ONTOLOGY DEVELOPMENT FOR CONVENTIONAL RETAINING WALLS: A STRUCTURAL KNOWLEDGE REPRESENTATION APPROACH

Supervisors: Prof. Dr. Timo Hartmann,

Dr. Mohamed Abdelfattah

Zahra Haji Heidari

Zahra.haji.heidari@campus.tu-berlin.de

Technische Universität Berlin - TU Berlin

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1. Introduction

Retaining walls are structures that are commonly used to support and hold back soil, liquid or other materials like coal or ore piles[1][2]. The design of any structure, including retaining walls, consist two major stages: conceptual design and detailed structural design. Conceptual design is a subjective process that transforms a set of requirements into an overall description and explores multiple design alternatives to determine the most suitable structural form. Therefore, this stage heavily relies on the experience and judgment of the engineer [3][4]. In contrast, ontology provides a formal representation of domain concepts that constitute a structured knowledge base [5]. Such knowledge bases can be applied in both conceptual and detailed design phases (proportioning[6]), not only to address design challenges but also to support construction and maintenance processes. In this report, an ontology is developed for conventional retaining walls, categorized according to Das [6]. The ontology encompasses walls types, materials, structural components, loads, design basis, construction details, use, failure reasons and fixing solutions.

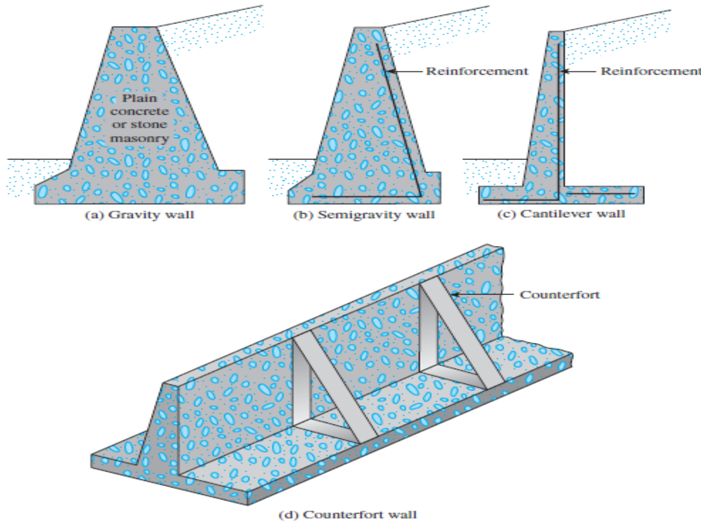


Figure 1. Types of Conventional Retaining Wall

2. Purpose

The following ontology introduce concepts and parameters effect the retaining wall design, construction details, failures and fixing solutions. This ontology primarily supports structural engineering applications and contributes to both the conceptual design and maintenance phases by serving as a structured knowledge base.

3. Scope

The Ontology includes retaining wall main concepts including type, material, structural components, loads, design basis, construction details, failure reasons, fixing solutions and possible use and defines their logical relationships.

4. Intended Users

The intended users of this ontology are structural engineers involved in the conceptual and detailed design of retaining walls. In addition, construction professionals and maintenance engineers may use the ontology to ensure consistency in documentation, material selection, and inspection data.

5. Intended Use

The ontology is intended to support the systematic representation and reuse of structural knowledge related to retaining walls, enabling better integration of design data, parameter limits, and structural types. It provides a common vocabulary that helps automate reasoning in conceptual design, compare design alternatives, and connect design models with construction and maintenance data.

6. Ontology Development

The ontology is developed based on the following taxonomy of concepts:

Table1. Ontology Development

Concept Group	Subclasses
Conventional Retaining Wall Types [6]	Gravity Wall, Semi Gravity Wall, Cantilever Wall, Counterfort Wall
Main Material [6]	Concrete (Cast in Place Plain Concrete, Cast in Place Reinforced Concrete, Pre-Cast Concrete), Stone Masonry
Structural Components [1][6]	Stem, Foundation(Heel, Toe), Base Key ,Counterfort
Loads[6][7][8]	Dead Load, Live Load, Soil Pressure, Earthquake, Underground Water Pressure, Liquid Pressure, Temperature, Collision Forces
Design Basis[1][2][6][8][9][10]	Soil Bearing and Stability Design(Overturinig , Sliding , Soil Bearing Capacity, Settlement), Strength Design(Bending Design, Shear Design, Tensile Design)
Construction Detail[6][11]	Drainage System(Perforated Drainage Pipe, Weep Holes), Joints System(Construction Joints, Contraction Joints, Expansion Joints)
Use[12]	Hillside Road, Elevated and Depressed Roads, Landscaping ,Canals and Locks, Erosion Protection, Flood Walls, Bridge Abutment

Failure Reasons[2]	Reinforcing not in the right positions, Saturated Backfill, Weep Holes That do not Weep, Design Error Because of Misinformation, Calculation Errors, Unanticipated Loads, Mistakes in Using Software, Detailing Errors, Foundation Problems, Inadequate Specifications and Notes, Shoddy Construction ,Age
Fixing Solutions[2]	Correct Surface Drainage Problem, Reduce the Retained Height, Use Tie-Backs, Extend the Footing, Remove and Replace Backfill Material, Reinforce the Front of The Wall, Add a Key

7. Design Options

Textbooks provide approximate dimensions for various components of retaining wall for initial stability checks called proportioning[6]. These dimensions serve as a guide for conceptual design and as initial input for detailed structural analysis, helping to reduce the number of iterations during modeling. This approach is particularly valuable because modeling and load assignments for retaining walls in software such as SAP2000 can be time-consuming. However, it should be noted that these recommended dimensions do not represent optimal or universal design limits. For example, if the soil bearing capacity is low, the suggested foundation width may be insufficient. Additionally, seismic analysis must be performed for retaining walls in seismic design categories D through F that support more than 1.83 m of backfill [10], which will govern the design. Therefore, these proportions should be interpreted as reference values rather than maximum acceptable dimensions.

7.1. Semi Gravity Wall

The Proportioning for semi gravity wall is presented below[6] and a design instance is shown based on an optimized version of an actual constructed wall at Dewarwadi [13]. (All dimensions are in meter.)

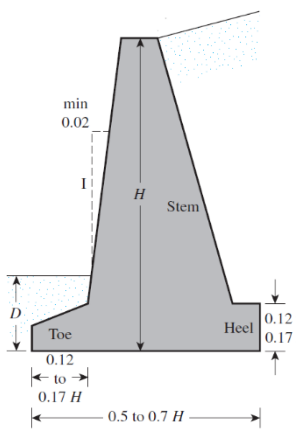


Figure 2. Approximate dimensions for Gravity Walls

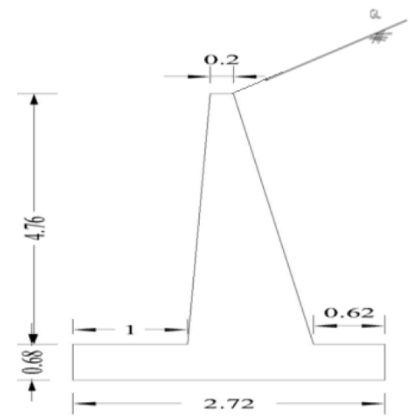


Figure 3. A Designed Wall

7.2. Cantilever Wall

The proportioning for a reinforced cantilever wall is presented below with two design options. Option 1 is based on the minimum allowable thicknesses for the wall and foundation, the minimum wall height, and lower bounds of foundation and toe widths under ordinary conditions [6][9]. Option 2 represents maximum recommended wall height and upper-bound proportions for typical cases [1][6][14].

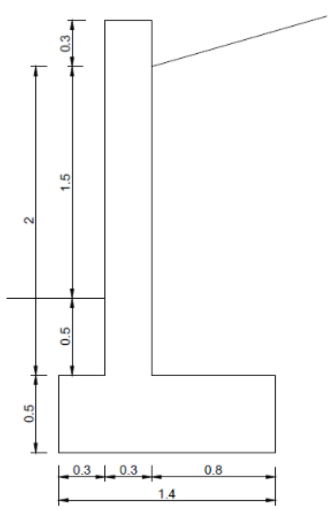


Figure 4. Proportioning Option 1

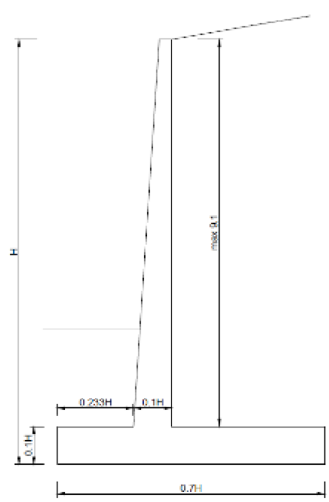


Figure 5. Proportioning Option 2

Two design instances with different heights have been considered, both derived from constructed retaining walls analyzed in SAP2000 according to ASCE 7, IBC, and ACI 318 standards [7][9][10]. (All dimensions are in meters.)

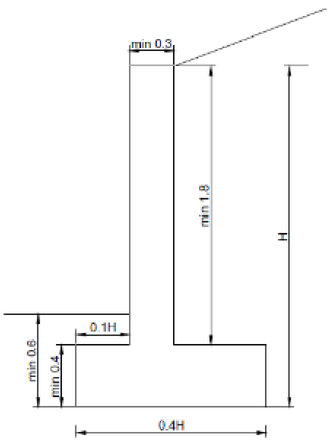


Figure 6.Option1 Draft

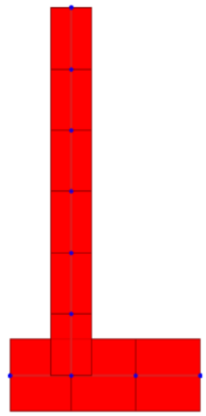


Figure 7. Option 1 Design

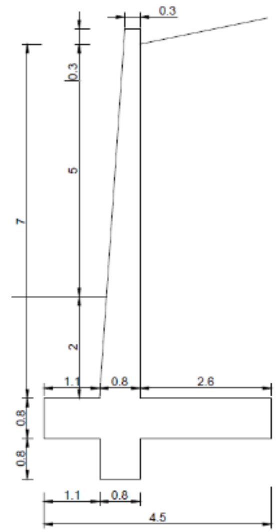


Figure 8. Option 2 Draft

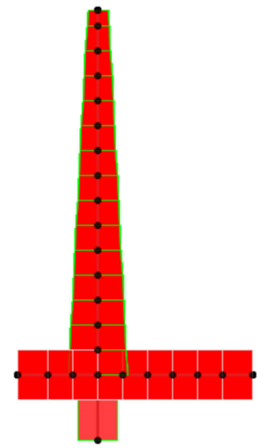
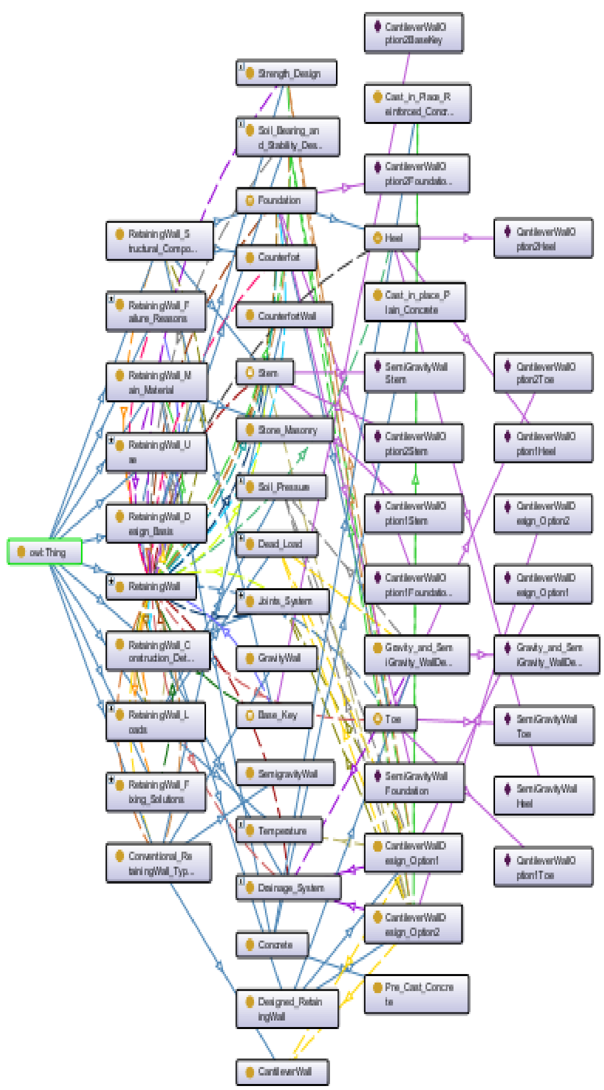


Figure . Option 2 Design

8. OntoGraph

The following figure shows a portion of the OntoGraph representation of the retaining wall ontology. (Some subclasses are not shown.)



9. Logical Axiom

The following table presents examples of logical axioms and their application within the ontology.[15]

Axiom	Semantics DL	Protégé syntax for axioms implementation
Individuals		**Individuals**
Atomic concept	A^I	Retaining Wall
Individual name	a^I	CantileverWallOption1Foundation
Roles		**Object Properties**
Atomic role	R^I	HasFoundation
Inverse role	$\{< x, y > \mid < y, x > \in R^I\}$	IsFoundationof
Concepts		**Classes**
Top concept	Δ^I	Domains (intersection) of R^I *is* C^I — Domains (intersection): RetainingWall
Bottom concept	$\emptyset$	Ranges (intersection) of R^I *is* D^I — Ranges (intersection): Foundation
Existential restriction	$\{x \mid some\ R^I - successor\ of\ x\ is\ in\ C^I\}$	$R^I\ some\ C^I$ — HasFoundation some Foundation
Nominal	$\{a^I\}$	$R^I\ value\ a^I$ — HasFoundation value CantileverWallOption1Foundation

10. How This Ontology can contribute to Engineering Challenges

The following cases demonstrate practical applications of this ontology in addressing real engineering challenges.

10.1 Material Selection Based on Client Needs

Scenario: A client plans to construct a short retaining wall (2 m high), but domestic skilled workers are unavailable, and hiring skilled labor from outside the region is not feasible. Therefore, the designer is expected to propose a design that satisfies all structural criteria while minimizing the need for specialized workers and ensuring construction simplicity.

Use Case: Engineers can refer to the ontology to identify suitable design options by considering height limits and selecting materials accordingly. The ontology provides insights into material choices aligned with client constraints. These insights can support the feasibility study phase, which is the project's starting point. For example, based on this ontology, the engineer may select stone masonry instead of concrete to simplify construction, even though it may extend the construction period [16]. This decision leads to a well-informed parametric model for structural analysis.

10.2 Type Selection Under Site Constraints

Scenario: A client requires a tall retaining wall (9 m high) to be built in a confined area located near existing underground utilities and structural foundations. Due to severe spatial constraints, the designer's goal is to develop a wall that occupies minimal space while ensuring stability.

Use Case: The ontology provides insights into different structural components of retaining walls which can influence geometry. Designers can combine these components to adapt to project limitations. Construction close to existing foundations can be challenging because of potential structural interaction [2]. The designer may reduce the base width by introducing a shear key and use counterforts to minimize stem thickness, even though this increases construction complexity and cost [1].The decision, supported by ontology knowledge, leads to an appropriate parametric model for structural analysis.

10.3 Knowledge Reuse for Maintenance Management

Scenario: An asset manager store retaining wall information in unstructured formats, which complicates data retrieval and planning for maintenance activities.

Use Case: The ontology enables asset managers to query all retaining walls within a facility, retrieve data such as wall type, material, and geometry, and link these attributes to inspection and maintenance schedules. In addition, ontology data can be integrated with software agents to automatically extract and structure information from multiple facilities, creating a valuable shared knowledge resource [5]..

10.4 Proposing Fixing Solutions

Scenario: In an actual case, a retaining wall was observed to lean excessively, and investigation revealed that the reinforcement protruding from the foundation had been placed on the wrong side of the wall [2].

Use Case: This ontology provides insights into potential failure causes, helping managers identify and mitigate the risk of structural failure. Furthermore, it suggests suitable corrective measures to address such challenges. For instance, in this case, the ontology would guide the manager toward a solution such as adding tie-backs [2].

11. Conclusion and Further Work

This ontology provides a systematic approach to analyzing retaining wall knowledge. It can be used as a knowledge base for engineers to gain general insight into the design process and to generate parametric model data for structural analysis. Furthermore, since this ontology represents relationships in a user-friendly visual format, it effectively highlights inconsistencies and provides a structured representation of retaining wall design. Moreover, explicitly presenting assumptions is valuable, as it ensures traceability and offers practical benefits for civil engineers without programming expertise [5].

Currently, it can be applied for basic design steps; however, with further refinement and added detail, it has the potential to become a valuable engineering asset. The ontology contains explicit domain assumptions and can be readily updated to reflect evolving engineering knowledge. New instances can be added by different engineers and integrated to form a more comprehensive ontology [5]. As a machine-readable model, it enables engineers to access and utilize knowledge that typically requires years of experience, precisely the type of resource that many Engineers seek.

12. References

[1] J. E. Bowles, *Foundation Analysis and Design*, 5th ed. New York, NY, USA: McGraw-Hill, 1995.

[2] H. Brooks, *Basics of Retaining Wall Design*, 8th ed. HBA Publications, 2010.

[3] M. Gedig, "A Framework for Form-Based Conceptual Design in Structural Engineering," M.A.Sc. thesis, Univ. of British Columbia, Vancouver, Canada, 2010. [Online]. Available: https://dx.doi.org/10.14288/1.0063122

[4] J. C. Miles and C. J. Moore, "An Expert System for the Conceptual Design of Bridges," *Computers & Structures*, vol. 40, no. 1, pp. 129–135, 1991, doi: 10.1016/0045-7949(91)90462-U.

[5] N. F. Noy and D. L. McGuinness, *Ontology Development 101: A Guide to Creating Your First Ontology*. Stanford, CA, USA: Stanford University, 2001.

[6] B. M. Das, *Principles of Foundation Engineering*, 7th ed. Boston, MA, USA: Cengage Learning, 2014.

[7] American Society of Civil Engineers, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures (ASCE 7-16)*. Reston, VA, USA: ASCE, 2016.

[8] European Committee for Standardization, *Eurocode 7: Geotechnical Design – Part 1: General Rules (EN 1997-1: 2004)*. Brussels, Belgium: CEN, 2004.

[9] American Concrete Institute, *Building Code Requirements for Structural Concrete (ACI 318-19) and Commentary*. Farmington Hills, MI, USA: ACI, 2019.

[10] International Code Council, *International Building Code (IBC 2018)*. Washington, DC, USA: ICC, 2018.

[11] E. G. Nawy, *Concrete Construction Engineering Handbook*, 2nd ed. Boca Raton, FL, USA: CRC Press, 2008.

[12] W. C. Teng, *Foundation Design*, 13th ed. Englewood Cliffs, NJ, USA: Prentice-Hall, 1992.

[13] V. Sureban, S. A. B. Subhash, T. P. Sumant, M. B. Venkatesh, and L. K. Yallappa, "A Case Study on Static Stability Analysis of Retaining Wall at Dewarwadi," *Int. J. Innovative Res. Sci., Eng. Technol.*, vol. 4, no. 5, pp. 4152–4158, 2015.

[14] B. F. Tanyu, P. J. Sabatini, and R. R. Berg, *Earth Retaining Structures*, Publication No. FHWA-NHI-07-071, Washington, DC, USA: Federal Highway Administration, 2008.

[15] M. Krötzsch, F. Simančík, and I. Horrocks, *A Description Logic Primer*. Oxford, U.K.: University of Oxford, 2013.

[16] P. R. Putra, W. Oetomo, and R. Marleno, "A Comparative Analysis of Cantilever and Gravity Retaining Wall Dimensions on the Temuireng-Jetis Road Section in Mojokerto District," *J. Social Research*, vol. 4, no. 2, pp. 209–216, 2025, doi: 10.55324/josr.v4i2.2425.