)

Minimum Factors of Safety FS = min. **2.0** for permanent load and wind loads (DIN)

FS = min. **1.5** for temporary loads, construction conditions

FS = min. **1.3** for extreme loadings, accidents, seismic

The individual coefficients are defined as follows:

Bearing Capacity Factors 'N'-values :

Nc = (Nq - 1) / tan phi	(AASHTO, Caquot, DIN 4017, Lang)
Nq = $e^{\text{pi tan phi}}$ $\tan^2$(45 + phi/2)	(AASHTO, Prandtl, DIN 4017, Lang)
Ng = 2 (Nq + 1) tan phi	(AASHTO 1993)
(Ng = 2 (Nq **-** 1) tan phi)	(Eurocode 1993, for comparison only)

Depth factors 'd' : B' = shorter dimension B' < L'

$dc = 1 + 0.007 \arctan (d / B')$ (Huder and Lang)

$dq = 1 + 2 (d / B') \tan phi (1 - \sin phi)^2$ (Brinch Hansen 1970, API rec.1984)

$dg = 1$ (Lang)

Load inclination factors 'i' :

a) AASHTO 1993 and Hongkong manual 1993

$ic = iq - (1 - iq) / (Nc \tan phi)$ (AASHTO, Hongkong manual)

$iq = [1 - T / (V + c' B' L' \cot phi)]^n$ (AASHTO, Hongkong manual)

$ig = [1 - T / (V + c' B' L' \cot phi)]^{n+1}$ (AASHTO, Hongkong manual)

$n = [(2 + L' / B') / (1 + L' / B')] \cos^2 theta +$ (AASHTO, Hongkong manual)

$+ [(2 + B' / L') / (1 + B' / L')] \sin^2 theta$ theta = angle of load eccentricity,

$n = (2 + B' / L') / (1 + B' / L')$ theta = 0 for retaining walls

b) German code DIN 4017, Winterkorn, (for comparison only)

$ic = iq - (1 - iq) / (Nq - 1)$ (German DIN 4017, Lang)

$iq = [1 - (0.7 T) / (V + c' B' L' \cot phi)]^3$ (German DIN, Winterkorn)

$ig = [1 - T / (V + c' B' L' \cot phi)]^2$ (German DIN, Winterkorn)

c) Eurocode 1993, (for comparison only)

$iq = [1 - 0.7 (T / V)]^3$

$ig = [1 - (T / V)]^3$

Down hill ground surface inclination factors 'g' : (omega = slope angle, radian)

$gc = e^{(- 2 \, omega \tan phi)}$ (Hongkong manual)

$gc = gq - (1 - gq) / (Nq - 1)$ (See Winterkorn, for comparison)

$gq = (1 - \tan omega)^2$ (Brinch Hansen, API rec., 1984,

$gg = (1 - \tan omega)^2$ and Hongkong manual 1993)

Foundation : inclined base factors 'f' : (alfa = foundation slant angle, radian)

$fc = fq - (1 - fq) / (Nc \tan phi)$ (AASHTO 93)

$fq = (1 - alfa \tan phi)^2$ (AASHTO 93)

$fg = (1 - alfa \tan phi)^2$ (AASHTO 93)

Footing shape factors 's' :

a) for continuous foundations

$sc = 1$ $sq = 1$ $sg = 1$ (AASHTO 93)

b) for individual foundations : (L' > = B', select them accordingly)

$sc = 1 + (B' / L') (Nq / Nc)$ (AASHTO 93)

$sq = 1 + (B' / L') \tan phi$ (AASHTO 93)

$sg = 1 - 0.4 (B' / L')$ (AASHTO 93)

$sc = 1 + (B' / L') (Nq / Nc)$ (Eurocode 1993, for comparison)

$sq = 1 + (B' / L') \mathbf{\sin} phi$ (Eurocode 1993, DIN)

$sg = 1 - \mathbf{0.3} (B' / L')$ (Eurocode 1993, DIN)

Minimum Safety Factor Requirement: Codes and literature used to require FS bearing capacity =

min. 3.0 for the **conventional** (1957) approach. Meanwhile the bearing capacity design concept has ben very much refined using these special (extra safety) factors for load inclination, down hill ground slope, inclined base, and footing shape. This means a number of additional features are now considered. That is the reason minimum safety factor for this complete approach is now **FS = min. 2.0.**

Definition of 'Bearing Capacity': The formulas above define ultimate load qu and bearing capacity = qu/2.0 as an allowable foundation pressure determined by subsoil and geometric conditions under the project conditions. However certain building codes define an allowable foundation pressure (sometimes called 'bearing capacity') as a general guidance, overridden by more up to date and much more sophisticated calculations as described above. Some codes, such as the strict German DIN, permit to override such code numbers of allowable foundation pressures by detailed bearing capacity analysis. As a consequence building codes allowable foundation pressures should be updated and replaced by the much more accurate bearing capacity analysis as described.

<u>Literature :</u>

[1] AASHTO 1993 - New interim addendum for Standard Specifications for Highway Bridges, 14th edition 1989, American Association of State Highway Officials (AASHTO).

[2] DIN - German code # 4017, 1979, DIN Taschenbuch, edition Beuth Berlin, Köln 1991

[3] Eurocode - 7 Part 1 (1993). Geotechnical design, general rules'. CEN European Committee for Standardization, Delft, The Netherlands, 1-114.

[4] Bodhan Zadroga (Prof. Gdansk, Poland) : 'Bearing Capacity of Shallow Foundation on Noncohesive Soils', Journal of Geotechnical Engineering ASCE, Vol. 120, No 11. Nov. 1994, page 1991.

[5] Lang and Huder (Prof. at Swiss Federal Institute of Technology, Zurich) : Soil Mechanics and Foundation Engineering, Springer edition, Berlin, Heidelberg, New York 1982

[6] API RP2A - Recommended Practice for Planning, designing, and constructing fixed offshore platforms. (1984). American Petroleum Institute, Dallas Texas, 43-111.

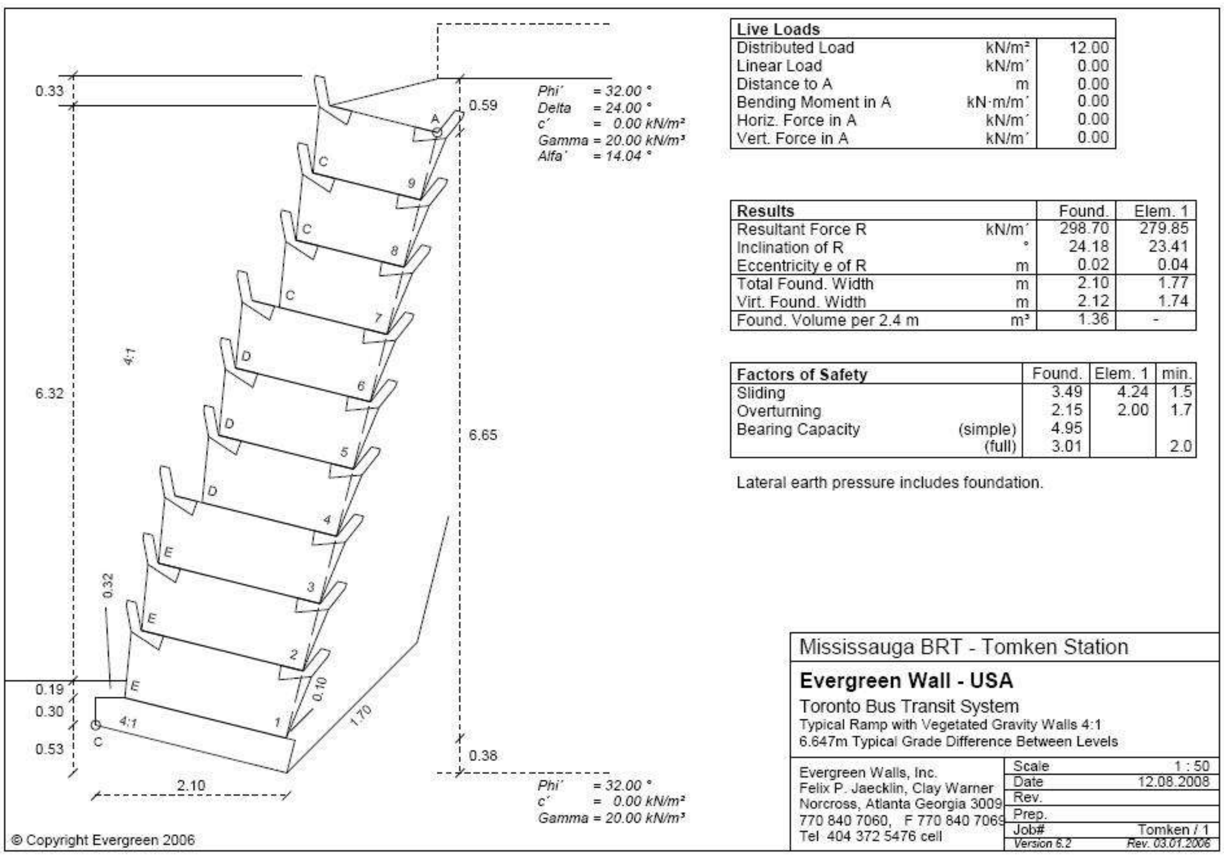
9. Software and some Printouts

Evergreen Software - The Evergreen team developed a design software specifically for Evergreen walls for easily defining optimum wall configurations and finding foundation and surcharge solutions under complicated conditions.

Initial Early Start - The initial start for this software made Felix P. Jaecklin in the early 1980ies using Hewlett Packard type programmable calculators, later 'Basic' programmable HP 80 machines and unsophisticated 'Spagetti'-programming techniques and automatic large size desk plotters .

Up-to-date Software Now - Meanwhile a sophisticate team transformed these early starts into windows and even vista compatible methods. Meanwhile various code requirements are built in as well as metric and imperial unit conversions for numerous types walls.

Design Samples



Live Loads		
Distributed Load	kN/m²	12.00
Linear Load	kN/m'	0.00
Distance to A	m	0.00
Bending Moment in A	kN·m/m'	0.00
Horiz. Force in A	kN/m'	0.00
Vert. Force in A	kN/m'	0.00

Results		Found.	Elem. 1
Resultant Force R	kN/m'	298.70	279.85
Inclination of R	°	24.18	23.41
Eccentricity e of R	m	0.02	0.04
Total Found. Width	m	2.10	1.77
Virt. Found. Width	m	2.12	1.74
Found. Volume per 2.4 m	m³	1.36	-

Factors of Safety		Found.	Elem. 1	min.
Sliding		3.49	4.24	1.5
Overturning		2.15	2.00	1.7
Bearing Capacity	(simple)	4.95		
	(full)	3.01		2.0

Design Calculations and Results for Typical Stack at 4:1 wall batter, 9 Units High

Typical Evergreen Software Plot -
On the left: Wall section with dimensions, soil parameters and geometry input data.
On the right: Live Loads,
Results,
Safety Factors,
Title Block **Plot concept: one page, one glance tells it all!**

Print List of Evergreen Design Calculations and Results

'Detailed print': List of all relevant data, for documentation and reference:

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Mississauga BRT - Tomken Station **Toronto Bus Transit System**
Typical Ramp with Vegetated Gravity Walls 4:1
6.647m Typical Grade Difference Between Levels

Evergreen Wall – USA

Job: Tomken / 1 12.08.2008

Wall Structure

Total Height	7.04 m	Wall Batter	14.04 °
Number of Elements	9		
Depth Earth Pressure	7.63 m (to base of foundation)		

Single Footing

Ledge Front	0.32 m	Depth Front	0.30 m
Ledge Rear	0.10 m	Size	1.70 m
Slant Base	14.04 °	Width Horizontal	2.10 m
Volume	1.36 m³	Weight	33.44 kN

Earth Cover and Slope

Top Cover	0.59 m	Top Slope (Beta)	0.00 °
Found. Cover	0.19 m	Found. Slope (Omega)	0.00 °

Live Loads

Distributed Load	12.00 kN/m²		
Linear Load	0.00 kN/m´	Distance to A	0.00 m
Bending Moment in A	0.00 kN·m/m´		
Horiz. Force in A	0.00 kN/m´	Vert. Force in A	0.00 kN/m´

Soil

Calculation Method	Coulomb, no TSF	
Number of Layers	1	
	Layer 1	**Subsoil**
Friction Angle (phi')	32.00 °	32.00 °
Wall Friction (delta)	24.00 °	
Cohesion (c')	0.00 kN/m²	0.00 kN/m²
Unit Weight (gamma)	20.00 kN/m³	20.00 kN/m³

Earth Pressure Coefficients

(Coulomb active earth pressure coefficients)

	Horizontal	Vertical
Layer 1	0.182	0.032

Earth Pressure and Forces **Horizontal**

Elem.	Eah (phi',p) (kN/m´)	Eh (c') (kN/m´)	Eh (P) (kN/m´)	Fi (kN/m´)	Fh (kN/m´)	Total H (kN/m´)
Earth Cover	1.92	0.00	0.00			1.92
9	4.19	0.00	0.00			4.19
8	6.18	0.00	0.00			6.18
7	8.17	0.00	0.00			8.17
6	10.16	0.00	0.00			10.16
5	12.14	0.00	0.00			12.14
4	14.13	0.00	0.00			14.13
3	16.12	0.00	0.00			16.12
2	18.11	0.00	0.00			18.11
1	20.09	0.00	0.00			20.09
Foundation	11.16	0.00	0.00			11.16
Total Horizontal Forces						122.36

Vertical

Elem.	Eav (phi',p) (kN/m´)	Ev (c') (kN/m´)	Ev (P) (kN/m´)	G (kN/m´)	Wgt (kN/m´)	Total V (kN/m´)
Earth Cover	0.34	0.00	0.00	6.98		7.32
9	0.74	0.00	0.00	20.87		21.61
8	1.09	0.00	0.00	20.87		21.96
7	1.43	0.00	0.00	20.87		22.30
6	1.78	0.00	0.00	25.54		27.32
5	2.13	0.00	0.00	25.54		27.67
4	2.48	0.00	0.00	25.54		28.02
3	2.83	0.00	0.00	30.36		33.19
2	3.18	0.00	0.00	30.36		33.54
1	3.53	0.00	0.00	30.36		33.89
Foundation	1.96	0.00	0.00	13.71		15.67
Total Vertical Forces						272.48

Distances to Foot of Foundation

Elem.	to Eh (m)	to Fi (m)	to Fh (m)	to Ev (m)	to G (m)	to Wgt (m)
Earth Cover	6.77			3.76	3.36	
9	6.11			3.66	3.07	
8	5.38			3.48	2.89	
7	4.65			3.29	2.70	
6	3.91			3.11	2.37	
5	3.17			2.92	2.19	
4	2.44			2.74	2.00	
3	1.70			2.55	1.67	
2	0.96			2.37	1.48	
1	0.22			2.19	1.30	
Foundation	-0.34			2.15	1.09	

Moment on Foot of Foundation

Elem.	Destabilizing Moments (kN·m/m´)	Stabilizing Moments (kN·m/m´)
Earth Cover	13.01	24.74
9	25.62	66.84
8	33.26	64.06
7	37.95	61.16
6	39.71	66.11
5	38.53	62.08
4	34.41	57.92
3	27.35	57.90
2	17.36	52.59
1	4.42	47.16
Foundation	0.00	22.89
	271.61	583.45

Transformation of Forces from foot of foundations to Points C

Foundation

Horizontal Distance	0.00	m
Vertical Distance	0.00	m
Total Horiz. Force	122.36	kN/m´
Total Vert. Force	272.48	kN/m´
Destab. Moment on C	271.61	kN·m/m´
Stab. Moment on C	583.45	kN·m/m´
Total Moment on C	311.84	kN·m/m´

Elem. 1

Horizontal Distance	0.32	m
Vertical Distance	0.30	m
Total Horiz. Force	111.21	kN/m´
Total Vert. Force	256.81	kN/m´
Destab. Moment on C	239.86	kN·m/m´
Stab. Moment on C	479.99	kN·m/m´
Total Moment on C	240.13	kN·m/m´

Elem. 4

Horizontal Distance	1.17	m
Vertical Distance	2.44	m
Total Horiz. Force	56.89	kN/m´
Total Vert. Force	156.20	kN/m´
Destab. Moment on C	83.58	kN·m/m´
Stab. Moment on C	220.26	kN·m/m´
Total Moment on C	136.68	kN·m/m´

Elem. 7

Horizontal Distance	2.02	m
Vertical Distance	4.59	m
Total Horiz. Force	20.46	kN/m´
Total Vert. Force	73.18	kN/m´
Destab. Moment on C	15.97	kN·m/m´
Stab. Moment on C	68.95	kN·m/m´
Total Moment on C	52.98	kN·m/m´

Results

Foundation

Resultant Force R	298.70	kN/m´
Inclination of R	24.18	°
Eccentricity e of R	0.02	m
Reduced Width B_eff	2.12	m
Res. Normal Force V	294.02	kN/m´
Res. Driving Force H	52.63	kN/m´
Safety Factor, Sliding (c=0)	3.49	
Safety Factor, Overturning	2.15	

Elem. 1

Resultant Force R	279.85	kN/m´
Inclination of R	23.41	°
Eccentricity e of R	0.04	m
Reduced Width B_eff	1.74	m
Res. Normal Force V	276.11	kN/m´
Res. Driving Force H	45.60	kN/m´
Safety Factor, Sliding (c=0)	4.24	
Safety Factor, Overturning	2.00	

Elem. 4

Resultant Force R	166.24	kN/m´
Inclination of R	20.01	°

Eccentricity e of R	-0.06	m
Reduced Width B_eff	1.52	m
Res. Normal Force V	165.33	kN/m´
Res. Driving Force H	17.31	kN/m´
Safety Factor, Sliding (c=0)	6.69	
Safety Factor, Overturning	2.64	

Elem. 7

Resultant Force R	75.99	kN/m´
Inclination of R	15.62	°
Eccentricity e of R	-0.09	m
Reduced Width B_eff	1.22	m
Res. Normal Force V	75.96	kN/m´
Res. Driving Force H	2.10	kN/m´
Safety Factor, Sliding (c=0)	25.30	
Safety Factor, Overturning	4.32	

Silo Length	2.58	m
Silo Width	1.33	m
Silo Pressure Pv	40.54	kN/m²

Bearing Capacity

Virtual Foundation Width B_eff	2.12	m
Foundation Length L	1.70	m
Virtual Foundation Area (B_eff · L)	3.61	m²

	Cohesion	Depth (q)	Width (g)
Bearing Capacity Factors	35.49	23.18	30.21
Depth Factors	1.22	1.16	1.00
Load Inclination Factors	0.74	0.75	0.62
Ground Slope Factors	1.00	1.00	1.00
Foundation Tilt Factors	0.70	0.72	0.72
Shape Factors	1.52	1.50	0.68

Ultimate Bearing Pressure	Cohesion	(kN/m²)	0.00
	Depth (q)	(kN/m²)	443.92
	Width (g)	(kN/m²)	154.56
	Total	(kN/m²)	598.48
Bearing Pressure: V / (B_eff · L)		(kN/m²)	198.82
Net Bearing Pressure		(kN/m²)	187.80
Safety Factor Bearing Capacity	simple		4.95
	full	**(min 2.0)**	**3.01**

Concrete Pressures

Elem. 1

Normal Force in Footing (V)	673.27	kN
Eccentricity of V	0.045	m
Horizontal Earth Pressure	20.09	kN/m´
Concrete Pressure in joint at front	2.77	N/mm²
Concrete Pressure in joint at rear	2.06	N/mm²
Concrete Pressure (average)	2.42	N/mm²

Elem. 4

Normal Force in Footing (V)	403.15	kN
Eccentricity of V	-0.065	m

Horizontal Earth Pressure	14.13	kN/m´
Concrete Pressure in joint at front	1.29	N/mm²
Concrete Pressure in joint at rear	2.18	N/mm²
Concrete Pressure (average)	1.74	N/mm²

Elem. 7

Normal Force in Footing (V)	185.22	kN
Eccentricity of V	-0.088	m
Horizontal Earth Pressure	8.17	kN/m´
Concrete Pressure in joint at front	0.57	N/mm²
Concrete Pressure in joint at rear	1.43	N/mm²
Concrete Pressure (average)	1.00	N/mm²

Longitudinal Beam in Lowest Element

pw front	7.65	kN/m´
ph front	7.26	kN/m´
pw back	17.08	kN/m´
ph back	5.57	kN/m´

Cantilever (A)

Vert. shear force front	9.86	kN
Horiz. shear force front	9.36	kN
Result. shear force front	13.60	kN
Vert. moment front	3.76	kN·m
Horiz. moment front	-3.57	kN·m
Result. moment front	5.19	kN·m
Vert. shear force rear	22.02	kN
Horiz. shear force rear	7.18	kN
Result. shear force rear	23.16	kN
Vert. moment rear	8.40	kN·m
Horiz. moment rear	2.74	kN·m
Result. moment rear	8.83	kN·m

Midspan (B)

Vert. moment front	-3.84	kN·m
Horiz. moment front	3.64	kN·m
Result. moment front	5.29	kN·m
Vert. moment rear	-8.57	kN·m
Horiz. moment rear	-2.80	kN·m
Result. moment rear	9.02	kN·m

Conclusions:

1. **The Evergreen software checks the relevant safety factors against sliding and overturning in every relevant joint.**
2. **Foundation bearing capacity is checked according to the old fashioned 'simple' version and in full details as now used in AASHTO and Eurocodes.**