PARAMETRIC MODELING AND STABILITY EVALUATION OF RETAINING WALL SYSTEMS USING DYNAMO

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, consists 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 [3]. In this phase, developing rough layouts is a valuable step for evaluating and selecting concepts before moving into the detailed design stage [4]. Dynamo is a visual programming environment allowing the creation of computational design logic which can be used in both conceptual design and detailed design phases. In this report, a Dynamo-based parametric model is developed for three types of retaining walls: a gravity (or semi-gravity) retaining wall, a cantilever retaining wall without base key, and a cantilever retaining wall with base key. The model generates each wall geometry based on proportioning guidelines from Das, Bowles, and the minimum requirements of ACI 318-19 [1][5][6]. It also calculates the concrete volume, sliding factor of safety, and overturning factor of safety for each wall type. This makes the model particularly useful at the early stage of design, where stability checks typically govern the preliminary selection of wall dimensions. Because the height of a retaining wall is generally the controlling design constraint, the model keeps the same height for each wall type to allow a clear comparison of material consumption and required foundation space. This comparison is important because increased concrete volume directly affects cost, and larger foundation may be problematic in projects with spatial limitations, such as those involving underground utilities or adjacent structural foundations.

2. Domain and Purpose

The domain of this report is the development of a parametric Dynamo model for gravity and cantilever retaining walls ,with and without base key. The purpose of this work is to provide a tool that supports early-stage structural decision-making by offering quick geometric generation, stability checks, and comparative analysis between alternative retaining wall systems.

3. Model Development

Textbooks provide approximate dimensions for various components of retaining wall for initial stability checks called proportioning[5]. 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 , whereas Dynamo allows rapid generation of multiple design alternatives. However, it is essential to note that proportioning guidelines do not represent optimal or universal design limits. Final design must follow accurate structural analyses based on soil properties and seismic parameters. For simplicity, seismic forces are neglected in this model.

The proportioning rules for gravity/semi-gravity walls [5] and cantilever walls are incorporated directly into the model. For reinforced cantilever walls, the model includes the minimum allowable wall and foundation thicknesses, minimum wall height, and lower bounds of toe and foundation widths under ordinary conditions [5][6], as well as the upper-bound recommendations for typical cases [1][5][7]. These bounds define the input ranges in the Dynamo model.

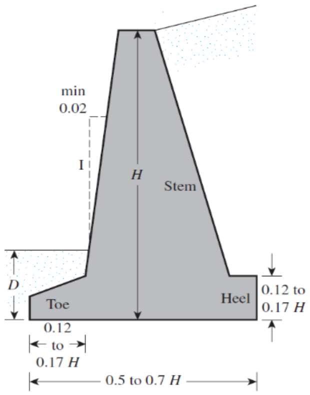


Figure 1. Approximate dimensions for Gravity Wall

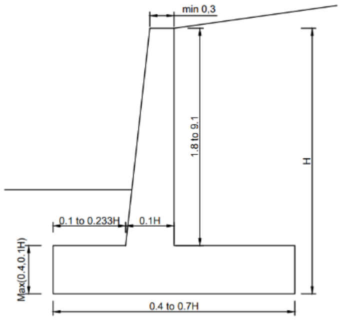


Figure 2. Approximate dimensions for Cantilever Walls

Overturning and sliding safety evaluations follow the ASCE 7 allowable stress design load combination D + H [8], where sliding and overturning must satisfy a minimum factor of safety of 1.5.

Although proportioning provides rough geometric dimensions, this model enhances the conceptual design process by performing actual stability checks using geotechnical inputs. Additionally, by keeping the same wall height—typically the dominant parameter in retaining wall design—the model automatically compares concrete volume and foundation footprint across the three wall types. As expected, gravity walls consume significantly more material and foundation space since they rely primarily on self-weight for stability [5]. Meanwhile, cantilever walls with shear keys demonstrate substantial improvements in sliding resistance, enabling narrower foundations[1][5]. However, the magnitude of these effects depends on wall height and soil conditions. The model quantifies these effects and provides clarity on which wall type best fits a project's requirements.

3.1. Input Data

For using this model, the user should fill the input data box consisting following data :(input data are filled for three models in this project)

Gravity and Semi Gravity Wall		Cantilever Wall with Base Key		Cantilever Wall with Base Key	
Parameter	**Value**	**Parameter**	**Value**	**Parameter**	**Value**
Gravity Wall Height(G_H)(m)	6	Cantilever Wall Height(C_H)(m)	6	Cantilever Wall Height(C_H)(m)	6
Top of Stem Thickness(G_TST)(m)	0.3	Top of Stem Thickness(C_TST)(m)	0.3	Top of Stem Thickness(C_TST)(m)	0.3
Bottom of Stem Thickness(G_BST)(m)	1.5	Bottom of Stem Thickness/ Total Height(C_BST_RATIO)	0.1	Bottom of Stem Thickness/ Total Height(C_BST_RATIO)	0.1
Foundation Thickness/ Total Height(G_FT_RATIO)	0.17	Foundation Thickness/ Total Height(C_FT_RATIO)	0.1	Foundation Thickness/ Total Height(C_FT_RATIO)	0.1

Toe Width/ Total Height(G_TW_RATIO)	0.12	Toe Width/ Total Height(C_TW_RATIO)	0.1	Toe Width/ Total Height(C_TW_RATIO)	0.1
Foundation Width/ Total Height(G_FW_RATIO)	0.7	Foundation Width/ Total Height(C_FW_RATIO)	0.7	Foundation Width/ Total Height(C_FW_RATIO)	0.6
Wall Length(G_LENGTH)(m)	20	Wall Length(C_LENGTH) (m)	20	Wall Length(C_LENGTH) (m)	20
Front Soil Depth(FSD)(m)	0.8	Front Soil Depth(FSD)(m)	0.8	Front Soil Depth(FSD)(m)	0.8
Active Pressure Coefficient(Ka)	0.33	Active Pressure Coefficient(Ka)	0.33	Active Pressure Coefficient(Ka)	0.33
Passive Pressure Coefficient(Kp)	3	Passive Pressure Coefficient(Kp)	32	Passive Pressure Coefficient(Kp)	3
Concrete Unit Weight(KN/m^3)(GAMMA_C)	23	Concrete Unit Weight(KN/m^3)(GAMMA_C)	25	Concrete Unit Weight(KN/m^3)(GAMMA_C)	25
Soil Unit Weight(KN/m^3)(GAMMA_S)	18	Soil Unit Weight(KN/m^3)(GAMMA_S)	18	Soil Unit Weight(KN/m^3)(GAMMA_S)	18
Base Friction Coefficient(FRICTION)	0.35	Base Friction Coefficient(FRICTION)	0.35	Base Friction Coefficient(FRICTION)	0.35
				Base Key Width(BKW)(m)	0.4
				Base Key Height(BKH)(m)	0.7

3.2. Modeling

The parametric modeling of the three wall types is shown below:

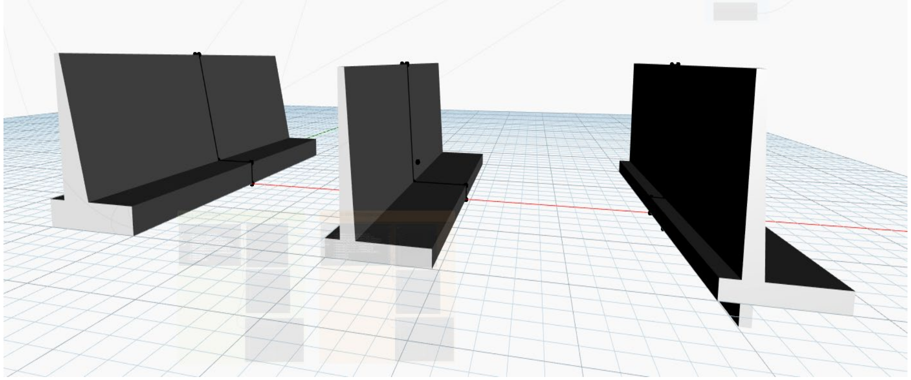


Figure 3. Geometric Model of Retaining Walls

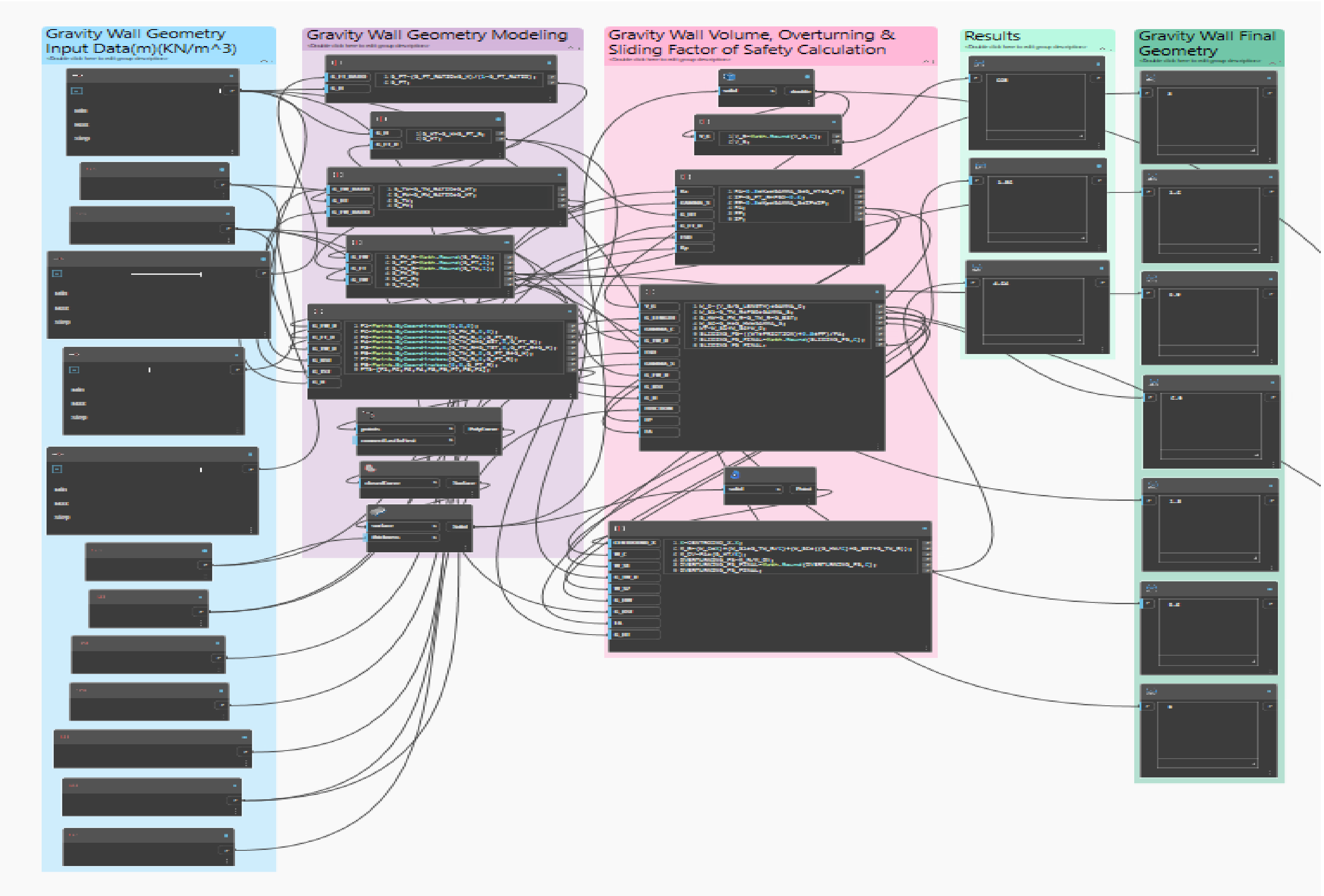


Figure 4. Model Development of Gravity Wall

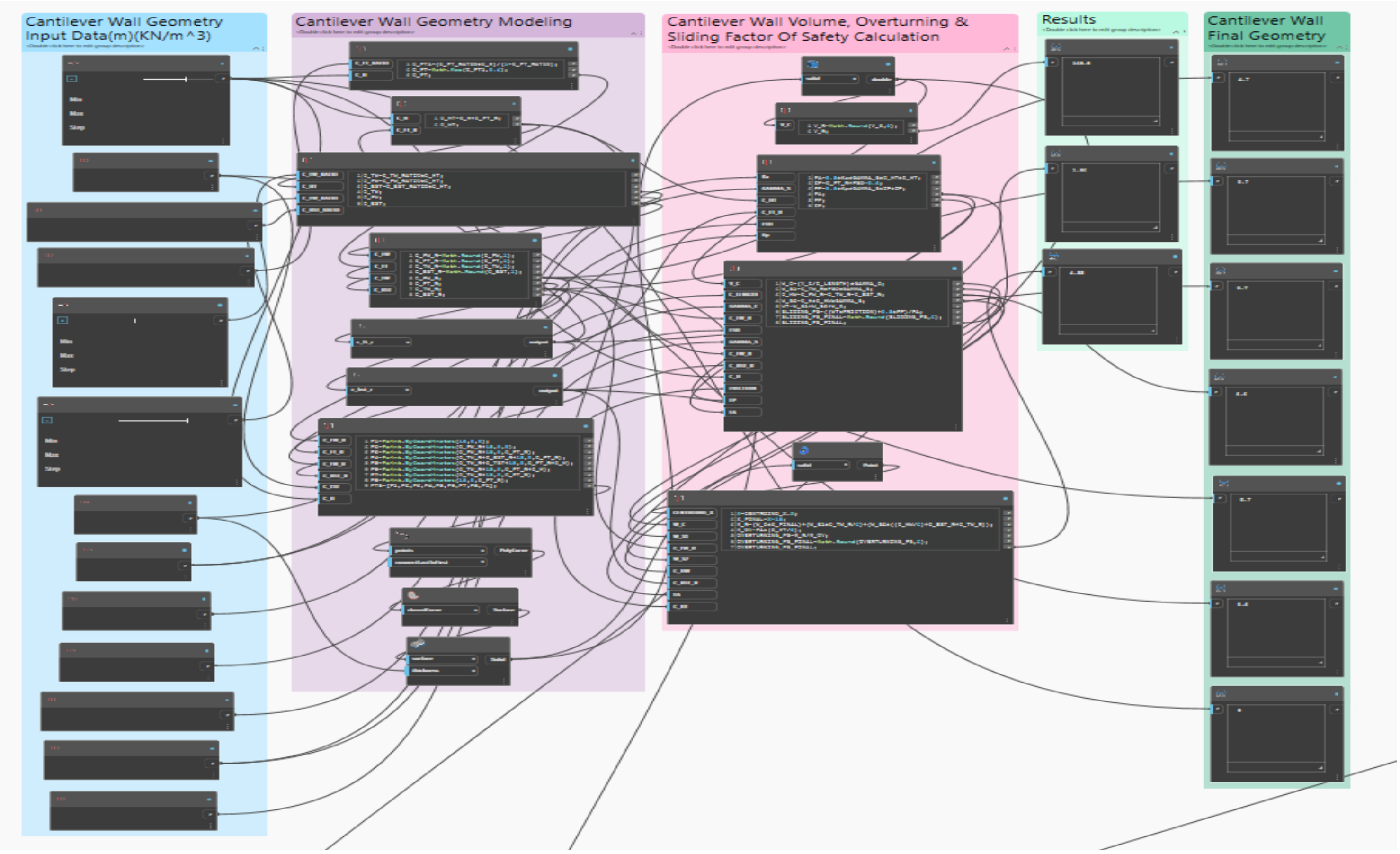


Figure 5. Model Development of Cantilever Wall

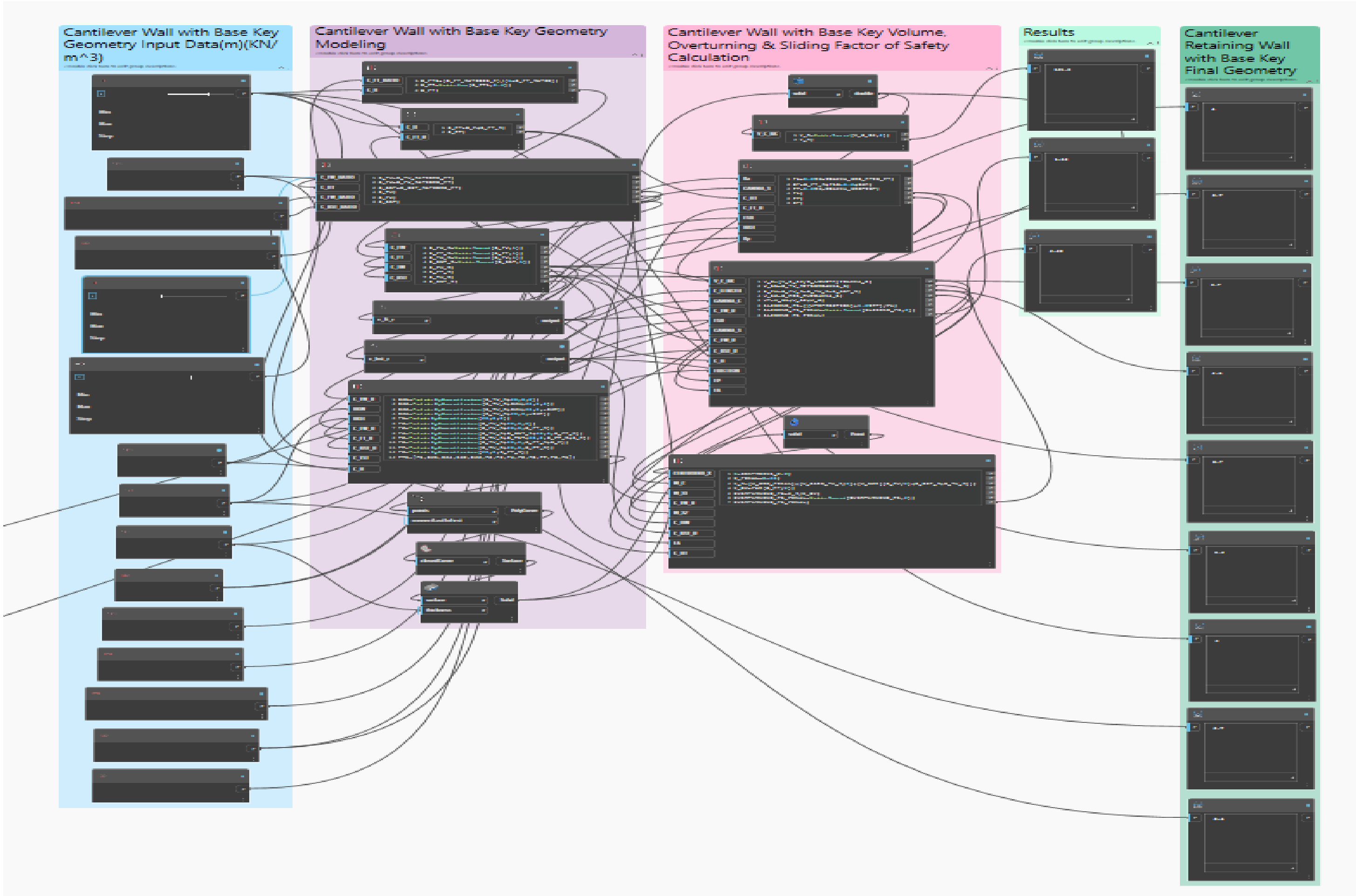
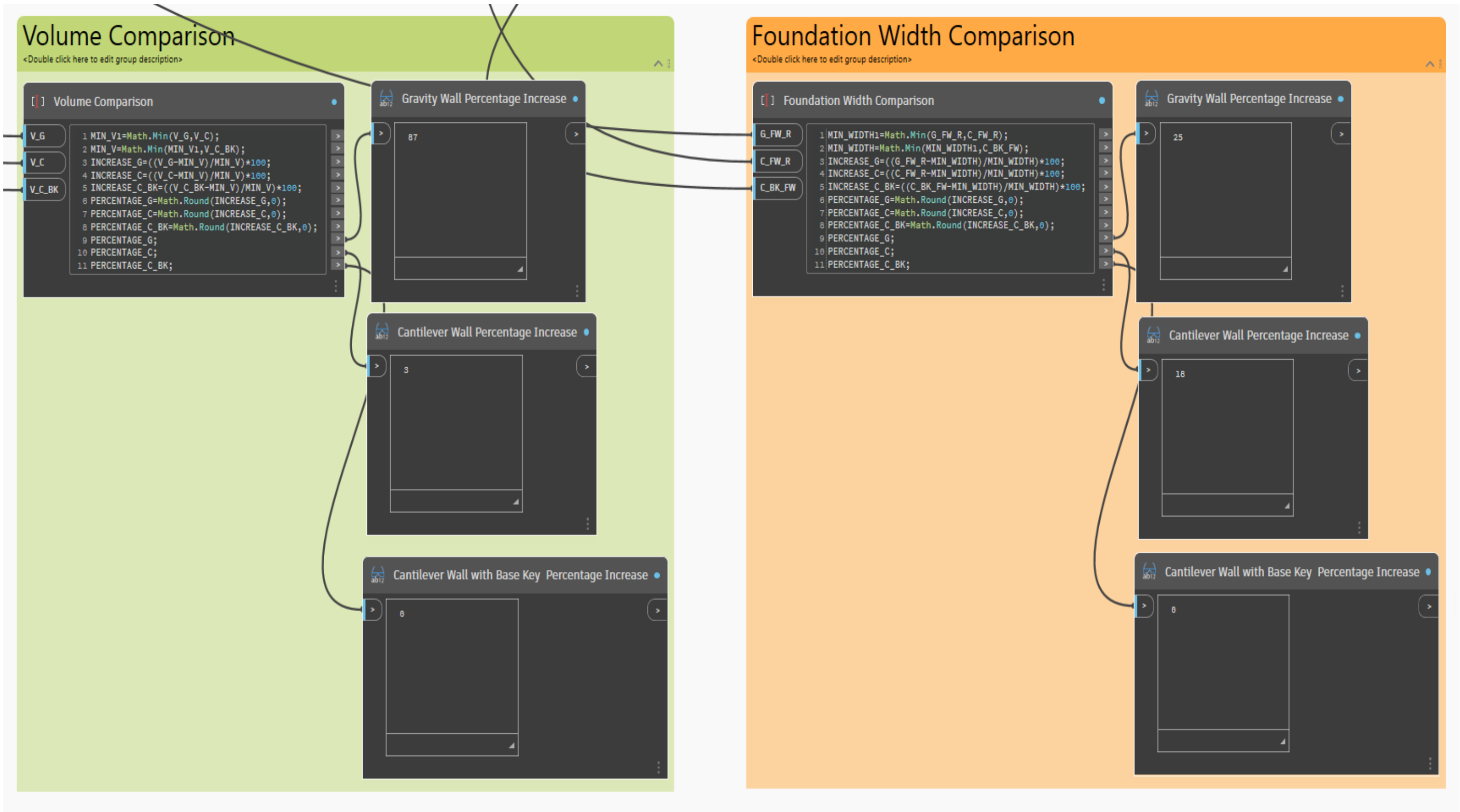


Figure 6. Model Development of Cantilever Wall with Base Key

4. Results and Discussion

The height of the wall and all soil parameters were kept the same for the three models, and the sliding and overturning factors of safety were controlled to remain above 1.5. The results show that the concrete volume required for the gravity wall is approximately 87% greater than that of the cantilever wall without a base key, while the cantilever wall with a base key requires about 3% more concrete than the cantilever wall without a key. This difference becomes especially meaningful when the retaining wall extends along long distances, where even small variations in cross-sectional geometry translate into substantial differences in total material use and overall project cost. In addition to concrete consumption, the foundation width also varies significantly: the gravity wall occupies roughly 25% more foundation space compared to the cantilever wall with a base key, and the cantilever wall without a base key occupies about 18% more foundation space than the wall incorporating a base key. It is also evident that the influence of the base key becomes more pronounced as the height of the wall increases. The comparisons in this section correspond to a 6-m-high wall with a specific set of input parameters; therefore, the numerical values will inevitably vary with changes in wall height. This variability demonstrates one of the main strengths of the developed model: because all geometric and geotechnical parameters can be adjusted, the model allows engineers to test alternatives rapidly, observe their performance, and determine which configuration satisfies the stability requirements of a specific project while minimizing material use and spatial constraints.



```
MIN_V1=Math.Min(V_G,V_C);
MIN_V=Math.Min(MIN_V1,V_C_BK);
INCREASE_G=((V_G-MIN_V)/MIN_V)*100;
INCREASE_C=((V_C-MIN_V)/MIN_V)*100;
INCREASE_C_BK=((V_C_BK-MIN_V)/MIN_V)*100;
PERCENTAGE_G=Math.Round(INCREASE_G,0);
PERCENTAGE_C=Math.Round(INCREASE_C,0);
PERCENTAGE_C_BK=Math.Round(INCREASE_C_BK,0);
PERCENTAGE_G;
PERCENTAGE_C;
PERCENTAGE_C_BK;
```

```
87
```

```
3
```

```
0
```

```
MIN_WIDTH1=Math.Min(G_FW_R,C_FW_R);
MIN_WIDTH=Math.Min(MIN_WIDTH1,C_BK_FW);
INCREASE_G=((G_FW_R-MIN_WIDTH)/MIN_WIDTH)*100;
INCREASE_C=((C_FW_R-MIN_WIDTH)/MIN_WIDTH)*100;
INCREASE_C_BK=((C_BK_FW-MIN_WIDTH)/MIN_WIDTH)*100;
PERCENTAGE_G=Math.Round(INCREASE_G,0);
PERCENTAGE_C=Math.Round(INCREASE_C,0);
PERCENTAGE_C_BK=Math.Round(INCREASE_C_BK,0);
PERCENTAGE_G;
PERCENTAGE_C;
PERCENTAGE_C_BK;
```

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25
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18
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0
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Figure 7. Volume and Foundation Width Comparison

5. Conclusion and Further Work

The results of this study show that developing a parametric model in Dynamo provides an effective way to conduct early-stage comparisons among different retaining wall configurations. By implementing proportioning guidelines and integrating basic stability checks, the model enables consistent evaluation of concrete volume, foundation width, and sliding and overturning performance under the same design constraints. Because the height of the wall is the dominant parameter, keeping it constant across the alternatives allows a fair comparison of their performance. however, the underlying relationships change when soil conditions, height, or other geometry limits are modified, supporting engineers in initial design stage by providing immediate insight into how different retaining wall forms respond to changes in geometry and site conditions.

Currently, this model can be applied for basic design steps; however, with further refinement and added detail, it has the potential to become a valuable engineering asset. Incorporating additional loads would extend its applicability to a broader range of design scenarios. The model could also be enhanced by including strength design checks in accordance with ACI 318, automated reinforcement estimation, and detailed bearing pressure evaluations. With these additions, the model would provide not only geometric generation and stability assessment but also structural design. This approach also offers practical advantages compared to traditional spreadsheet-based methods. While Excel sheets are commonly used for retaining wall calculations, they do not provide direct geometric visualization. The Dynamo model is more compelling because it produces a three-dimensional representation of the wall that updates automatically whenever input parameters are modified. This real-time visual feedback, combined with the ease of adjusting soil or geometric inputs, makes Dynamo a flexible and powerful tool that can be tailored to the needs of any specific project. As a result, it supports clearer decision-making during conceptual design and has the potential to streamline the workflow significantly.

6. References

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