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Post Tensioned Segmental Retaining Wall

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(56) Related Art
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M Javedi et al., "Numerical investigation on the behaviour of post-tensioned mechanically stabilised earth walls (PT-MSEW)", Computers and Structures vol. 299, article no. 107403, pp. 1-22, 8 May 2024
M Javedi et al., "Experimental study on cyclic behavior of post-tensioned segmental retaining walls (PSRWs)", Engineering Structures, Volume 229, 15 February 2021
WO 84/04768 A1
WO 2005/100712 A2
WO 2016/086948 A1

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ABSTRACT

The proposed design introduces Post-tensioned Segmental Retaining Walls (PSRWs) and Post-tensioned Mechanically Stabilised Earth Walls (PT-MSEWs), or a combination of both, as an advanced alternative to traditional retaining wall systems. This innovative design shows superior performance across various loading conditions and addresses critical factors such as wall-footing interfaces, concrete properties, and post-tensioning forces. It highlights benefits such as faster construction, customization, cost savings, and enhanced environmental sustainability. Specifically, it recommends PSRWs for use in urban, remote, and waterfront sites where space and time are limited. Testing of full-scale precast concrete T-shaped segment walls revealed that increasing wall aspect ratios affected stiffness and ductility differently, with shorter walls needing higher post-tensioning forces. The findings suggest that PSRWs with low aspect ratios are ideal for earth-retaining structures, while those with larger ratios are better for water-retaining applications. Unbonded PSRWs offer increased ductility and self-centring, making them particularly suitable for seawalls.

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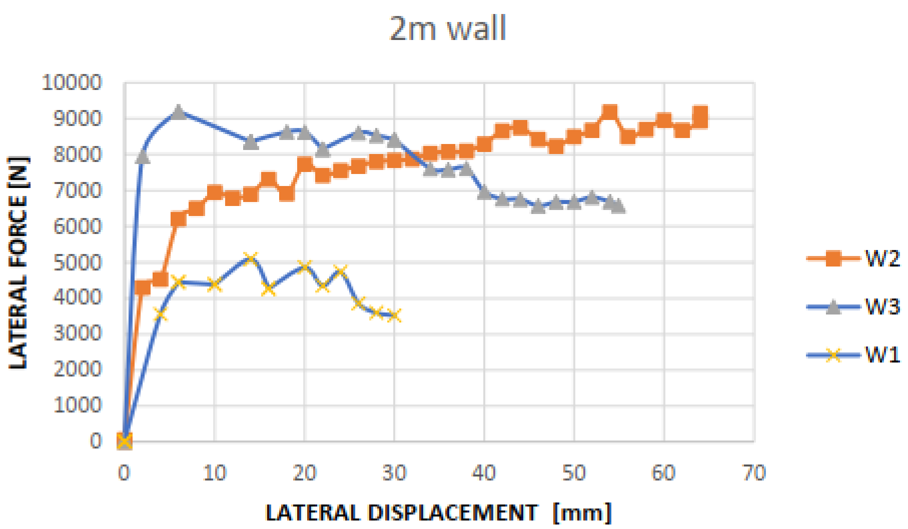
DETAILED DESCRIPTION OF EMBODIMENTS

This section explains the design required for a 2m tall PSRW to clarify the process to use PSRW system for other heights. The proposed PSRW in this application only includes 2,3, and 4m tall PSRWs. This application only includes the wall's structural requirements of the retaining wall and does not include foundation sizes. The foundation sizes can be calculated using first principles of civil engineering to provide global stability for the retaining wall.

See Figure-1 and Figure-2 for precast segment height, web and flange, PT duct locations) required to design and build a 2m tall PSRW.

Once the precast segment size is adopted from the table for the respective wall height, Precast PSRW matrix shown in Figure-2 can be used to either select W1, W2 or W3 specifications (each comes with a different PT force providing different stiffness, strength and ductility to the structural system).

The below graph can be used to calculate the lateral strength and expected lateral displacement of the PSRW. The ultimate strength of the wall is the peak point of the presented graph. The below graph is plotted under the assumption that a point load is acting on top of the wall.



Below figure shows the lateral point load location to plot the above graph:

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POST TENSIONED SEGMENTAL RETAINING WALL

TECHNICAL FIELD

The Post Tensioned Segmental Retaining Wall (PSRW) sought to improve retaining wall practices by integrating post-tensioning into segmental walls, addressing issues of localised failures and inefficiencies in conventional methods.

BACKGROUND OF THE INVENTION

Retaining walls are often constructed to retain water or soil. Their construction, particularly in urban developed areas can be challenging because of time and often space restrictions. Construction of retaining walls using conventional methods in remote areas is also a challenge due to limitations in the availability of construction materials or labour. Safer and more economical solutions and, delivery of projects in less time with limited budgets have become an inseparable part of everyday engineering practice. A conventional reinforced concrete retaining wall construction may involve the construction of formwork, placement of reinforcement and concrete followed by curing. All these processes are time-consuming and add to the project cost.

The use of pre-cast concrete, with or without prestressing, has significantly increased due to its advantages over cast-in-site concrete. The advantages include, but not limited to, higher strength, good quality control, and quicker construction time leading to higher economic and environmental benefits.

This invention is a new type of retaining wall, namely, the Post-tensioned Segmental Retaining Wall (PSRW) system and Post-tensioned Mechanically Stabilised Earth Wall (PT-MSEW) and a hybrid. Cantilever-type PSRW, which is very similar in behaviour to conventional cantilever retaining walls with the only difference being modular pre-cast units for construction and post-tensioning.

In this proposed system, the external stability of the retaining wall is achieved through a cantilever action. The cantilever foundation provides additional resistance against overturning and sliding forces, ensuring the overall stability of the wall. By combining the internal stability provided by PT and the external stability offered by the cantilever foundation, a robust and structurally adequate retaining wall system can be achieved.

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This approach offers potential advantages in terms of construction simplicity, reduced material requirements, and improved cost-effectiveness. However, it is important to carefully consider the design and ensure that the PT forces, segments configuration and foundation design are appropriately selected to provide the necessary stability and structural performance. The documentation provided sets the structural system requirements.

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SUMMARY OF THE INVENTION

The PSRW retaining system can be customised for different types of foundations and can be adjusted to exhibit self-centring behaviour. This can be achieved by leaving the PT reinforcement unbonded or making it less flexible through grouting (bonding) the PT reinforcement.

The suggested PSRW consists primarily of three components. Firstly, there are T-shaped precast concrete segments stacked on top of each other having dry joints (no mortar) that are post-tensioned. Secondly, horizontal lightweight infill panels (made of concrete or timber) are placed between the two post-tensioned elements. Lastly, the foundation can be either shallow or deep depending on the soil conditions at the site, which provides global stability to the retaining system. Alternatively, the segment can be post-tensioned to a pile. Lateral pressure is exerted on the lightweight panels and transmitted to the lateral force transfer system, which is the post-tensioned element. This force is then transferred to the foundation or pile.

The PT-MSEW retaining system consists of a levelling pad and wall face precast segments that are stacked on top of each other using dry joints and post-tensioning with horizontal lightweight infill panels. Horizontal soil reinforcements, such as geogrids or reinforcing strips, are then placed at regular intervals within the backfill layers of the wall. These reinforcements are essential for providing tensile strength and overall stability of the system. A limited number of previous studies in the literature show that in masonry retaining walls using prestressing as a clamping force can enhance its lateral stability.

PSRW can be adopted for a design to suit a wide range of situations (e.g., space limitation, different retained heights). For the proposed PSRW wall, construction time can be significantly reduced because all elements of the wall are prefabricated off-site and can be handled and installed on-site. Some of the other potential benefits of the PSRW walls include better quality control in precast concrete, flexibility to use different self-centring capacities of the wall (unbonded PT), applicability for retaining soils as well as waterfront structures, and low repair costs. The PSRW wall system can also be an appropriate option for temporary retaining walls.

Modular construction offers a range of advantages, including the ability to quickly disassemble and reuse segments and wall elements in other projects. This feature brings about several benefits, such as cost savings, environmental sustainability, and enhanced project flexibility. Firstly, the reusability of modular components reduces the need for new materials and

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minimizes waste, resulting in significant cost savings. Additionally, the streamlined construction process associated with modular construction often leads to shorter project timelines and reduced labour costs. Secondly, the reusability aspect aligns well with sustainability objectives, as it reduces energy consumption, carbon emissions, and construction waste. This contributes to a more circular economy and helps minimize the environmental impact of construction projects. Thirdly, modular construction offers enhanced project flexibility, allowing for easy modifications and expansions. Segments and wall elements can be disassembled and reused, accommodating changing needs without extensive demolition or reconstruction. Moreover, the controlled factory environment in modular construction ensures high-quality components, which carry forward when they are reused in other projects. Finally, the time and labour efficiency of modular construction is further optimised when reusing components, enabling faster project completion and potential cost savings. Overall, the advantage of quick disassembly and reusability in modular construction brings multiple benefits, making it an attractive option for various projects.

PSRW walls would also be constructed to a much larger height than previously possible with conventional techniques. Previous research on the integrity of segmental PT elements suggested that a certain range of stress ratios is required. It may be possible to retain any required height if the integrity of concrete elements and the global stability of the retaining system is maintained.

Flood barriers and water-retaining structures are vital for protecting coastal and urban areas against erosion and inundation. However, conventional construction methods and materials used in these structures, such as timber and steel, have limitations in terms of durability and susceptibility to decay or corrosion. This has led to the exploration of alternative systems, including glass flood defences and modular GFRP hollow profiles, to improve the longevity and performance of water retaining structures. Concrete has emerged as a more suitable material due to its resistance to deterioration, and precast concrete has been identified as a viable alternative for constructing water retaining walls in challenging environments.

The current design practices for water retaining structures focus on material properties and wall dimensions, often resulting in heavy and expensive gravity walls which requires planning and execution long before the flood event requiring heavy machinery. These conventional structures may require additional mass to withstand various loads, such as wave impacts, earthquakes, and buoyancy. However, the increased mass can have adverse effects on inertia forces during seismic events. To address these shortcomings, PSRWs have been proposed as an innovative alternative. In PSRWs, T-shaped precast concrete segments are stacked with dry joints, and the structural stability relies on post-tensioning forces rather than wall mass. PSRWs offer a large ductility capacity and self-centring behaviour, making them more flexible and capable of reducing lateral pressures during flood or inundation events. The wall can also be applied for temporary flood barriers, assembled and disassembled quickly with minimum labour required. The conventional flood barrier structures may require piles to provide global stability to the retaining system, which can be time-consuming having a long lead time due to limited available resources. However, the proposed PSRW system components can be prefabricated off-site, including the foundation and transported to areas of interest in case of emergencies.

The introduction of PSRWs brings two post-tensioning methods: bonded and unbonded. Bonded PSRWs involve encapsulating the post-tensioning reinforcement permanently with grout, providing corrosion protection and higher load capacities. On the other hand, unbonded PSRWs eliminate the need for grouting and allow for easy stressing, de-stressing, and re-stressing of the post-tensioning reinforcement. Unbonded PSRWs exhibit self-centring behaviour and reduce residual deformation and damage. The research aims to investigate the effects of PSRW aspect ratio, post-tensioning force, and bonding condition on the structural performance of the system, particularly for seawall and flood barrier applications. The study examines variables such as damage patterns, hysteretic behaviour, load-carrying capacity, joint openings, concrete strains, and plastic hinge length to evaluate the feasibility and effectiveness of PSRWs. The findings of this research contribute to the development of an accelerated retaining wall construction method suitable for water retention.

The proposed PT-MSEW system has the potential to reduce or completely remove many of the failure modes commonly observed in conventional MSE walls. Due to similarities of the PT-MSEW system, with MSE walls, understanding the failure modes of an MSE wall would be required. Failure modes in an MSE wall system can be categorised into three clusters, i.e., external, internal, and facing. External instabilities include base sliding, overturning and soil bearing failure. Internal failure modes include pull-out of reinforcements, tensile overstress and internal sliding. Facing failures include connection failure, bulging sliding of face segments at joints and toppling of wall face segments. Internal water (like leaking drainage systems, broken water mains, and infiltrating or perched water) and external water (like water from the retained zone, tension cracks and elevated water levels) accounted for 37% and 23%

of the facing failures, respectively. The post-tensioning force introduced in the PT-MSEW system increases the shear resistance and bending capacity of the face segments against horizontal pressure exerted on the wall face segments by internal hydrostatic pressure as well as soil pressure. The wall face failure due to internal or external water can be directly solved using PT of the facing elements as proposed in the PT-MSEW system.

It may be anticipated that in a PT-MSEW system, PT in the wall face segments may increase its rigidity. The increased wall face rigidity in MSE walls can significantly reduce soil reinforcement (geogrids or geotextiles) forces leading to reduced soil reinforcement length. This is combined with the speculation that a PSRW system can be designed as a combination of cantilever and PT-MSEW types, which would allow construction in narrow or tight spaces as well as to greater heights. The footing slab, along with the soil reinforcement, will actively participate in maintaining the external stabilities (safe against sliding, overturning, and bearing capacity failure).

One interesting aspect of the proposed PSRW system is the potential removal of soil reinforcement in the design of segmental retaining walls. Typically, segmental retaining walls incorporate soil reinforcement elements, such as geogrids or geotextiles, to provide internal stability for the wall as a reinforced soil mass retaining the backfill soil. However, this study explores the possibility of relying solely on PT providing wall's structural integrity to face precast segments, while utilising a cantilever foundation or a rigid pile cap (connected to precast wall face segments via PT) for global stability against sliding and overturning.

By incorporating PT into the retaining wall system, the internal stability can be significantly improved. The PT force applied to the wall helps to counteract the lateral earth pressure acting on the wall face, reducing horizontal displacement, and enhancing overall stability. This allows for a more efficient and simplified design, as the need for soil reinforcement elements is eliminated. Removing soil reinforcement can also offer cost savings in terms of material and construction stages. The soil behind the wall does not need to be compacted and meet high standard requirements.

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BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is indicates the temporary bracing required for assembly of the wall, main structural components and dimensions annotations.

Figure 2 and 3 shows the wall designations, dimensions and structural requirements for wall heights up to 4m tall. This figure also includes force-displacement curves that enables the designer to calculate the strength and deflections of the wall depending on the forces acting behind it.

Figure 4 indicates the typical temporary brace design for 1.6m tall wall.

Figure 5 indicates the typical assembly set up and dimensions for 1m and 2m tall walls as well as formwork set up requires to construct the concrete precast segments.

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CLAIMS

1. A PSRW suitable for 2,3, and 4m tall retaining system made of precast reinforced concrete

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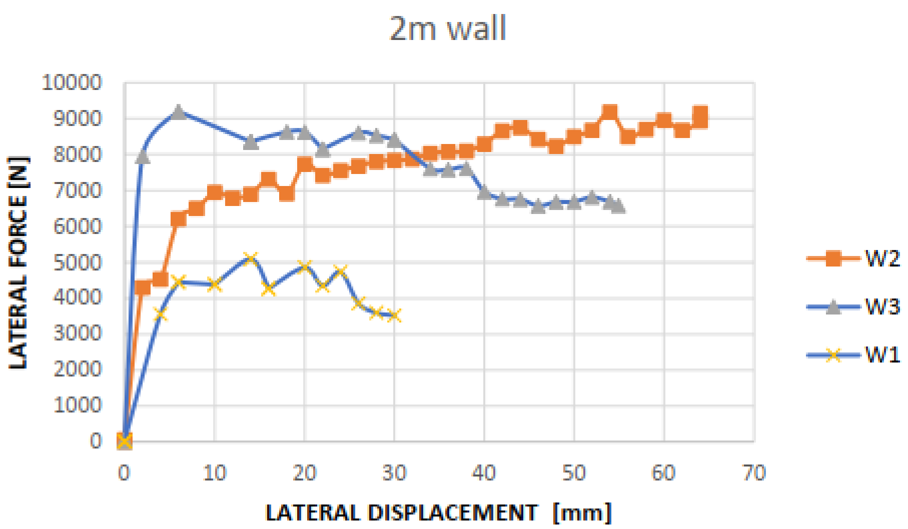

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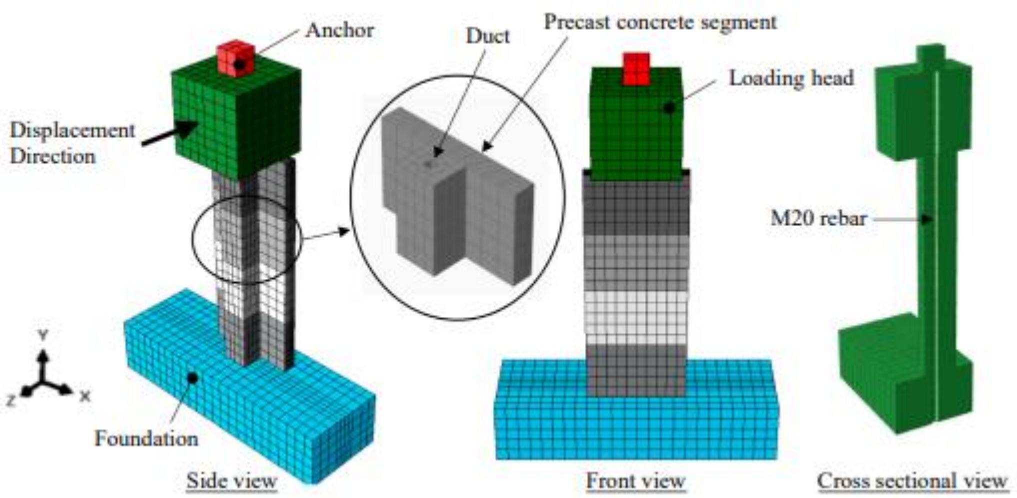

Similar approach can be used to specify a PSRW for 3, and 4m tall retaining system.

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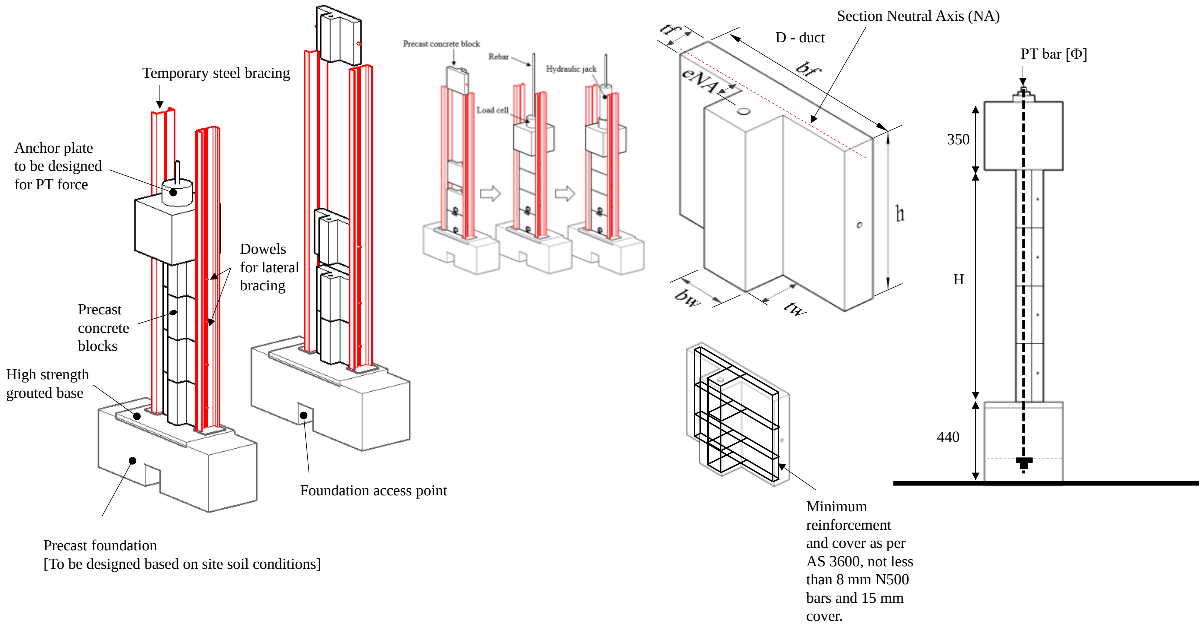

Figure 1

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Precast PSRW matrix										
Wall designation in design guide		**W1**	**W2**	**W3**	**W4**	**W5**	**W6**	**W7**	**W8**	**W9**
Wall height [H]		2.0	2.0	2.0	3.0	3.0	4.0	4.0	4.0	4.0
Axial stress ratio		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Eccentricity		0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Concrete f'c [Mpa]		36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5
PT force [kN]		105.6	214.7	258.3	192.0	472.5	300.9	619.1	746.4	810.0
PT bar size Φ [m]		0.020	0.020	0.020	0.028	0.028	0.036	0.036	0.036	0.036
PT stress [MPa]		336.5	683.7	822.6	311.9	767.7	295.8	608.5	733.7	796.2
PT str/PT ult		0.31	0.62	0.75	0.28	0.70	0.27	0.55	0.67	0.72
Section designasion		2.0	2.0	2.0	3.0	3.0	4.0	4.0	4.0	4.0
PT duct diameter [mm]		30.0	30.0	30.0	32.0	32.0	40.0	40.0	40.0	40.0
Wall height [mm]	Segment dimensions [mm]									
	bf	tf	tw	bw	h	Ixx [mm4]	Sxx [mm3]	Ag[mm2]	eNA	Section number
1000	420	60	100	120	250	69585806	667851	37200	54	1
2000	450	95	100	170	500	161944458	1352248	59750	70	2
3000	640	120	150	220	1000	574703852	3392060	109800	94	3
4000	830	145	200	270	1000	1500028088	6847161	174350	119	4

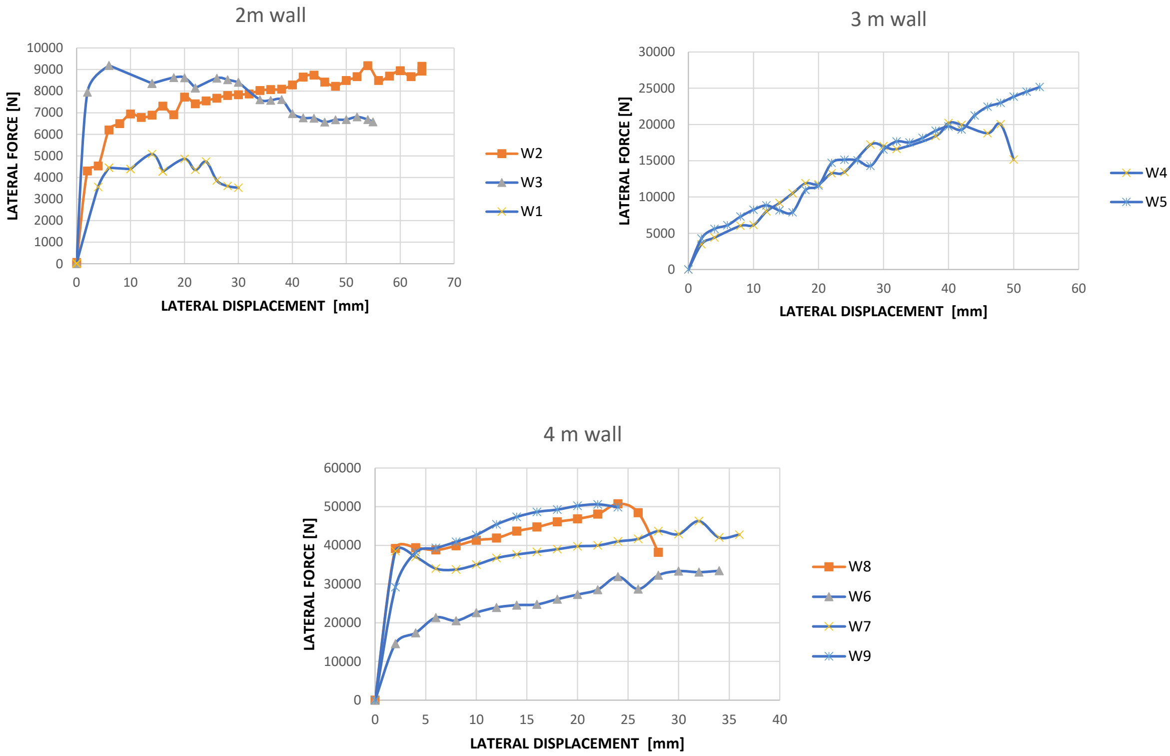

Figure 2

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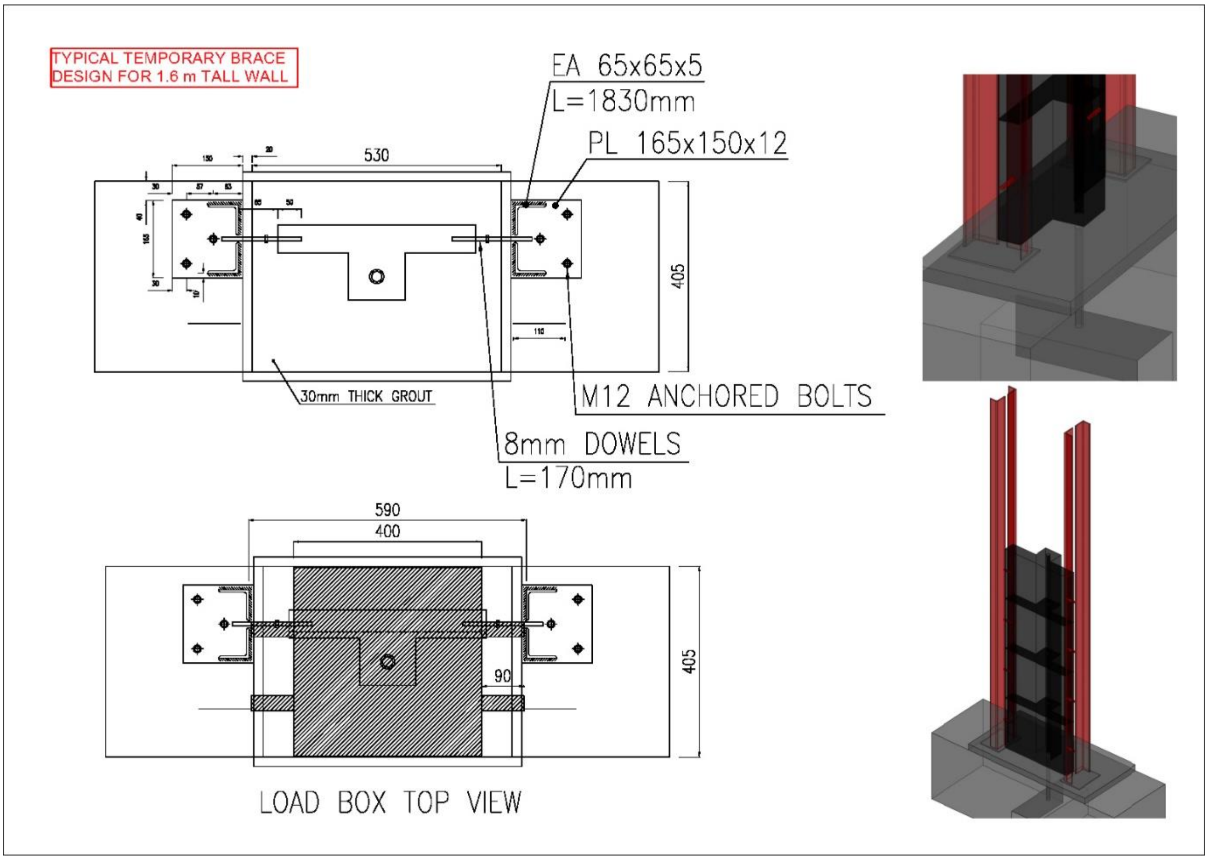

Figure 3

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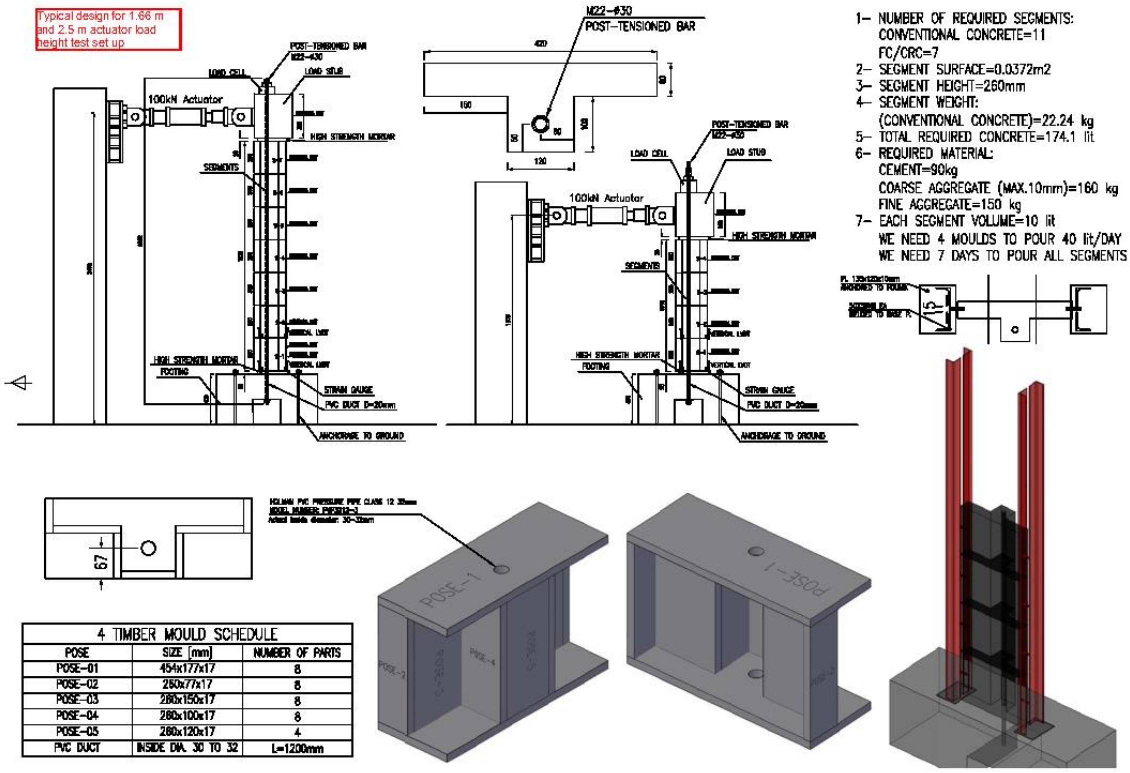

4 TIMBER MOULD SCHEDULE		
POSE	SIZE [mm]	NUMBER OF PARTS
POSE-01	454x177x17	8
POSE-02	260x77x17	8
POSE-03	260x150x17	8
POSE-04	260x100x17	8
POSE-05	260x120x17	4
PVC DUCT	INSIDE DIA. 30 TO 32	L=1200mm

Figure 4