GTS NX_支撐預力_2D/3D_比對

Peck 視土壓力分佈圖/GTS NX固定支撐預力法/AVERAGE AREA 空間折減係數(Spatial Reduction Factor)

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Agenda

- **Part1. 支撐預力_綜合比對**

- Part2. 經驗公式法
  - 2.1經驗公式方式一： Peck 視土壓力分佈圖
  - 2.2經驗公式方式二： **AVERAGE AREA**
  - 2.3支撐預力

- **Part3. GTS NX-固定支撐預力法**

- **Part4.分析條件說明**
  - 4.1-2D測試標準模型
  - 4.2-2D_單一土壤
  - 4.3-2D_混合土壤

Analytical by Peck's & Influence area solutions will be compared to the 2D model

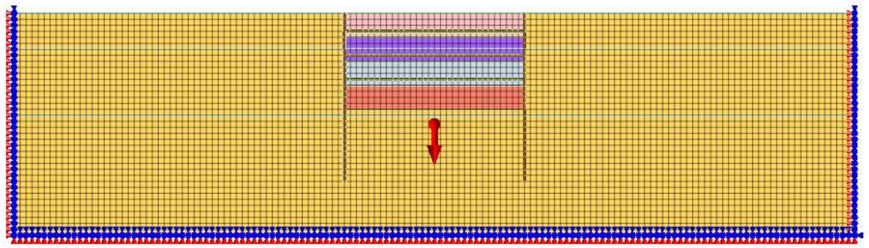
- **Part5. 3D空間效應對於預力計算之影響**
  - 深開挖3D VS. 2D 空間效應對於支撐預力計算之影響
  - 3D測試標準模型
  - 3D_單一土壤
  - 3D_混合土壤

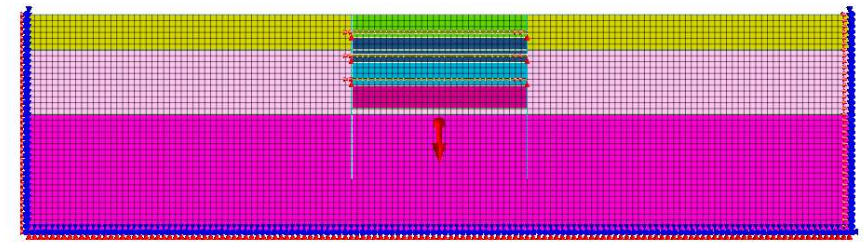
2D & 3D comparison

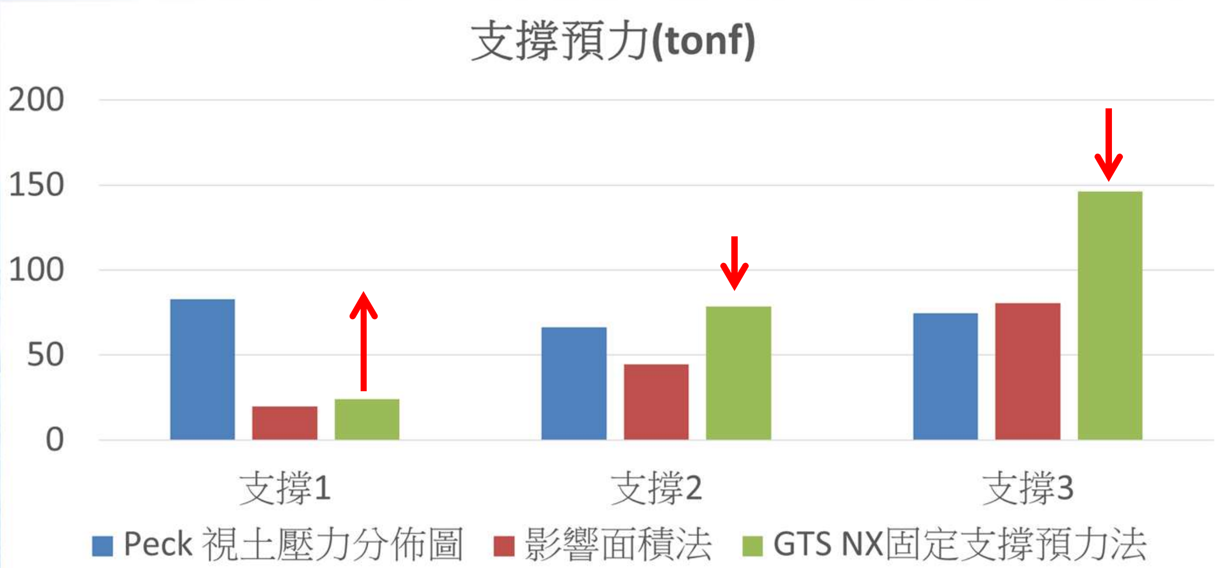
Part1.支撐預力_綜合比對

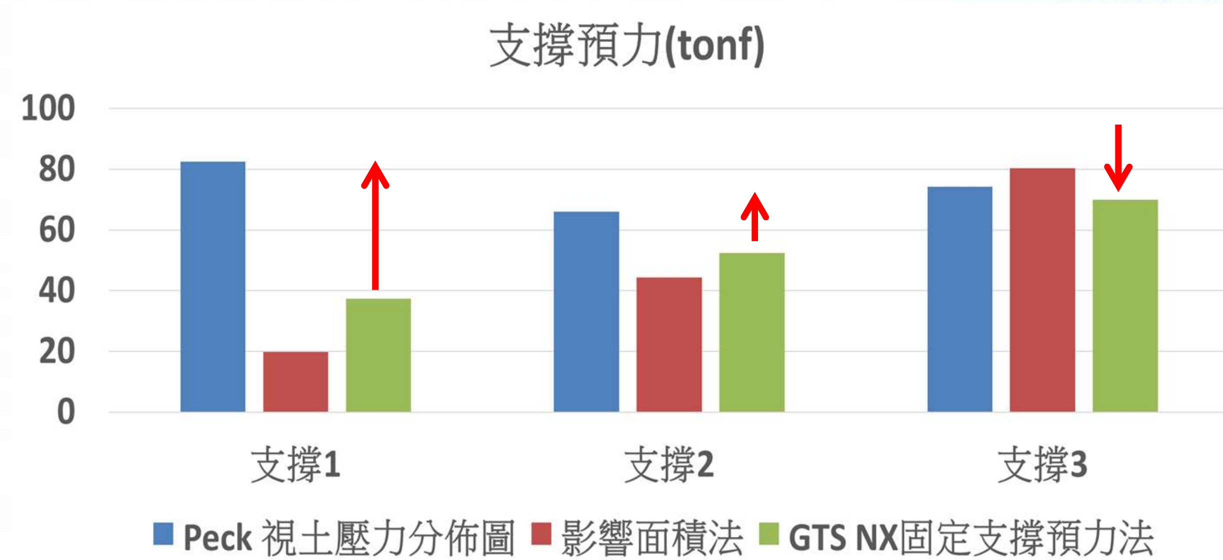
(2D Strut Force Comparison GTS NX/Analytical)

1.1支撐預力_綜合比對支撐預力_綜合比對 (Comparison)









The general formula method is mainly used to calculate density, while the finite element method can take soil stiffness into account.

Part2.經驗公式法

(Analytical methods)

2.1經驗公式方式一： Peck 視土壓力分佈圖

$$P_a = 0.65 \cdot \gamma_{\text{avg}} \cdot H \cdot K_a$$

$$K_a = \tan^2\left(45° - \frac{\varphi_{\text{avg}}}{2}\right)$$

γ_{avg} : Depth-weighted effective unit weight

φ_{avg} : Depth-weighted soil friction angle

H: Total excavation cut depth

NOTE:

Peck's envelope represents an empirical earth pressure distribution used specially for braced excavations. It does not represent actual earth pressures at any single stage, but rather an envelope of maximum strut loads experienced during construction.

2.2經驗公式方式二：影響面積法(AVERAGE AREA)

1

Active earth pressure coefficient (K_a):

$$K_a = \tan^2\left(45^\circ - \frac{\phi}{2}\right)$$

where,

ϕ : Internal friction angle of soil

K_a : Active earth pressure coefficient

2

Active pressure intensity at depth:

$$p(z) = K_a \cdot \gamma \cdot z$$

where,

K_a : Active earth pressure

γ : Unit weight ($tonf/m^3$)

z : Depth of pressure (m)

$p(z)$: Active pressure intensity at depth z

NOTE:

This method assumes a classical linearly increasing triangular/trapezoidal earth pressure distribution. It calculates the actual soil pressure at the top and bottom of each strut's tributary area.

2.2經驗公式方式二：影響面積法(AVERAGE AREA)

3 Tributary zone boundaries:

$$\text{Upper bound}: z_{upper,i} = \frac{z_{i-1} + z_i}{2} \quad (\text{for top strut } i = 1, z_{upper,1} = 0)$$

$$\text{Lower bound}: z_{lower,i} = \frac{z_i + z_{i+1}}{2} \quad (\text{for bottom strut } i = n, z_{lower,n} = H)$$

4 Vertical tributary height:

$$S_v = z_{lower} - z_{upper}$$

5 Average pressure intensity across tributary zone:

$$p_{avg} = \frac{p(z_{upper}) + p(z_{lower})}{2} = K_{a,} \cdot \gamma \cdot \left(\frac{z_{upper} + z_{lower}}{2} \right)$$

6 Strut design load:

$$P_{d,i} = p_{avg,i} \times S_h \times S_{v,i}$$

Reference:

Peck, R. B. (1969). *"Deep Excavations and Tunnelling in Soft Ground."* Proceedings of the 7th International Conference on Soil Mechanics and Foundation Engineering (ICSMFE), Mexico City, State-of-the-Art Volume, pp. 225–290.

2.3支撐預力 (Strut Prestress)

Prestress load equation:

P_d is obtained from Peck's empirical equation

$$P_{pre} = \alpha \cdot P_d$$

where,

P_{pre} : Applied hydraulic jack prestress load (tonf)

α : Prestress coefficient / factor(dimensionless ratio, typically $0.30 \le \alpha \le 0.70$)

P_d : Strut design load calculated from earth pressure analysis (tonf)

α is selected, then the prestress load can be designed

Prestress factor:

- Sand/ Dense soils: α = 0.5 – 0.8 (Higher preloading for stiff soils)
- Soft to Medium Clays: α = 0.3 – 0.5 (Excessive preloading in soft clays can push the RW backward)
- Standard Urban Practice: α = 0.5 (50% of the maximum anticipated earth pressure load)

2.3支撐預力 (Strut Prestress)

- Avoid over-preloading: Preloading above 80% of Pd can force the RW outward into the retained soil mass. That will create passive earth pressure zones and damage nearby buried structures

- Monitor prestress losses: Compensate for 10 – 20% load loss caused by wedge seating slip, waler deflection, and connection slack

References:

Peck (1969): *Deep Excavations and Tunnels in Soft Ground.* Established the foundational Apparent Earth Pressure Diagrams based on envelope measurements from field instrumentations.

CIRIA Report C517 / C760 (UK): *Temporary Propping of Deep Excavations - Guidance on Design.* Standard reference for prop stiffness, preloading ratios, and temperature-induced stress allowances in temporary steel bracing.

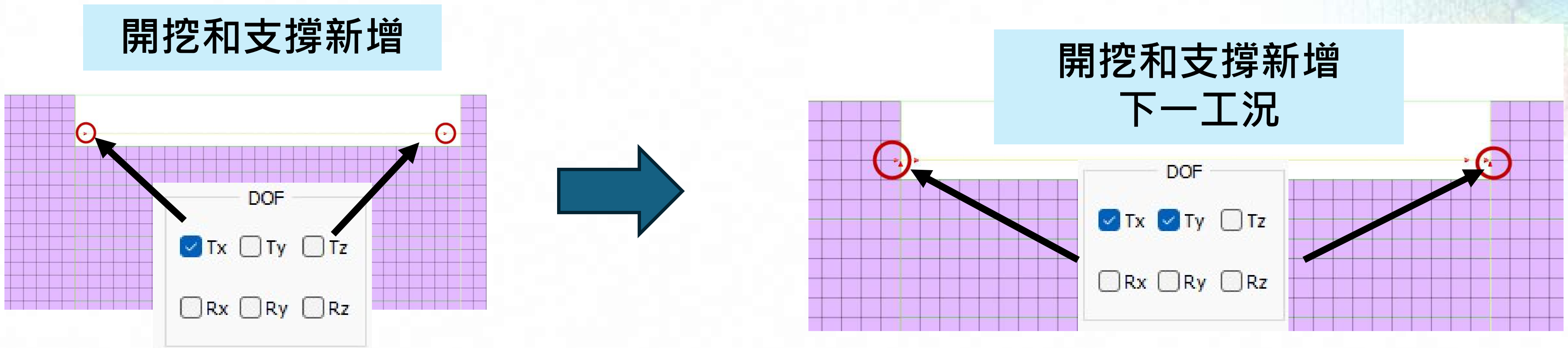
Twine and Roscoe (1999): Extended Peck's empirical methods by introducing Distributed Prop Load (DPL) envelopes tailored for stiffer wall systems (diaphragm walls and secant pile walls) subjected to preloading.

JGA (Japan Geotechnical Society) / TGA (Taiwan Geotechnical Society): Local design codes for dense urban excavations providing empirical tables for recommended preloading levels based on diaphragm wall thickness and excavation depth.

Part3. GTS NX-固定支撐預力法

(GTS NX solution for strut force design)

3.1GTS NX-固定支撐預力法



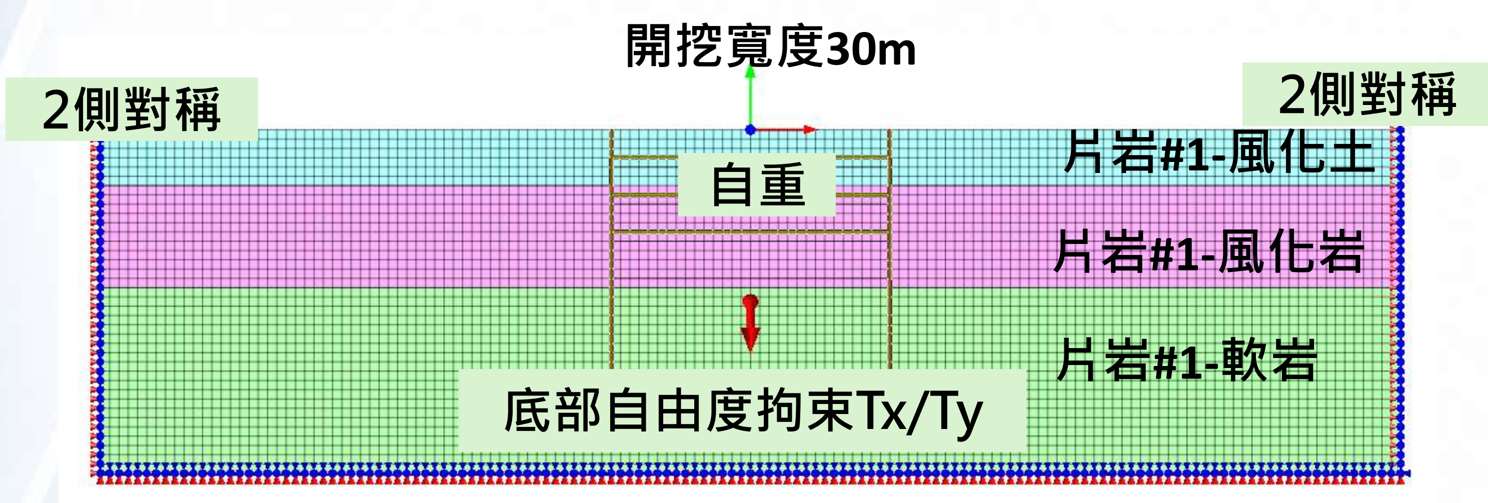
❖ **Remark:**

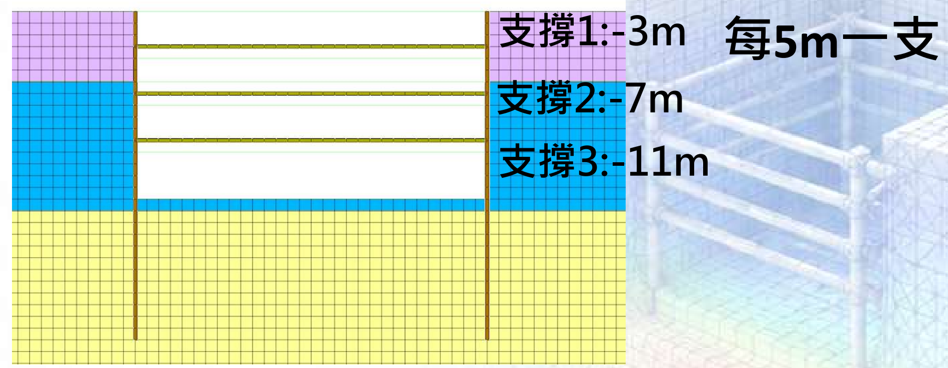
- The constraint position should be created near the wall to not make the force reduce its initial magnitude by transfer into strut. Therefore, we can obtain the force on strut by FEM in GTS NX
- This study uses constraint Tx at 0.5 m from the head's strut

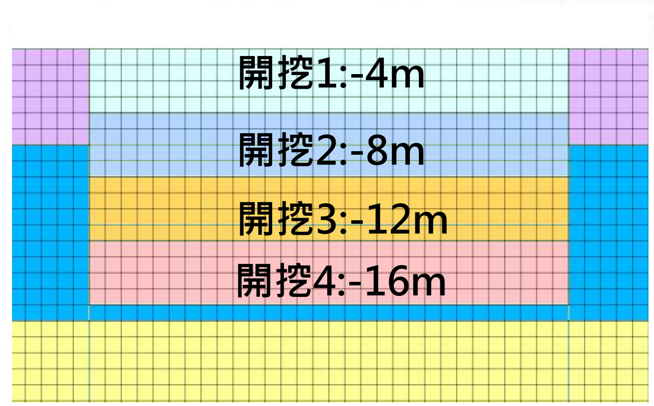
Part4.分析條件說明

(Explanation of analysis conditions)

4.1-2D測試標準模型

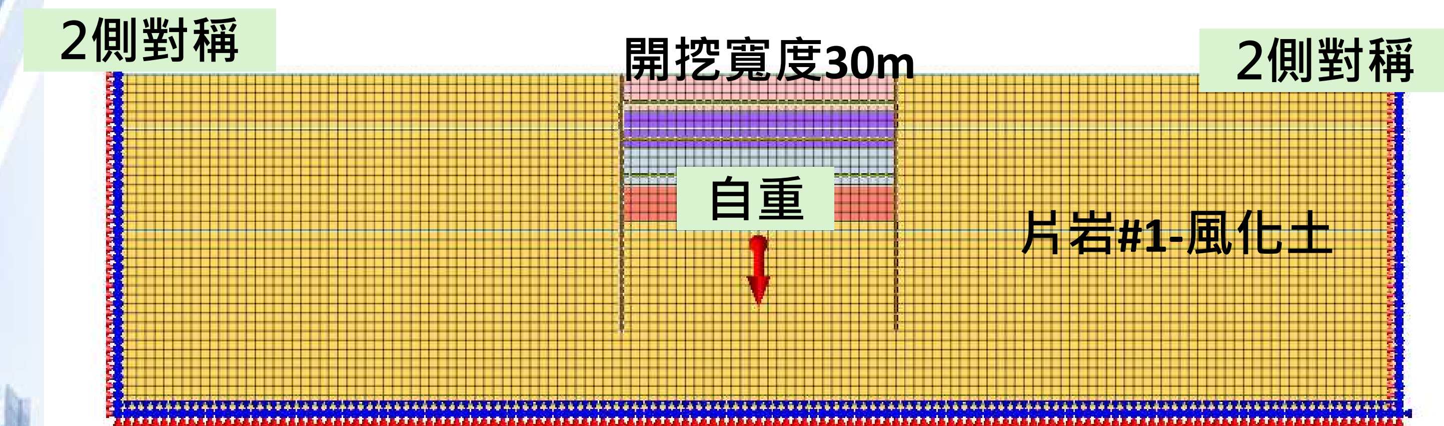


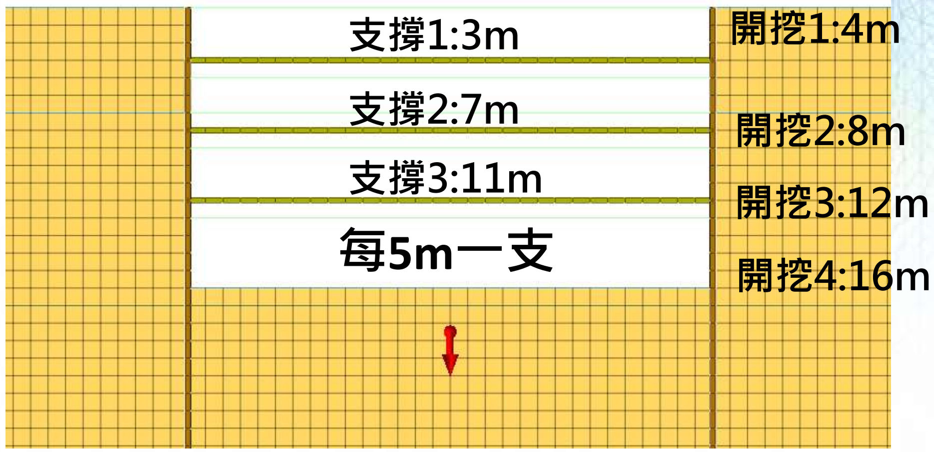




	Modulus of Elasticity(E) (tonf/m²)	Poisson's Ratio(ν)	Unit Weight(γ) (tonf/m³)	Unit Weight(Saturated) (tonf/m³)	Cohesion(C) (tonfm²)	Friction Angle(φ)
片岩#1-風化土	3721.96418	0.33	1.88647499	1.98844662	1.78450337	31
片岩#1-風化岩	15295.7432	0.3	2.14140405	2.24337567	5.09858106	33
片岩#1-軟岩	188647.499	0.28	2.44731891	2.54929053	18.3548918	35.5

4.2-2D_單一土壤-1





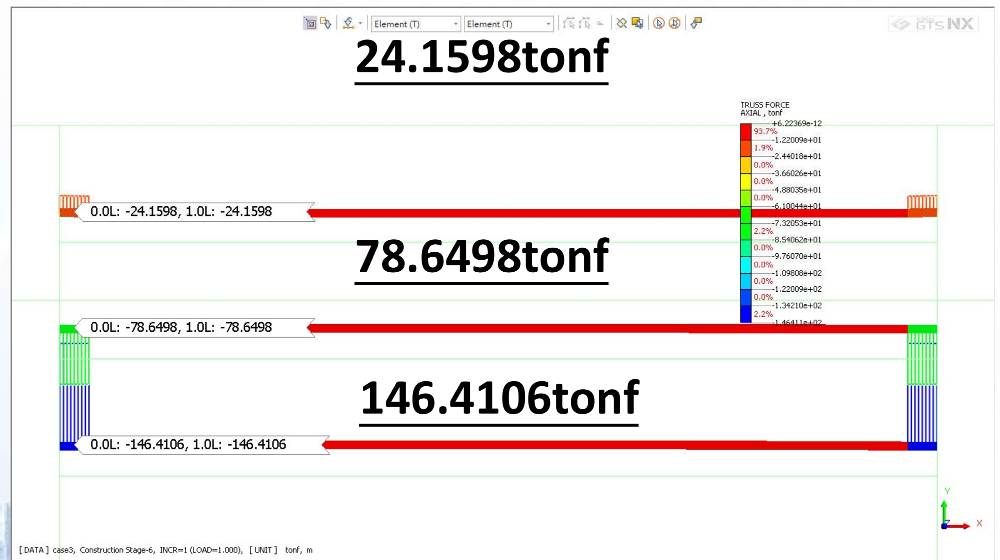
	Modulus of Elasticity(E) (tonf/m²)	Poisson's Ratio(ν)	Unit Weight(γ) (tonf/m³)	Unit Weight(Saturated) (tonf/m³)	Cohesion(C) (tonfm²)	Friction Angle(ϕ)
片岩#1-風化土	3721.96418	0.33	1.88647499	1.98844662	1.78450337	31

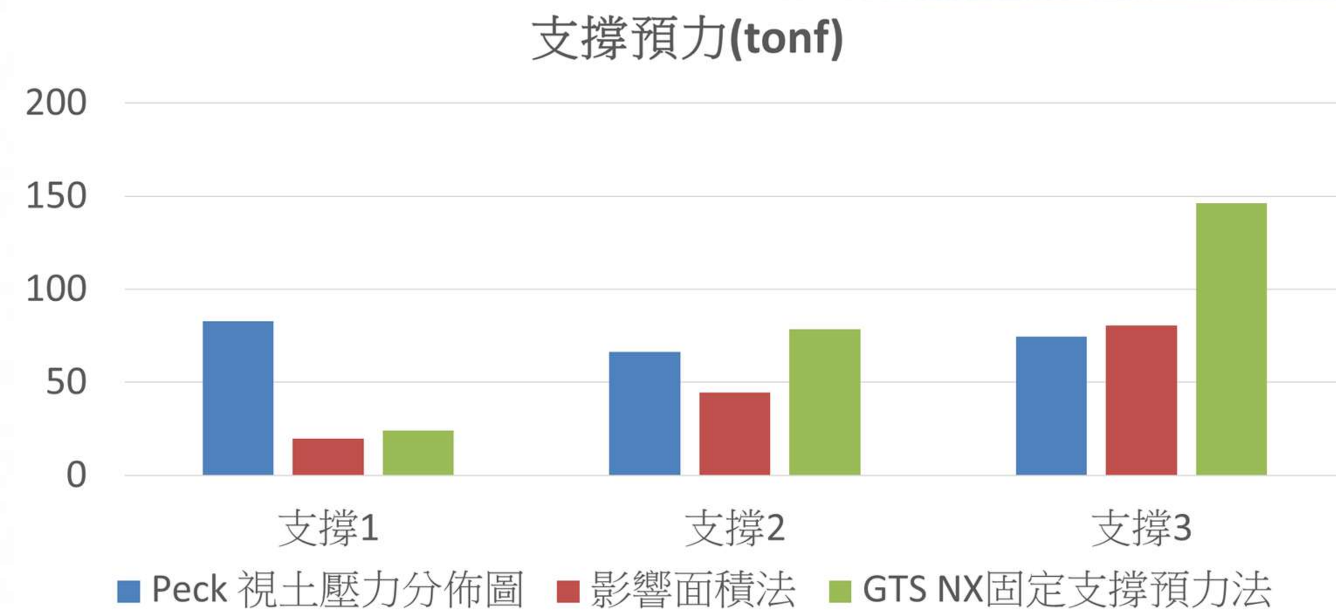
4.2-2D_單一土壤-2

經驗公式支撐預力(tonf)

$P_{預力} = 0.5 \times P_{軸力}$

GTS NX固定支撐預力法





	Peck 視土壓力分佈圖	影響面積法	GTS NX固定支撐預力法
支撐1	82.8	19.9	24.1598
支撐2	66.2	44.6	78.6498
支撐3	74.5	80.6	146.4106

4.2-2D_單一土壤-3

1. Global Excavation & Support System Input Parameters

Parameter Name	Symbol	Value	Unit	Formula / Description Reference
Total Excavation Depth	H	16.0	m	Input: Total depth of excavation model
Excavation Width	B	30.0	m	Input: Width of excavation area
Horizontal Strut Spacing	Sh	5.0	m	Input: Center-to-center horizontal strut spacing
Prestress Factor	α	0.5	-	Input: Prestress factor (typically 0.3 ~ 0.5)

2. Stratified 3 Soil Layer Thicknesses & Geotechnical Parameters

Soil Layer / Description	Layer Thickness (h_i) (m)	Unit Weight (γ_i) (tonf/m³)	Cohesion (C_i) (tonf/m²)	Friction Angle (ϕ_i) (deg °)	Layer Active Coeff. (K_a,i)	Weighted γ × h_i	Weighted K_a,i × h_i
支撐**1**	37.00	1.99	1.78	31	0.320	73.63	11.84
TOTAL THICKNESS & EQUIVALENT (WEIGHTED)	**37.00**	**1.99**			**0.320**	**73.63**	**11.84**

Peck's Global Apparent Pressure, p_a (tonf/m²) = 0.65 * γ_{eq} * H * Ka_{eq} = **6.62**

4.2-2D_單一土壤-3

3. Multi-Layer Strut Elevation & Dual Design Load Calculation Table

Strut Level / ID	Strut Depth (z_i) (m)	Upper Bound (z_{upper}) (m)	Lower Bound (z_{lower}) (m)	Trib Height ($S_{v,i}$) (m)	[Method 2] Active Top p_{top} (t/m²)	[Method 2] Active Bot p_{bot} (t/m²)	[Method 2] Active Design Load (tonf)	[Method 1] Peck Uniform p_a (t/m²)	[Method 1] Peck Design Load (tonf)
Strut Layer 1	3.00	0.00	5.00	5.0	0.0	3.2	39.8	6.6	165.6
Strut Layer 2 (Middle)	7.00	5.00	9.00	4.0	3.2	5.7	89.2	6.6	132.5
Strut Layer 3	11.00	9.00	13.50	4.5	5.7	8.6	161.2	6.6	149.1

Peck 視土壓力分佈圖

Strut 1 Load= 165.6 tonf

Ppre: 82.8 tonf

Strut 2 Load= 132.5 tonf

Ppre: 66.2 tonf

Strut 3 Load= 149.1 tonf

Ppre: 74.5 tonf

影響面積法(AVERAGE AREA)

Strut 1 Load= 39.8 tonf

Ppre: 19.9 tonf

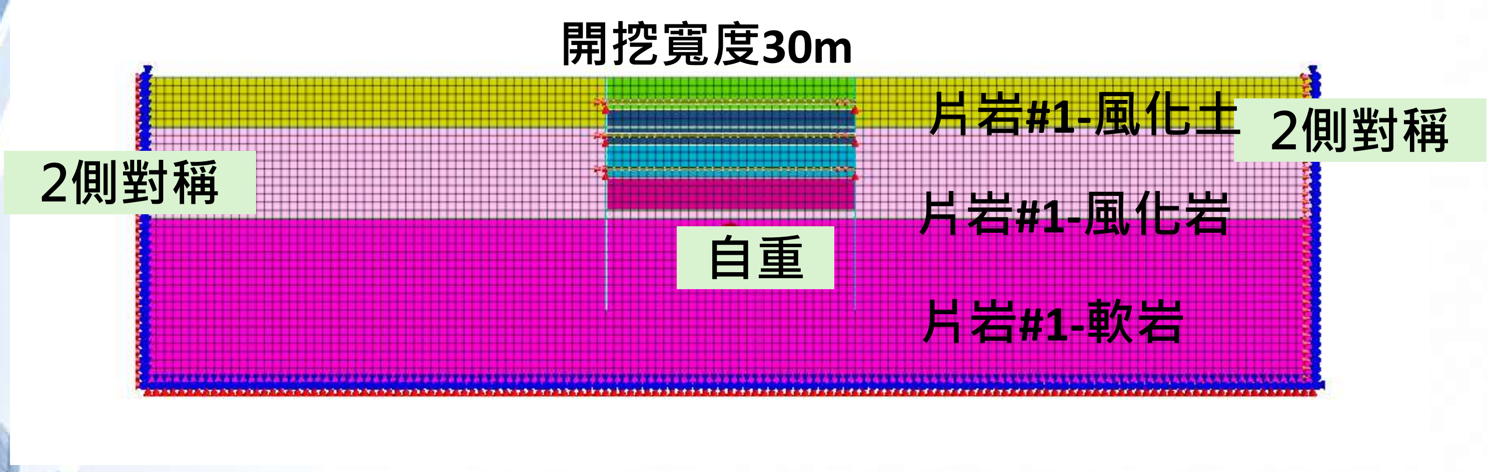
Strut 2 Load= 89.2 tonf

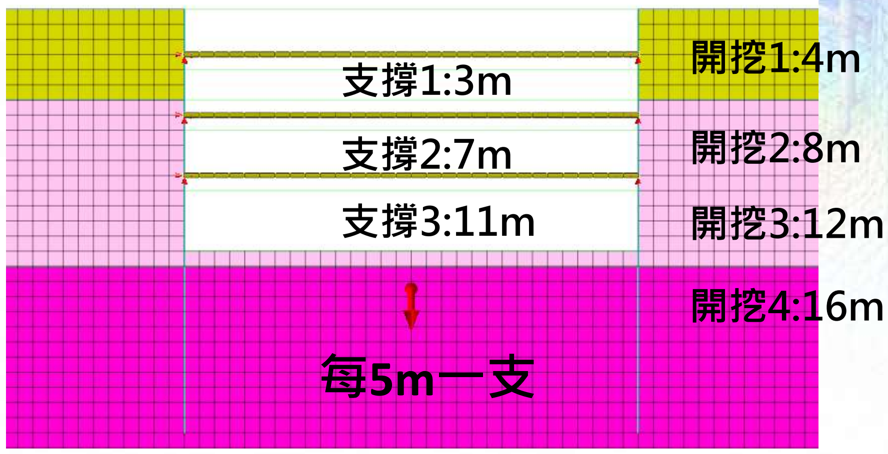
Ppre: 44.6 tonf

Strut 3 Load= 161.2 tonf

Ppre: 80.6 tonf

4.3-2D_混合土壤-1





	Modulus of Elasticity(E) (tonf/m^2)	Poisson's Ratio(ν)	Unit Weight(γ) (tonf/m^3)	Unit Weight(Saturated) (tonf/m^3)	Cohesion(C) (tonfm^2)	Friction Angle(ϕ)
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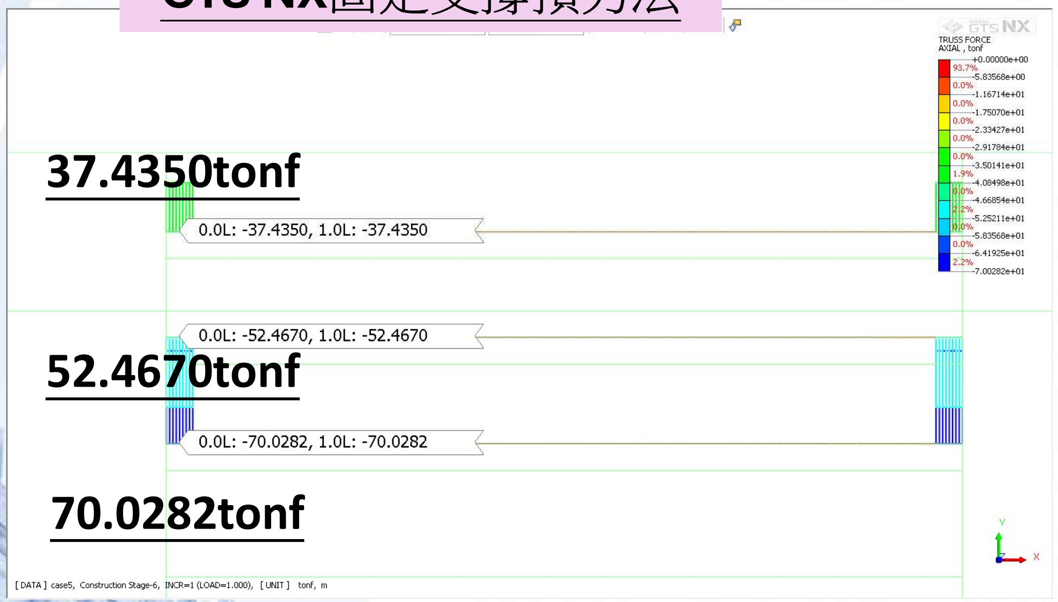
片岩#1-軟岩	188647.499	0.28	2.44731891	2.54929053	18.3548918	35.5

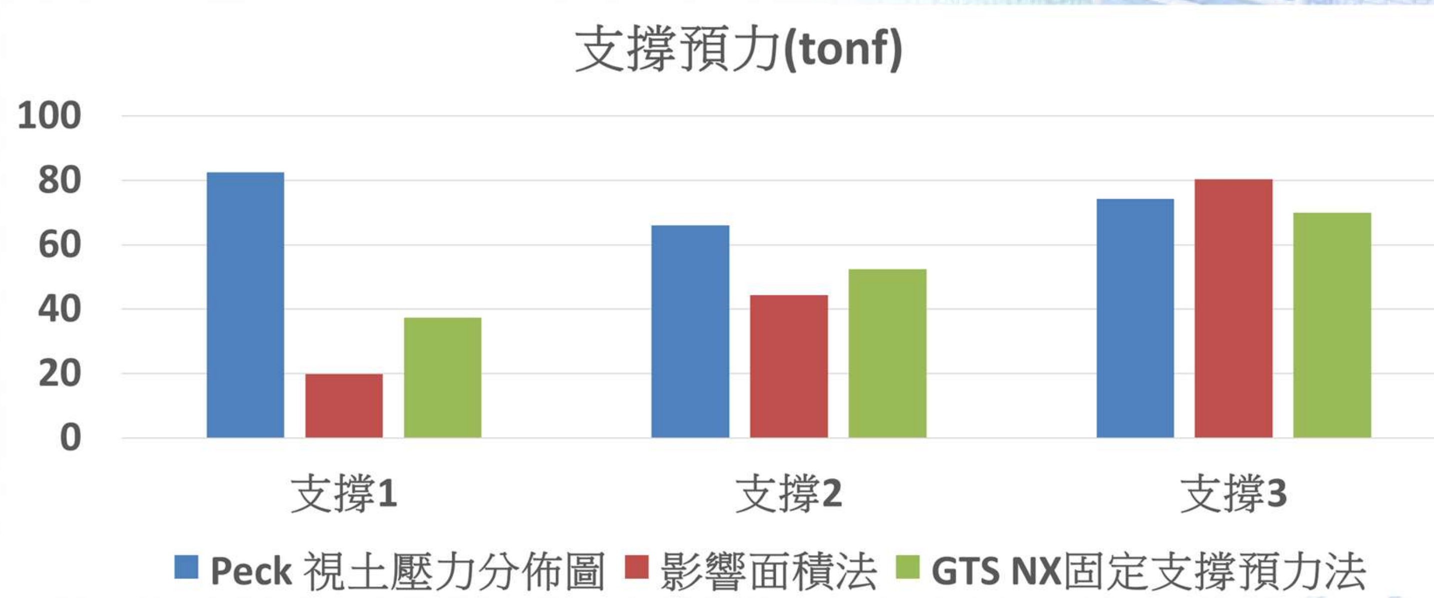
4.3-2D_混合土壤-2

經驗公式支撐預力(tonf)

$P_{預力} = 0.5 \times P_{軸力}$

GTS NX固定支撐預力法





	Peck 視土壓力分佈圖	影響面積法	GTS NX固定支撐預力法
支撐1	82.5	19.8	37.435
支撐2	66	44.4	52.467
支撐3	74.2	80.3	70.0282

4.3-2D_單一土壤-3

1. Global Excavation & Support System Input Parameters				
Parameter Name	Symbol	Value	Unit	Formula / Description Reference
Total Excavation Depth	H	16.0	m	Input: Total depth of excavation model
Excavation Width	B	30.0	m	Input: Width of excavation area
Horizontal Strut Spacing	Sh	5.0	m	Input: Center-to-center horizontal strut spacing
Prestress Factor	α	0.5	-	Input: Prestress factor (typically 0.3 ~ 0.5)

2. Stratified 3 Soil Layer Thicknesses & Geotechnical Parameters							
Soil Layer / Description	Layer Thickness (h_i) (m)	Unit Weight (γ_i) (tonf/m³)	Cohesion (C_i) (tonf/m²)	Friction Angle (ϕ_i) (deg °)	Layer Active Coeff. (K_a,i)	Weighted γ × h_i	Weighted K_a,i × h_i
支撐1	6.00	1.89	1.78	31	0.320	11.34	1.92
支撐2	11.00	2.14	5.09	33	0.295	23.54	3.24
支撐3	20.00	2.45	18.35	36	0.260	49.00	5.19
TOTAL THICKNESS & EQUIVALENT (WEIGHTED)	37.00	2.27			0.280	83.88	10.36

Peck's Global Apparent Pressure, p_a (tonf/m²) = 0.65 * γ_{eq} * H * Ka_{eq} = 6.60

4.3-2D_單一土壤-3

3. Multi-Layer Strut Elevation & Dual Design Load Calculation Table

Strut Level / ID	Strut Depth (z_i) (m)	Upper Bound (z_{upper}) (m)	Lower Bound (z_{lower}) (m)	Trib Height ($S_{v,i}$) (m)	[Method 2] Active Top p_{top} (t/m²)	[Method 2] Active Bot p_{bot} (t/m²)	[Method 2] Active Design Load (tonf)	[Method 1] Peck Uniform p_a (t/m²)	[Method 1] Peck Design Load (tonf)
Strut Layer 1	3.00	0.00	5.00	5.0	0.0	3.2	39.7	6.6	165.0
Strut Layer 2 (Middle)	7.00	5.00	9.00	4.0	3.2	5.7	88.8	6.6	132.0
Strut Layer 3	11.00	9.00	13.50	4.5	5.7	8.6	160.6	6.6	148.5

Peck 視土壓力分佈圖

Strut 1 Load= 165.0 tonf
Ppre: 82.5 tonf

Strut 2 Load= 132.0 tonf
Ppre: 66.0 tonf

Strut 3 Load= 148.5 tonf
Ppre: 74.2 tonf

影響面積法(AVERAGE AREA)

Strut 1 Load= 39.7 tonf
Ppre: 19.8 tonf

Strut 2 Load= 88.8 tonf
Ppre: 44.4 tonf

Strut 3 Load= 160.6 tonf
Ppre: 80.3 tonf

Part5.3D空間效應對於預力計算之影響
(3D model impact on strut prestress)

5.1深開挖3D VS. 2D 空間效應對於支撐預力計算之影響

在深開挖數值分析中，3D 模型計算出的支撐預力(及軸力)通常遠小於 2D 模型，是因為 2D 分析的「平面應變(Plane Strain)」假設，完全忽略了真實世界的三維空間束制（Spatial Confinement）。

In numerical analysis of deep excavation, the support preload (and axial force) calculated by the 3D model is usually much smaller than that of the 2D model. This is because the "plane strain" assumption of the 2D analysis completely ignores the **spatial constraints** of the real world.

3D&2D數值落差，主要來自以下四個核心力學機制的差異
(The key reason causes to the difference between 3D & 2D)

1.擋土牆的雙向剛度與「角隅效應」(Corner Effect)
2.水平向「土壤拱效應」(Horizontal Soil Arching)
3. 圍苓(Waler Beam)的空間載重分配 (Load distribution on Waler)
4. 預力設定的基準目標不同 (Prestressing baseline targets)

實務上通常會以保守的 2D 計算結果為基準，再依據基地長寬比與距離角隅的位置，引入「空間折減係數(Spatial Reduction Factor)」來進行預力的漸變配置
In practice, a conservative 2D calculation result is usually used as a benchmark, and then a **"spatial reduction factor"** is introduced to gradually configure the prestressing force based on the **aspect ratio** of the site and **the location of the corner**.

5.1空間折減係數(Spatial Reduction Factor)-1

台灣科技大學歐章煜教授（Ou et al., 1996, 1998）**提出的**平面應變比（Plane Strain Ratio, PSR）與角隅效應折減曲線，是深開挖設計中最廣泛應用的基準。

The plane strain ratio (PSR) and corner effect reduction curve proposed by Professor Ou et al. (1996, 1998) of National Taiwan University of Science and Technology are the most widely used benchmarks in deep excavation design.

步驟一：計算幾何參數與「平面應變比 (PSR)」

首先，必須確認基地幾何形狀對空間效應的影響程度。PSR 定義為：**3D 中央最大變形 / 2D 最大變形**。

根據 Ou et al. 的研究，PSR 取決於基地的**長寬比**（L/B）**與開挖深度比**（H_e/B）：

- L：開挖面的長度（平行於擋土牆）。
- B：開挖面的寬度（對撐的長度）。
- H_e：最終開挖深度。

實務上可查閱 Ou et al. 建立的經驗圖表（或無因次曲線）來求得中央斷面的 PSR 值。

- **狹長基地** ($L/B > 5$)：PSR 趨近於 1.0（接近純 2D 平面應變）。
- **方型基地** ($L/B \approx 1$)：PSR 通常落在 0.4 ~ 0.6 之間（空間效應極強）。

Step 1:
Calculate geometric parameters and plane strain ratio (PSR)

(Depending on L/B ratio, the PSR is defined)

5.1空間折減係數(Spatial Reduction Factor)-2

步驟二：中央預力的基礎折減

取得 PSR 後，即可對 2D 軟體（如 Rido或 Plaxis 2D）計算出的中央支撐預力（T_{2D}）進行初步折減。

- **實務公式：** $T_{center\_3D} = T_{2D} \times \mathrm{PSR} \times$ 安全係數
  - **注意：** 變形折減（PSR）與受力折減並非完美的 1:1 線性關係。實務上為了保守起見，通常會取一個比 PSR 稍大的「軸力折減係數」。例如 PSR=0.5 時，預力折減係數可能取 0.65 到 0.7 左右。

Step 2:
Basic reduction of central preload

(The central strut preload is then adjusted by 2D model)

步驟三：依「距角隅距離」進行分區漸變設計

空間效應在角隅處最大，往中央逐漸遞減。Ou et al. 的研究指出，擋土牆的變形曲線在平面上呈現近似**拋物線**或**餘弦曲線**。因此，同一階層的預力不能全區統一，必須「分區配置」：

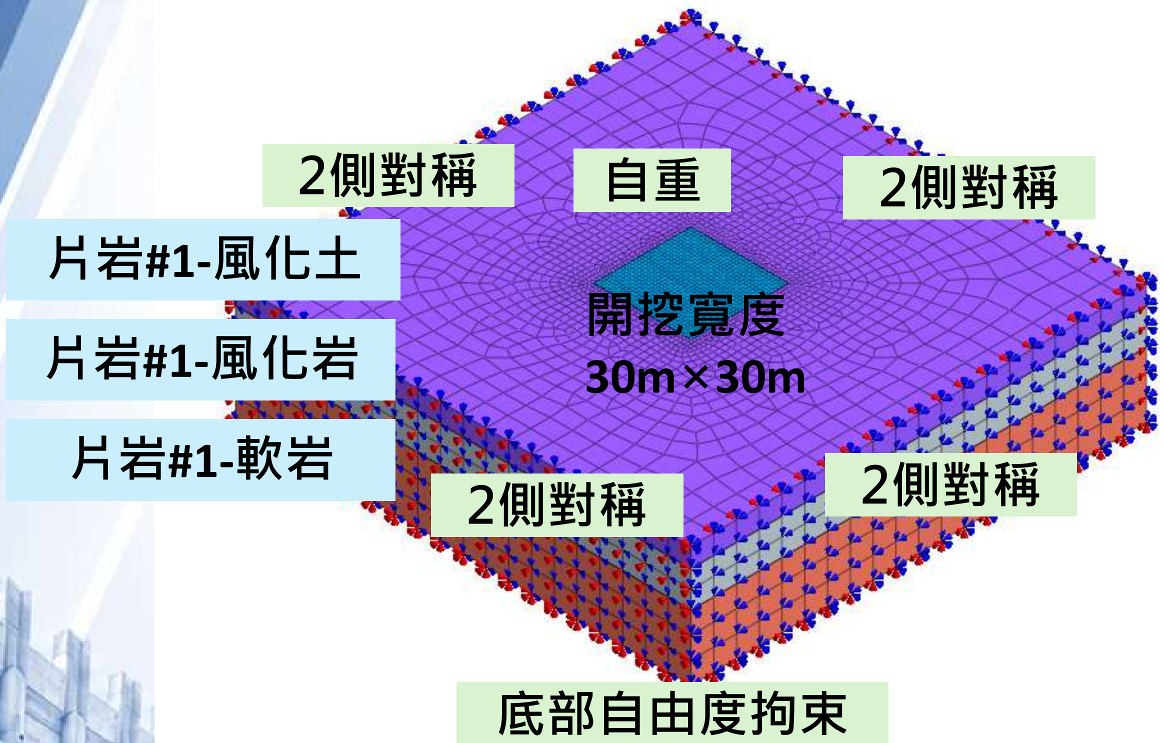
假設基地單側牆長 L，距離角隅為 d：

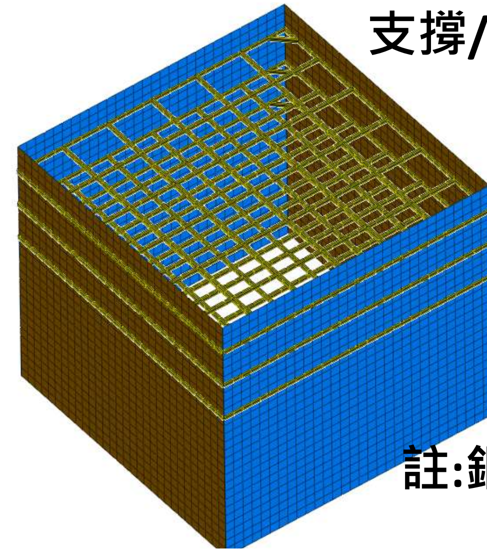
1. **主影響區 (中央區段，例如 $d = L/4 \sim 3L/4$)：**
   - 受空間效應保護最少。
   - **預力設定：** 採用步驟二算出的 T_{center_3D}。此區預力最大。
2. **過渡區 (例如 $d = L/8 \sim L/4$)：**
   - 受圍苓傳力與角隅約束的混合影響。
   - **預力設定：** 取中央區預力的 70% ~ 85%。
3. **角隅極強約束區 (例如 $d = 0 \sim L/8$)：**
   - 位移極小，若施加過大預力極易造成連續壁背側反向開裂。
   - **預力設定：** 取中央區預力的 40% ~ 60%。若是斜撐（角撐），則需另外轉換分力計算。

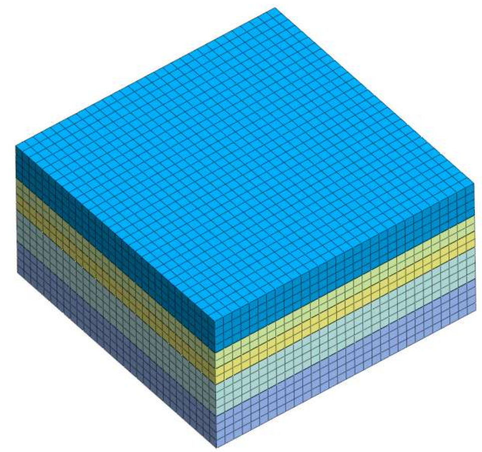
Step 3:
Zoned gradual design based on corner distance

(The preload for struts on the same level distributes uniform across all zones)

5.2 3D測試標準模型-1



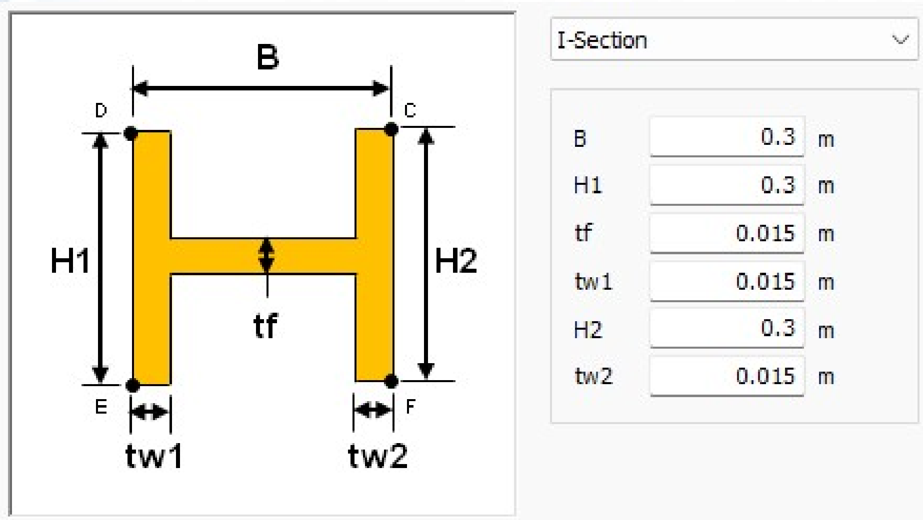




	Modulus of Elasticity(E) (tonf/m^2)	Poisson's Ratio(ν)	Unit Weight(γ) (tonf/m^3)	Unit Weight(Saturated) (tonf/m^3)	Cohesion(C) (tonfm^2)	Friction Angle(ϕ)
片岩#1-風化土	3721.96418	0.33	1.88647499	1.98844662	1.78450337	31
片岩#1-風化岩	15295.7432	0.3	2.14140405	2.24337567	5.09858106	33
片岩#1-軟岩	188647.499	0.28	2.44731891	2.54929053	18.3548918	35.5

5.2 3D測試標準模型-2

鋼板樁換算等效厚度



註:2D分析採H型鋼作為擋土母樁

折算為單一厚度的平板/牆

如果你需要將整個截面等效為一個寬為 B(0.3 m)、具有相同軸向抗壓/抗拉剛度(或抗彎剛度)的單一平面殼(Shell)模型：

計算截面總面積 (A)

由 3 個板塊組成（兩個高 0.3 m、厚 0.015 m 的豎向板塊，和一個長 0.3 m、厚 0.015 m 的橫向板塊）：

$$A = 3 \times (0.3\,\mathrm{m} \times 0.015\,\mathrm{m}) = 0.0135\,\mathrm{m}^2$$

等效厚度 (t_{eq})

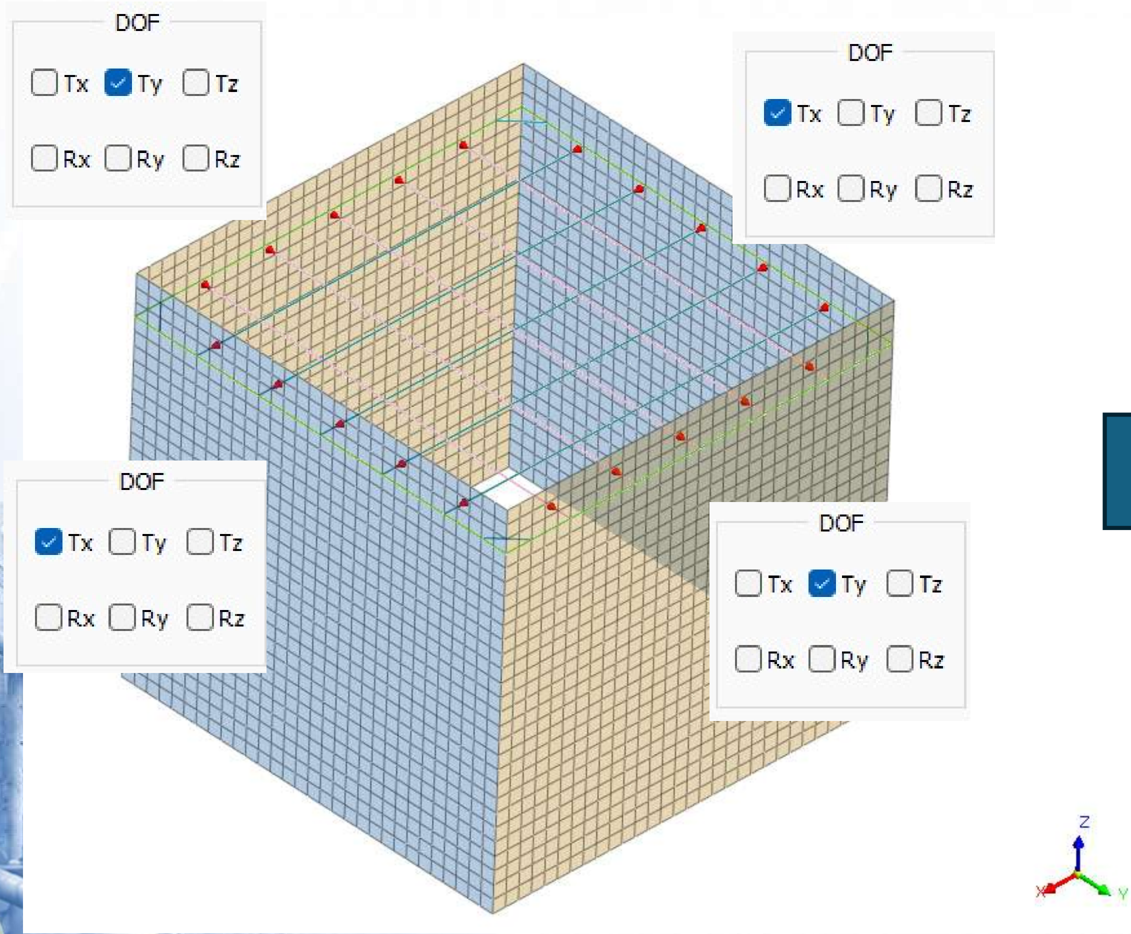
按投影寬度B = 0.3 m計算面積

$$t_{eq} = A/B = 0.0135\,\mathrm{m}/0.3\,\mathrm{m} = 0.045\,\mathrm{m}$$ （即 45 mm）

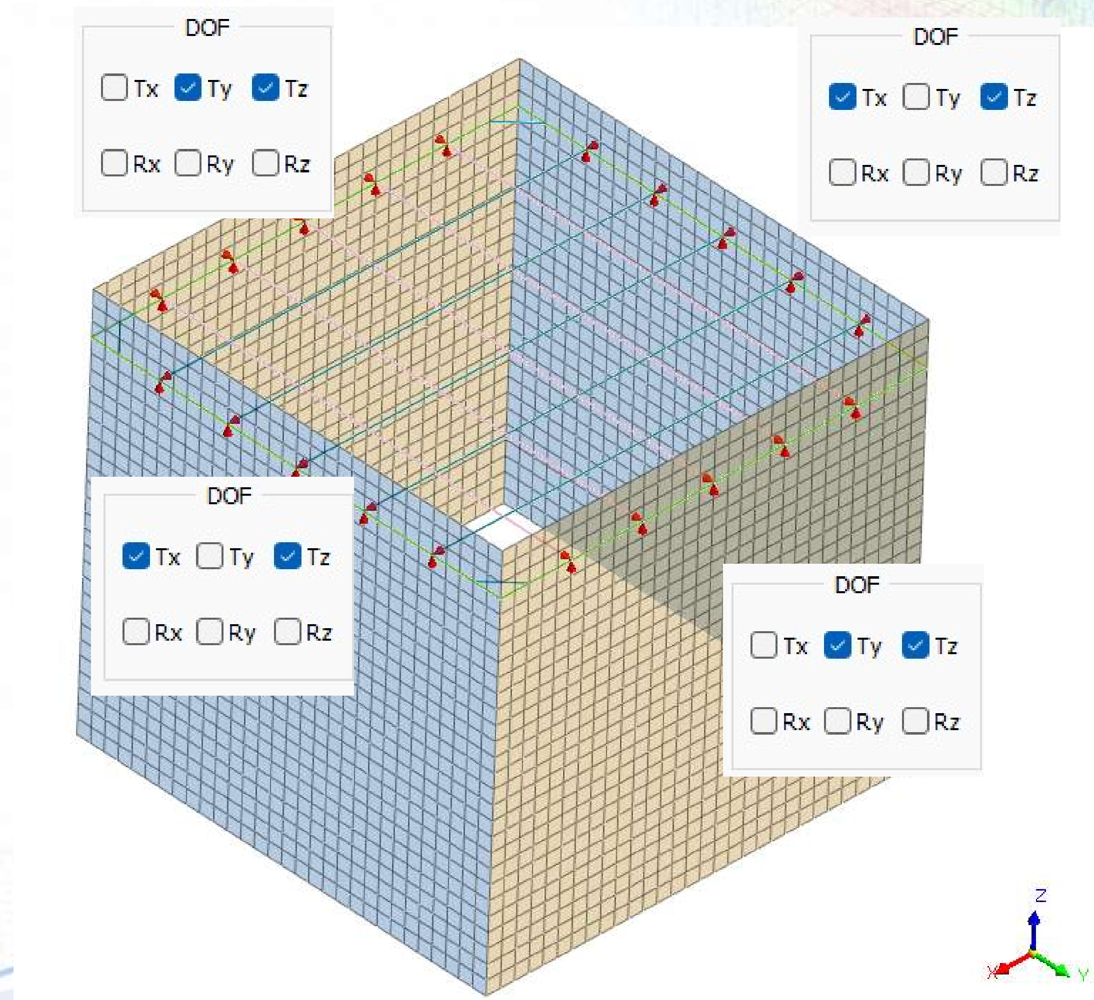
5.2 3D測試標準模型-3

GTS NX-3D固定支撐預力法

開挖和支撐新增

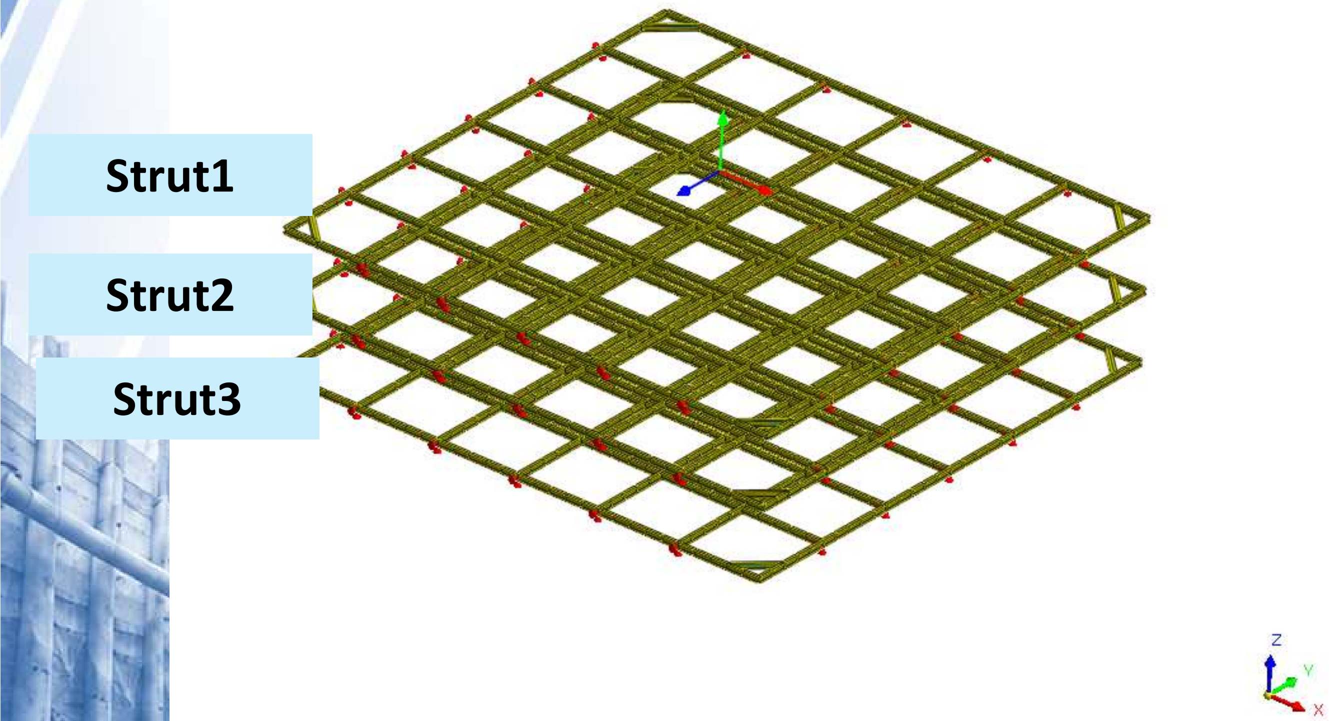


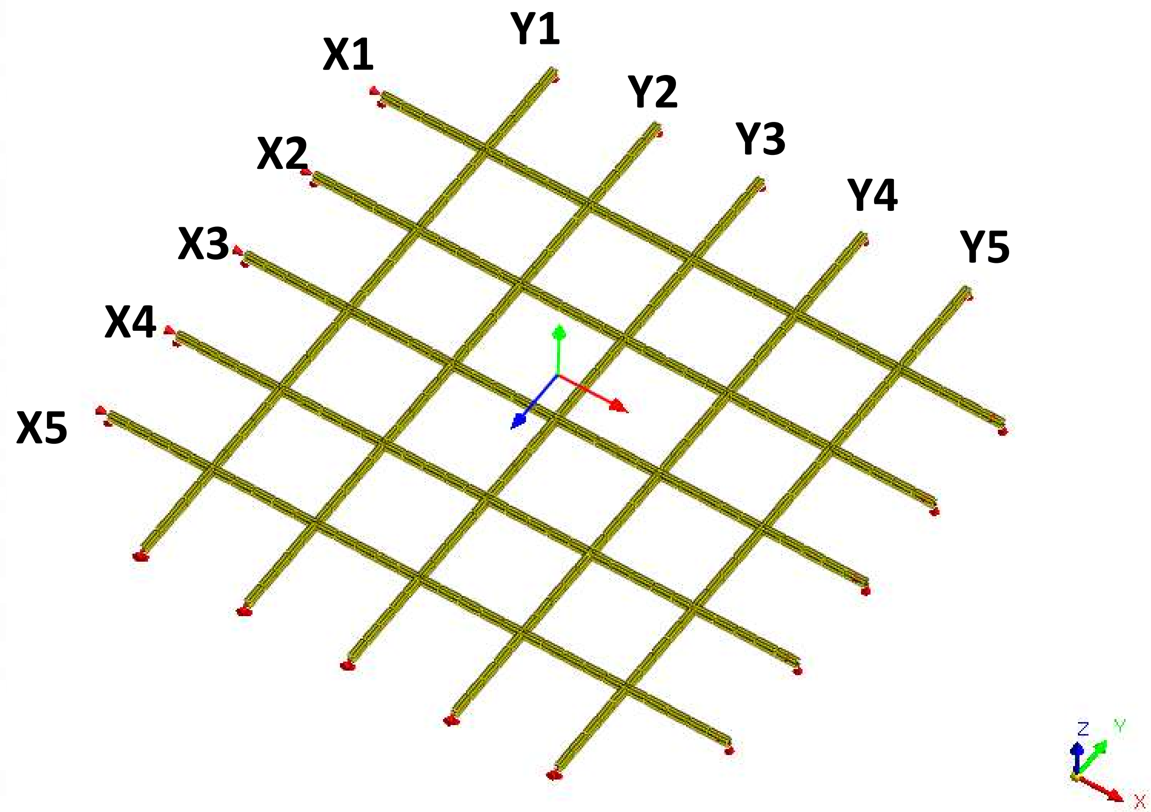
開挖和支撐新增
下一工況



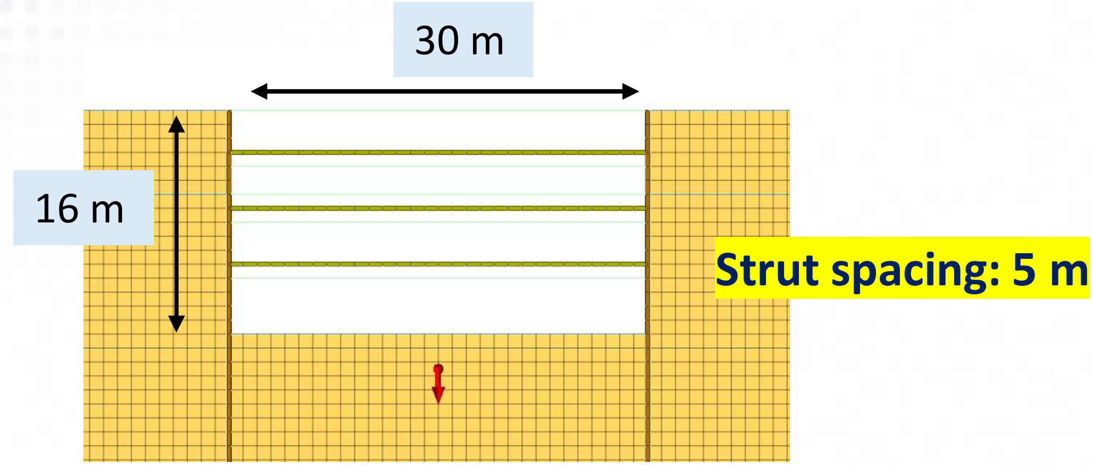
5.2 3D測試標準模型-5

支撐名稱位置說明

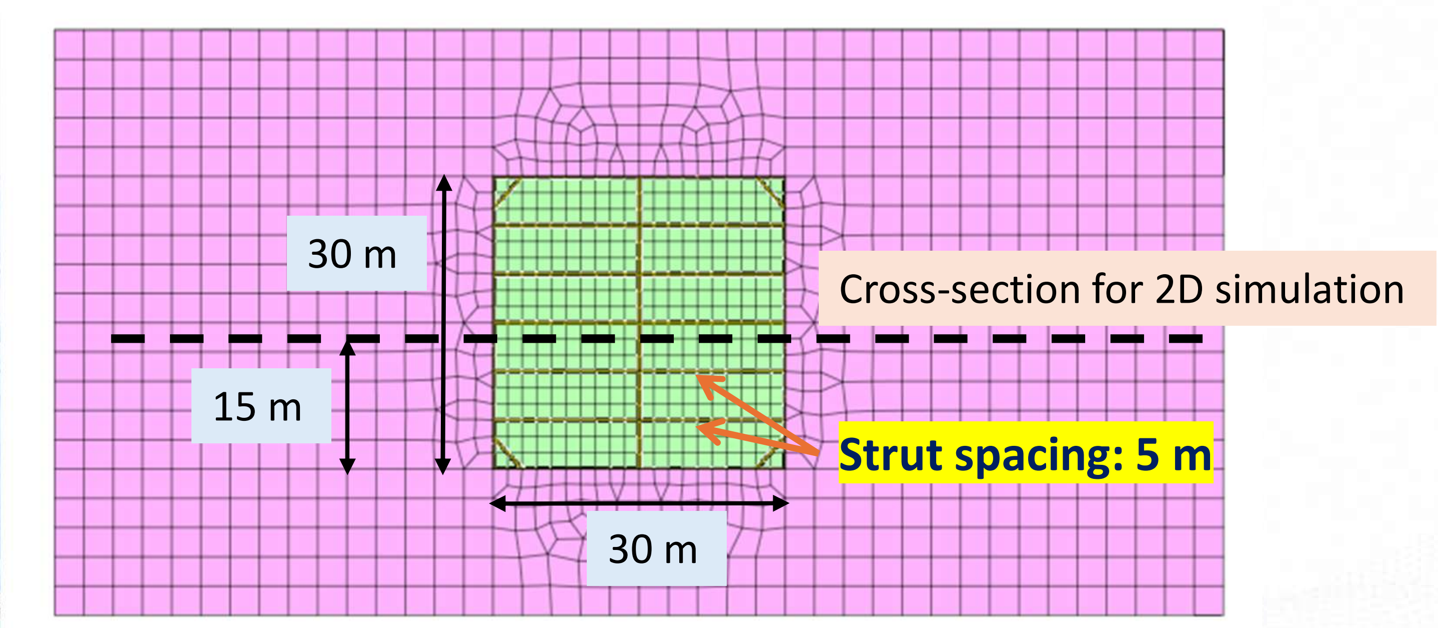




5.2 三維模型中的二維局限性-6

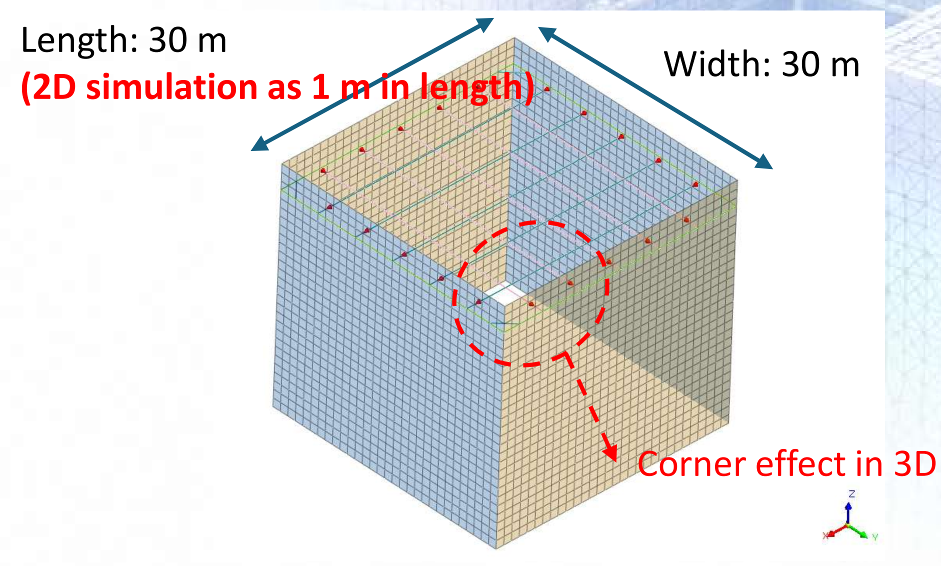


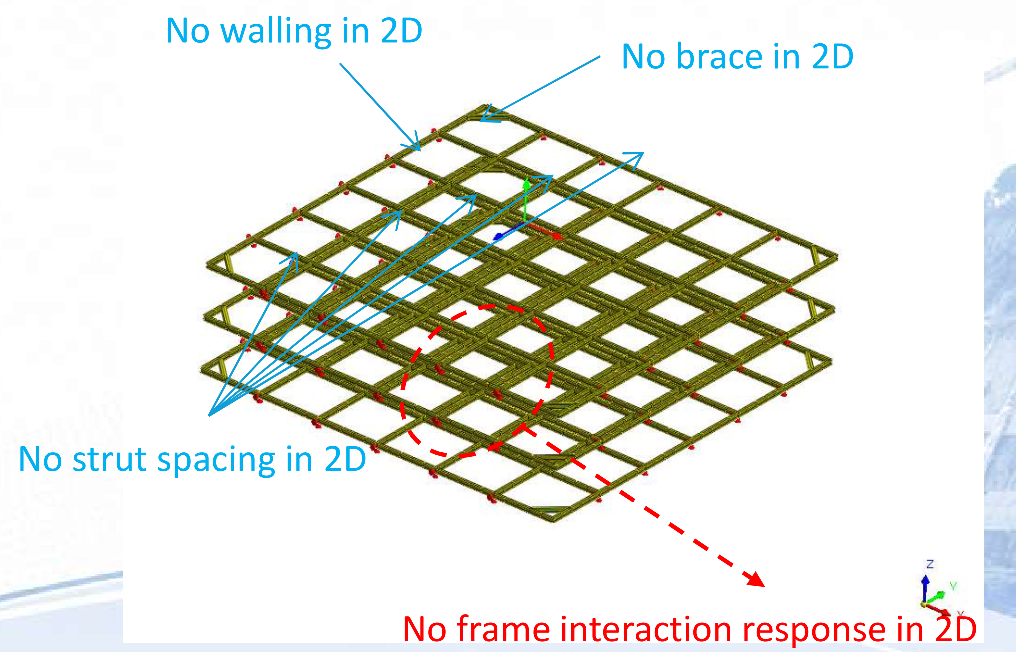
2D/3D comparison



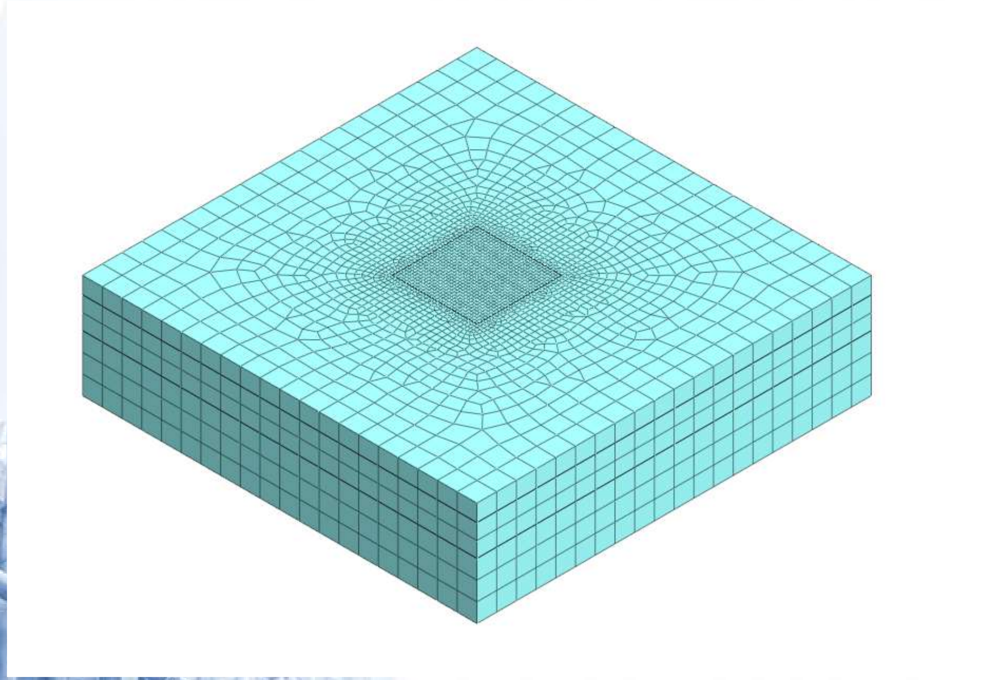
- **2D cross-section from 3D model**

- **2D limitation in 3D model**

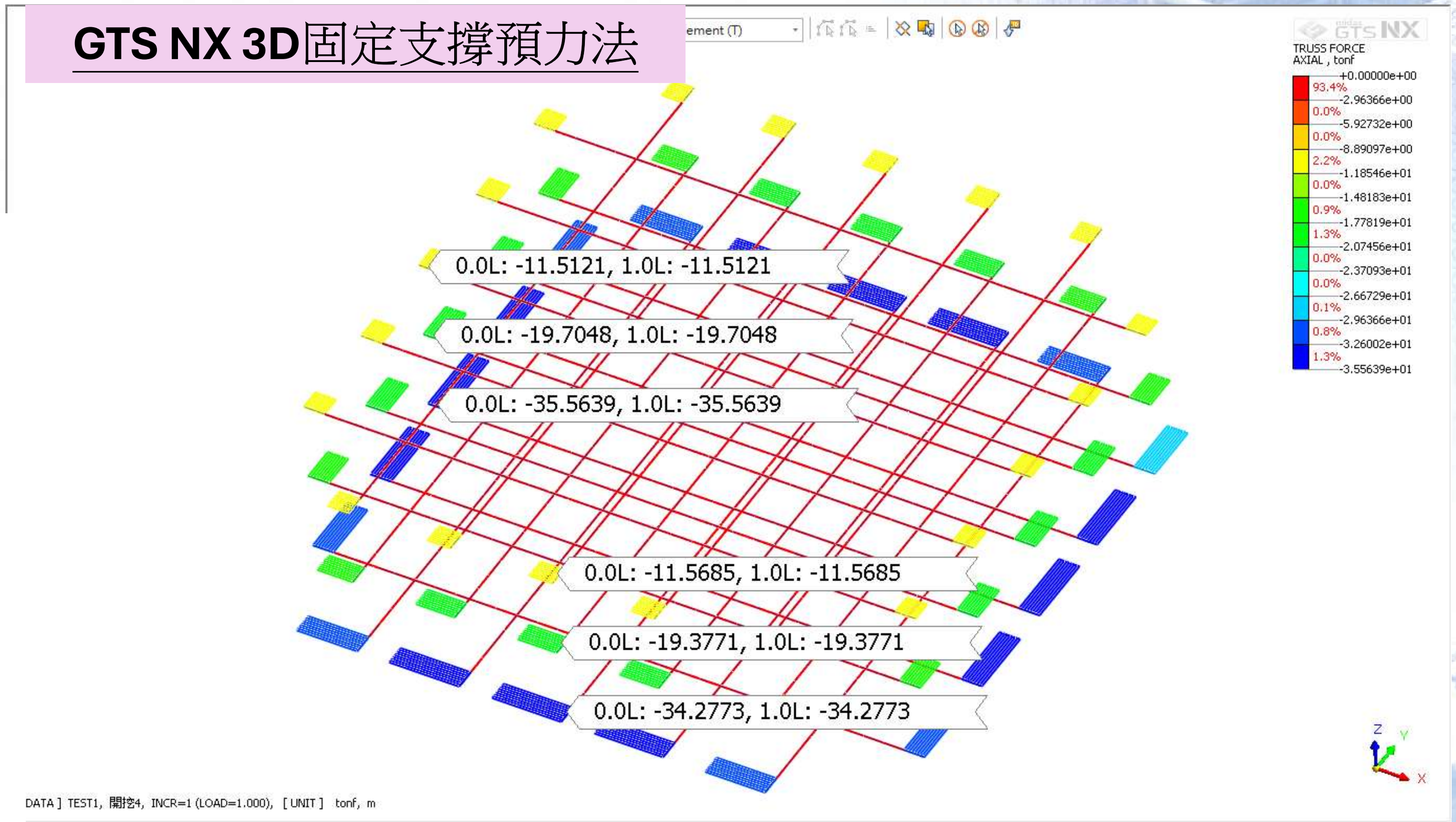




5.3 3D_單一土壤-1

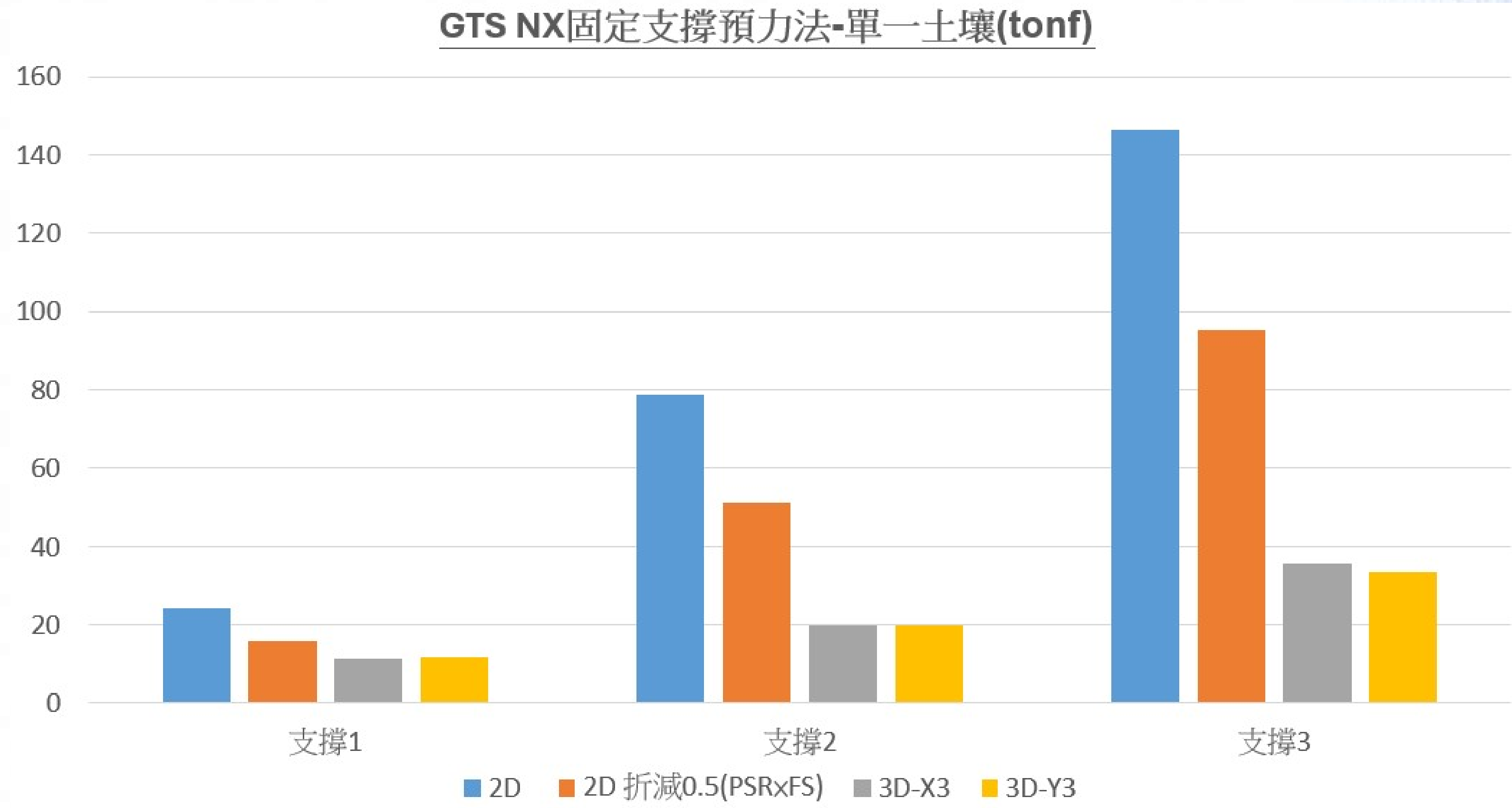


GTS NX 3D固定支撐預力法



	Modulus of Elasticity(E) (tonf/m²)	Poisson's Ratio(ν)	Unit Weight(γ) (tonf/m³)	Unit Weight(Saturated) (tonf/m³)	Cohesion(C) (tonfm²)	Friction Angle(ϕ)
片岩#1-風化土	3721.96418	0.33	1.88647499	1.98844662	1.78450337	31

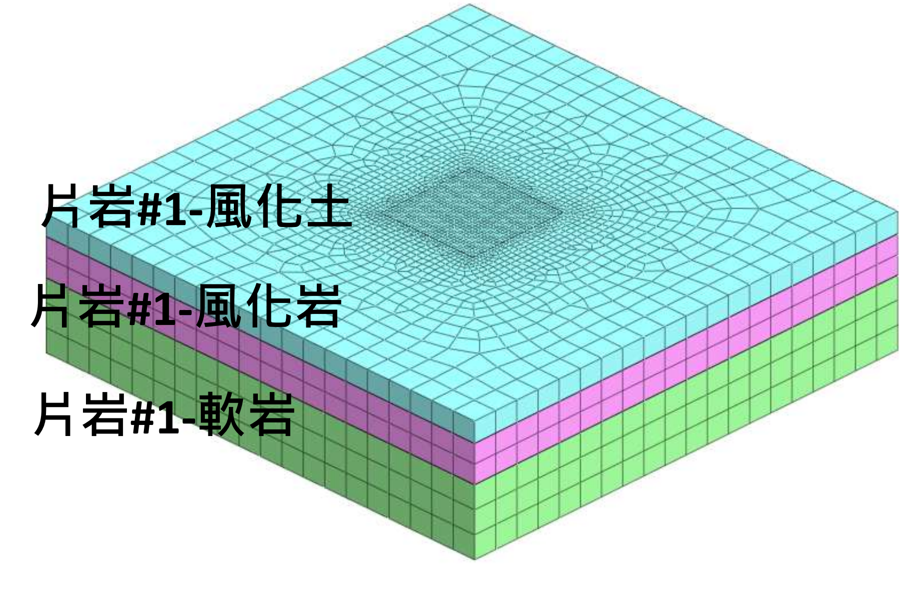
5.3 3D_單一土壤-2

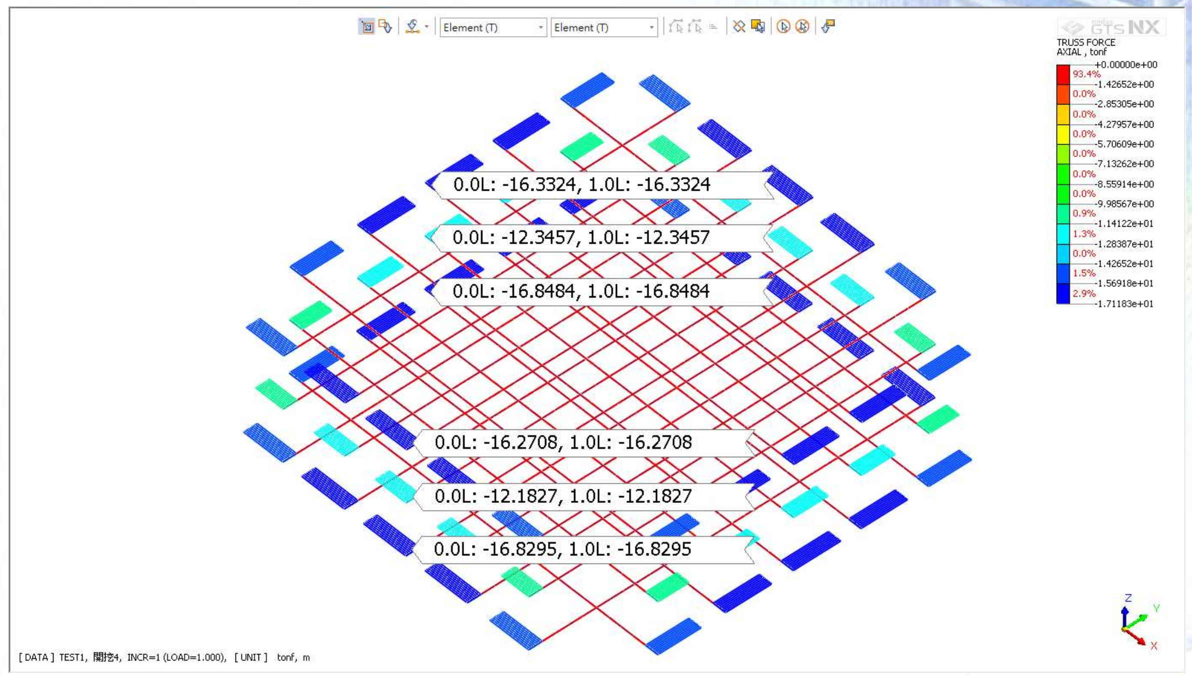


	2D	2D 折減0.5(PSR×FS)	3D-X3	3D-Y3
支撐1	24.1598	15.70387	11.5121	11.6842
支撐2	78.6498	51.12237	19.7048	19.771
支撐3	146.4106	95.16689	35.5639	33.552

5.4 3D_混合土壤-1

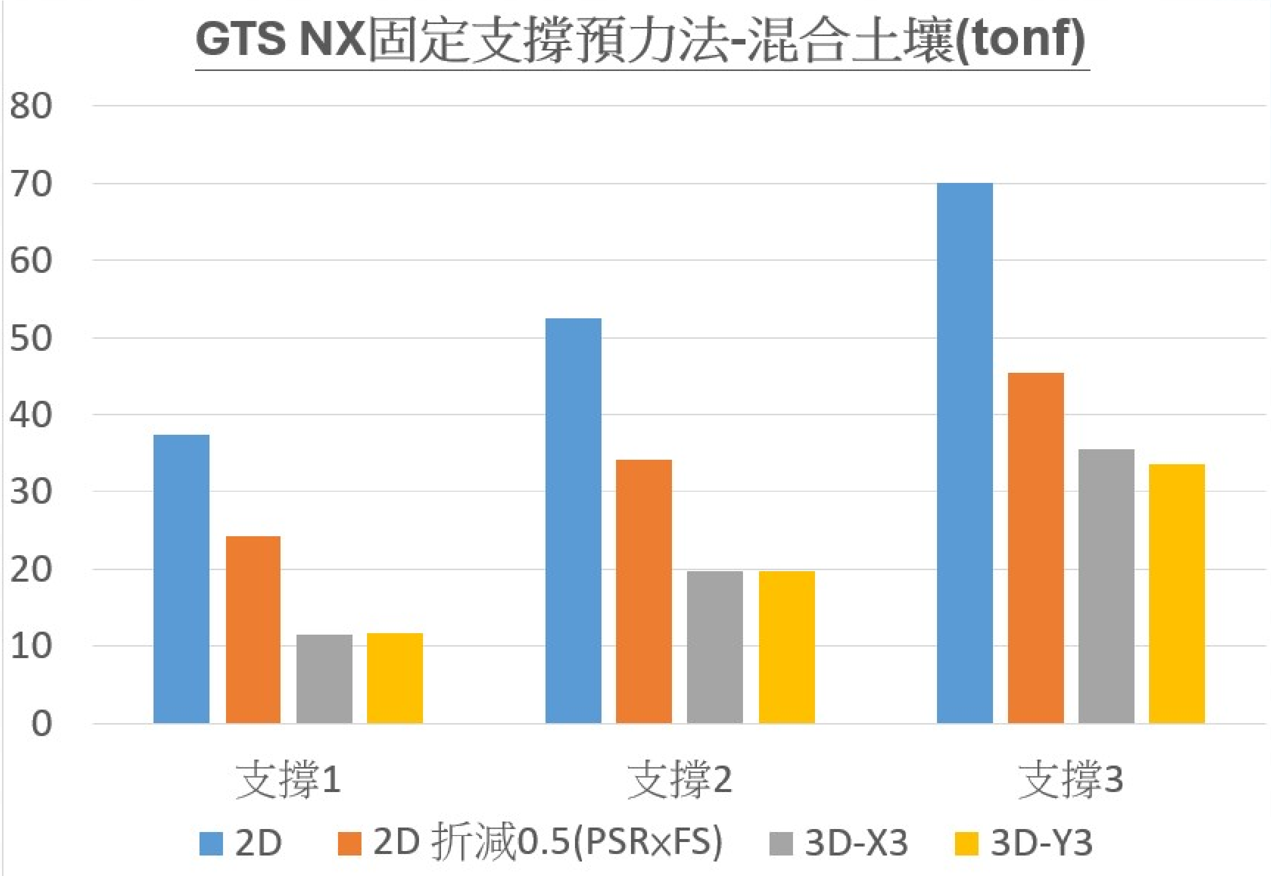
GTS NX 3D固定支撐預力法





	Modulus of Elasticity(E) (tonf/m²)	Poisson's Ratio(ν)	Unit Weight(γ) (tonf/m³)	Unit Weight(Saturated) (tonf/m³)	Cohesion(C) (tonfm²)	Friction Angle(ϕ)
片岩#1-風化土	3721.96418	0.33	1.88647499	1.98844662	1.78450337	31
片岩#1-風化岩	15295.7432	0.3	2.14140405	2.24337567	5.09858106	33
片岩#1-軟岩	188647.499	0.28	2.44731891	2.54929053	18.3548918	35.5

5.4 3D_混合土壤-2



	2D	2D 折減0.5(PSR×FS)	3D-X3	3D-Y3
支撐1	37.435	24.33275	11.5121	11.6842
支撐2	52.467	34.10355	19.7048	19.771
支撐3	70.0282	45.51833	35.5639	33.552

Conclusion

- By validated for different conditions of cases, the results show that 2D/3D FEM by GTS NX and Analytical methods can be validated each other

- The difference could be explained by 2D/3D FEM including **stress re-distribution/Wall bends/structure interaction** while analytical methods just based on **failure state of pressure envelope/ equivalent parameters for two soil layers. Especially, 3D case including corner effect can change the prestress force on strut.**

From validated results,
GTS NX users can use FEM as a solution to obtain the

--> **'strut design force for strut prestress solution'**

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