MANUAL FOR DESIGN OF BAMBOO STRUCTURES

2025

बाँस संरचना डिजाईन मार्गदर्शन - २०८२

Government of Nepal
Ministry of Urban Development
Department of Urban Development and Building Construction
Babarmahal, Kathmandu

“बाँस संरचना डिजाईन मार्गदर्शन – २०८२”

(Manual for Design of Bamboo Structures – 2025)

मा. कुलमान घिसिङ
मन्त्री
शहरी विकास मन्त्रालय
सिंहदरबार, काठमाडौं, नेपाल

Hon'ble Kul Man Ghising
Minister
Ministry of Urban Development,
Singhadurbar, Kathmandu, Nepal

पत्र संख्या/Let. No.:
चलानी नं./Ref. No.:

MESSAGE

It is with immense pleasure and a sense of pride that I extend my endorsement to the *Manual for the Design of Bamboo Structures - 2025*, a significant stride towards advancing sustainable, affordable, and eco-friendly approaches in the nation's physical infrastructure and housing development. This manual provides a comprehensive and scientifically grounded framework for the structural use of bamboo in buildings. It incorporates recent research findings, international practices, laboratory testing and contextualized engineering solutions suitable for Nepal's varied geophysical and climatic conditions. By offering clear design principles, technical specifications and practical guidance, this publication equips engineers, architects, builders, and local governments with the tools needed to responsibly and effectively utilize bamboo in the built environment.

This initiative masterfully bridges our indigenous, locally available bamboo—deeply rooted in Nepal's terrain and traditional knowledge—with cont0emporary construction technology. Acknowledging the economic burden, environmental impact, and limited rural accessibility associated with over-reliance on materials like steel and concrete, this manual opens an alternative avenue for building cost-effective, durable, and natural structures. Bamboo is a fast-growing, renewable resource with excellent carbon sequestration capacity. By promoting its structural use, we not only encourage affordable housing but also empower families living below the poverty line to access durable shelters.

Furthermore, this manual incorporates detailed technical criteria covering everything from harvesting, grading, and chemical treatment to storage and application. The publication of this manual marks a historic step towards adding economic value to locally produced bamboo, generating employment, and promoting green construction technology. I am confident that it will equally inspire architects, engineers, builders, local governments, and communities, fostering a culture of bamboo-based construction from villages to cities across the country.

I extend my heartfelt gratitude to all the technical experts, academic institutions, stakeholders, and the dedicated officials and staff of the Department of Urban Development and Building Construction (DUDBC), Ministry of Urban Development whose invaluable contributions made this manual possible. Following their translation and simplification into Nepali, this manual will pave the way for the creation of formal bamboo building codes and standards. It is my sincere expectation that all the concerns will effectively implement this guideline and actively promote bamboo-based construction practices.

Kulman Ghising
Minister of Urban Development

December, 2025

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Phone : 977-01-4200034, 4200035 | Fax : 977-1-4200246 | Website : www.moud.gov.np

Government of Nepal
MINISTRY OF URBAN DEVELOPMENT
Phone : 4211693, 4211883, 4211673
Fax : 977-1-4211873
Singhadurbar,
Kathmandu, Nepal

Ref. No.:-

Government of Nepal
Ministry of Urban Development
Singhadurbar, Kathmandu

Foreword

It is with great pride that the Ministry of Urban Development is publishing the National Guideline for Bamboo Structure a landmark document that reinforces Nepal's commitment to building safer, more inclusive and more sustainable cities and settlements. Guided by our national vision of creating well-organized, clean and beautiful urban spaces with reliable infrastructure and services this guideline marks a significant step toward expanding access to safe, affordable and environmentally responsible housing for all.

As Nepal continues to urbanize rapidly, the demand for resilient and cost-effective construction solutions has never been greater. Bamboo, which is abundant, renewable, and structurally versatile, offers tremendous potential as a nature-based, low-carbon building material. With this design manual, the Ministry provides clear standards, technical specifications and regulatory direction to ensure bamboo structures are designed and constructed with safety, durability and aesthetic integrity.

This document also reflects the Ministry's broader mandate to formulate and implement policies, laws, standards, and regulations that advance urban development, promote safe and comfortable buildings, support housing for marginalized, poor and vulnerable population and strengthen national urban infrastructure. It aligns with our work in updating the National Building Code promoting orderly and well-equipped settlementsand mobilizing national and international cooperation for sustainable urban growth.

The "Manual for Design of Bamboo Structure-2025" is the result of multi-year technical study, consultation and collaboration among government agencies, experts, development partners, and communities. Its endorsement represents not only a regulatory milestone but also a renewed commitment to innovation, resilience and equity in Nepal's built environment.

I would like to acknowledge the efforts made by the Department of Urban Development and Building Construction. Likewise, the staff of the MoUD who have provided their valuable feedback and guidance deserve immense recognition. I would also like to extend my gratitude to Ms. Eliza Sthapit, National Director of Habitat for Humanity Nepal for their support to prepare this design manual. Last, but not least, I would like to extend my gratitude to all the professionals who were engaged in the process of preparing this document for giving it a final shape.

Er. Gopal Prasad Sigdel
Secretary
Ministry of Urban Development

Government of Nepal
Ministry of Urban Development
Department of Urban Development and Building Construction
Babarmahal, Kathmandu

Ref. No. :-

ACKNOWLEDGEMENT

Nepal, as a developing country, faces unique challenges in providing affordable, durable, and sustainable housing solutions for its people. In this context, bamboo emerges as an essential eco-friendly and green construction material that aligns with our goals of sustainability and resilience.

Traditionally, bamboo has been used in various forms of construction across Nepal. However, we believe that the Manual for Design of Bamboo Structure will mark significant advancement by focusing on the use of treated bamboo, which offers enhanced durability and enables construction of permanent bamboo structures. This approach not only provides a viable solution for the marginalized communities who often need safe and secure housing but also opens bamboo as a viable alternative structural material for entire Nepalese people.

The benefits of using treated bamboo are manifold. It is a lightweight material, making it easier to handle and transport, and its natural flexibility makes it less vulnerable to seismic activities, a crucial consideration in our earthquake-prone region. Moreover, bamboo is a renewable resource, contributing to our efforts to promote green and sustainable construction practices. Crucially, bamboo can be sourced locally, thus promoting local production and consumption, and ultimately increasing Nepal's economy.

This design manual has been meticulously developed to provide clear and practical instructions for the use of bamboo in construction. By following these recommendations, we can build structures that are not only affordable, durable, and structurally safe but also environmentally responsible. This initiative represents a step forward in our commitment to improving the quality of life for all, particularly those in marginalized communities.

On behalf of the Department, I would like to thank respected Secretary MoUD and my predecessors who collaborated Habitat for Humanity Nepal in preparing this Manual. We are grateful to Habitat for Humanity Nepal for providing the technical support. I would like to extend sincere gratitude to all the experts, academia, stakeholders and all Department staff who provided their invaluable comments and suggestions for the development of this document.

Er. Rabindra Bohara
Director General
Department of Urban Development and Building Construction

Phone No. : +977-1-5362927, 5362367, 5357912, 5362594, 5363406
E-mail: info@dudbc.gov.np, Website: www.dudbc.gov.np

Foreword

At Habitat for Humanity, our vision is a world where everyone has a decent place to live. By 2028, we aim to improve housing conditions for 2.75 million Nepali people through affordable, sustainable, inclusive, and resilient homes. As climate change intensifies, Nepal continues to face significant losses each year due to recurring natural hazards, leaving communities vulnerable and weakening local economies. The need for eco-friendly housing solutions has become urgent, requiring us to rethink conventional construction practices.

Among Nepal's natural resources, bamboo stands out as an affordable, durable, renewable, and culturally significant construction material. Yet, it remains underutilized in mainstream housing due to the absence of clear standards. Only a limited number of homes nationwide use bamboo, often without consistent construction quality. Through strong partnerships with government, communities, and the private sector, Habitat Nepal has piloted and demoed bamboo technologies such as cement bamboo frame technology (CBFT) that meet high-quality standards in the southern plains of Nepal. This underscores the opportunity that standardized guidelines for construction with bamboo can unlock by promoting wider adoption of treated bamboo as a reliable, structurally sound, green construction material.

The endorsement of this document for the design of bamboo structure is a pivotal step towards expanding similar bamboo housing technologies on a larger scale. By standardizing bamboo construction practices, bamboo can be more widely integrated into the construction sector. We extend our sincere gratitude to the Ministry of Urban Development, Department of Urban Development and Building Construction, local governments, the Hilti Foundation, Base Bahay Foundation, private sector partners, and development partners for this significant milestone.

This guideline marks the start of a transformative shift toward a greener, more sustainable future for Nepal.

Habitat For Humanity International ★ Nepal ★

Eliza Sthapit
National Director
Habitat for Humanity Nepal

PREFACE

The *Manual for the Design of Bamboo Structures - 2025* has been prepared to provide a comprehensive and technically sound reference for the analysis design and construction of engineered bamboo structures in Nepal. With increasing interest in sustainable and resilient building materials, bamboo has emerged as a viable, affordable, and environmentally responsible alternative for housing and community infrastructure. This manual consolidates research findings, experimental results, global practices, and nationally relevant design provisions into a unified guideline that supports safe and durable bamboo construction.

This document outlines the engineering principles required for designing bamboo structures using braced frames and composite bamboo shear wall systems. It presents detailed information on bamboo material properties, harvesting and grading procedures, chemical treatment, durability considerations, structural modeling and design requirements for beams, columns, joints, trusses and panels as a shear wall. The manual also includes annexes covering testing procedures, storage requirements, good practices for durability and sample design calculations.

The development of this manual was made possible through an extensive, collaborative effort among government agencies, academic institutions, development partners, technical experts and research organizations. The Department of Urban Development and Building Construction (DUDBC) expresses sincere gratitude to all individuals and institutions whose contributions, guidance, and expertise were instrumental in shaping this document.

The whole document has been spread over 4 chapters with 4 ANNEXES separately for harvesting, chemical treatment, storage and sample design calculations.

We extend heartfelt appreciation to:

Building Construction Management Upgrading (Consolidation) Committee

Building Construction Management Upgrading (Consolidation) Committee consists of the following experts and professionals:

Er. Gopal Prasad Sigdel, Secretary, Ministry of Urban Development	Chairperson
Representative, National Planning Commission	Member
Representative, Ministry of Law, Justice and Parliamentary Affairs	Member
Member-Secretary, Nepal Quality Standards Council	Member
Representative, Dean Office, Institute of Engineering TU	Member
Representative, Ministry of Federal Affairs & General Administration	Member
Representative, Research Centre for Applied Science & Technology	Member
Ar. Bharat Sharma, Expert	Member
Er. Manohar Raj Bhandari, Export	Member
Er. Machakaji Maharjan, Director General, DUDBC	Member Secretary

Advisory Committee

Advisory Committee consists of the following experts and professionals:

Er. Prakirna Tuladhar, Deputy Director General, DUDBC	Coordinator
Er. Sudip Acharya, SDE, Urban Infrastructure Technology Research and Training Centre, MoUD	Member
Ar. Kishor Shrestha, Section Chief, Maintenance, Evaluation and Byelaws Section-DUDBC	Member
Ar. Dipak Shrestha, Section Chief, Health Building Section-DUDBC	Member
Ar. Nisha KC, Section Chief, Building Design and Services Section-DUDBC	Member
Er. Anil Shakya, SDE, Representative, Nepal Bureau of Standards and Metrology	Member
Prof. Dr. Gokarna Bahadur Motra, Representative, Institute of Engineering, Pulchowk Campus	Member
Representative, Nepal Engineers' Association	Member
Representative, Structural Engineers' Association Nepal (SEANep)	Member
Representative, Society of Nepalese Architect	Member
Er. Manohar Raj Bhandari, Structural Engineer, Expert	Member
Er. Manoj Nakarmi, Section Chief, Building Code Section, DUDBC	Member Secretary

Working Committee

Working Committee consists of the following experts and professionals:

Er. Manoj Nakarmi, Section Chief, Building Code Section, DUDBC	Coordinator
Er. Rudra Narayan Mishra, Engineer, Building Design and Services Section-DUDBC	Member
Er. Madhav Katwal, Engineer, Building Code Section-DUDBC	Member
Er. Bibek Nepal, Engineer, Building Code Section-DUDBC	Member
Er. Ashish Karki, Engineer, Urban Infrastructure Technology Research and Training Centre, MoUD	Member
Er. Alisa Siwakoti, Engineer, Health Building Section-DUDBC	Member
Ar. Samriddhi Baidar, Engineer, Maintenance-Evaluation and Byelaws Section-DUDBC	Member
Asso. Prof. Dr. Kshitiz Charan Shrestha, Representative, Institute of Engineering, Pulchowk Campus	Member
Er. Debendra Dev Khanal, Structural Engineer, DUDBC	Member Secretary

Guidance to this revision came from:

Ar. Padma Kumar Mainali, Former Director General-DUDBC/ Joint-Secretary, Ministry of Urban Development

Er. Dilip Bhandari, Joint-Secretary, Ministry of Urban Development

Er. Rabindra Bohara, Director General, DUDBC

Er. Sunil Kumar Thakur, Deputy Director General, Building Division-DUDBC

Ar. Ekraj Adhikari, Deputy Director General, Urban Development Division-DUDBC

Ar. Prakash Aryal, Deputy Director General, Reconstruction-Rehabilitation /Retrofitting Division-DUDBC

Er. Lila Khatiwada, Deputy Director General, Housing Division-DUDBC

Er. Parikshit Kadariya, SDE, Building Section -MoUD

Er. Pradip Khanal, SDE, Housing Section -DUDBC

Er. Rupak Acharya, SDE/Section Chief, Building Code Section-DUDBC

Ar. Shyam Chandra Budhathoki, SDE, Building Section-MoUD

Ar. Mira Gyawali, Former SDE-DUDBC

Ar. Priya Barma, Engineer- Housing Section, DUDBC

Ar. Sudha Ghimire, Engineer- Housing Section, DUDBC

Er. Garima Bharati, Engineer, Building Section-MoUD

Er. Nikash Regmi, Engineer, MoUD

Er. Ugen Maharjan, Structural Engineer - DUDBC

Er. Suraj Kafle, Civil Engineer - DUDBC

Er. Ukesh Dawadi, Civil Engineer - DUDBC

Er. Prabin Regmi, Geotechnical Engineer - DUDBC

Input to prepare this document came from following Members

Mr. Abhishek Shrestha (Habitat for Humanity Nepal)

Mr. Bibek Shrestha (Habitat for Humanity Nepal)

Mr. Angelito Mangalili (Structural Engineer, Base Bahay Foundation)

Mr. Anshu Kumar Pal (Structural Engineer, Habitat for Humanity Nepal)

Mrs. Anusha Manandhar (Habitat for Humanity Nepal)

Mr. Bharat Mandal (Associate professor, Institute of Engineering Pulchowk Campus)

Mr. Jese Mar Gallarde (Civil Engineer, Base Bahay Foundation, Inc.)

Mrs. Jyoti Bhandari (Habitat for Humanity Nepal)

Mr. Luis Felipe Lopez (General Manager, Base Bahay Foundation, Inc.)

Mr. Nischal Prasad Nhuchhe Pradhan (MBUST; Head of Base Innovation Center, Base Bahay Foundation, Inc.)

Mrs. Salina Pradhan (Habitat for Humanity Nepal)

Mr. Vembee Gohetia (Structural Engineer, Base Bahay Foundation, Inc.)

Mr. Sarowar Poudel (MSc Student, Institute of Engineering Pulchowk, Central Material Testing Laboratory)

Mr. Saurav Ghimire (Research Assistant- Institute of Engineering Pulchowk Campus)

Mr. Sushant Dahal (Research Assistant - Institute of Engineering Pulchowk Campus)

Academic and Research Support

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The DUDBC extends deep appreciation to all individuals and organizations who contributed directly or indirectly to this effort. Their expertise and dedication have ensured that this manual reflects the latest research, tested practices, and contextual understanding needed for bamboo-based construction in Nepal. We hope this manual will serve as a valuable resource for designers, engineers, builders and institutions committed to promoting safe, resilient and sustainable bamboo structures across the country.

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LIST OF ACRONYMS

A	Cross sectional area of a single culm member as per Section 3.3.7
A_n	Cross-sectional area of multiple culm member as per Section 3.3.7
A_a	Seismic base shear coefficient
A_p	Roof area (in m^2) including eaves, for one-story homes, can be replaced by $\frac{2A_p}{3}$ if light materials (e.g. metal sheets) are used for roof cover. Mezzanine area plus roof area (in m^2) for the ground floor walls in one-story with mezzanine house, can be replaced by $\frac{2A_p}{3}$ if light materials (e.g. metal sheets) are used for floor decking and roofing.
ΣA	Sum of cross-section area of all individual culms comprising the member
a	distance between maximum moment and nearest point of contraflexure; assume $a = L/2$ for simply supported beam of length L with uniformly distributed load
α_e	External taper
B	Moment amplification factor
b	Length of composite bamboo shear wall (CBSW) panel
b_{max}	Maximum perpendicular distance from the center of the culm cross section to the chord drawn from the centers of the ends of a bamboo pole
b_o	Maximum measured bow at mid-length of culm comprising compression member
C_B	Coefficient as a function of the seismic base shear acceleration coefficient at the location of the building
C_{bow}	Reduction factor to account for an initial bow in culms comprising a compression member
C_{DE}	Modification factor for service class and load duration for modulus
C_{DF}	Load duration factor for resistance and strength
C_{EB}	Modification factor for end bearing condition
C_R	Member redundancy factor given in Table 8
C_T	The modification factor for service temperature given in Table 2Table 2 : Elevated Service Temperature Factor, C_T. This factor shall be applied for structural members that will experience sustained exposure to elevated temperatures up to 65 °C. The factor is not required for transient elevated temperature exposure of less than 3 hours.
C_v	Modification factor accounting for shear deformations
C_g	Reduction coefficient per group
$C_h(T)$	Spectral Shape Factor coefficient as per NBC105:2020
D	Nominal culm diameter determined from a grading procedure in accordance with Section III of Annex C
D_b	Average of two perpendicular outer diameters measured at the base of the pole
D_t	Average of two perpendicular outer diameters measured at the top of the pole
Δ_u	Ultimate joint displacement
Δ_y	Yield joint displacement
e	Edge distance of splicing plate (bamboo/ wooden/ metal)

E_d	Allowable Young's Modulus of Elasticity
E_k	Characteristic bending Young's Modulus of Elasticity
$(EI)_d$	Allowable flexural stiffness
F_c	Compression force in end member of CBSW resisting overturning moment
F_T	Tensile force in end member of CBSW resisting overturning moment
F_{resf}	Restraint force-oriented perpendicular to the principal axis of an axial load carrying or flexural member
F_{resc}	Force oriented perpendicular to the principal axis of the member about which restraint is being calculated
FS_j	Joint factor of safety given in Table 17
FS_m	Material factor of safety given in Table 4
$F_{y,k}$	5^{th} percentile characteristic resistance of joint with 75% confidence
$F_{y,d}$	Allowable joint capacity
$F_{c,d}$	Design compression force acting on the member
$F_{t,d}$	Design tension force acting on the member
F_b	End bearing resistance of unfilled bamboo culms
$F_{e,r,d}$	Allowable buckling resistance of a member
$F_{v,r,d}$	Allowable shear resistance of a member
$F_{cc,r,d}$	Allowable compression resistance of a member
$F_{c,r,d}$	Allowable crushing resistance of a member
$F_{t,r,d}$	Allowable tension resistance of a member
f'_{gr}	Minimum compressive strength of grout infill
$f_{c,d}$	Allowable compression strength parallel to fibers (i.e. Along the length of a bamboo pole)
$f_{i,d}$	Allowable strength; for e.g. equals $f_{c,d}$ when representing allowable compression strength parallel to fibers
$f_{i,k}$	5^{th} percentile characteristic strength with 75% confidence
$f_{m,d}$	Allowable bending strength parallel to fibers
$f_{t,d}$	Allowable tensile strength parallel to fibers
f_c	Compressive strength parallel to fibers
f_m	Bending strength parallel to fibers
f_v	Shear strength parallel to fibers
$f_{t,90}$	Tensile strength perpendicular to fibers
$f_{m,90}$	Bending strength perpendicular to fibers
$f_{t,90,d}$	Allowable tension strength perpendicular to fibers
$f_{m,90,d}$	Allowable bending perpendicular to fibers
$f_{v,d}$	Allowable shear strength parallel to fibers
$f_{c,k}$	Characteristic 5^{th} percentile compression strength parallel to fibers with 75% confidence
$f_{m,k}$	Characteristic 5^{th} percentile bending strength parallel to fibers with 75% confidence
$f_{v,k}$	Characteristic 5^{th} percentile shear strength parallel to fibers with 75% confidence
$f_{t,k}$	Characteristic 5^{th} percentile tensile strength parallel to fibers with 75% confidence

$f_{t,90,k}$	Characteristic 5th percentile tension strength perpendicular to fibers with 75% confidence
$f_{m,90,k}$	Characteristic 5th percentile bending strength perpendicular to fibers with 75% confidence
$f_{t,m,90,k}$	Characteristic 5th percentile tensile strength perpendicular to fibers with 75% confidence
h	Height of the building measured from the base to the highest floor or mid-point of roof
i	Axis of analysis
I	Moment of inertia of a single culm
I_n	Moment of inertia of multiple culm members, taken as sum of moment of inertia of single culm members, Section 3.3.7
I_{min}	Minimum moment of inertia of the individual culms comprising a member
K	Effective length coefficient for bamboo members
k_e	Stiffness of a joint
$k_{e,k}$	Mean characteristic joint stiffness with 75% confidence
$k_{e,d}$	Allowable joint stiffness
k_m	Axial stiffness of the member without end-connections
L	Working length of axial load carrying member between points of lateral restraint
L_i	Minimum length of the wall along direction i
L_s	Splicing length
L_{xi}	Length of a braced wall i along the direction X
L_{yi}	Length of a braced wall i along the direction Y
L_{ref}	Reference length of the pole, equal to the typical length of the structural member
$M_{r,d}$	Allowable moment resistance
M_d	Design moment acting on the member
p	Pitch distance
w_{EMC}	Equilibrium moisture content
n	Number of culms in a multi-culm member
S	Elastic section modulus of a single culm, as per Section 1.6.4
S_n	Elastic section modulus of a multiple culm member, as per Section 1.6.4
t	Nominal culm wall thickness is determined from a grading procedure in accordance with Section III of Annex C.
t_{xi}	Thickness of the braced wall of length L_{xi}
t_{yi}	Thickness of the braced wall of length L_{yi}
T	Fundamental time period of Composite Bamboo Shear Walled house (in seconds)
x_i	The distance (in m) in direction X from the vertical (Y) axis to the middle of the neutral axis of the wall i
y_i	The distance (in m) in direction Y from the horizontal (X) axis to the middle of the neutral axis of the wall i
μ	Ductility defined in Section 4.1.1. If ductility is unknown, a value $\mu = 1.25$ shall be assumed.
ρ_k	Characteristic density of bamboo culm
$\rho_{0.05,k}$	Characteristic 5th percentile density of bamboo culm with 75% confidence
$\rho_{mean,k}$	Characteristic mean density of bamboo culm with 75% confidence

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1 INTRODUCTION

1.1 BACKGROUND

This document incorporates the latest advances in bamboo construction technology to present state-of-the-art recommendations on structural design of permanent full-culm bamboo structures. Specifically, it guides the designers in performing engineered design of single story (including mezzanine floor) bamboo houses using braced frames or shear wall structural systems.

The document details requirements for bamboo poles used in structural applications, covering aspects such as harvesting, grading, chemical treatment, storage, preservative use, and best practices to ensure the long-term durability of bamboo structures. The design framework considers exposure conditions like sunlight and humidity and covers seismic and wind design using two common Nepalese bamboo species, *Bambusa nutans cupulata* (mal bans) and *Bambusa balcooa* (Dhanu or harauti bans). The design covers key structural components such as flexural members, axial load-bearing members, joints, trusses and composite shear walls, and presents formulas for calculating resistance, and deflection of these elements.

1.2 PURPOSE

This document provides the methodology for analysis and design of bamboo structures in Nepal. It is prepared for design professionals to conduct structural analysis and design of bamboo structures.

1.3 OBJECTIVE AND SCOPE

This document applies to the design of bamboo structures whose primary load bearing structure is made up of round bamboo or composite bamboo shear wall systems in which the framing members are made from round bamboo.

This document guides engineered design and construction of safe, disaster resilient and affordable bamboo houses using round bamboo poles. It presents minimum quality requirements of bamboo poles in terms of grading and treatment and specifies minimum requirements of structural design.

The following are the bamboo species covered by this document:

- *Bambusa balcooa* (Dhanu or Harauti bans)
- *Bambusa nutans cupulata* (Mal bans)

This document applies to single -story (including mezzanine) building structures not exceeding 7 m in height.

This document concerns solely the requirements for mechanical resistance, serviceability, and durability of bamboo structures.

This document uses the allowable stress design (ASD) also known as working stress design principle for the design of bamboo structures.

This document presents several modification factors C_i. These are empirically derived factors, based on best available engineering judgement, which are believed to be universally applicable to bamboo materials that are appropriate for building construction. Parameters affecting bamboo material performance are many and are addressed explicitly using experimentally determined characteristic values of strength and stiffness.

1.3.1 LIMITATIONS

This document does not apply to the following:

- Ordinary buildings with maximum area of individual floor panel not exceeding 100 square meters (area of floor panel is the clear short span times the clear long span of any room/space).
- Structures made of engineered bamboo products such as glue-laminated bamboo, cross-laminated bamboo, oriented strand, or densified bamboo materials.
- Bamboo-reinforced materials where bamboo is not the primary load-bearing constituent. This includes bamboo-reinforced concrete, masonry, and soil. Note that bamboo should not be used as a reinforcement in concrete in general.
- Scaffold structures, constructed with bamboo.

Other requirements, such as those concerning thermal or sound insulation, are not considered. Bamboo structures may require consideration of additional requirements beyond the scope of this document. Execution is covered to the extent that it impacts the quality of construction materials and products required to comply with the design requirements contained herein.

1.4 NORMATIVE REFERENCES

The following codes and standards are referred to in this document.

- ISO 12122-1:2014, Timber structures — Determination of characteristic values — Part 1: Basic requirements
- ISO 12122-5:2016, Timber structures — Determination of characteristic values — Part 5: Mechanical connections
- ISO 12122-6:2016, Timber structures — Determination of characteristic values — Part 6: Large components and assemblies
- ISO 16670:2003, Timber structures — Joints made with mechanical fasteners — Quasi-static reversed-cyclic test method
- ISO 19624:2018, Bamboo structures — Grading of bamboo culms — Basic principles and procedures
- ISO 21581:2010, Timber structures - Static and cyclic lateral load test methods for shear walls
- ISO 21887:2007, Durability of wood and wood-based products — Use classes
- ISO 22157:2019, Bamboo structures — Determination of physical and mechanical properties of bamboo culms — Test methods
- ISO/TR 21141:2022, Timber structures – Timber connections and assemblies – Determination of yield and ultimate characteristics and ductility from test data
- NBC 102:1994 Nepal National Building Code, Unit weight of materials
- NBC 103:1994 Nepal National Building Code, Occupancy load
- NBC 104:1994 Nepal National Building Code, Wind load
- NBC 105:1994 Nepal National Building Code, seismic design of buildings in Nepal (*For Load combination*)
- NBC 105:2020 Nepal National Building Code, seismic design of buildings in Nepal (*For Load calculation*)
- IS 456:2000 Plain and Reinforced Concrete - Code of Practice (*For Footing Design calculation*)

1.5 TERMS AND DEFINITIONS

ASSEMBLY OR MULTIPLE-CULM ASSEMBLY is a structural member comprised of more than one bamboo culm constructed in such a fashion that the multiple culmstogether serve as a single structural member.

BAMBOO CULM OR BAMBOO POLE is a single shoot of bamboo. A culm is comprised of the entire unaltered bamboo cross section and is usually a hollow cylinder except at nodes.

CONNECTION allows transfer of force between two elements

CROSS SECTIONAL AREA, A is an area of the section perpendicular to the direction of the longitudinal axis of the culm.

DUCTILITY, μ – ratio of the experimentally determined ultimate displacement to the yield displacement. The ratio is determined according to ISO/CD TR 21141 forjoints.

EQUILIBRIUM MOISTURE CONTENT, w_{EMC} is the moisture content at which bamboo is neither gaining moisture from, nor losing moisture to, the environment.

FIBRE SATURATION POINT, w_{FSP} is the moisture content below which only water bound in the cell walls remains, i.e., condition in which there is no free water in the cell cavities.

FLATTENED BAMBOO is an element obtained by opening the bamboo culm and making longitudinal cuts partially through the culm wall to make a flat member.

POINT OF CONTRAFLEXURE, POINT OF INFLECTION is a location of zero moment where the curvature of the member is zero.

INTERNODE is typically the hollow region of bamboo culm between two nodes.

JOINT a union of two or more members composed of one or more connections.

LASHING is a means of connecting bamboo culms bycontinuous wrapping of material around culm and joint region.

COMPOSITE BAMBOO SHEAR WALL (CBSW) is a composite bamboo shear wall system constituted from a cement mortar render applied onto strip, flattened or small diameter bamboo, which are fixed onto bamboo and/or timber studs or framing. The cement mortar render is reinforced by a small-gauge metal mesh such as “chicken wire”. An alternative technique in which the cement mortar render is applied directly onto expanded metal lath sheets, which are in turn fixed onto the frame, is also accepted.

MOISTURE CONTENT, w is a portion of culm weight consisting of water expressed as percentage of oven-dry weight.

NODE is a transverse diaphragm region located along the length of culm separating adjacent internodes.

NON-REDUNDANT, a structural member is non-redundant if there is no alternative and sufficient load path in the structure to transmit the load carried by the member in the event of its removal (member failure) from the load path. Failure of a non-redundant member leads to failure of the load path in which it is a part.

OUTER DIAMETER, D is a diameter of the cross section of a piece of bamboo, typically made near the center of an internode, taken as the average of two perpendicular measurements made across opposite points on the outer surface or calculated from a measurement of the perimeter.

SPLICE is a connection of two bamboo culms along their common longitudinal axis; used to extend the length of a structural member beyond the length of an individual culm.

BAMBOO STRIP is a bamboo piece with outer and innerlayers intact, made by cutting bamboo culm in longitudinal direction.

CULM, WALL THICKNESS, t is a thickness of wall ofbamboo culm, typically made near the center of an internode, taken as the average of four measurements takenaround the circumference of the culm at angular spacings of 90°.

WORKING POINT (structural assemblage, most often a truss) is a location where the resultants of axial loads carried by connecting members intersect.

1.6 MATERIAL PROPERTIES OF BAMBOO

1.6.1 GENERAL

This section presents characteristic material properties of bamboo poles needed for structural analysis and design.

The pertinent characteristic material properties are then multiplied by various modification factors as per design conditions to determine allowable material strengths. Finally, the allowable strengths are multiplied with corresponding geometric parameters to return component resistance or stiffness.

Component capacities are estimated for a single culm, or a multiple-culm assembly intended for use as a structural member.

1.6.2 CHARACTERISTIC MATERIAL AND COMPONENT PROPERTIES

The characteristic value of a component or material property is determined in accordance with ISO 12122-1 from experimental tests on representative samples of the population.

The characteristic value refers to 5^{th} percentile value with 75% confidence for strength (see Table 3) and resistance. This includes density (see Table 5Table 7) when it is used to derive strength or resistance, and Young's Modulus of Elasticity (see Table 7) when estimating strength or resistance (e.g. buckling).

The characteristic value refers to the mean value with 75% confidence for stiffness. This includes density (see Table 5) when estimating self-weights, and Young's Modulus of Elasticity (see Table 7) for estimating deflections.

1.6.3 ALLOWABLE STRENGTH

The allowable strength shall be determined by applying all relevant adjustment factors to the calculated characteristic material strength determined in accordance with Section 1.6.2 as given by:

$$f_{i,d} = f_{i,k} C_R C_{DF} C_T \left(\frac{1}{FS_m}\right)$$

Permissible strength refers to characteristic material strength divided by solely the material factor of safety.

Bamboo culms or multiple-culm members shall be designed such that they are not subject to torsion.

Herein,

$f_{i,d}$	the allowable strength; for e.g. equals $f_{c,d}$ when representing allowable compression strength parallel to fibers
$f_{c,d}$	the allowable compression strength parallel to fibers (i.e. along the length of a bamboo pole)
$f_{m,d}$	the allowable bending strength parallel to fibers
$f_{v,d}$	the allowable shear strength parallel to fibers
$f_{t,90,d}$	the allowable tension strength perpendicular to fibers (i.e. along the circumference of a bamboo culm)
$f_{m,90,d}$	the allowable bending perpendicular to fibers
$f_{i,k}$	the 5th percentile characteristic strength with 75% confidence, in ISO 12122-1, the value is denoted $f_{i,0.05,0.75}$ (refer Table 3 for characteristic values of Bamboo species); for e.g. equals $f_{c,k}$ when representing characteristic compressive strength parallel to fibers
$f_{c,k}$	the characteristic compressive strength parallel to fibers.
$f_{m,k}$	the characteristic bending strength parallel to fibers
$f_{v,k}$	the characteristic shear strength parallel to fibers
$f_{t,90,k}$	the characteristic tension strength perpendicular to fibers.
$f_{m,90,k}$	the characteristic bending strength perpendicular to fibers
$f_{t,k}$	the characteristic tensile strength parallel to fibers
C_R	the member redundancy factor given in Table 8
C_{DF}	the modification factor for service class and load duration given in Table 1. The duration factor selected for load combinations shall be that for the component of the combination having the shortest duration.
C_T	the modification factor for service temperature given in Table 2. For structural members that will experience sustained exposure to elevated temperatures up to 65 °C this factor shall be applied. The factor is not required for transient elevated temperature exposure less than 3 hours.

FS_m	the material factor of safety given in Table 4

Table 1 : Load Duration Factor for resistance and Strength, C_{DF}

Load Duration	**Service Class defined in Section 3.3.5**		
	1	**2**	**3**
Permanent and longterm applied load (i.e. dead load)	0.6	0.55	0.45
Transient loads (i.e. live load)	0.75	0.65	0.5
Instantaneous loads (i.e. wind or seismic load)	1.0	0.85	0.7

Table 2 : Elevated Service Temperature Factor, C_T

Elevated Service Temperature Factor	**Service Class defined in Section 3.3.5**
	1, 2, or 3
$T \leq 38$ °C	1.0
38 °C < $T \leq 52$ °C	0.9
52 °C < $T \leq 65$ °C	0.8

Table 3: 5th percentile characteristic values with 75% confidence (wc = 12%), $f_{i,k}$

Bamboo Species	$f_{c,k}$ (MPa)	$f_{m,k}$ (MPa)	$f_{v,k}$ (MPa)	$f_{t,k}$ (MPa)	$f_{m,90,k}$ (MPa)	$f_{t,m,90,k}$ (MPa)
Bambusa balcooa	37.9	76.7	6.34	63.4	3.16	0.51
Bambusa nutans cupulata	28.6	53.8	4.15	44.5	2.22	0.36

Table 4 : Material Factor of Safety, FS_m

	f_c	f_t	f_m	f_v	$f_{t,90}$	$f_{m,90}$
FS_m	2.0	2.0	2.0	4.0	4.0	2.0

Table 5: Characteristic density of bamboo culm ρ_k (w=12%) with 75% confidence

Bamboo Species	Characteristic 5th percentile density, $\rho_{0.05,k}$ (kg/m^3)	Characteristic mean density, $\rho_{mean,k}$ (kg/m^3)

Bambusa balcooa	556.5	741.7
Bambusa nutans cupulata	527.1	760.3

1.6.4 MODULUS OF ELASTICITY

The allowable Young's Modulus of Elasticity E_d is:

$$E_d = E_k C_{DE} C_T$$

Herein,

E_k = characteristic bending Young's Modulus of Elasticity, equal to (see Table 7 for values):

- $E_{0,05,0.75}$ when modulus governs resistance, e.g. buckling
- $E_{mean,0.75}$ for estimating deflections

C_{DE} = modification factor for service class and load duration given in Table 6.

C_T = the modification factor for service temperature given in Table 2. For structural members that will experience sustained exposure to elevated temperatures up to 65°C this factor shall be applied. The factor is not required for transient elevated temperature exposure less than 24 hours

Table 6 : Load Duration Factor for Modulus, C_{DE}

Load Duration	**Service Class defined in 3.3.5**		
	1	**2**	**3**
Permanent and long term applied load (i.e. dead load)	0.5	0.45	0.3
Transient loads (i.e. live load)	1.0	0.95	0.75
Instantaneous loads (i.e. wind or seismic load)	1.0	1.0	0.9

Table 7: Characteristic Bending Young's Modulus of Elasticity, E_k $(w = 12\%)$*, (MPa)*

Bamboo Species	$\boldsymbol{E_{mean,0.75}}$ (MPa)	$\boldsymbol{E_{0,05,0.75}}$ (MPa)
Bambusa balcooa	18483	14250
Bambusa nutans cupulata	18000	13000

2 LOADS AND LOAD COMBINATIONS

2.1 LOADS

When designing any element, member or structure, the following loads (actions) and their effects are considered:

- Self-weight and superimposed dead loads in accordance with NBC 102
- Imposed or live loads experienced due occupancy and function of structures as per NBC 103
- Wind loads on structure as per NBC 104
- Seismic loads as per NBC 105

Any other loads due to secondary effects such as handling, erection, temperature, settlements, etc. are considered as deemed necessary.

2.2 LOAD COMBINATIONS

The following load combinations shall be considered for analysis and design:

- DL
- $DL + LL$
- $0.7DL \pm EL$
- $DL + LL \pm EL$
- $DL + LL \pm WL$
- $DL \pm WL$
- $0.6DL \pm WL$

where DL stands for dead loads (incl. self-weight and superimposed), LL refers to live load or the imposed load, EL denotes earthquake load, and WL is wind load. Wind load and earthquake loads are not assumed simultaneously in a single load combination.

3 ANALYSIS AND DESIGN

3.1 GENERAL

This document is based on allowable stress design (ASD) approach to ensure the safety and performance of the structure.

Bamboo culms used for construction shall meet the quality assessment and control requirement of Section III of Annex C.

A structure shall be designed and constructed such that,

a) with acceptable probability, it will remain fit for its intended use, having due regard to its intended life and costs,
b) with appropriate reliability, it will resist all actions and influences likely to occur resulting from its intended use over its intended life, and have adequate durability in relation to maintenance requirements, and

c) it will not represent a hazard to human life by exceptional events such as explosion, impact, or consequence of human error, to an extent disproportional to the magnitude of the exceptional event

3.2 DESIGN METHODOLOGY

Bamboo structures shall be designed based on calculations, verifying that no relevant allowable resistance is exceeded. The following are assumed:

a) Structures are designed by appropriately qualified and experienced design professionals.
b) Structures are constructed by personnel having appropriate skills and experience.
c) Adequate supervision and quality control are provided in factories, plants and on-site.
d) Construction materials and products are used as specified in this document or in the relevant material or product specifications.
e) Structures are adequately maintained.
f) Structures will be used in accordance with their intended occupancy and design.

3.3 LATERAL LOAD RESISTING SYSTEM

The lateral load resisting systems constructed out of bamboo shall have a direct load path to the foundations in the form of (a) braced frames, and/or (b) composite bamboo shear walls. Bamboo moment frames or portal frames alone (i.e. without diagonal bracings) are not suitable for resisting lateral loads.

Braced Frame: A single triangulated frame that transfers the loads down to the foundation by axial (tension and compression) load in the braced elements (Figure 1). The load can be tension only, compression only or both tension and compression.

Figure 1: Example of Bamboo Braced Frame System

Composite Bamboo Shear Walls: It is a composite bamboo shear wall system constituted from a cement mortar render applied onto strip, flattened or small diameter bamboo, which are fixed onto bamboo and/or timber studs or framing (Figure 2). The cement mortar render is reinforced by a small-gauge metal mesh such as "chicken wire". An alternative technique in which the cement mortar render is applied directly onto expanded metal lath sheets, which are in turn fixed onto the frame, is also accepted. It transfers the load down to the foundations by a shear force distributed along the length of the wall.

Figure 2: Example of Light Composite Bamboo Shear Wall (CBSW) System

3.3.1 TIME PERIOD OF BAMBOO STRUCTURES AND PEAK SPECTRAL ACCELERATION

The site spectra used for allowable stress design principle corresponds to the serviceability limit state design of NBC105:2020. Herein, the time-period of bamboo structures falls on the plateau of the response spectrum curves (i.e. corresponds to maximum spectral acceleration). Therefore, for calculation of seismic loads, assume the design Spectral Shape Factor coefficient as $C_h(T) = 2.5$ for Soil Types A to C, and $C_h(T) = 2.25$ for Soil Type D. Assume the overstrength factor equals $\Omega_s = 1$ for estimation of the horizontal base shear coefficient under serviceability limit state.

3.3.2 SUSCEPTIBILITY TO SPLITTING

Bamboo culms are susceptible to longitudinal splitting. Splitting is commonly related to changes in the moisture content of the culm in service. The susceptibility to splitting can lead to non-redundant members (Section 3.3.3.1) and may necessitate the replacement of culms in a member or structure. The effects of splitting are controlled using radial clamping.

3.3.3 REDUNDANCY

To the extent possible, non-redundant structures and/or structural members or components should not be used.

The member redundancy factor C_R, shall be defined by Table 8.

Table 8: Member Redundancy Factor, C_R

Redundancy of Member in Structure	C_R
Non-redundant as definedin 3.3.3.1	0.90
Redundant as defined in 3.3.3.2	1.10
All other structures	1.00

3.3.3.1 NON-REDUNDANT STRUCTURAL MEMBERS

Non-redundant structural members shall be those satisfying the following criteria.

a.) Load-bearing members whose removal from the structure or load path result in failure of the structure, or

b.) Load-bearing members made of multiple culms for which the removal of any single culm from the multiple culm assembly results in failure of the member.

3.3.3.2 REDUNDANT STRUCTURAL MEMBERS

Redundant structural members must satisfy the following criteria:

Four structural members of the similar stiffness are connected to a continuous load distribution path (such as the case with floor joists, rafters, purlins, and trusses). In addition, either,

a) The continuous load distribution path is capable of redistribution of loads, or
b) The structural members are no more than 600 mm apart, the load distribution members are continuous over at least two spans, and any connections in the load distribution members are staggered.

3.3.4 SERVICEABILITY CONSIDERATIONS

Deflections of the structure or its components likely to affect the use or occupancy of the structure or damaged finishes or non-structural components shall be considered.

3.3.5 SERVICE CLASSES

Bamboo within a structure shall be assigned to one of the service classes based on the environment to which the bamboo is exposed. Table 9 summarizes the typical uses and preservation requirements. Different elements or members in the same structure may have different service classes.

Table 9: Use Classes, Typical Uses and Required Preservation for Bamboo

Service class	Service conditions	Protection against biological agents		
		Fungal	Insects	Termites
1	Interior, dry	not required	required	required
2	Interior, occasional short-term dampness Exterior, above ground, protected from driving rain and UV	required	required	required
3	Interior, but frequent or long-term wetting Exterior, above ground, exposed to driving rain or UV	required	required	required
Bamboo cannot be used in service class 3 except for temporary construction. Interior structural members refer to bamboo poles enclosed within a building (e.g. beams, columns, trusses, braces, etc. not exposed to outdoor environment). Exterior structural members refer to bamboo poles exposed to outdoor conditions (e.g. bamboo rafters and purlins supporting roof overhangs; columns and braces of open pavilions without walls).				

Service class 1 is characterized by an equilibrium moisture content in the bamboo not exceeding 12%. It is representative of bamboo culms under cover, fully protected from weather and not exposed to wetting. The relative humidity is maintained below 65%.

Service class 2 is characterized by an equilibrium moisture content in the bamboo not exceeding 19%. It is representative of bamboo culms under cover. It can be subjected to occasional wetting but dries off quickly and is not long-term. It excludes locations where relative humidity exceeds 85% regularly or for prolonged periods.

Service class 3 is characterized by bamboo culms not under cover and not in contact with ground. It is either continuously exposed to weather or is protected from the weather but subject to frequent or long-term wetting. Bamboo cannot be used in Service class 3 except for temporary construction.

Bamboo poles cannot be used in ground or in contact with ground (e.g. sole plates or columns at ground, columns built into ground, piles) and bamboo poles permanently exposed to water (piles, marine piles including splash zone).

3.3.5.1 RESISTANCE TO CORROSION OF METALLIC ELEMENTS

Metal fasteners and other structural connections shall be either inherently corrosion-resistant or protected from corrosion.

3.3.6 EFFECTS OF ELEVATED TEMPERATURE

When heated, the strength and stiffness of bamboo decrease. The effects of elevated temperature are immediate, and their magnitude varies depending on the moisture content of the bamboo. Up to $65\ °C$, the immediate effect is reversible upon return to normal ambient temperature. Prolonged exposure to temperature greater than $65\ °C$ will cause permanent loss of strength and stiffness in bamboo culms. As bamboo is cooled below normal ambient temperatures, its strength increases.

The reference design values of this document apply to ordinary temperature fluctuations and occasional short-term heating to temperatures no greater than $65\ °C$.

Bamboo shall not be used for structures experiencing prolonged exposure to temperatures greater than $50\ °C$ or short-term exposure to temperatures greater than $65\ °C$.

3.3.7 CULM GEOMETRY FOR USE WITH ALLOWABLE STRESS DESIGN

D is the nominal culm diameter determined from a grading procedure in accordance with Section III of Annex C.

t is the nominal culm wall thickness determined from a grading procedure in accordance with Section III of Annex C

Cross sectional area of a single culm A is:

$$A = \frac{\pi}{4}[(D^2 - (D - 2t)^2)]$$

The moment of inertia of a single culm I is:

$$I = \frac{\pi}{64}[(D^4 - (D - 2t)^4)]$$

The elastic section modulus of a single culm S is:

$$S = \frac{\pi}{32D}[(D^4 - (D - 2t)^4)]$$

Multi-culm members cannot attain composite action. Instead, their properties are sum of single culm members:

$$A_n = \sum A$$

$$I_n = \sum I$$

$$S_n = \sum S$$

where, n is the total number of culms in a multi-culm member.

3.4 STRUCTURAL MODELLING

Structural modelling is the process of 'translating' the physical reality of a building structure into a mathematical model from which necessary design calculations may be carried out.

Required load bearing or stress demands shall be calculated at critical locations as determined using the load combinations given in Section 2.2.

The design of bamboo members and structures shall be based on calculations applying the principles of fundamental applied mechanics. Typically, models of bamboo structures will make the following assumptions:

- Bamboo is modelled as a linear elastic material. Assume $E_{mean,0.75}$ (see Table 7) and $\rho_{mean,k}$ (for self-weight) without any modification factors.
- Bamboo culms are modelled such that they satisfy Bernoulli beam theory (i.e., plane sections remain plane)
- Nominal value of diameter and thickness equal to the smallest dimensions of the adopted grade shall be used.
- Built-up members consisting of multiple culms cannot attain composite action (see Section 3.3.7)
- Joints in bamboo structures shall be assumed to be pinned (hinged).
- The joint stiffness k_e shall be accounted for in the analysis. Under lack of more appropriate values (Section 4.1.3), equivalent axial stiffness of a member with end-connections may be taken as:

Table 10 : Equivalent Axial Stiffness of a member with end-connections

End Connection Type	Equivalent Axial Stiffness of a Member
Fish mouth type connections or dowel type connections	$0.33k_m$

Where,

k_m = the characteristic mean axial stiffness of the member without end-connections.

3.5 FLEXURAL MEMBERS (BEAMS)

3.5.1 GENERAL

The design moment acting on a flexural member shall be equal to or less than the allowable moment resistance, $M_{r,d}$, of the member defined by Section 3.5.2.1.1

The design shear force acting on a flexural member shall be equal to or less than the allowable shear resistance, $F_{v,r,d}$, of the member defined by Section 3.5.2.1.2

To the extent possible, allowable resistance of members subject to flexure shall not be governed by shear- dominated failure modes.

3.5.2 MULTIPLE CULM FLEXURAL MEMBERS

Multiple culm flexural members arranged into a triangular bundle shall have one side of the triangle oriented along the compression face of the member.

Culms in multiple culm flexural members should be in contact to the extent possible. In no case shall culms be separated by more than a clear distance equal to the average culm diameter in the member.

Multiple culm members cannot attain composite action (see Section 3.3.7).

Connections between adjacent culms in multiple culm flexural members shall be provided at the ends of all unbraced lengths and between adjacent culms at a spacing no greater than ten times the smallest culm diameter. Connections shall be designed based on Section 4 to adequately transfer a minimum force of 1,500 N/m between adjacent culms of the member.

3.5.2.1 FLEXURAL MEMBER RESISTANCE

3.5.2.1.1 ALLOWABLE MOMENT RESISTANCE

The allowable moment resistance of a member is given by:

$$M_{r,d} = f_{m,d}(\Sigma S)$$

Where,

$f_{m,d}$ = the allowable bending strength parallel to fibers

ΣS = the sum of the elastic section moduli, defined in 3.3.7 of the individual culms comprising the member.

3.5.2.1.2 ALLOWABLE SHEAR RESISTANCE

The allowable shear resistance of a member is given by:

$$F_{v,r,d} = f_{v,d} \sum \frac{A}{2}$$

Where,

$f_{v,d}$ = the allowable shear strength parallel to fibers

ΣA = the sum of cross-section area of all individual culms comprising the member.

3.5.2.2 BRACING REQUIREMENTS OF MULTIPLE CULM FLEXURAL MEMBERS

When a multiple culm flexural member is bent about major axis, and the member depth-to-width ratio exceeds 1.5, lateral bracing is required to satisfy the following:

The compression region of the member is laterally restrained at intervals not exceeding 10 times the width of the member.

Both the compression and tension regions of the member are laterally restrained at all supports.

Lateral restraints shall provide sufficient restraint and stiffness to inhibit lateral movement of the restraint point. The sum of all restraints provided to a member shall be capable of resisting a total force ΣF_{resf} oriented perpendicular to the principal axis of the flexural member of not less than that given by:

$$\Sigma F_{resf} \geq (M_d/d) \times 0.04$$

Individual lateral restraints shall be capable of resisting a force F_{resf}, oriented perpendicular to the principal axis of the flexural member of not less than that given by:

$$F_{resf} \geq (M_d/d) \times 0.015$$

where

M_d = the design moment acting on the member, obtained from structural analysis

d = is the overall depth of the flexural member.

The total restraint force, ΣF_{resf}, shall be divided between the intermediate lateral restraints in proportion to their spacing.

The lateral restraint shall be connected to an appropriate system of bracing capable of transferring the restraint force to the effective points of support of the member, or else connected to an independent part of the structure capable of fulfilling a similar function. Where two or more parallel members require intermediate lateral restraint, it is not adequate to connect the members together such that they become mutually dependent.

3.5.3 CALCULATION OF DEFLECTION

Deflections shall be calculated using elastic section properties. The elastic flexural stiffness is determined as given in Sections 3.5.3.1.

3.5.3.1 ALLOWABLE FLEXURAL STIFFNESS

The allowable flexural stiffness $(EI)_d$, determined from materials and geometric properties for the calculation of deflection shall be given by

$$(EI)_d = E_d \sum I \, C_v$$

Where,

E_d = the allowable modulus of elasticity defined as per Section 1.6.4

$\sum I$ = the allowable moment of inertia of multiple culm members defined as per Section 3.3.7

C_v = the modification factor accounting for shear deformation:

$$C_v = 0.5 + 0.05\left(\frac{a}{D}\right) \leq 1.0$$

Where,

a = distance between point of maximum moment and nearest point of contraflexure; for e.g., equals $L/2$ for simply supported beam of length L with uniformly distributed load

D = the nominal diameter of the culm

3.5.3.2 LONG TERM DEFLECTIONS

Total long-term deflections of a flexural member shall be calculated by applying appropriately determined values of E_d (see Section 1.6.4) separately to permanent and transient components of applied loads and summing the components of deflection together.

3.6 AXIAL LOAD CARRYING MEMBERS

3.6.1 GENERAL

The design compression force acting on the axial member shall be equal to or less than the allowable compression resistance, $F_{cc,r,d}$ of the member defined by Section 3.6.3.1.

The design tension force acting on the axial load carrying member shall be equal to or less than the allowable tension resistance, $F_{t,r,d}$, of the member defined by Section 3.6.4.

Multiple culm axial load carrying members shall be arranged such that they are

- Symmetric about one principle axis;
- Radially symmetric; or,
- Arranged in a triangular arrangement having anequal number of culms on each side.

Single culm axial load carrying members are considered as non-redundant (see Section 3.3.3.1).

Culms in multiple culm axial load carrying members shall be separated by no more than a clear distance equal to the average culm diameter in the member.

Connections between adjacent culms in multiple culm members shall be provided at the ends of all unbraced lengths and between adjacent culms at a spacing no greater than ten times the smallest culm diameter.

When required, lateral bracing requirements for compression members shall be determined as per Section 3.6.2.1.

3.6.2 COMPRESSION MEMBER EFFECTIVE LENGTH

The effective of length of compression load carrying members shall be determined as the working length of the member between points of lateral restraint, L multiplied by the recommended effective length coefficient for bamboo members,

K_L given in Table 11 : The effective length may different about the two principal axes of the member.

Table 11 : Effective Length Coefficient, K_L

Restraint	Compression member end conditions			Truss element
	Pin-Pin	Pin- Fixed	Fixed-Fixed	
Laterally Restrained	1.10	0.80	0.65	1.00
No Lateral Restraint	2.40	2.10	1.20	Not permitted

3.6.2.1 LATERAL RESTRAINT OF COMPRESSION MEMBERS

Lateral restraints shall provide sufficient restraint and stiffness to inhibit lateral movement of the restraint point. Restraints shall be capable of resisting a force F_{resc}, oriented perpendicular to the principal axis of the member about which restraint is being calculated.

$$F_{resc} \geq 0.01\left(\frac{F_{c,d}}{C_{bow}}\right)$$

Where,

$F_{c,d}$ = the design compression force acting on the compression member.

C_{bow} = the reduction factor to account for an initial bow in the culms comprising the compression member.

$$C_{bow} = 1 - \left(\frac{b_o}{0.02}\right)$$

Where,

b_o = the maximum bow at mid-height of any culm comprising a load bearing member. The b_o shall not exceed the limit given in Section III of Annex A.

The lateral restraint shall be connected to an appropriate system of bracing capable of transferring the restraint force to the effective points of support of the member, or else connected to an independent part of the structure capable of fulfilling a similar function.

Where two or more parallel members require intermediate lateral restraint, it is not adequate merely to connect the members together such that they become mutually dependent.

3.6.3 COMPRESSION CAPACITY

The use of summations of culm capacities and geometric properties in this clause allows for use of multiple culm members including those comprised of different sized culms.

3.6.3.1 ALLOWABLE COMPRESSION CAPACITY FROM GEOMETRIC AND MATERIAL PROPERTIES

The allowable compression resistance of a member $F_{cc,r,d}$ is:

$$F_{cc,r,d} = \frac{F_{c,r,d} + F_{e,r,d}}{1.6} - \sqrt{\left(\frac{F_{c,r,d} + F_{e,r,d}}{1.6}\right)^2 - \frac{F_{c,r,d} F_{e,r,d}}{0.8}}$$

Where,

$F_{c,r,d}$ = the allowable crushing resistance defined in Section 3.6.3.2.

$F_{e,r,d}$ = the allowable buckling capacity defined in Section 3.6.3.3.

3.6.3.2 ALLOWABLE CRUSHING RESISTANCE

Allowable crushing resistance of a member under compression is

$$F_{c,r,d} = f_{c,d} \sum A$$

Where,

$f_{c,d}$ = the allowable compressive strength parallel to fibers given in Section 1.6.3.

$\sum A$ = the sum of the cross-sectional areas,defined in 3.3.7, of the individual culms comprising the member.

3.6.3.3 ALLOWABLE BUCKLING RESISTANCE

Allowable buckling resistance of a compression member, $F_{e,r,d}$ is:

$$F_{e,r,d} = \frac{n\pi^2 E_d I_{min} C_{bow}}{(K_L L)^2}$$

Where,

n = the number of culms comprising the member

E_d = allowable Young's Modulus of Elasticity as per Section 1.6.4

I_{min} = the nominal minimum moment of inertia, defined in Section 3.3.7, of the individual culms comprising the member

C_{bow} = a reduction factor to account for an initial bow in the culms comprising the compression member defined in Section 3.6.2.1

$K_L L$ = the effective compression member length as per Section 3.6.2

3.6.4 ALLOWABLE TENSION RESISTANCE

It is very rare for axial tension to govern the resistance of a member. Special attention shall be paid to connections imparting a tensile load to a member. The allowable tension resistance of a member is:

$$F_{t,r,d} = f_{t,d} \sum A$$

Where,

$f_{t,d}$ = the allowable tensile strength parallel to fibers given in 1.6.3

$\sum A$ = the sum of the cross-sectional areas, defined in 3.3.7, of the individual culms comprising the member

3.6.5 COMBINED AXIAL AND FLEXURAL LOADS

Members subject to combined axial load and moment shall meet the following failure criteria:

For net axial compression:

$$\frac{F_{c,d}}{F_{cc,r,d}} + \frac{BM_d}{M_{r,d}} \leq 1.0$$

$$B = \left[1 - \frac{F_{c,d}}{F_{e,r,d}}\right]^{-1}$$

For net axial tension

$$\frac{F_{t,d}}{F_{t,r,d}} + \frac{M_d}{M_{r,d}} \leq 1.0$$

Where,

$F_{c,d}$ = the design compression force acting on the member, obtained from structural analysis

$F_{cc,r,d}$ = The allowable compression resistance defined in Section 3.6.3

$F_{t,d}$ = the design tensile force acting on the member, obtained from structural analysis

$F_{t,r,d}$ = the allowable tensile resistance defined in Section 3.6.4

M_d = the design moment acting on the member, obtained from structural analysis

$M_{r,d}$ = the allowable moment resistance defined in Section 3.5.2.1

B = the moment amplification factor

$F_{e,r,d}$ = the allowable buckling resistance defined in Section 3.6.3.3

3.7 COMPOSITE BAMBOO SHEAR WALL

3.7.1 GENERAL

Composite bamboo shear wall (CBSW) also known as light cement bamboo frame (LCBF) construction is a modern technique utilizing composite shear panels constituted of a wall matrix of flattened bamboo plus chicken wire mesh or metal lath (rib lath) fixed onto a bamboo or sawn timber framing system, plastered with cement or lime mortar render.

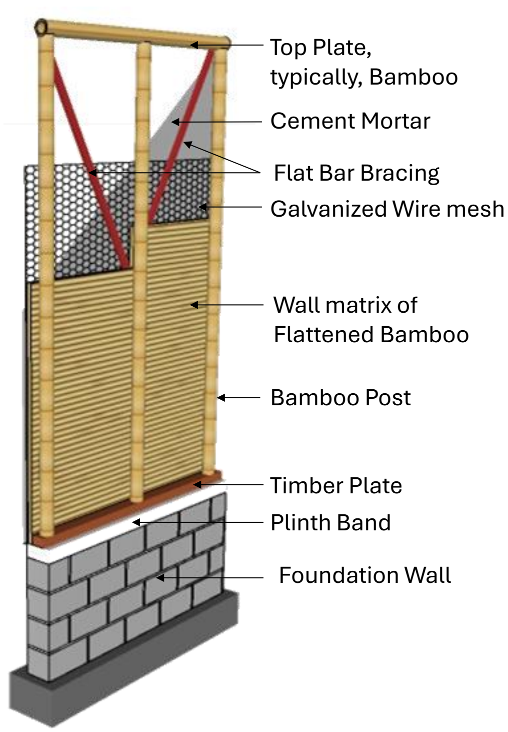
Panels shall have a height-to-length ratio no greater than 4.0. Panels will resist tributary gravity loads as described in Section 3.7.2.3. Braced CBSW panels or walls resist short-term lateral forces from wind, impact or seismic action as described in Figure 4: CBSW panel loads. Allowable in-plane resistance shall be that defined in Section 3.7.3.4. Unbraced CBSW panels cannot resist lateral loads.

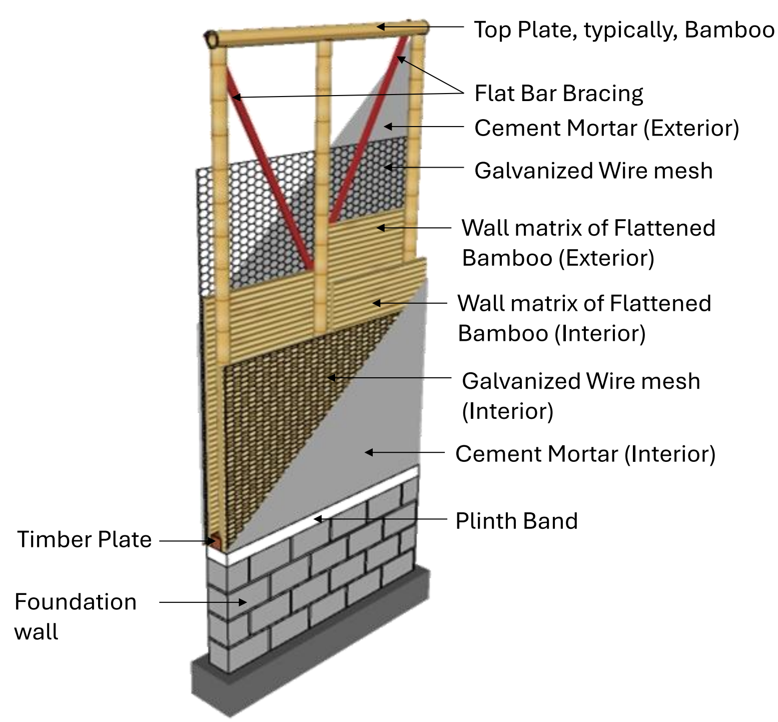
The bamboo elements of a CBSW shall meet the requirements of this document. The design of sawn timber elements shall meet the requirements of applicable timber standards and the intent of this section.

The CBSW panel may be of single cladding (matrix applied to one side only) or of double cladding (matrix applied to both sides). For single cladding flattened bamboo matrix, the mortar render may be applied to one or both sides of the matrix. For single cladding rib lath matrix, the mortar render shall be applied in both sides of the matrix.

This document does not cover systems where the wall matrix is placed in the centerline of the bamboo framing, such that the matrix is not continuous across adjacent panels.

Figure 3 shows examples of a single and double cladding CBSW. Example prescriptive details for elements of CBSW systems are described in Section 3.7.4.





a.) Single Cladding System b.) Double Cladding System

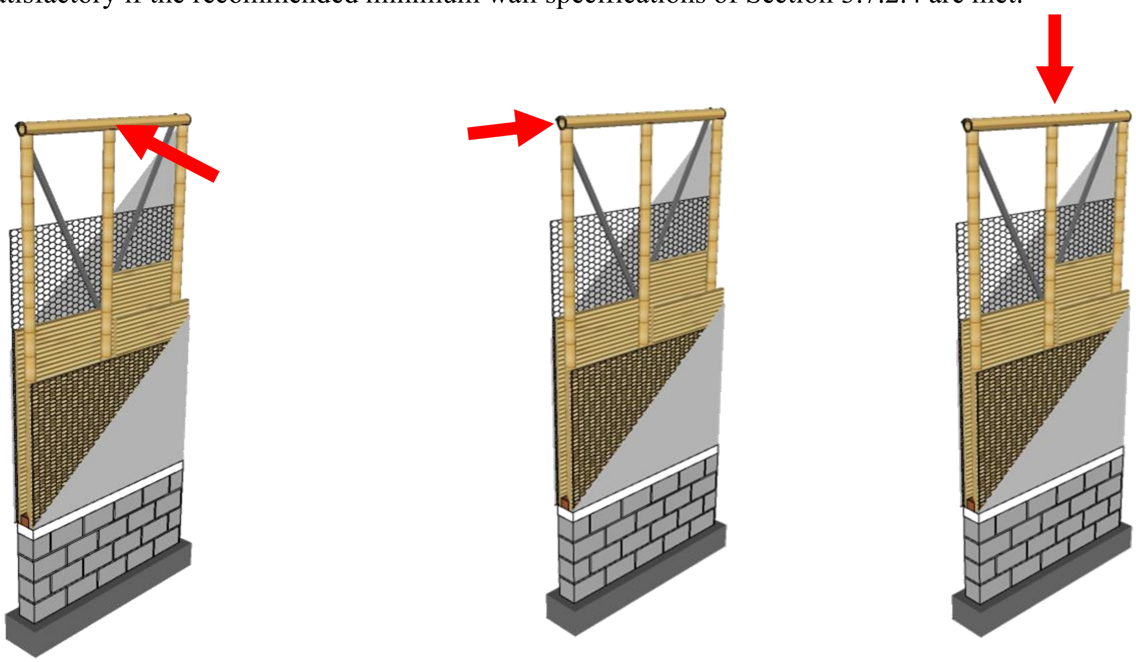
Figure 3: Examples of Light Cement Bamboo Frame (CBSW) Construction

3.7.2 LOAD TRANSFER PROCESS

CBSW shall be capable of resisting applicable combinations of vertical and/or lateral loads (see Figure 4), and consist of load paths described in Sections 3.7.2.1, 3.7.2.2 and 3.7.2.3.

3.7.2.1 OUT-OF-PLANE LOADS

Out-of-plane loads originating from wind, impact or seismic action at the floor-diaphragm or roof eaves induce flexure in the panel about its weaker axis (see Figure 4a). The flexural resistance to out-of-plane loads may be considered satisfactory if the recommended minimum wall specifications of Section 3.7.2.4 are met.



a) Out-of-Plane Loads b) In-plane horizontal loads c) In-plane vertical loads

Figure 4: CBSW panel loads

3.7.2.2 IN-PLANE LOADS

In-plane, CBSW panels or walls shall be designed as vertical cantilevers (see Figure 5). Panel shear resistance, compression resistance and tension resistance at the extreme framing members, as well as overturning and sliding failure at the wall connections shall be considered.

To adequately resist in-plane loads, CBSW systems shall be designed and detailed such that the following flow of forces is reliably established:

a) Shear from upper story and/or roof, walls and the floor diaphragm is transferred to the continuous top plate.

b) The top plate transfers horizontal shear into the CBSW wall panel. The composite mortar and wall matrix combined with in-plane diagonal bracing, shall be assumed to resist 100% of the in-plane shear force (refer 3.7.3.4 for allowable in-plane shear resistance per meter length of panels).

c) Axial forces (compression and tension) generated due to overturning shall be resisted by the vertical framing members at the ends of the CBSW panel only. The capacities of these members and their connections shall be determined from Sections 3.6 and 4. Framing members can be assumed to be restrained against buckling in the plane of the wall. Intermediate framing members in a CBSW panel do not contribute to resisting forces resulting from overturning.

d.) The CBSW panels shall be adequately anchored to the foundation. The axial load paths shall be established to the foundation of the structure through appropriate connection between framing elements and top and bottom plates.

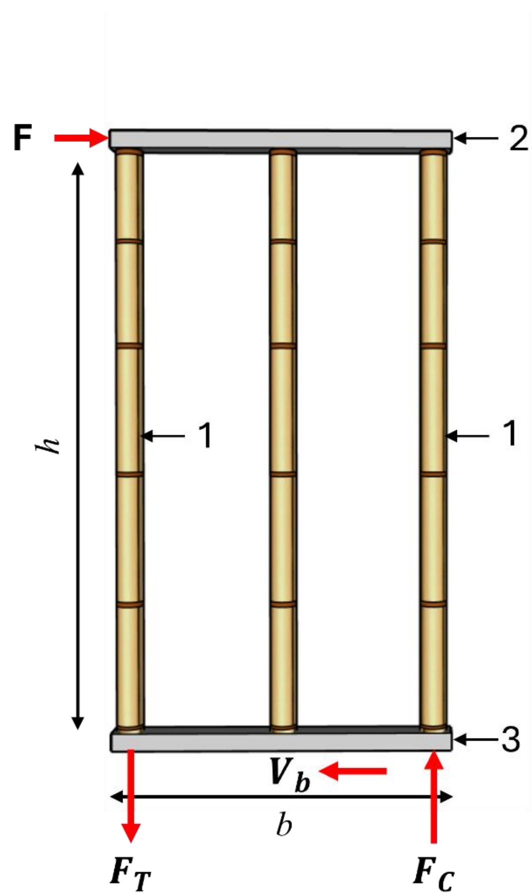


Figure 5: CBSW Panel Acting as a Cantilever

Legend:

1 = framing members at ends of CBSW panel

2 = top plate

3	=	bottom plate
F	=	applied horizontal force (from wind or seismic analysis)
V_b	=	base shear force resisting F
F_T	=	tensile force in end member resisting overturning moment; $F_T = \frac{(F \times h)}{b}$
F_C	=	Compression force in end member resisting overturning moment; $F_c = \frac{(F \times h)}{b}$
h	=	height of CBSW panel
b	=	length of CBSW panel

3.7.2.3 GRAVITY LOADS

The vertical frame elements (bamboo studs) spanning between top and bottom plates solely resists the gravity loads acting on the CBSW panels. The compression capacities of these members shall be determined from Section 3.6. No contribution from the composite mortar and wall matrix shall be assumed, although vertical framing members can be assumed to be restrained against buckling in the plane of the wall.

Effects of gravity load shall be superimposed on the effects of lateral load shown in Figure 5.

3.7.2.4 SIMPLE CHECK FOR MINIMUM LENGTH OF WALLS IN ORTHOGONAL DIRECTIONS

A minimum length of confined walls shall be provided in each of the main plan directions.

$$L_i \geq C_B \times A_P$$

Buildings with wall lengths less than L_i is allowed if found safe under detailed analysis from Section 3.7.3.1.

The values of C_B as per seismic base shear coefficient are given below:

Table 12: Values of C_B as per Seismic Base Shear Coefficient

A_a	C_B
0.4	0.28
0.35	0.26
0.3 and below	0.23

Herein,

A_a	=	Seismic base shear coefficient
C_B	=	Coefficient as a function of the seismic base shear acceleration coefficient at the location of the building
L_i	=	Minimum length of the wall along direction i
A_p	=	Roof area (in m^2) including eaves, for one-story homes, can be replaced by $\frac{2A_p}{3}$ if light materials (e.g. metal sheets) are used for roof cover.

Mezzanine area (or first floor deck area) plus roof area (in m^2) for the ground floor walls in one-story with mezzanine house, can be replaced by $\frac{2A_p}{3}$ if light materials (e.g. metal sheets) are used for floor decking and roofing.

3.7.3 DETAILED ANALYSIS OF THE BUILDING

3.7.3.1 FLOOR PLAN IRREGULARITY CHECK (DISTRIBUTION OF WALLS)

Walls are arranged symmetrically in the plan of the building to reduce irregularities and torsion in the building. The equation below reflects this requirement and must be satisfied in absolute values.

$$\left[\frac{\sum\left(L_{yi}t_{yi}x_i\right)}{\sum L_{yi}\,t_{yi}} - \frac{B}{2}\right] \leq 0.15B$$

$$\left[\frac{\sum\left(L_{xi}t_{xi}y_i\right)}{\sum L_{xi}\,t_{xi}} - \frac{H}{2}\right] \leq 0.15H$$

Where,

i	=	wall label
L_{xi}	=	length of each braced wall i along the direction X
L_{yi}	=	length of each braced wall i along the direction Y
t_{xi}	=	corresponding thickness of the braced wall of length L_{xi}
t_{yi}	=	corresponding thickness of the braced wall of length L_{yi}
x_i	=	the distance (in m) in direction X from the vertical (*Y*) axis to the middle of the neutral axis of the wall of length L_{yi}
y_i	=	the distance (in m) in direction Y from the horizontal (*X*) axis to the middle of the neutral axis of the wall of length L_{xi}
B	=	length of the side (in m) of the rectangle that completely contains the projected area of the roof or second floor slab, measured along the X direction
H	=	length of the side (in m) of the rectangle that completely contains the projected area of the roof or second floor slab, measured along the Y direction

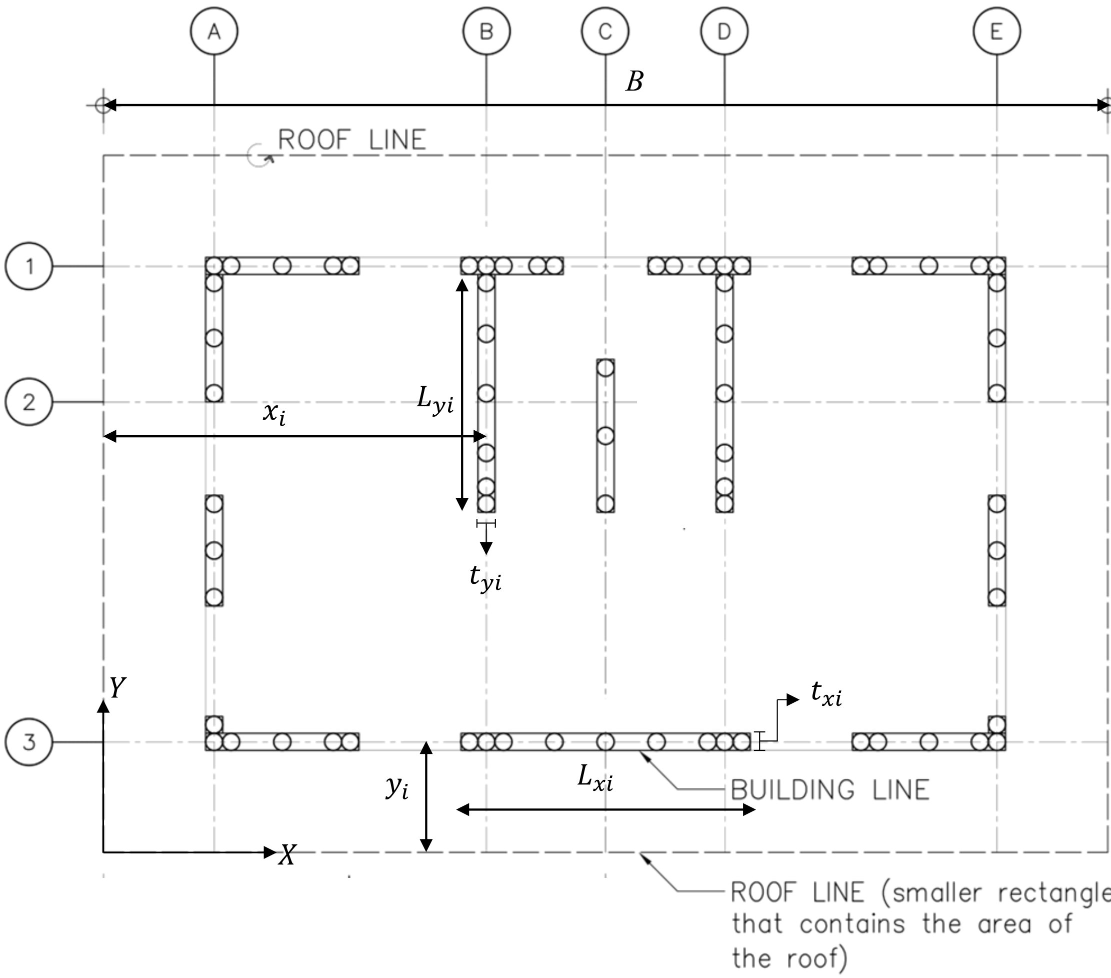


Figure 6: Description of Each of the Variables for Calculating Wall Symmetry

3.7.3.2 DISTRIBUTION OF LATERAL FORCES

The lateral forces of earthquake and winds are distributed, in each direction, in proportion to the lengths of the braced walls parallel to that direction.

3.7.3.3 DISTRIBUTION OF VERTICAL FORCES

Gravity loads are distributed in proportion to the length of the walls, with respect to the total area of the level considered.

3.7.3.4 ALLOWABLE IN-PLANE SHEAR RESISTANCE OF COMPOSITE BAMBOO SHEAR WALL

Table 13 presents the permissible shear resistance per unit length of composite bamboo shear wall with different materials. Note that the permissible shear resistance is for double cladding systems in which wall cladding is provided in both faces of bamboo culm. The resistance of single cladding is half of the double cladding.

The design in-plane force applied to a wall in the direction under consideration, obtained from structural analysis, shall be lower than the total allowable shear resistance of the wall panels. The allowable resistance per unit length is obtained by multiplying the permissible resistance per unit length in Table 13 with the corresponding modification factors for service class and load duration C_{DF} (Table 1) and temperature C_T (Table 2).

Table 13: Permissible Shear Resistance of Composite Bamboo Shear Wall

Wall Type	Wall Matrix	Permissible Shear Resistance per unit length (Double Cladding) (kN/m)
Type 1: Bottom Plate: Wood Top Plate: Wood Vertical Stud: Bamboo Bracing: Flat Bar Cladding: Two-sides	Flattened Bamboo or riblath	12
Type 2: Bottom Plate: Wood Top Plate: Wood Vertical Stud: Bamboo Bracing: Bamboo Cladding: Two-sides	Flattened Bamboo or riblath	10
Type 3: Bottom Plate: Wood Top Plate: Bamboo Vertical Stud: Bamboo Bracing: Flat Bar Cladding: Two-sides	Flattened Bamboo or riblath	8
Type 4: Bottom Plate: Wood Top Plate: Bamboo Vertical Stud: Bamboo Bracing: Bamboo Cladding: Two-sides	Flattened Bamboo or riblath	7

3.7.3.5 OVERTURNING

Due to the light weight of houses of composite bamboo shear wall, it is necessary to perform an overturning check of each wall of the house with the identified seismic and wind loads. The walls are assumed as individual elements working as cantilever (see Figure 7 and Figure 8).

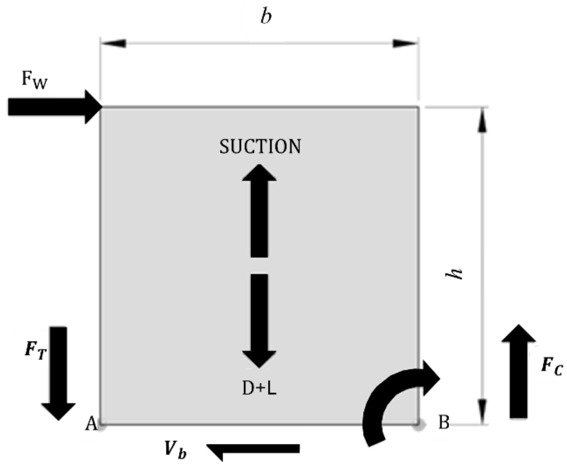


Figure 7: Overturning Check for Wind Load Combinations

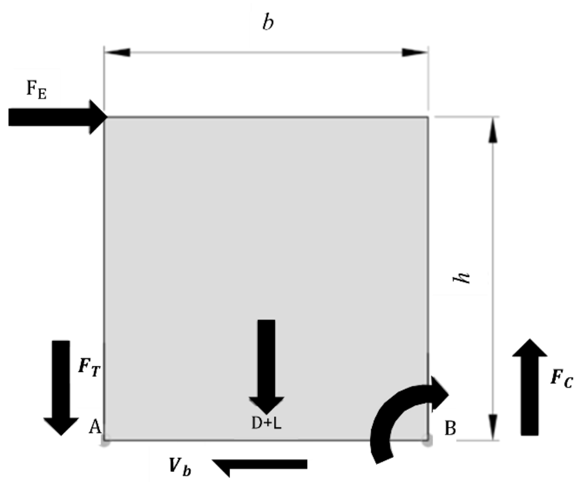


Figure 8: Overturning Check for Seismic Load Combinations

Table 14 : Permissible Tensile Resistance of End Studs in Walls Subjected to Overturning

End Studs	Permissible Tension Resistance (kN)	Commentary
Bamboo	12.5kN	Tensile resistance is provided with an embedded 12mmø deformed bar, with an embedment length inside the bamboo of at least 600 mm and 2 nodes

Once the static analysis of the wall is completed, the maximum tension and compression are identified with the objective to verify the load bearing resistance of the studs in the wall. If the load on the exterior stud is greater than in Table 14, double (or more) studs shall be used.

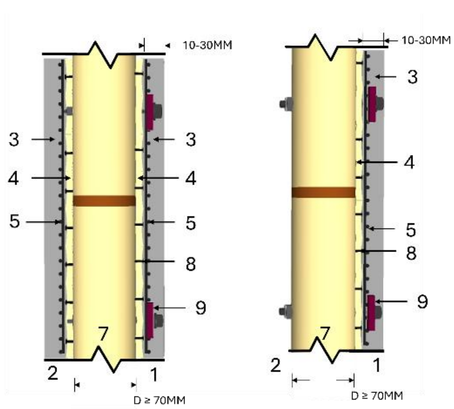
3.7.4 Requirements of Composite Bamboo Shear Wall Components

3.7.4.1 Wall Matrix

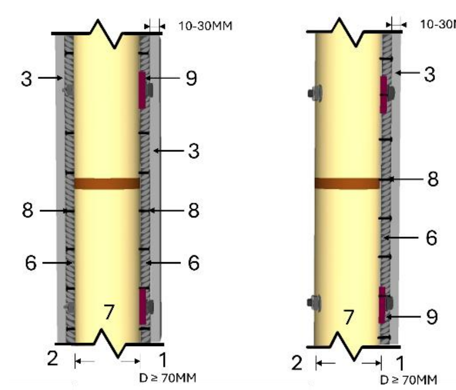
The wall matrix can consist of flattened bamboo plus chicken mesh, or galvanized metal lath (rib lath) (see Figure 9). Table 15 provides a combination of wall matrices and stud spacing known to satisfy the requirements of Section 3.7.2.1.

Table 15 : Combinations of Wall Matrices, Stud Spacing, and Attachments Known to Comply with the Requirements of Section

Matrix Type	Matrix Material Dimensions	Matrix Spacing Required to Ensure Good Connection with Mortar	Maximum Stud Spacing	Mechanical Attachment of Matrix to Frame
Flattened bamboo plus chicken mesh	Minimum thickness of 8 mm	2 mm to 10 mm gaps between matrix elements	600 mm center to center	1 ½" common wire nails spaced at 100 mm on center in staggered position into bamboo culms having a minimum wall thickness of 8 mm
Expanded metal lath (rib lath)	Minimum lath weight of 1,400 g/m2	n.a.	600 mm center to center	1 ½" common wire nails spaced at 100 mm on center in staggered position into bamboo culms having a minimum wall thickness of 8 mm



Section through double cladding (left) and single cladding (right) CBSW panel with strip or flattened bamboo matrix.



Section through double cladding (left) and single cladding (right) CBSW panel with expanded metal lath matrix.

Figure 9: Sections through CBSW Panels with Different Matrices(Refer Table 13 for detail specification)

Legends for Figure 9:

1 = exterior façade

2 = interior façade
3 = cement or lime mortar render
4 = flattened bamboo
5 = galvanized wire mesh
6 = expanded metal lath
7 = vertical CBSW member (stud)
8 = nail connection
9 = flat bar for cross bracing

3.7.4.2 Render (Plaster)

Plaster should have a minimum cladding thickness of 10 mm and a maximum cladding thickness of 30 mm.

The plaster should consist of cement-sand mortar having a compressive strength of at least 4 MPa. The render mix should have adequate workability, minimal porosity and provide an alkaline environment, especially when used in perimeter walls. The plaster must be durable enough to provide corrosion protection to any embedded steel reinforcement for the design life of the structure. Mortar ratios known to satisfy this requirement are cement: lime: sand = 1.0:0.5:4 and cement: sand = 1:4. Ratios with lower concentrations of cement are unlikely to achieve the above requirements.

Polymer dispersions may be incorporated in cement mortar mixes to improve bond strength, resistance to rain penetration and durability. Care should be taken to utilize only those polymers that are known to be suitable for exterior use.

3.7.4.3 Render (Plaster) Reinforcement

Unless metal lath is used in the wall matrix (see Section 3.7.1) render reinforcement is required in each render cladding and on both sides of the matrix where render is applied on both sides.

Render reinforcement will normally consist of galvanized chicken wire mesh of approximately 0.7 to 1.0 mm diameter and maximum mesh size of 20 mm.

The reinforcement should be fixed to the frame with screws, staples, or nails, taking care to not split the framing elements.

3.7.4.4 Vertical Members (Studs)

Vertical members should consist of timber or bamboo studs. Bamboo studs should have a diameter no smaller than 70 mm. Sawn timber elements should be at least 38 × 89 mm (nominal 2 × 4 in.) with the larger dimension orientated perpendicular to the length of the panel.

The maximum center-to-center spacing of the bamboo studs is 600 mm.

Studs should be capable of resisting all applied tension and compression loads due to gravity and overturning, without buckling or crushing the bottom or top plates. A direct path to transmit tension between the end studs in a panel and the foundation should be provided.

The connection between the studs and bottom or top plate must be capable of transferring all expected in-plane and out-of-plane forces including tension.

3.7.4.5 Bracing

Bracing should consist of bamboo, timber, or steel. Bamboo bracing should have a diameter no smaller than 70 mm. Sawn timber bracing should be at least 38 × 89 mm (nominal 2 × 4 in.) with the larger dimension-oriented perpendicular to the length of the panel. Steel flat bar bracing should be at least 3 mm thickness and 25 mm width.

Bracing members can be designed to resist tension-only, compression-only or both tension and compression. Where bracing is used, at least one active bracing element must be installed in each CBSW panel.

3.7.4.6 Top and Bottom Plates

Top and bottom plates should consist of timber or bamboo members. Bamboo top and bottom plates should have a diameter no smaller than 70 mm. Sawn timber elements should be at least 38 × 89 mm (nominal 2 × 4 in.) with the larger dimension orientated perpendicular to the length of the panel. Note that use of sawn timber plates enables simpler connections to the vertical bamboo studs.

Top and bottom plates should be continuous, spanning between out-of-plane restraints. End connections should be designed for the full-out of plane load.

Top and bottom plates should be capable of resisting the transverse loads imparted to them by the vertical framing elements and braces. This is especially important at the end of panels where vertical elements resist gravity and compression forces associated with overturning.

Bottom plates should bear directly on the foundation to the extent possible and must be fixed to the foundation at a spacing not exceeding 600 mm. Additional anchorage to resist uplift forces at the ends of CBSW panels should be provided as required.

3.7.4.7 Connection between Adjacent Wall Panels

Adjacent wall panels are connected to each other using steel dowels. The maximum spacing of steel dowels is H/3 (where H is the height of the panel), such that there are at least 2 dowel connections in total.

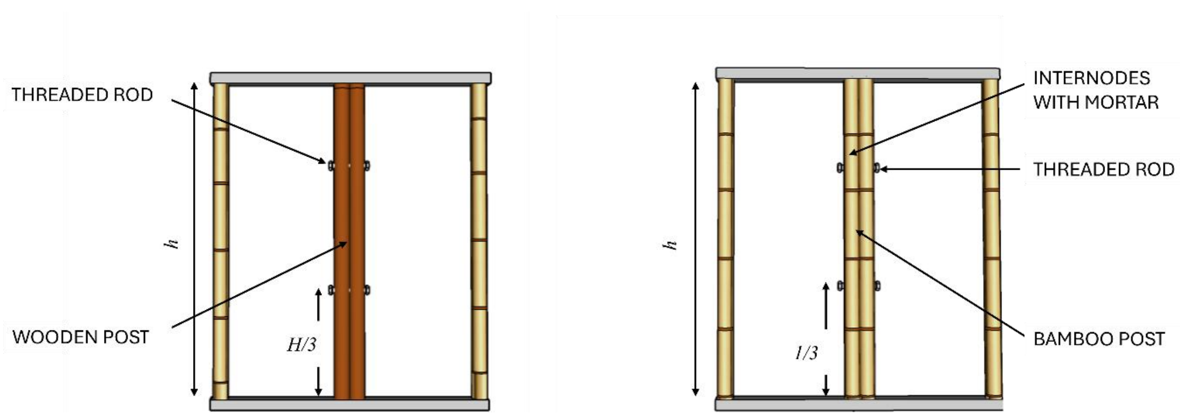


Figure 10: Minimum requirements for connecting two wall panels

3.7.5 Fire Resistance of Cement Bamboo Frame Walls

Bamboo has very little fire resistanceby itself. Adequate fire resistance shall be achieved by means of cladding on both sides of the frame/wall (see Table 16).

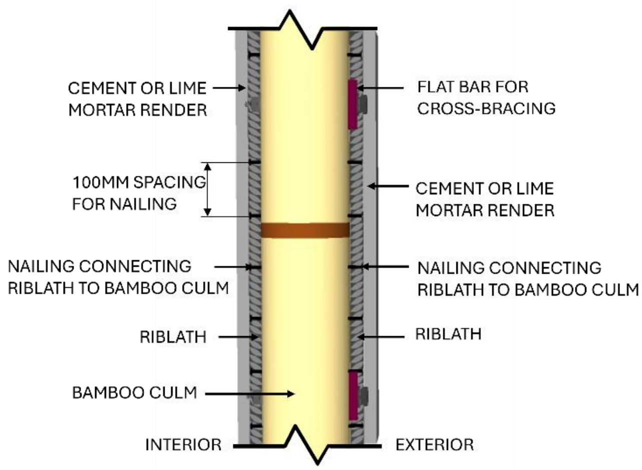


Figure 11: CBFT double cladded wall section

Table 16:Fire resistance of Composite bamboo shear walls

Composite bamboo shear walls with riblath matrix and no openings	Minimum thickness (mm) with no penetrating cracks	Fire resistance rating
cladding on both sides (see Figure 11)	25	120 mins

3.8 FLOW CHART OF DESIGN

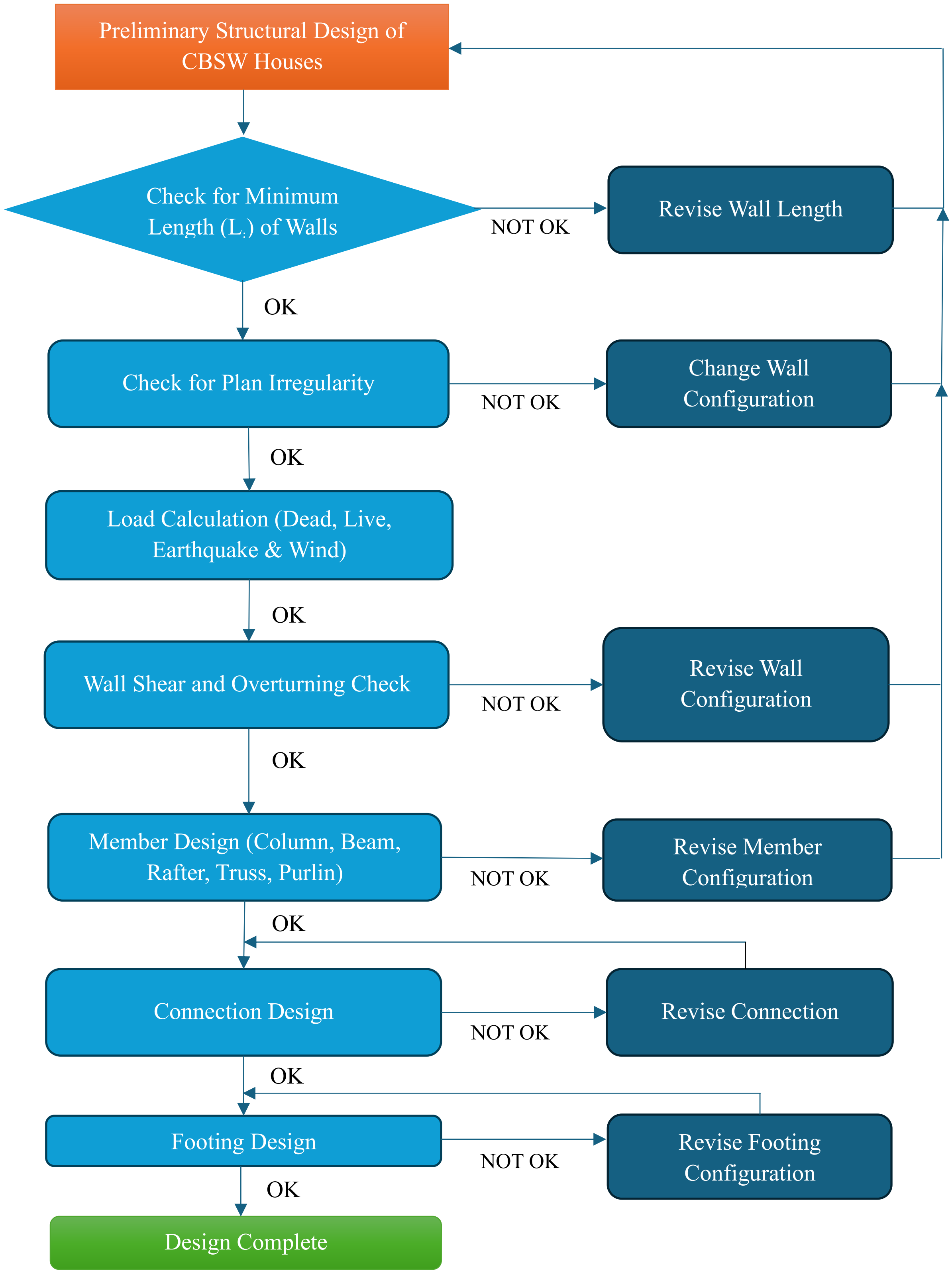


Figure 12: Flowchart of Design of CBSW Buildings

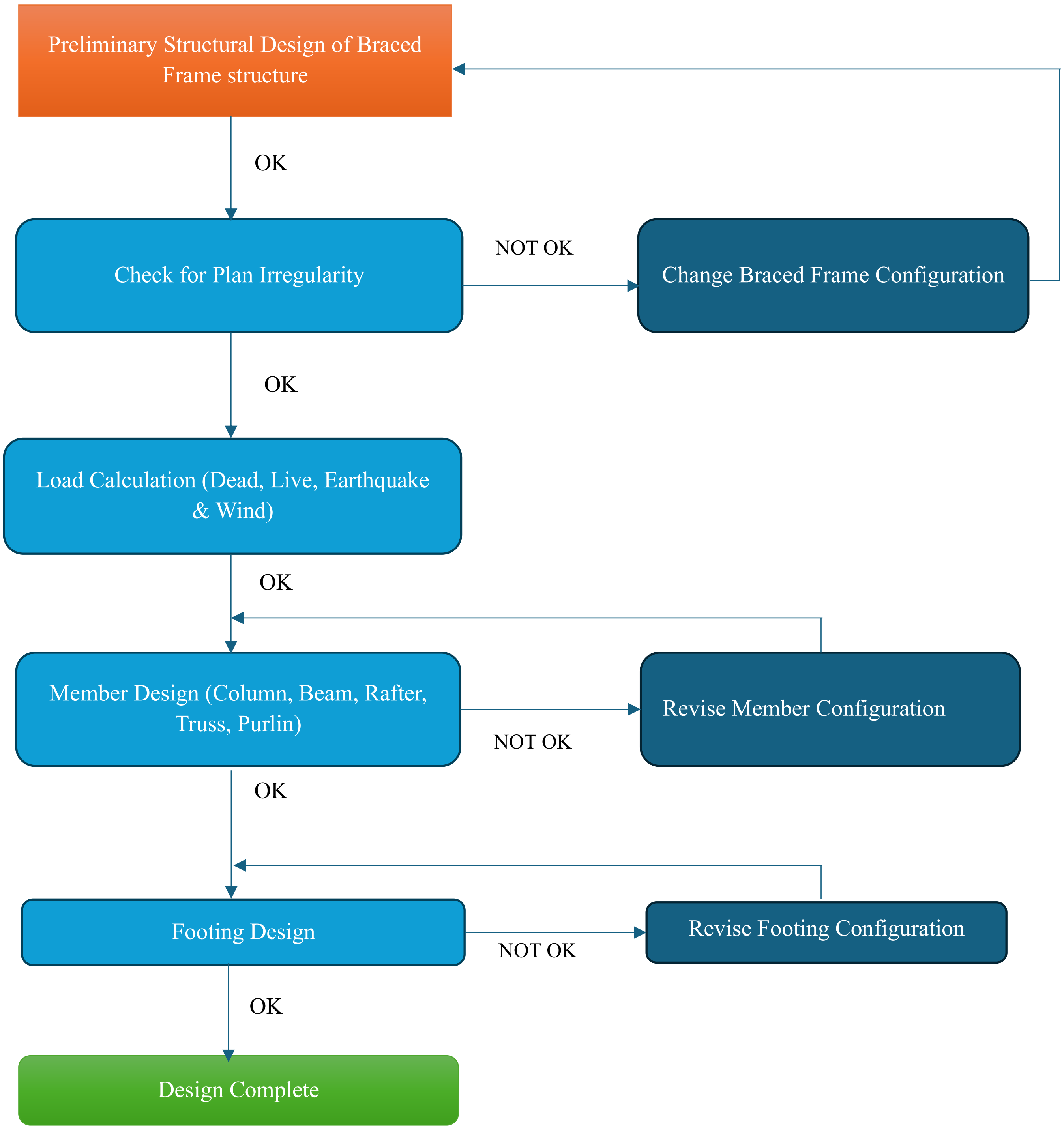


Figure 13: Flowchart of Design of Braced Frame Buildings

4 JOINTS AND SPLICES

4.1 GENERAL

Joints are critical connections that allow the transfer of forces between two or more bamboo elements or structural components. These connections must be designed to ensure safe and reliable force transmission under expected loads and exhibit predictable deformation behavior in line with their function and design assumptions.

The performance of bamboo joints depends on their detailing, material properties, and connection techniques. End bearing resistance varies with the type of cut—straight cuts offer better strength, while fish mouth cuts are less resistant. Dowels (bolts, screws) transfer forces through bamboo walls, and their spacing, size, and alignment are critical to prevent splitting. Grout-filled joints enhance strength by filling hollow sections and preventing crushing, provided the grout is compatible and flowable. Cutting techniques like straight, fish mouth, and flute peak cuts ensure proper fit and stability. For joints with multiple bolts, reduction factors are applied to adjust load capacities.

4.1.1 DUCTILITY OF JOINTS

Joints with ductility $\mu < 1.25$ shall not be used in load bearing structures.

Joints having ductility $\mu \leq 2.5$ shall not be used in the main lateral force resisting system of a structure.

4.1.2 ALLOWABLE JOINT RESISTANCE

The strength of a joint is determined by applying appropriate adjustment factors to its characteristic resistance. The allowable joint resistance is calculated as:

$$F_{y,d} = F_{y,k} C_{DF} \left(\frac{1}{FS_j} \right)$$

Where,

$F_{y,d}$ = Allowable joint capacity (safe load the joint can handle)

$F_{y,k}$ = characteristic 5th percentile resistance with 75% confidence (i.e. $F_{y,0.05,0.75}$ as per ISO 12122), described by experimental value or equations (e.g. European Yield Models) calibrated from experiments

C_{DF} = The modification factor for service class and load duration (see Table 1). The duration factor selected for load combinations shall be that for the component of the combination having the shortest duration.

FS_j = The joint factor of safety dependent on ductility (given in Table 17)

Table 17 : Joint Factor of Safety, FS_j

	$\mu < 1.5$	$1.5 \leq \mu < 4.0$	$\mu \geq 4$
FS_j	3.0	2.5	2.0

Ductility, μ, is determined in accordance with ISO/TR 21141 as the ratio of the experimentally determined ultimate displacement, Δu, to the yield displacement, Δy.

Where,

μ = the ductility. If ductility is unknown, a value $\mu = 1.25$ shall be assumed.

4.1.3 JOINT STIFFNESS

The stiffness of a joint determines how much it deforms under load. The allowable joint stiffness $k_{e,d}$ is

$$k_{e,d} = k_{e,k} C_{DE}$$

Where,

$k_{e,k}$ = the mean characteristic joint stiffness with 75% confidence, denoted as $k_{e,mean,0.75}$

C_{DE} = the modification factor for service class and load duration given in Table 6. The duration factor selected for load combinations shall be that for the component of the combination having the shortest duration

4.1.4 ROBUSTNESS AGAINST CULM SPLITTING

Bamboo culms are prone to splitting under longitudinal stress. To prevent this, metallic straps or clamps must be provided to confine bamboo.

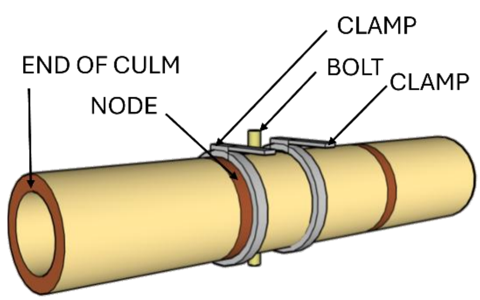


Figure 14: Joint with Clamp

Permanent clamps are required at the joints of a main structural element if the demand – resistance ratio of the element is greater than 0.7.

The straps must fit uniformly around the bamboo and should not damage it when tightened.

All components of metallic clamping straps shall be corrosion resistant (Section 3.3.5.1)

The confinement provided by the clamps shall be permanent, i.e., applied throughout the design life of a bamboo culm. Lashing cannot be considered as permanent confinement.

4.1.5 SPLICES JOINTS

Splice joints are a class of joints intended to connect two culms along their longitudinal axes (see Figure 15 to Figure

18). Splice joints are filled with grout infill minimum of two internodes or 600mm whichever is greater, at each connecting bamboo culm.

Lap splices connect two members along parallel axes separated by the diameter of the culms being spliced. Lap splices shall be designed considering the effects of moment arising from the eccentricity of culm axes.

To the extent possible, splices shall be located away from other connections.

To the extent possible, splices located in a moment resisting member shall be located at the location of least moment

The presence of a splice reduces the resistance of the member in which the splice is located. The resistance of spliced members shall be determined from Sections 3.5 or 3.6 including the presence of the splice.

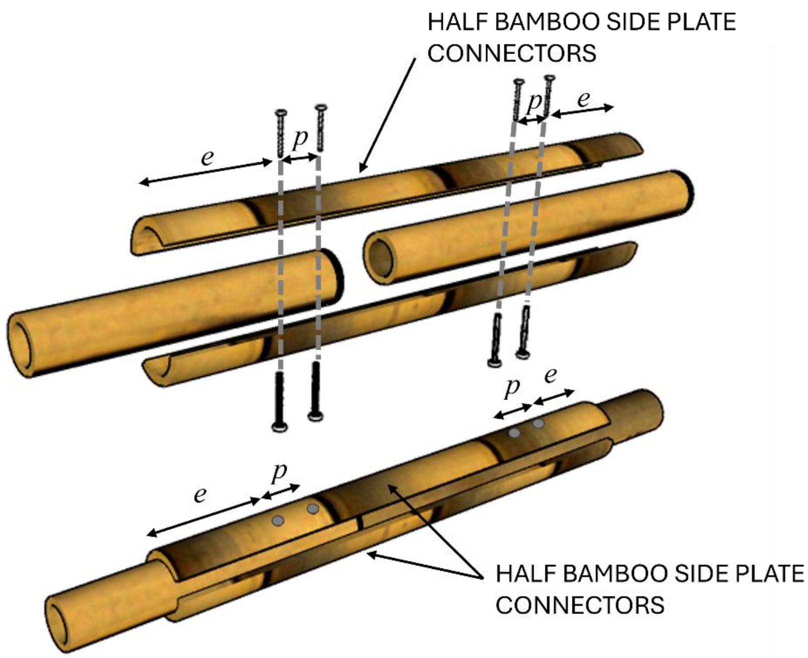


Figure 15: Concentric Splice with Half Bamboo Side Plate Connectors

Where,

e – Minimum edge distance should be 100mm c/c

p – Minimum pitch distance should be 50mm c/c and not greater than 300mm c/c

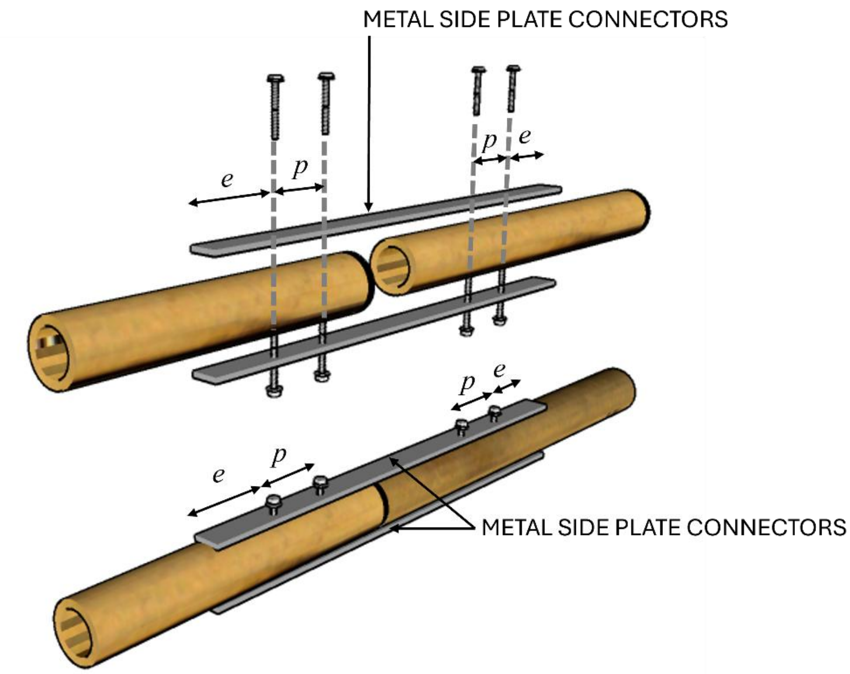


Figure 16: Concentric Splice with Metal Side Plate Connectors

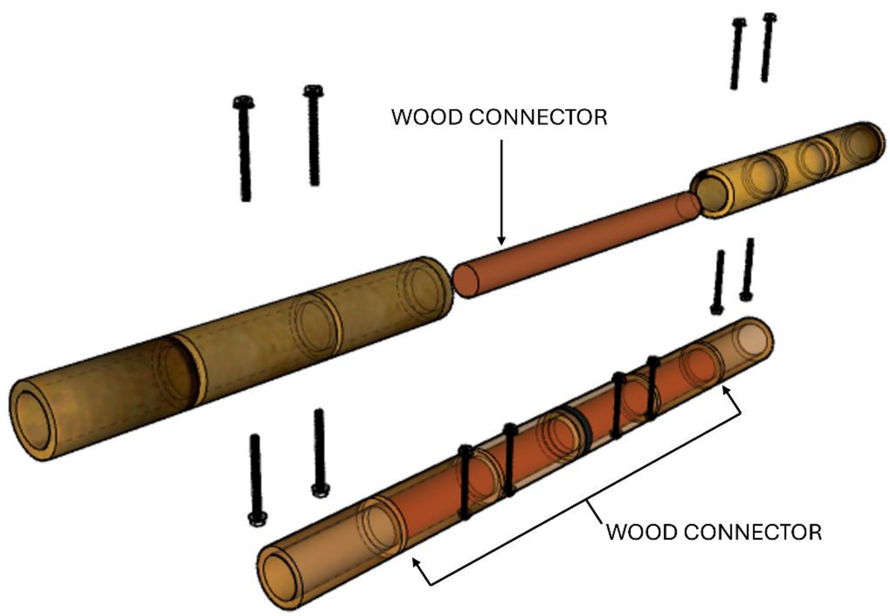


Figure 17: Concentric Splice with Wood Connector

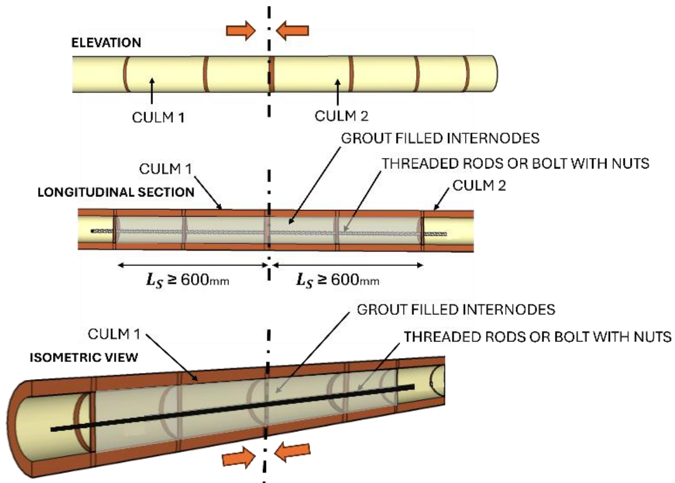


Figure 18: Concentric Splice with Threaded Rod Connector

4.1.6 REQUIREMENTS FOR NON-BAMBOO COMPONENTS OF JOINTS

4.1.6.1 METALLIC COMPONENTS OF JOINTS

All metallic connectors of joints should have the following characteristics:

- **Corrosion Protection**: All metallic parts must be protected from rust based on environmental exposure.
- **Material Compatibility**: Use the same type of metal to avoid galvanic corrosion when multiple components are in contact.
- **Strength**: Metals used in bolted connections must have a minimum yield strength of 240 MPa.
- **Bolt Holes**: Must be well-aligned and no larger than 110% of the bolt diameter.
- **Washers**: Metal washers must be used between the bolt and bamboo for uniform load distribution, with minimum dimensions as per Table 18:

Table 18: Minimum Dimensions of Washers for Bolted Connections

Bolt Diameter (mm)	Washer Thickness (mm)	External diameterwashers (mm)
10	2.1	25
12	2.8	35
16	3.4	45

4.1.6.2 JOINTS UTILIZING GROUT INFILL MATERIAL (GROUTED JOINTS)

Flowable infill material may be used in the internode regions of a joint or connection for the following reasons:

- Provide anchorage for embedded components of the joint or connection; or,
- Enhance bearing resistance of an internode region.

Minimum requirements for grout infill are as mentioned below:

- Grout must be compatible with bamboo, flowable, and non-shrinking.
- Minimum compressive strength of grout should be 6 MPa.
- Bamboo must be dry and at equilibrium moisture content before filling.
- Grout holes should not exceed 20 mm in diameter and must be sealed after filling.

4.1.6.3 LASHING

Lashing cannot be used for structural connections.

4.1.7 END BEARING RESISTANCE OF BAMBOO CULMS

The end bearing resistance of unfilled culms including the “mouth” portion of fish-mouth connection shall be determined by formula:

$$F_b = C_{EB} f_c A$$

Where,

fc	=	The allowable compression strength parallel to fibers given in Section 1.6.3; and
A	=	the cross-sectional area of the culm given in Section 3.3.7
C_{EB}	=	0.80 for straight cuts bearing onto a flat surface
C_{EB}	=	0.40 for fish-mouth connections bearing onto another piece of bamboo

4.1.8 JOINTS HAVING THROUGH CULM WALL DOWELS

This section refers to connections intended to transmit shear force involving pins, dowels, bolts, screws or other similar anchors (collectively called dowels) that penetrate the culm wall or pass diametrically through the culm engaging one or two culm walls.

4.1.8.1 CAPACITY OF A SINGLE DOWEL

For a dowel penetrating a single culm wall, the allowable bearing resistance F_b may be estimated as

$$F_b = d_b t f_{c,k} C_\theta$$

where

d_b = is the diameter of the dowel; for screws, d_b is 1.1 times the root diameter of the screw.
t = is the culm wall thickness
$f_{c,k}$ = is the characteristic compressive strength parallel to fibers
C_θ = is a correction factor accounting for the angle of loading relative to the longitudinal axis (0°) of the culm

Table 19: Values for C_θ

Dowel load condition	angle of loading relative to the longitudinal axis (0°) of the culm	
dowel engaging single culm wall	0.3	0.2
dowel engaging both culm walls	0.7	0.4

The allowable bearing resistance for cases $0° < C_\theta < 5°$, shall not exceed the shear tear-out capacity

$$F_b \leq 1.6 s t f_{v,k}$$

where
s = is the least spacing between adjacent dowels located along the same shearing plane or the distance from the dowel to the end of the culm in the direction of loading
t = is the culm wall thickness
$f_{v,k}$ = is the characteristic shear strength parallel to the fibers

Note that the above equations return conservative values. They should be judiciously used under lack of experimental data or calibrated equations from Section 4.1.2.

4.1.9 TYPES OF BAMBOO CUTS FOR CONNECTION

The three most common bamboo cuts for the fabrication of bamboo connections are: (1) Straight Cut, (2) Fish Mouth Cut and (3) Flute Peak Cut.

4.1.9.1 STRAIGHT CUT

A straight cut is a flat, perpendicular cut made at a 90° angle to the bamboo's longitudinal axis. This cut is primarily used to create clean and stable ends for simple connections, ensuring uniform load transfer and structural stability. To maximize its effectiveness, the cut should be made close to a bamboo node, ideally within 50 mm.

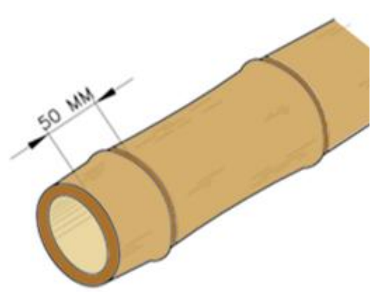


Figure 19: Straight Cut

4.1.9.2 FISH MOUTH CUT

A fish mouth cut is a curved, concave cut specifically designed to allow one bamboo pole to fit snugly against another. This type of cut ensures a tight and secure connection between bamboo elements, enhancing stability and minimizing gaps between the joined pieces. Similar to a straight cut, a fish mouth cut should be made close to a node, ideally within 50 mm, to prevent cracking and improve the joint's strength. The curvature of the cut must match the diameter of the bamboo it is connecting to ensure a proper fit. Fish mouth cuts are commonly used in frames and trusses, particularly where two bamboo poles intersect.

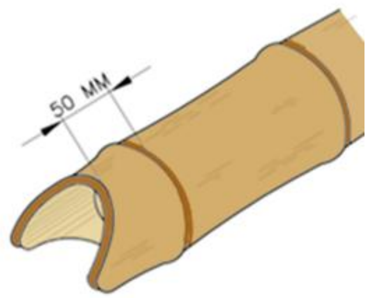


Figure 20: Fish mouth cut

4.1.9.3 FLUTE PEAK CUT

A flute peak cut is a combination of a straight cut and a fish mouth cut, designed for diagonal or bracing connections. This type of cut enables the bamboo to fit securely against both a flat surface and a cylindrical bamboo element, ensuring a strong and stable connection. As with other cutting techniques, the flute peak cut should be made near a node, ideally within 50 mm, to maximize structural stability and reduce the risk of splitting. Flute peak cuts are typically used in braces or diagonal members within shear wall systems, trusses, and frames that require more complex connections

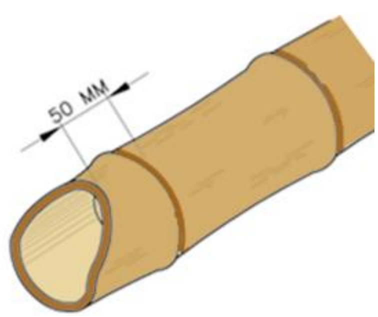


Figure 21: Flute Peak Cut

4.1.10 CONNECTIONS WITH GROUT INFILL

The permissible loads for bolted connections subjected to double shear shall be determined based on the P, Q and T values given in Table 20 to Table 30 depending on the outer diameter of the bamboo, the wall thickness, or the anchorage length and the diameter of the bolt.

The spacing between the dowels shall not be less than 100 mm and not more than 300 mm. The maximum number of aligned bolts that can be placed in one internode shall be two. In case the connection requires more than two bolts, the other bolts shall be placed to the next internode. Provide clamp on every bolt that are placed aligned to each other on a single internode.

The distance from the bolt to the free end of the element must be greater than 150 mm in joints subjected to tension and 100 mm in joints subjected to compression.

The mix ratio for grout infill is 1(cement) : 4(sand), and recommended ratio of mix is 1(cement) : 2(sand).

4.1.11 COMMON TYPES OF DOWELLED CONNECTIONS

4.1.11.1 P-TYPE CONNECTION, LOAD PARALLEL TO FIBER

P-type (infilled) connections refer to two distinct configurations. The first configuration (Figure 22) consists of dowel inserted across the diameter of the bamboo culm. This connection resists both compression and tension forces parallel to the bamboo culm axis. Permanent confinement in the form of metal straps/clamps is recommended.

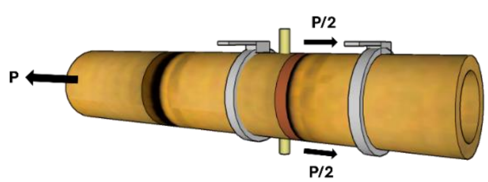


Figure 22: P-type connection

The second configuration (called henceforth as P_E type, Figure 23) comprises of the rod embedded into the hollow interior, along the longitudinal direction of the bamboo culm. The P_E connection can transfer loads in tension solely.

The P_E connection is a common method for connecting bamboo culms to reinforced concrete foundations. Note that only the steel rod is cast into the foundation; the bamboo studs/culms rest on top of the hardened concrete. The steel rod should extend at least 600 mm inside the bamboo and pass through at least two nodes. All hollow sections (internodes) where the rod passes must be filled with grout.

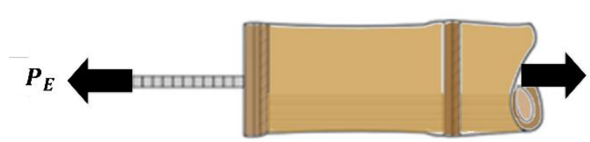


Figure 23: Load P_E with embedded connector parallel to the element axis

4.1.11.2 Q-TYPE CONNECTION, LOAD PERPENDICULAR TO THE FIBER

Q-type connections are used to handle forces acting perpendicular to the bamboo's length and come in two configurations. In the first type Figure 24, a dowel is inserted across the diameter of the bamboo to resist tension forces. To strengthen the connection and prevent splitting, metal straps or clamps must be placed on both sides of the dowel.

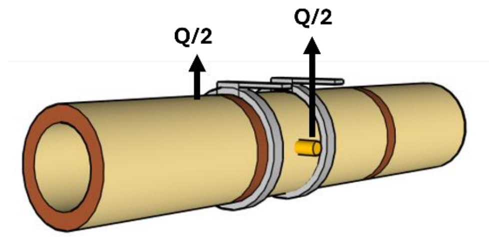


Figure 24: Load Q with Connector Perpendicular to the Axis of The Element

The second configuration (called henceforth as Q_E type, Figure 25) uses a steel rod embedded into the hollow bamboo along its length. The Q_E connection transfer loads perpendicular to the axis of the embedded rod. The Q_E forces commonly arise during earthquakes or winds.

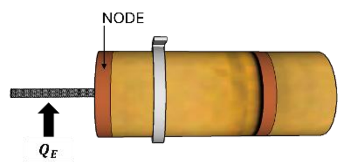


Figure 25: Q_E type loading on embedded rebar

Similarly to the P_E connection

Figure 1, the minimum anchorage length of the rod must be 600 mm into the bamboo culm and must pass through 2 nodes. The bamboo end must terminate at a node. Waterproofing is necessary for bamboo ends resting on concrete pedestals, to protect the bamboo from moisture entering through the concrete. All hollow sections (internodes) where the rod passes must be filled with grout, and metal straps or clamps should be used.

4.1.11.3 T-TYPE CONNECTION, CRUSHING LOAD

In T connection (Figure 26), the bamboo culm is subject to forces perpendicular to its axis. The force is transferred to the culm by means of a nut and a washer connected to the rod in tension. T-connection component shall be provided with confinement (using e.g. hose-clamps) and infilled with grout.

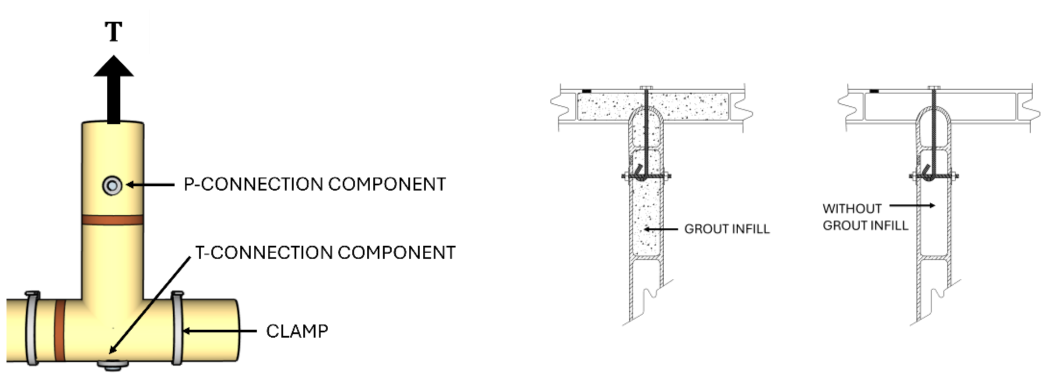


Figure 26: T-connection in combination with a P-connection

4.1.12 ALLOWABLE RESISTANCE OF COMMON DOWELLED CONNECTIONS

The permissible resistances given in Table 21 to Table 30 are representative of bamboo with a moisture content of 12% and which will remain dry during their service time. In connections of 4 or more members each cutting plane will be evaluated as a simple shear connection. The value of the connection shall be calculated with the lowest nominal value thus obtained, multiplied by the number of cutting planes.

The allowable resistance is obtained by multiplying the permissible resistance in Table 21 to Table 30 with the corresponding modification factors for service class and load duration C_{DF} (Table 1) , and temperature C_T (Table 2).

Table 20: Permissible resistance (kN) of P -Type joint with Grout Infill of 9 MPa

External Diameter (mm)	Permissible resistance P-type (kN) with 9 MPa mortar infill	
	Bolt Diameter (mm)	
	10	12
70	2.28	2.55
80	3.10	3.47
90	3.92	4.96
100	4.74	6.44

Table 21: Permissible resistance (kN) of P -Type joint without Grout Infill

External Diameter (mm)	Permissible resistance P-type (kN) without mortar infill	
	Bolt Diameter (mm)	
	10	12
70	2.28	2.55
80	2.62	2.91
90	2.82	3.13
100	3.02	3.35

Table 22 : Permissible resistance (kN) of P_E type Embedded Rod joints with Grout Infill

Number of Nodes through which the Rod Passes	Permissible resistance (kN) for embedded rod diameter	Grout Infill Compressive Strength, (MPa)

	12 mm	
<2	Not allowed	9
2	12.5	

Table 23: Permissible resistance (kN) of Double Shear Bolted Joints Q -Type with 9 MPa Grout Infill

External Thickness (mm)	Permissible resistance of Q-Type (kN) with 9 MPa Grout Infill	
	Bolt Diameter (mm)	
	10	12
6	1.86	1.99
7	1.91	2.05
8	1.97	2.11
9	2.03	2.17

Table 24 : Permissible resistance (kN) of Q -Type joints with 9 MPa Grout Infill and confinement

External Thickness (mm)	Permissible resistance of Q-Type (kN) with 9 MPa Grout Infill and confinement	
	Bolt Diameter (mm)	
	10	12
6	3.78	4.66
7	3.91	4.74
8	4.05	4.82
9	4.18	4.91

Table 25 : Permissible resistance (kN) of Q -Type joints with confinement and without Grout Infill

External Thickness (mm)	Permissible resistance of Q-Type (kN) without Grout Infill but with confinement	
	Bolt Diameter (mm)	
	10	12
6	1.93	2.30
7	2.02	2.55
8	2.11	2.81

9	2.19	3.06

Table 26 : Permissible resistance (kN) of Q_E -Type Bolted Joints with 9 MPa Grout Infill, with end-node, and Minimum Anchor Length of 600 mm and passing through 2 nodes.

Wall thickness (mm)	End-node present	Permissible resistance of Q_E -Type (kN) with 9 MPa Grout Infill and without confinement	
		Embedded rebar diameter (mm)	
		10	12
any	no	Not-allowed	
6	yes	1.03	1.64
7	yes	1.27	1.69
8	yes	1.51	1.75
9	yes	1.74	1.80

s

Table 27 : Permissible resistance (kN) of Q_E-Type Bolted Joints with 9 MPa Grout Infill, with end-node, confinement and Minimum Anchor Length of 600 mm and passing through 2 nodes.

Wall thickness (mm)	End-node present	Permissible resistance of Q_E-Type (kN) with 9 MPa Grout Infill and with confinement	
		Embedded rebar diameter (mm)	
		10	12
any	no	Not-allowed	
6	yes	2.21	4.75
7	yes	2.47	5.34
8	yes	2.74	5.92
9	yes	3.00	6.50

Table 28 : Permissible resistance (kN) of T-connection component without Grout Infill, with confinement, and washer diameter as per Table 18

Wall thickness (mm)	Permissible resistance of T-Type (kN) without Grout Infill, and with confinement	
	Bolt Diameter (mm)	
	10	16
6	0.33	0.33
7	0.58	0.72
8	0.75	1.10

9	0.92	1.48

Table 29 : Permissible resistance (kN) of T-connection component with 9 MPa Grout Infill, confinement, and washer diameter as per Table 18

Wall thickness (mm)	Permissible resistance of T-Type (kN) with 9 MPa mortar infill and confinement	
	Bolt Diameter (mm)	
	10	16
6	3.4	7.2
7	3.4	7.5
8	3.4	7.7
9	3.4	8.0

The permissible resistance in Table 20 to Table 29 correspond to joints with a single bolt. When a joint requires more than two bolts in line parallel to the direction of the load, the permissible resistance of the joint shall be obtained by multiplying the permissible values per bolt obtained from that table, by the number of bolts and by a reduction coefficient per group, C_g, according to Table 30. The reduction coefficient per group can only be applied to P type connection.

Table 30: Reduction Coefficient by Group C_g

Type of Connector	**Number of bolts**				
	2	**3**	**4**	**5**	**6**
Parallel dowels connected with bamboo	1.0	0.97	0.93	0.89	0.82
Parallel dowels connected with flat bar	1.0	0.98	0.95	0.92	0.90

5 TRUSSES

Trusses are assemblies of pin-connected members. Trusses may be planar (2D) or space truss (3D) structures. Multiple culm members are permitted. In planar trusses all members and connection points shall be symmetric about the plane of the truss. In space trusses all members at a connection shall be arranged such that their lines of action are collinear with the working point of the connection.

Members shall be designed to resist axial compression and tension as specified in Section 3.6. For compression members, the length of a member, L, shall be taken as that between points of restraint in the axis of member buckling and the effective length factor shall be $K_L = 1$ (Section 3.6.2). Members shall be designed to resist flexure (Section 3.5) as required.

Trusses shall be supported against out-of-plane buckling and lateral deformation at every joint along the compression chord. Lateral restraints shall provide sufficient restraint and stiffness to inhibit lateral movement of the restraint point. Restraints shall be capable of resisting a force F_{resf}, determined as given in Section 3.6.2.1 oriented perpendicular to the plane of the truss.

To the extent possible, tension and compression chords shall be continuous over at least the shear span of a truss. Spliced members are permitted. Splices shall be designed based on the requirements of Section 4 .

Joints in trusses shall be designed such that they provide minimal rotational restraint and are generally not capable of imparting moments into the members they connect, i.e., they are “pinned” connections. Truss joints shall be designed based on the requirements of Section 4 to resist the design forces determined from analysis compliant with Section 3.4.

ANNEX A : HARVESTING AND STRUCTURAL GRADING

I. HARVESTING

Matured bamboo culms of age 3-5 years are harvested for construction. Immature culms (1-2 years) and older culms (older than 5 years) cannot be used for structural applications.

Flowered bamboo culms cannot be used for structural applications.

Freshly harvested poles cannot be used for construction. They shall undergo grading and chemical treatment process as soon as possible. In particular, the chemical treatment process should start no later than 1 week after harvest.

II. STRUCTURAL GRADING

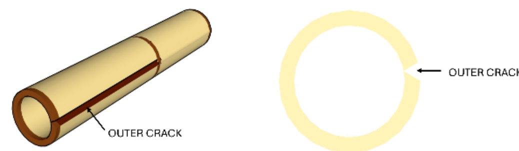
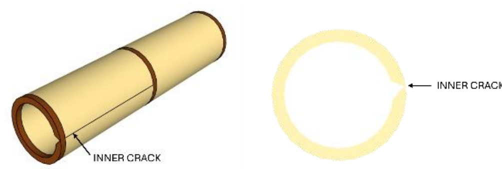
Bamboo culms shall be graded in accordance with ISO 19624:2018. Following sections present specific rules for production of construction grade poles.

a) VISUAL ASSESSMENT OF CONDITION PROPERTIES

Freshly harvested bamboo poles received from the site are first assessed for signs of defects as described in the Table 31.

Table 31: Visual defects in bamboo (condition properties) and their allowable limits

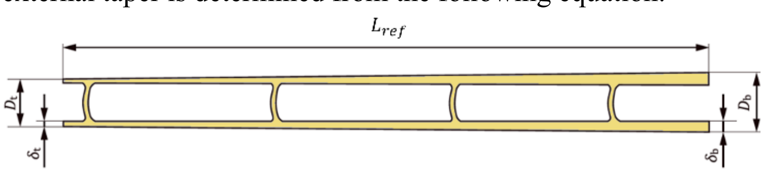
Defects	Allowable limits	Illustrations
A. insect infestation	Reject the entire bamboo pole if insect holes are seen.	 *Figure 27: Bamboo poles with insect infestation*
B. fungal attack	Reject the entire bamboo poles if fungal attacks are seen.	 *Figure 28: Bamboo poles with fungal damage*

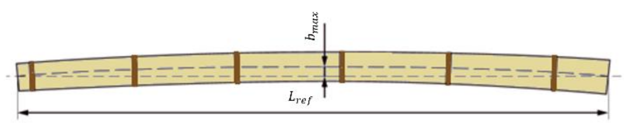
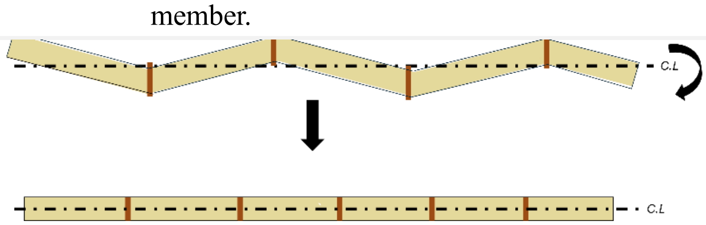
Defects	Allowable limits	Illustrations
C. Sunlight (UV) damage	Exposed poles are observed by discoloration. Reject the entire bamboo pole that show signs of UV damage.	 *Figure 29 : Discoloration in Bamboo culms*
D. Cracks a. Outer crack b. Inner cracks	Reject the entire bamboo pole if • Crack width exceeds 2 mm for outer crack • Crack width exceeds 1 mm for inner crack • Sum of the lengths of all longitudinal cracks > 20 % of length of bamboo culm. • Cracks extend to three adjacent internodes Initial bamboo poles with cracks may be cut into smaller lengths, with the cracked regions removed.	 *Figure 30: Outer Crack*  Figure 31: Inner Crack

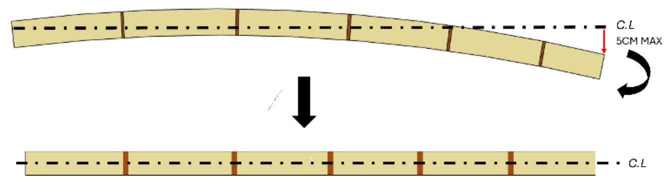
III. GEOMETRIC GRADING

Bamboo poles passing the visual assessment (Section 0) are then cut into required lengths while complying the geometric requirements of Table 32.

Table 32 : Geometric properties of cut bamboo poles and their allowable limits

Property	Description	Allowable limit
A. External Diameter	Range of external diameters of the cut bamboo poles	70 mm and 100 mm
B. External Taper	Taper is the change in diameter of bamboo over length. The external taper is determined from the following equation:  *Figure 32 : External Taper* $\alpha_e = \frac{D_b - D_t}{L_{ref}}$	The external taper is limited to 0.5%. Construction arrangement is such that, the lower part of the structural member, e.g. base of column, shall correspond to the end with diameter D_b. Diameter of bamboo culm used for design shall correspond to D_t.

	where, α_e External taper D_b Average of two perpendicular outer diameters measured at the base of the pole D_t Average of two perpendicular outer diameters measured at the top of the pole L_{ref} Reference length of the pole, equal to the typical length of the structural member	
C. Out-of-straightness imperfection		
1. Bow	This deformation is recognized by placing the part on a flat surface and observing if there is separation between the support surface and the part.  *Figure 33:Elevation of a bamboo culm showing bow* The bow, b_o , is determined by the equation $$b_o = \frac{b_{max}}{L_{ref}}.$$ Where, b_{max} maximum perpendicular distance from the center of the culm section to the chord drawn from the centers of either end of the bamboo piece L_{ref} reference length of the bamboo piece, Select reference length (L_{ref}) to the intended use of the culm, e.g. typical length of the structural member.	The initial bow (i.e. curvature) of bamboo culms must be smaller than 1/50 (2%) of the length of the member. The bow may be neglected if the bamboo pole is assumed within the structural design to work in the form of an arc, using its natural curvature.
2. Irregular curvature	 *Figure 34: One radial axis of bamboo culm with irregular curvature and another radial axis of same bamboo culm with regular curvature*	Bamboo with irregular curvature or other related shape is acceptable if its one radial axis is straight. Bamboo poles with irregular curves of shall meet the requirement of bow.
3. End curve	End curve is the curve located before 1/3 and after 2/3 of its length. -Initial bamboo poles with large value end curve are cut to shorter lengths, removing (where possible) regions of significant end curve.	Bamboo with end curve is acceptable if it has one radial axis straight. End curve should not be more than 5cm (for all cut

	 *Figure 35 : Figure showing end-curve of bamboo culm and another radial axis of same bamboo culm with regular curvature*	poles), and shall met the requirement of bow

ANNEX B : CHEMICAL TREATMENT

Bamboo poles graded and cut as per Section III of Annex A are then chemical treated. This section presents general steps for chemical treatment using soaking method.

Step 1 – Quality Control on Graded and Cut Bamboo Poles

Chemical treatment for the bamboo poles should start within one week of harvesting. The bamboo poles graded and cut as per Section III are assessed for damage and defects.

Step 2- Cleaning and Node Punching

The poles passing Step 1 are washed and cleaned thoroughly. All inner node-diaphragms of the bamboo poles are punched through with a long 10 mm diameter steel rod to facilitate entry of chemicals.

Step 4 – Starch Removal

The bamboo poles are then immersed in running water for at least 3 days to remove starch. The water is changed every day. After the 3 days of immersion, the bamboo poles are erected vertically under shade for 1-2 days to semi-dry.

Step 5 – Quality Control

The semi-dried bamboo poles are examined for cracks and defects formed during starch removal and draining process. Unviable poles are discarded.

Step 6 – Chemical Treatment

Bamboo culms are chemically treated by soaking on Boric acid: Borax solution for 7 days. Refer Section II for specific details on chemical preservatives.

Step 7 – Dripping

Chemically treated culms are then taken out, kept upright resting on a fixed support to allow preservatives to drain out for 2-3 hrs. Bamboo poles are turned periodically to aid the dripping process.

Step 8 – Shade Drying

The bamboo poles are erected vertically and shade-dried for 1 to 3 days. The bamboo poles are turned periodically for uniform drying.

Step 9 – Racking and Final Drying

The semi-dried bamboo poles are stacked horizontally in dry, shaded and well-ventilated racks to dry gradually over several weeks.

9 STEP TREATMENT PROCESS


Step 1. Receiving and QC raw poles


Step 2. Washing and Scrubbing

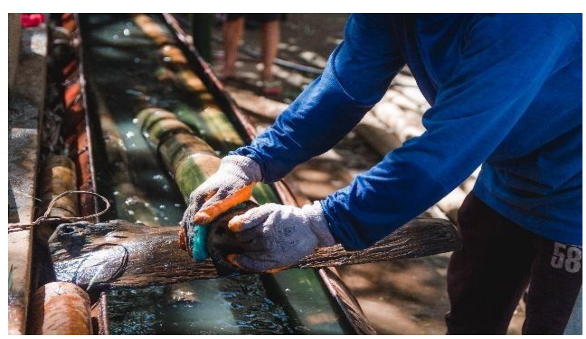

Step 3. Node Punching


Step 4. Washing


Step 1. Receiving and QC raw poles


Step 2. Washing and Scrubbing


Step 3. Node Punching


Step 4. Washing

ANNEX C : STORAGE AND CHEMICAL PRESERVATIVES

I. STORAGE

Treated bamboos poles are stored (and air-dried) in shaded and well-ventilated horizontal racks with following requirements:

- The stored bamboo poles are not in contact to the ground. Proper airflow is maintained by leaving a gap of at least 300 mm from the ground to bamboo racks.
- The stored bamboo poles are not exposed to sunlight, rain, and standing water.
- Proper ventilation/ air circulation is maintained by providing bamboo spacer / slats / wood pile in-between each horizontal layer of bamboo poles
- The relative humidity is maintained at 50% for storage. Storage under low humidity will result in cracking, while under high humidity will reduce the strength of bamboo.

II. CHEMICAL PRESERVATIVES

Table 33 presents the specifications of two different chemical preservatives for treating raw bamboo poles. Among the two, Boric acid: Borax solution is the recommended preservative for the treatment of bamboo poles used in nearly all structural applications. The treatment using Copper-chrome-boron (CCB) composition is not recommended in general due to its toxicity to humans. It shall be selected only if Boric acid: Borax method is deemed not suitable.

For example, Boric acid: Borax solution obtained by mixing 3.3 kg boric acid, 4.7 kg borax with 92 l of water satisfies the Table 33 proportion of Boric acid: Borax and minimum concentration.

Table 33 : Chemical preservatives for treating freshly harvested bamboo poles

Chemical preservative	Preservative proportion	Concentration	Service class	Minimum soaking time	Toxicity to humans
Boric acid: Borax	1: 1.4 (boric acid: borax)	8%	1, 2	7 days	Minimal
Copper chrome-boron (CCB) composition	1.5: 3: 4 (boric acid: copper sulphate: sodium or potassium dichromate)	8%	3	20 days	Yes

III. QUALITY REQUIREMENTS OF BAMBOO FOR DURABLE STRUCTURES

The bamboo used as structural element (e.g. in column shape, beam, joist, stud, framework intermediate flooring, etc.), shall meet the following quality requirements:

- The bamboo culms shall be of species *Bambusa balcooa* or *Bambusa nutans cupulata*. Other bamboo species shall be used only after completing material testing and characterization by a certified laboratory.
- The harvesting age for the structural bamboo shall be between 3 and 5 years. The term "mature" is used to describe this condition.
- Bamboo culms are graded to meet the design specifications and are free of defects.
- Bamboo culms are chemically treated to resist insects and fungal attacks.
- Dry bamboo culms with moisture content < 19% shall be used for construction. The moisture content of the bamboo shall be in equilibrium with the construction site conditions. To ensure this, the dry bamboo culms shall be stored on site in a shaded area for at least two weeks before being used.
- The service class (see Section 3.3.5) of the bamboo culms is reduced by good design and detailing (for e.g. see Table 34). Consistent with the service classes, they shall not be in contact with soil, and remain protected from solar radiation, rain and water collection.

Table 34: Good design practices for durable bamboo structures

Protection measure	Against
Separate bamboo structure from ground: Elevate bamboo above the ground level on a plinth or upstand, isolating the bamboo from the plinth or foundation with a damp-proof membrane. This prevents water ingress from soil to the superstructure.	Water, UV rays, Insects/pests
Roofing: Provide sloped roof coverings with long overhangs or verandas to protect bamboo members against windblown or driving rain. A typical way to check is to draw a $45°$ line from the end of the overhang to the wall, any part of the structure below the wall are exposed to rain.	Water, UV rays
Drip details: at roof overhangs, eaves, bases of walls and columns to prevent water collection.	Water
Waterproof layers: external facing walls directly exposed to driving rain, damp proof layer at the foundation to prevent seepage from the ground; waterproof roofs to prevent seepage.	Water
Connection detail: Connections are designed to ensure that standing water is unlikely to accumulate or enter inside of the culm. It can be done by plugging or sealing exposed ends of the culms.	Water insects/pests
Use of treated bamboo: Use correct chemical treatment procedure and preservative solutions. The service class of a bamboo member also determines the type of chemical preservative to be used. For example, boric- acid borax preservative leaches out of the treated bamboo poles when they are exposed to water. Such poles become vulnerable to insects.	Water, insects/pests
Ventilation: Bamboo culms expand and contract as the humidity changes. Ventilation holes are provided on the cavity walls to allow air circulation. Never cast bamboo poles into concrete or masonry structures.	Rot
Corrosion resistant components: Steel components used for bamboo connection such as nails, bolts, steel straps and chicken wire mesh are protected against corrosion or be of corrosion resistant material (e.g., stainless steel).	Water, weathering
Thermal cracking: Separate bamboo rafters/purlins from direct contact with roof (e.g., CGI roofs, which undergo large changes in temperature throughout the day) to avoid thermal	Weathering

cracking. This is achieved by adding an intermediate timber or bamboo slat between the rafters/purlins and the roofing sheet.	

IV. MAINTENANCE, INSPECTABILITY AND REPLACEMENT CONSIDERATIONS

For a variety of reasons, bamboo culms may split longitudinally or be otherwise damaged while in service.

To the extent possible, provision should be made to permit maintenance and inspection of bamboo load-bearing members; particularly members forming part of a non- redundant load path.

To the extent possible, designs should accommodate the future needs to replace individual culms in a member or structure.

Annex D : SAMPLE DESIGN CALCULATION

The building shown in

Figure 36 is a residential structure with mono slope roof located in Bharatpur. It is a 6.5m by 3.3m rectangular building with eave height of 2.70m. Details of the structure are listed below:

Location	Bharatpur
Occupancy Category	Standard Occupancy
Dimensions	6.5m x 3.3m in plan Monoslope roof slope is 16° 0.6 m roof overhang at both direction 2.70m eave height
Structural System	Cement bamboo frame technology Wall panels are 2.44m-high resting on top of an upstand 0.3m above natural grade line

Steps for the calculation:

1. Step – 1 : Check minimum length of wall
2. Step – 2 : Check plan irregularity
3. Step – 3 : Calculation of all the loads (Dead, Live, Wind, Earthquake)
4. Step – 4 : Shear Check
5. Step – 5 : Overturning Check
6. Step – 6 : Design of roof truss
7. Step – 7 : Design of connections
8. Step – 8 : Design purlins
9. Step – 5 : Design of column
10. Step – 9 : Design of footing

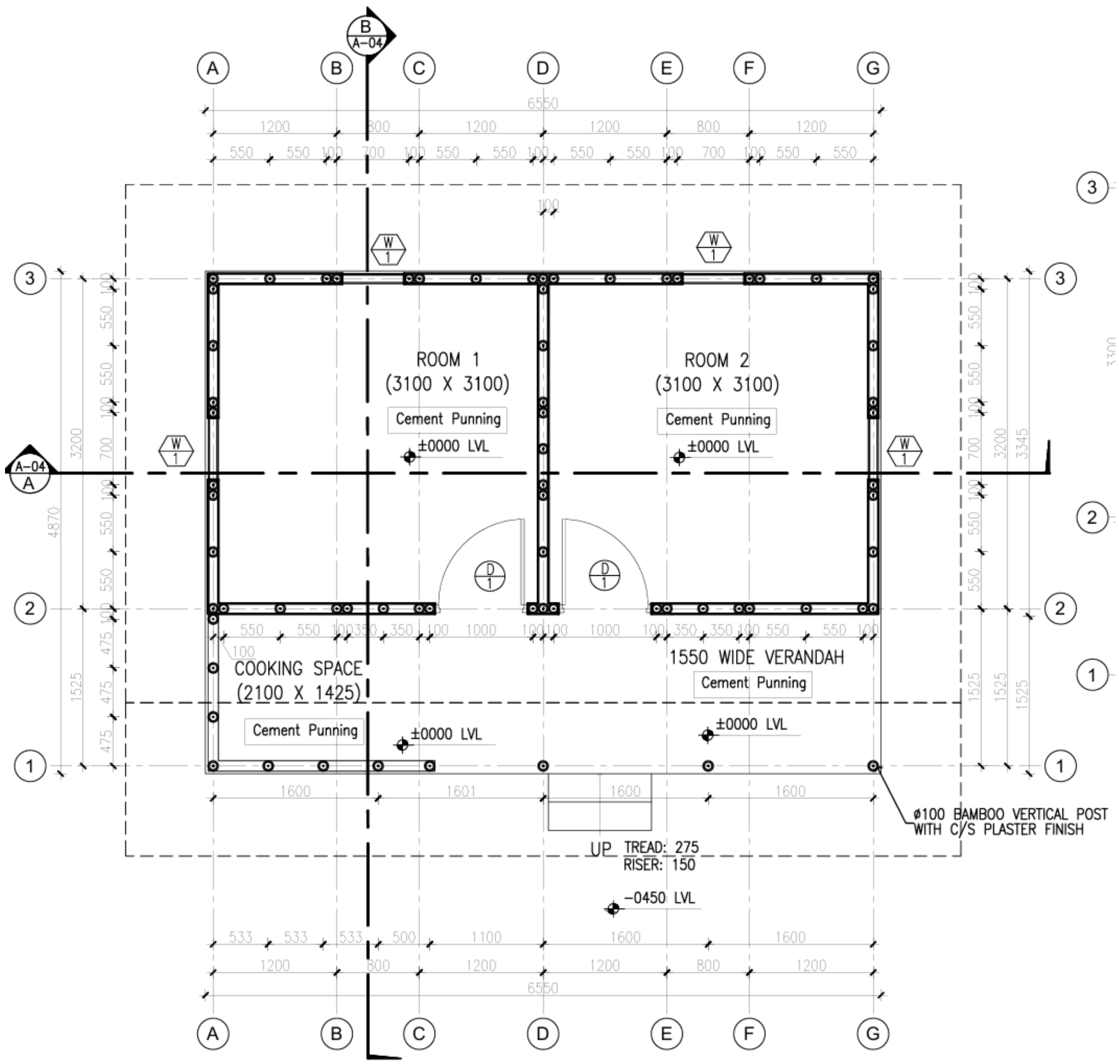


Figure 36. Floor Plan

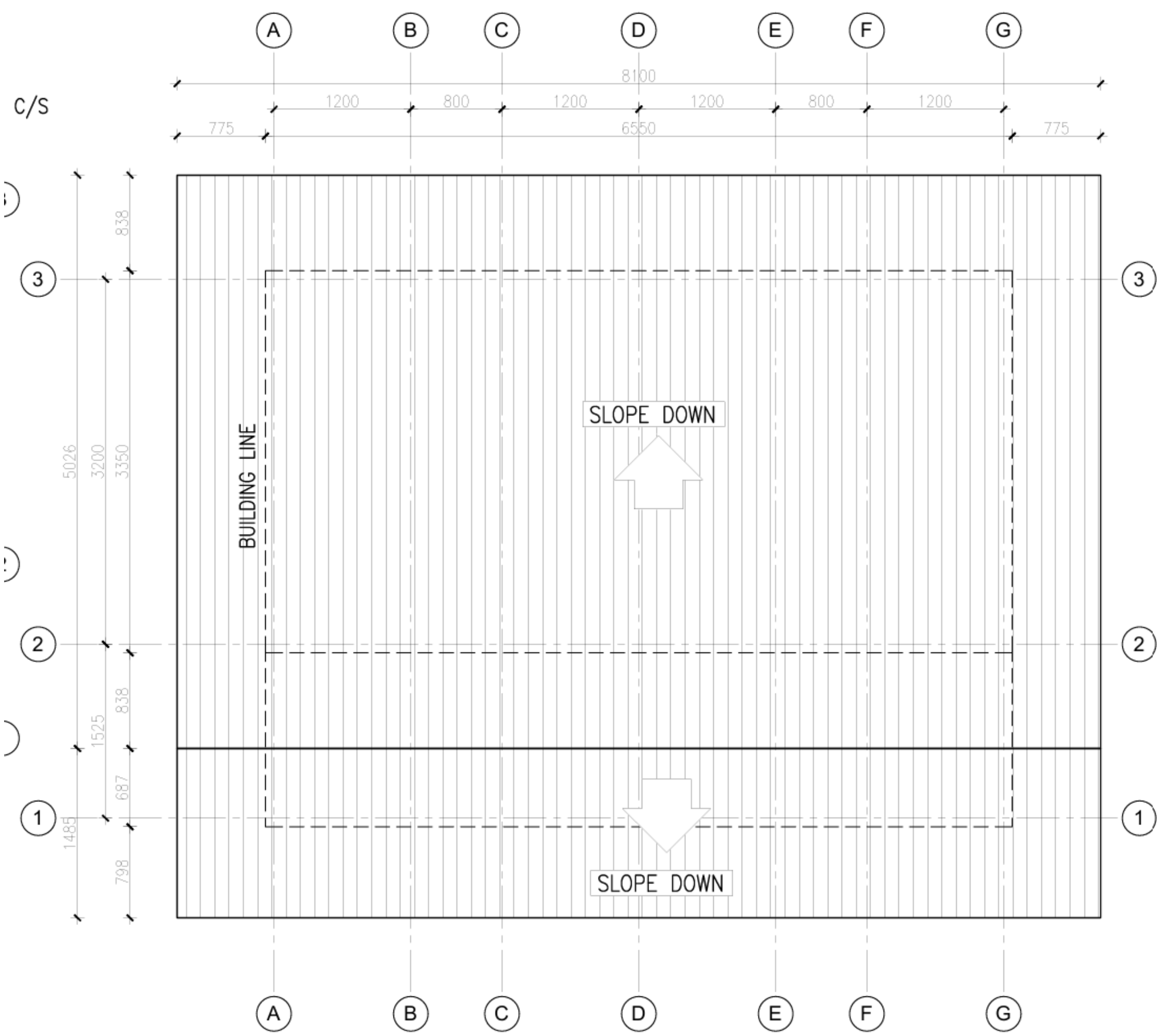


Figure 37. Roof Plan

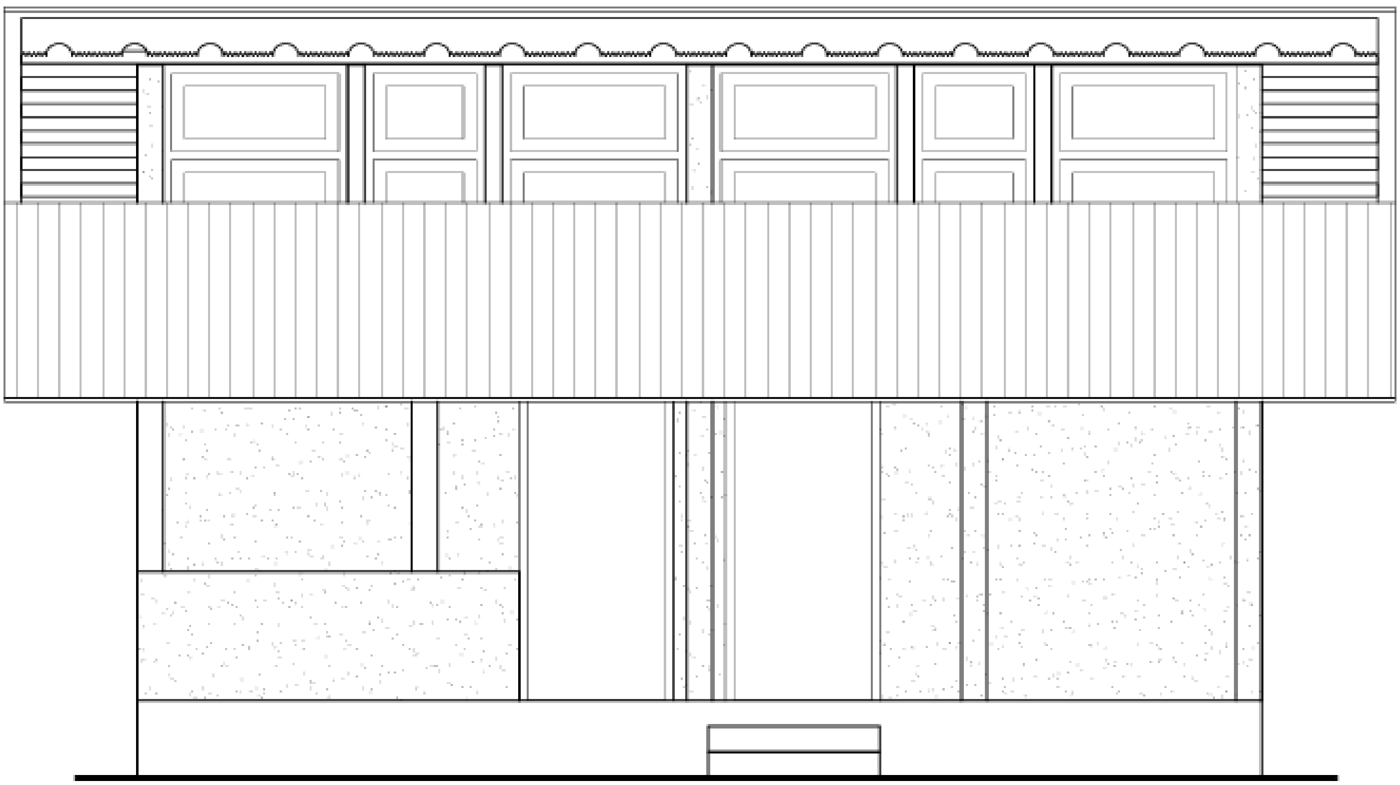


Figure 38. Front Elevation

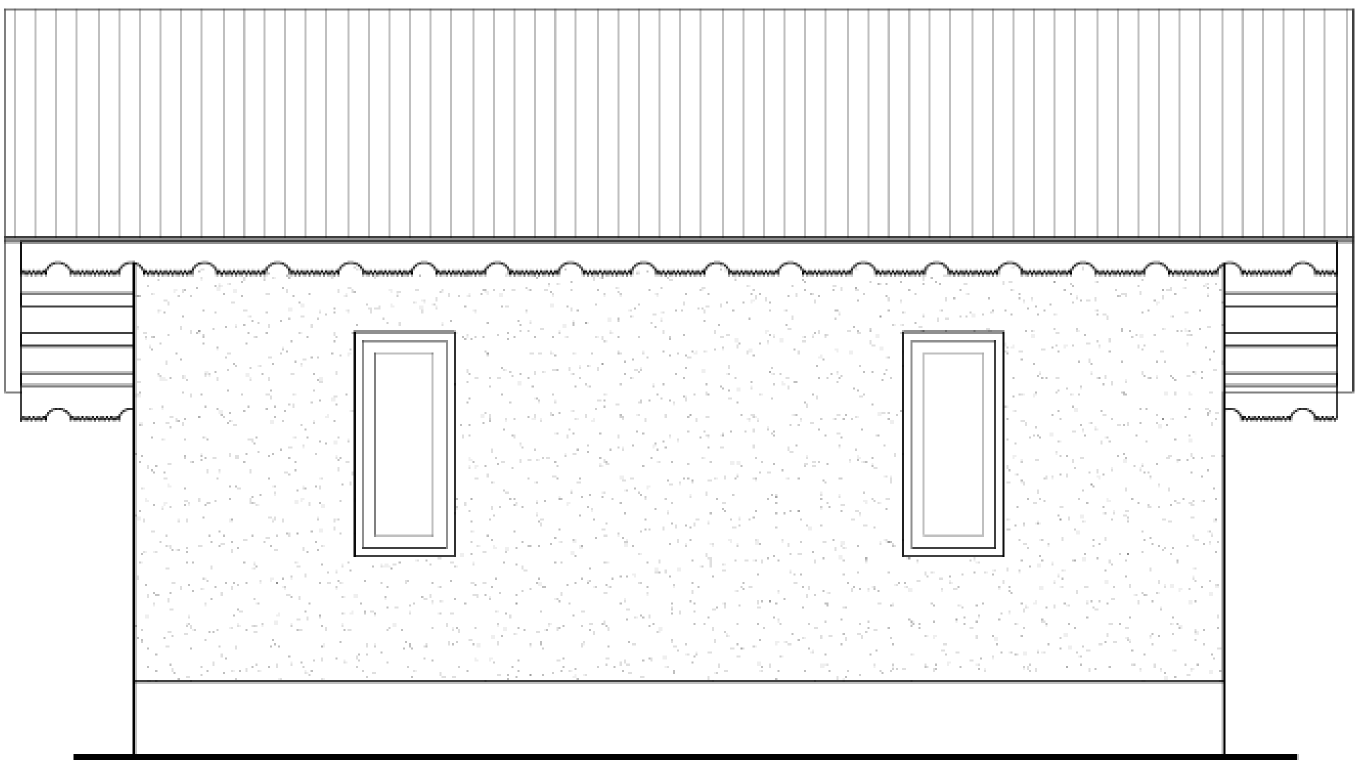


Figure 39. Back Elevation

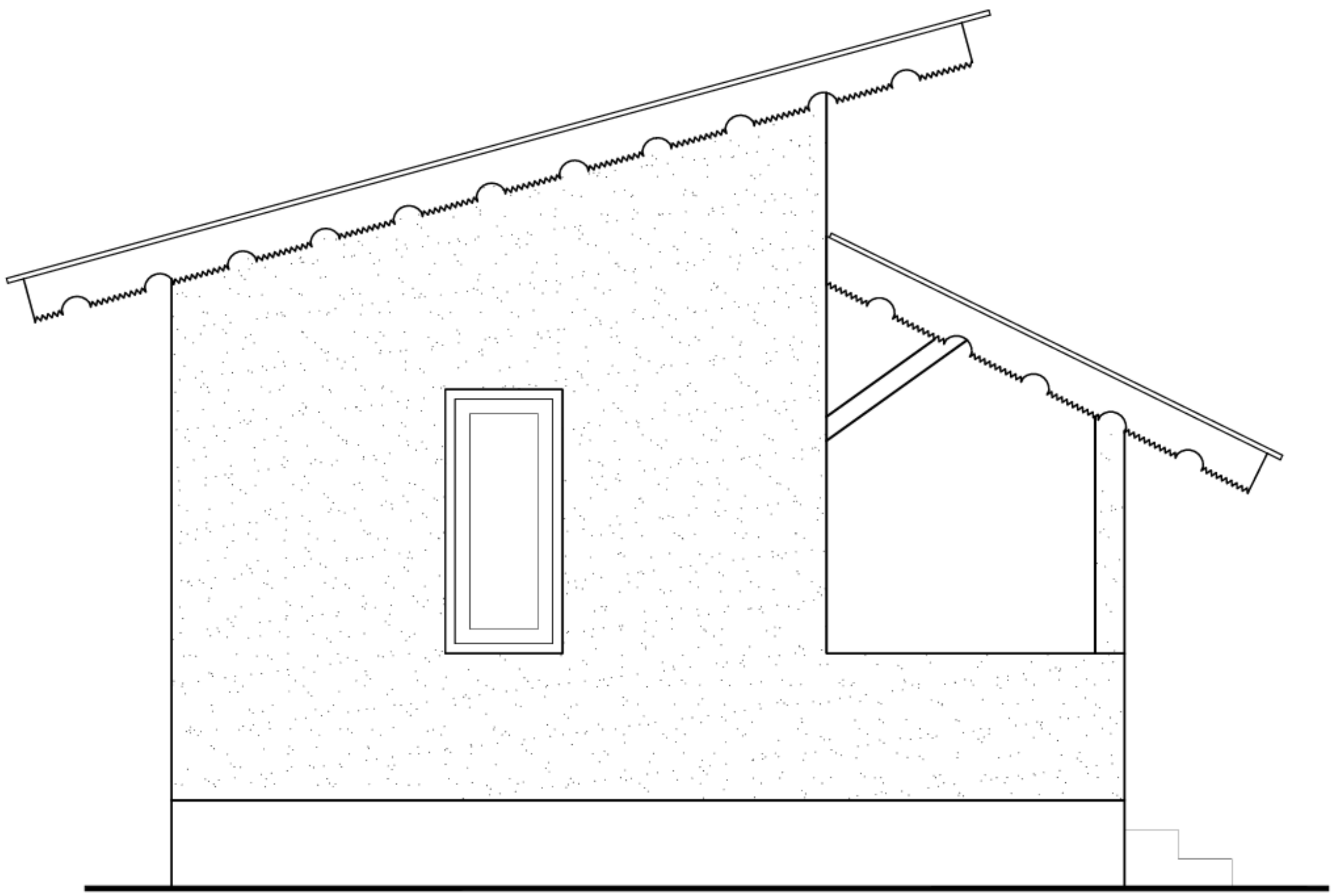


Figure 40. Left Elevation

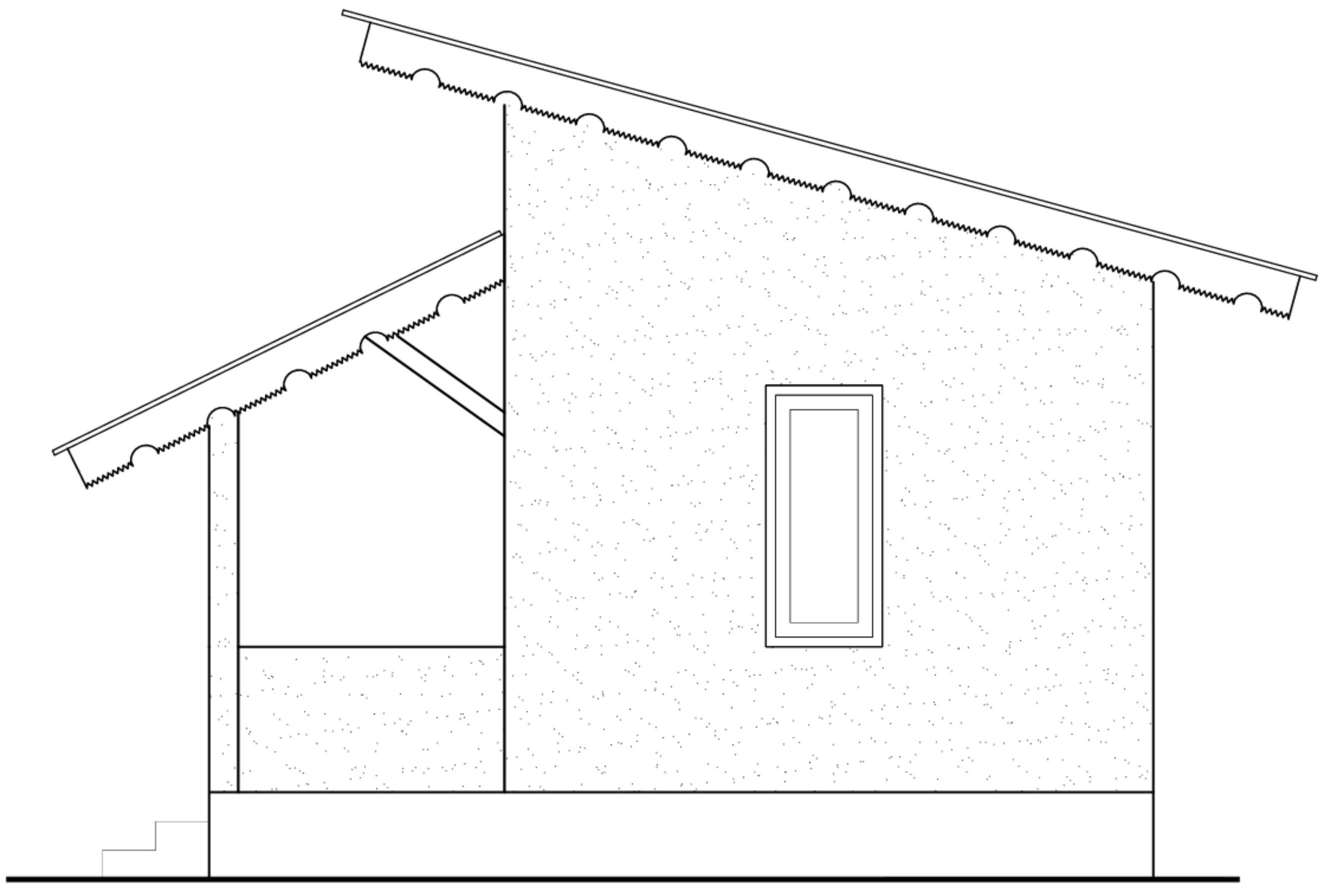


Figure 41. Right Elevation

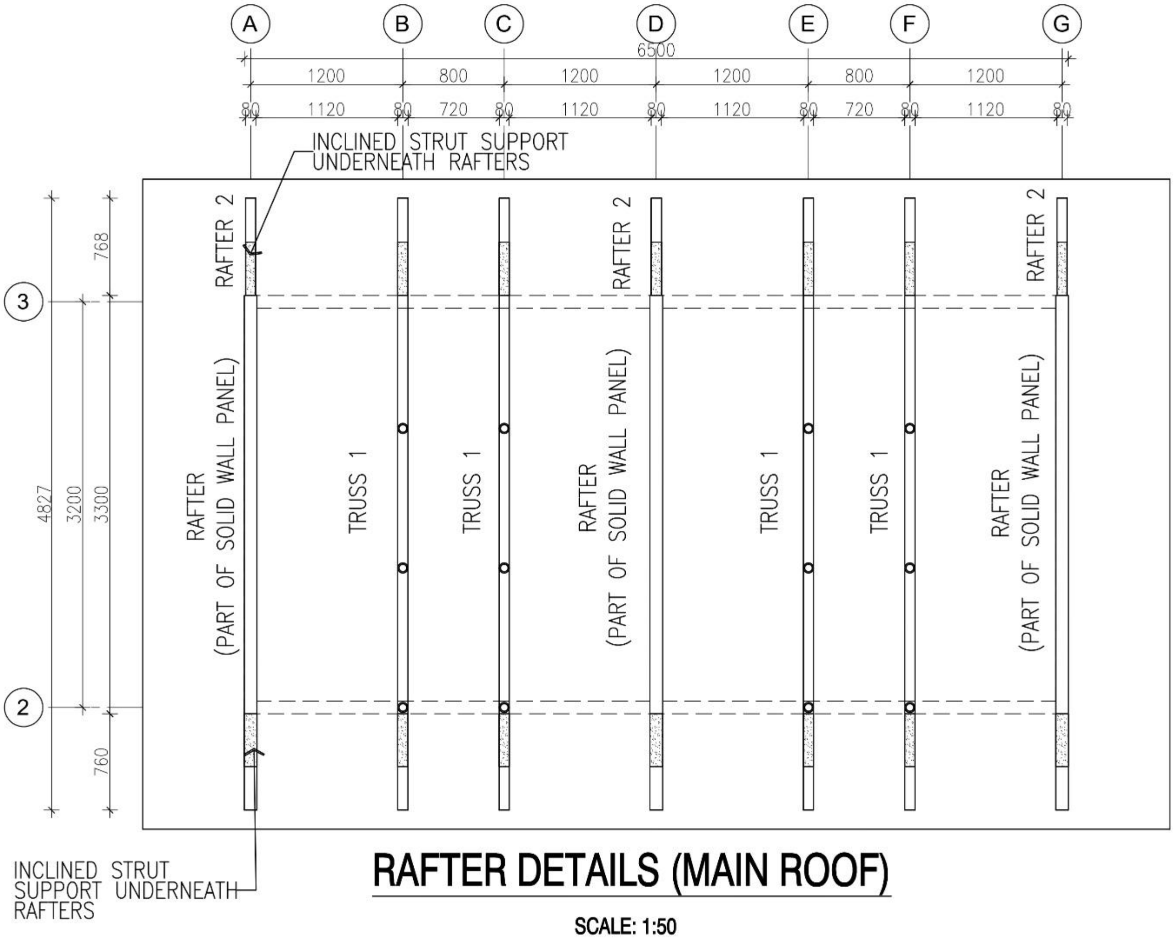


Figure 42. Roof Framing Plan

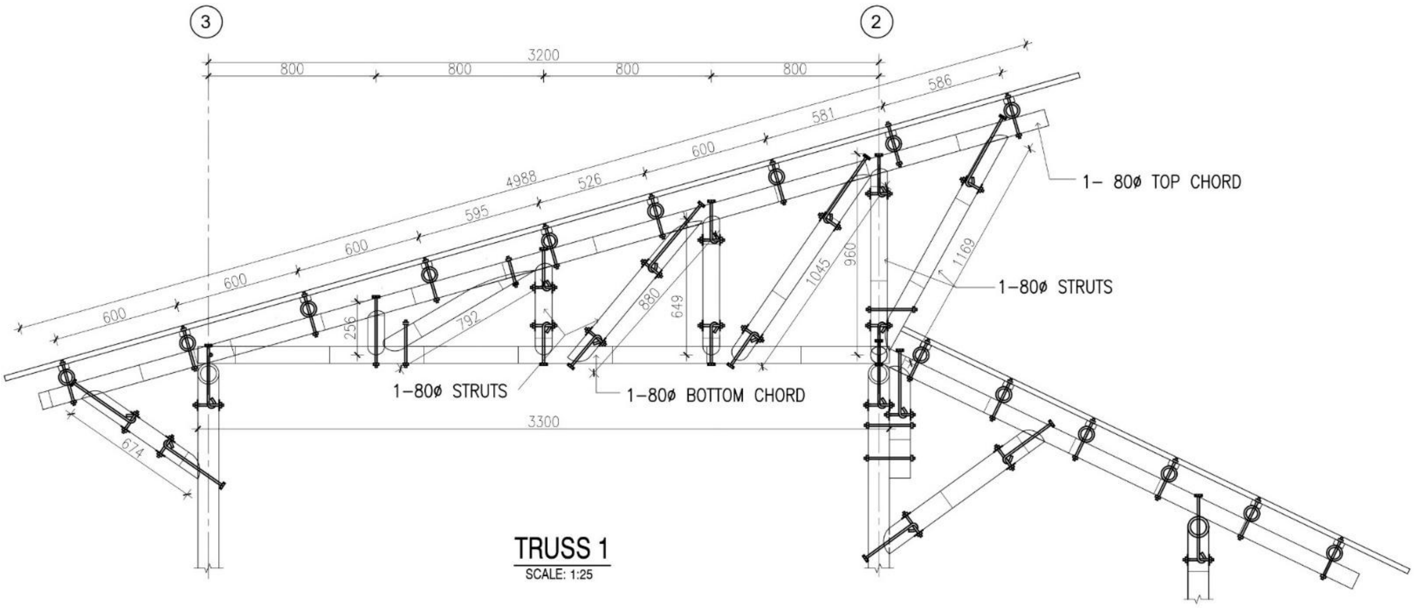


Figure 43. Truss Elevation

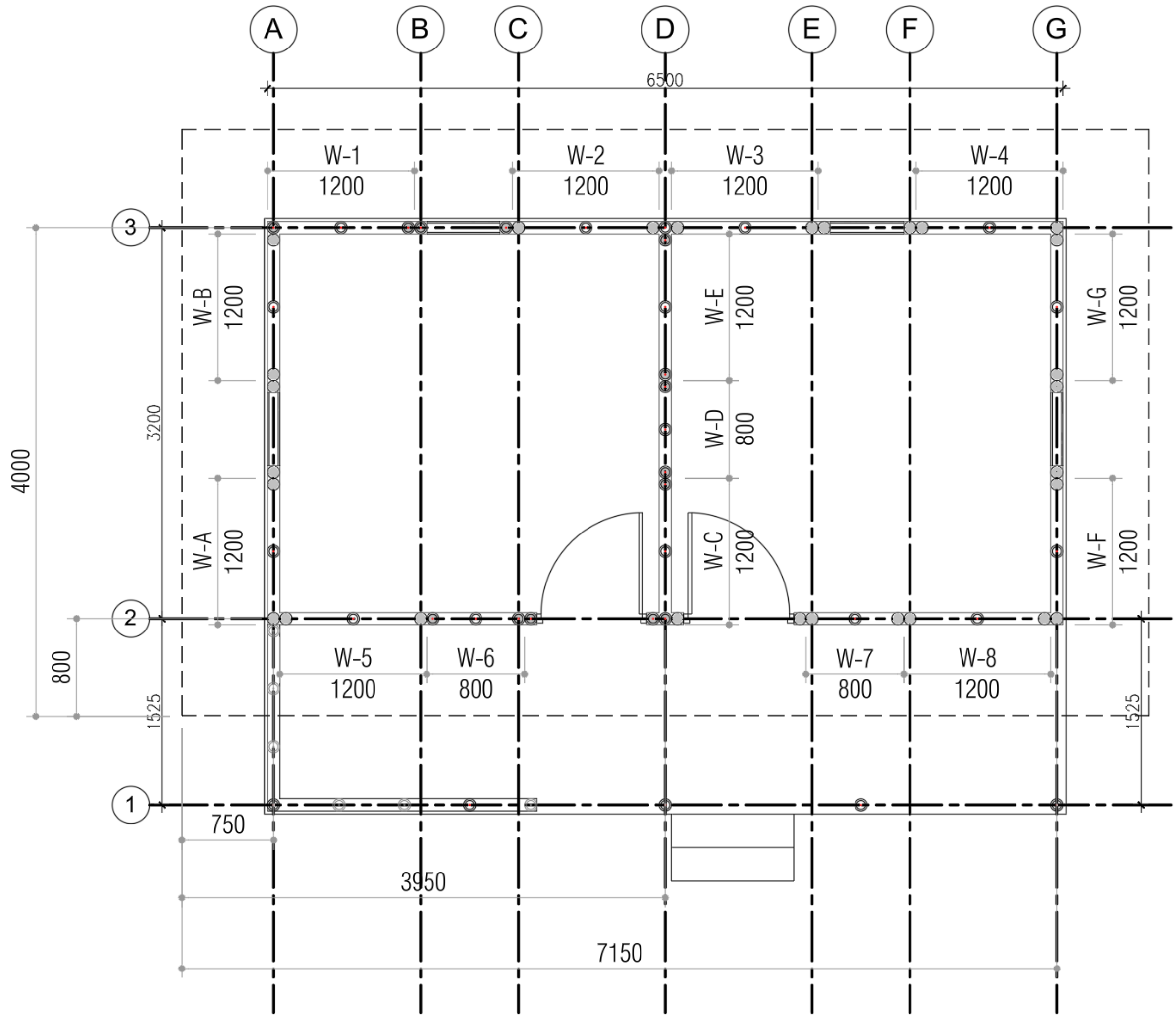


Figure 44. Structural Wall Configuration

ITEM	CALCULATION PROCEDURE	REFERENCE
STEP-1: Minimum Length of Bamboo Frame Wall	Minimum length of confined walls shall be provided in each orthogonal direction. To calculate for the minimum required length of wall, simple check using section 3.7.2.4 shall be performed. *Calculation of minimum required length of wall in each direction* $\boldsymbol{L_i \geq C_B \times A_P}$ $C_B = 0.28$ (Bharatpur) $A_P = \left(\frac{2}{3}\right)(7.9\ m)(4.8\ m)$ $A_P = \mathbf{25.28\ m^2}$ $\boldsymbol{C_B \times A_P = (0.28)(25.28\ m^2)}$ $\boldsymbol{C_B \times A_P = 7.08\ m}$ To get the total length of structural walls along each direction, refer to the plan with wall distinctions. Note that structural walls should not include any door and window openings. *Length of walls along x-axis* $L_x = W_1 + W_2 + W_3 + W_4 + W_5 + W_6 + W_7$ $L_x = 1.2\ m + 1.2\ m + 1.2\ m + 1.2\ m + 1.2\ m + 0.8\ m + 0.8\ m + 1.2\ m$ $L_x = \mathbf{8.8\ m\ \geq 7.08\ m}\ \therefore \boldsymbol{TOTAL\ LENGTH\ OF\ WALL\ ALONG\ X\ IS\ ADEQUATE}$ *Length of walls along y-axis* $L_y = W_A + W_B + W_C + W_D + W_E + W_F + W_G + W_H$ $L_y = 1.2\ m + 1.2\ m + 1.2\ m + 0.8\ m + 1.2\ m + 1.2\ m + 1.2\ m$ $L_y = \mathbf{8.0\ m\ \geq 7.08\ m}\ \therefore \boldsymbol{TOTAL\ LENGTH\ OF\ WALL\ ALONG\ Y\ IS\ ADEQUATE}$	3.7.2.4 Figure 44 Figure 44
STEP-2: Plan Irregularity	The deviation of center of rigidity to the center of the structure should not be more than 15% of the width perpendicular to the direction being analyzed. Checking of the plan irregularity are shown in the succeeding tables.	

ITEM	CALCULATION PROCEDURE	REFERENCE
Check	*Plan irregularity check along x-axis*	3.7.3.1
	$$\left\| \frac{\sum(L_{xi}t_{xi}y_i)}{\sum L_{xi}\, t_{yi}} - \frac{H}{2} \right\| \leq 0.15H$$	Figure 44

Bamboo Frame Wall at Storey 1 along X - Direction

Wall Mark	L_x (m)	No. of Sides with Plastering	t_x (m)	y_i (m)	H (m)	L_x x t_x (m^2)	L_x x t_x x y_i (m^3)
W-1	1.20	1	0.125	4	4.8	0.150	0.600
W-2	1.20	1	0.125	4		0.150	0.600
W-3	1.20	1	0.125	4		0.150	0.600
W-4	1.20	1	0.125	4		0.150	0.600
W-5	1.20	1	0.125	0.8		0.150	0.120
W-6	0.80	1	0.125	0.8		0.100	0.080
W-7	0.80	1	0.125	0.8		0.100	0.080
W-8	1.20	1	0.125	0.8		0.150	0.120
TOTAL	**8.8**					**1.1**	**2.8**

Figure 44

$$\left[\frac{2.8\, m^3}{1.1\, m^2} - \frac{4.8\, m}{2} \right] \leq 0.15(4.8\text{ m})$$

$0.145\, m \ \leq\ 0.72$ m ∴ **PLAN IS REGULAR ALONG X**

	Plan irregularity check along y-axis	3.7.3.1

ITEM	CALCULATION PROCEDURE	REFERENCE
	$$\left\lvert\frac{\sum(L_{yi}t_{yi}x_i)}{\sum L_{yi}\,t_{xi}} - \frac{B}{2}\right\rvert \leq 0.15B$$	
	(table below)	Figure 44

Bamboo Frame Wall at Storey 1 along Y - Direction							
Wall Mark	L_y (m)	No. of Sides with Plastering	t_y (m)	x_i (m)	B (m)	L_y x t_y (m^2)	L_y x t_y x x_i (m^3)
W-A	1.20	2	0.15	0.75		0.180	0.135
W-B	1.20	2	0.15	0.75		0.180	0.135
W-C	1.20	2	0.15	3.95		0.180	0.711
W-D	0.80	2	0.15	3.95	7.9	0.120	0.474
W-E	1.20	2	0.15	3.95		0.180	0.711
W-F	1.20	2	0.15	7.15		0.180	1.287
W-G	1.20	2	0.15	7.15		0.180	1.287
TOTAL	**8.0**					**1.2**	**4.7**

$$\left[\frac{4.7\,m^3}{1.2\,m^2} - \frac{7.9\,m}{2}\right] \leq 0.15(7.9\text{ m})$$

$$0.033\,m \;\leq\; 1.185\text{ m} \;\therefore\; \textbf{PLAN IS REGULAR ALONG Y}$$

ITEM	CALCULATION PROCEDURE	REFERENCE
STEP-3: Dead STEP-3: Load Calcula	Selfweight and superimposed dead loads present on the structure shall be calculated using the respective pressure and densities of the materials used. Dead load should include all materials and equipment constantly present throughout the lifespan of the structure. <u>Roof Load</u>	

ITEM	CALCULATION PROCEDURE	REFERENCE
tion	Area of Roof = (7.9 m)(4.8 m) Area of Roof = 37.92 m^2 A. Roof Corrugated G.I. Sheets Gauge # = 28 Sheet Thickness = 0.3 mm Unit Pressure = 0.0314 kPa Uniform Weight = 0.0314 kPa Concentrated Load = $(37.92 \text{ m}^2)(0.0314 \text{ kPa})$ Concentrated Load = 1.19 kN B. Roof Structural Members (Trusses, Rafters, & Purlins) Uniform Weight = 0.30 kPa (Manually calculated) Concentrated Load = $(37.92 \text{ m}^2)(0.30 \text{ kPa})$ Concentrated Load = 11.38 kN	
	C. Roof Ceiling Ceiling Thickness = 12 mm Unit Weight = $0.008 \text{ kN/m}^2\text{/mm}$ Uniform Weight = $(12 \text{ mm})(0.008 \text{ kN/m}^2\text{/mm})$	

ITEM	CALCULATION PROCEDURE	REFERENCE

Uniform Weight $= 0.096\ \text{kPa}$

Concentrated Load $= (37.92\ \text{m}^2)(0.096\ \text{kPa})$

Concentrated Load $= 3.64\ \text{kN}$

D. MEPF & Miscellaneous

Uniform Weight $= 0.05\ \text{kPa}$

Concentrated Load $= (37.92\ \text{m}^2)(0.05\ \text{kPa})$

Concentrated Load $= 1.90\ \text{kN}$

Roof Dead Load

Item	Loading Description	Covered Area (m^2)	Uniform Area Load (kPa)	Concentrated Load (kN)
A	Corrugated G.I Sheets	37.92	0.0314	1.19
B	Bamboo Structure (Rafter & Purlins)	37.92	0.3000	11.38
C	Ceiling	37.92	0.0960	3.64
D	MEPF & Miscellaneous	37.92	0.0500	1.90
Total Dead Load at Roof			**0.476**	**18.11**
Total Dead Load at Roof with 20% Additional Load[1]			**0.571**	**21.73**

Notes:

1. *20% additional load is included to account for the weight of the mortar-filled internodes. The designer may calculate the weight of these internodes manually.*

Wall Dead Load

Weight of wall with mortar plastering at both sides	=	1.2	kPa
Weight of wall with mortar plastering at one side only	=	0.7	kPa

Bamboo Frame Wall at Storey 1 along X - Direction

Wall Mark	Length, L(m)	Area (m^2)

ITEM	CALCULATION PROCEDURE	REFERENCE

		Average Height (m)		No. of Sides with Mortar Plastering	Weight of Wall (kN)
W-1	1.20	2.70	3.24	1	2.27
W-2	1.20	2.70	3.24	1	2.27
W-3	1.20	2.70	3.24	1	2.27
W-4	1.20	2.70	3.24	1	2.27
W-5	1.20	2.70	3.24	1	2.27
W-6	0.80	2.70	2.16	1	1.51
W-7	0.80	2.70	2.16	1	1.51
W-8	1.20	2.70	3.24	1	2.27
TOTAL	**8.80**				**16.63**

Bamboo Frame Wall at Storey 1 along Y - Direction

Wall Mark	Length, L(m)	Average Height (m)	Area (m^2)	No. of Sides with Mortar Plastering	Weight of Wall (kN)
W-A	1.20	3.53	4.24	2	5.08
W-B	1.20	2.96	3.55	2	4.26
W-C	1.20	3.53	4.24	2	5.08
W-D	0.80	3.25	2.60	2	3.12
W-E	1.20	2.96	3.55	2	4.26
W-F	1.20	3.53	4.24	2	5.08
W-G	1.20	3.25	3.89	2	4.67
TOTAL	**8.00**	**25.95**			**31.55**

TOTAL WALL DEAD LOAD[1] **57.82 kN**

Notes:

1. *Since the walls defined here are solid panels only, 20% additional load is included to account for the weight of the panels with opening (e.g. door and window panel). The designer may calculate the weight of these panels manually.*

Seismic Load Calculation

ITEM	CALCULATION PROCEDURE	REFERENCE
	Seismic Data Parameters Important Class — I - Ordinary Structures (Residential Buildings — (Clause 4.1.5) Siesmic Importance Factor, I — 1.0 — (Clause 4.1.5) Soil Type — C — (Clause 4.1.3) Seismic Zone Factor, Z — 0.4 — (Clause 4.1.4) Overstrength Factor for SLS, Ω_s — 1 — (Clause 5.4.2) Ductility Factor of Structural System, R_s — 1.0 — (Clause 5.3.2) Spectral Shape Fator, $C_h(T)$ — 2.5 — (Clause 4.1.2) Structure Height above Plinth, H — 2.7 m Period Coefficient for Structural System, K_t — 0.050 — (Clause 5.1.2) Time Period, T_1 — $T = K_t * (H)^{3/4}$ = 0.105 sec. — (Clause 5.1.2) Amplified Time Period, T — $1.25T_1$ = 0.132 sec. — (Clause 5.1.3) Elastic Site Spectra for SLS,C_s(T — $0.2*C_h(T)*Z*I$ = 0.200 — (Clause 4.2) Seismic Weight, W — W = 88.08 kN vertical distribution factor — k = 1 — (Clause 6.3) **Calculation of Design Base Shear** Horizontal Base Shear Coefficient for SLS, $C_d(T_1)$: $C_d(T_1) = C_s(T) / \Omega_s$ — $C_d(T_1)$ = 0.200 — (Clause 6.1.2) As per NBC 105 : 2020, clause 6.2, the total horizontal seismic base shear, V, acting at the base of the structure, in the direction being considered, shall be calculated as follows: $V = C_d(T_1) * W$ — V_x = 0.200 W — (Clause 6.2) V_y = 0.200 W Design Base Shear, V_{ex} = **17.6157** kN V_{ey} = **17.6157** kN	
Wind Load Calculation	**Input Data** Basic Wind Speed, V_b — 47.0 — m/s — (Clause 6.2 and Figure 1) Terrain Category — Category 2 — (Clause 6.3.1) Class of Structure — Class A — (Table 1 Clause 6.3.1) Life of Structure — 50.0 — years — (Table 1 Clause 6.3.1) Building Height, h — 2.70 — m Building Width (W) — 3.30 — m	

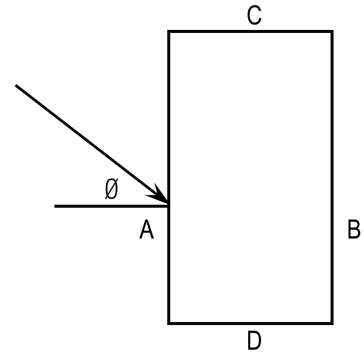
ITEM	CALCULATION PROCEDURE				REFERENCE
	Building Length (L)	6.40	m		
	Roof Type	Gable			
	Roof Slope	16	deg.	0.28 rad	
	Roof Width	5.10	m		
	Roof Length	8.10	m		
	height of lower eave	2.97	m		
	height of upper eave	3.16	m		
	Resulting Parameters and Coefficients:				
	Risk Coeffecient, k_1	1		(Table 1 Clause 6.3.1)	
	Topography Factor, k_2	1		(Table 2 Clause 6.3.2.2)	
	Terrain & Height Factor, k_3	1		(Clause 6.3.3)	
	Importance Factor for the Cyclonic Region, k_4	1		(Clause 6.3.4)	
	Wind Directionality Factor, K_d	0.9		(Clause 7.2.1)	
	Area Averaging Factor, K_a	1		(Clause 7.2.2)	
	Combination Factor, K_c	0.9		(Clause 7.3.3.13)	
	Design Wind Speed, $V_z = V_b \times k_1 \times k_2 \times k_3 \times k_4$	47	m/s		
	Wind Pressure, $P_z = 0.6 \times V_b^2$	1325.4	N/m²	(Clause 7.2)	
	Design Wind Pressure, $P_d = K_d \times K_a \times K_c \times P_d$; $P_d \geq 0.7 \times P_z$	1073.574	N/m²	(Clause 7.2)	
	Design Wind Load				

Wind Load Calculation of Side Walls:
The Guiding Condition for External Coefficients for WORST CASE design,

Building Height Ratio		Building Plan Ratio
$\frac{h}{w}$ = 0.818		$0.5 < h/W \leq 0.5$

ITEM	CALCULATION PROCEDURE	REFERENCE

$\frac{L}{w}$ = 1.939   1 < L/W <1.5



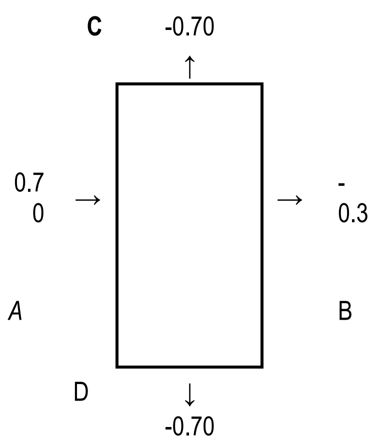
External Pressure Coefficients for Wall (Refer to Table 5)

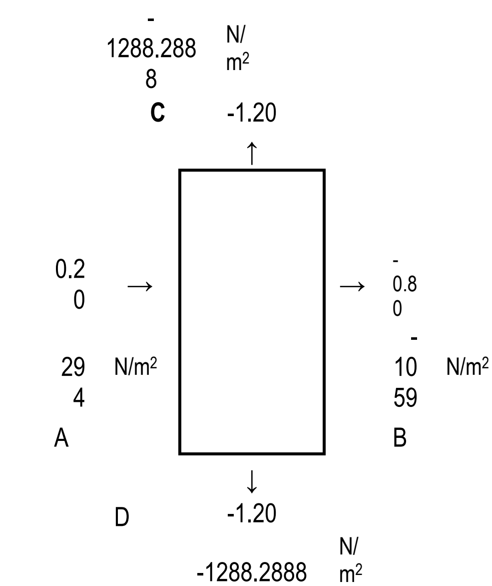
Wind Angle Ø = 0				Wind Angle Ø = 90			
Wind Along Y				Wind Along X			
A	B	C	D	A	B	C	D
0.70	-0.30	-0.70	-0.70	-0.50	-0.50	0.70	-0.10

Internal Wind Coefficient = ±0.5 (Medium Opening with 5% to 20% of Wall Area)

Wind Along Y:

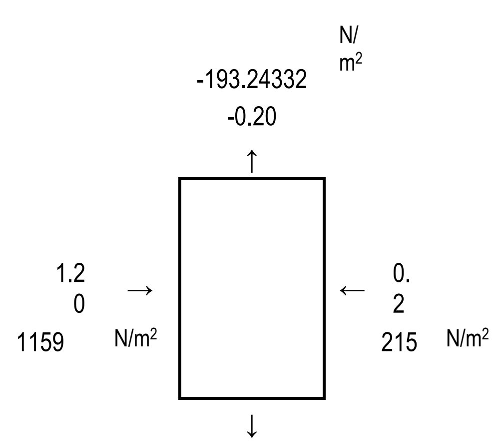
For C_{pi} = (+) 0.50





External Pressure Coefficient

For C_{pi} = (-) -0.50



Wind Along X:

ITEM	CALCULATION PROCEDURE	REFERENCE

For C_{pi} = 0.50 -0.20

-193.24332 N/m²

B -0.50 ↑

C 0.70 → [ ] → -0.10 D

↓

A -0.50

External Pressure Coefficient

-966.2166 N/m²

B -1.00 ↑

C 0.20 → [ ] → -0.60 D

214.7 N/m² -580 N/m²

↓

A -1.00

-966.2166 N/m²

0 N/m²

For C_{pi} = -0.50

0.00 ↑

1.20 → [ ] ← 0.4

1588 N/m² 588 N/m²

↑ 0.00

0 N/m²

External Pressure Coefficients for Roof (Refer to Table 7)

Wind Angle Ø = 0		Wind Angle Ø = 90		Local Coefficients					
Wind Along Y		Wind Along X							
H	L	H	L	H1	H2	L1	L2	He	Le
-0.88	-0.50	-1.00	-0.68	-1.8	-0.88	-1.8	-1.4	-2	-2

ITEM	CALCULATION PROCEDURE	REFERENCE

local width y 0.768 m

Wind Angle	Pressure Coefficient			$(C_{pe} +/- C_{pi})$		Roof Wind Load (Pa)		AREA	
	C_{pe}		C_{pi}						
	H	L		H	L	H	L	H	L
0	-0.88	-0.50	-0.5	-0.38	0.00	-407.96	0.00	10.7	10.73
			0.5	-1.38	-1.00	-1481.53	-1073.57	10.7	10.73
90	-1	-0.68	-0.5	-0.5	-0.18	-536.79	-193.24	10.3	10.37
			0.5	-1.35	-1.06	-1449.32	-1140.14	10.3	10.37

For Overhang

Wind Angle	Pressure Coefficient			$(C_{pe} +/- C_{pi})$		Roof Wind Load (Pa)		AREA	
	C_{pe}		C_{pi}						
	H	L		H	L	H	L	H	L
0	-0.88	-0.50	0	-0.88	-0.50	-944.75	-536.79	4.8	4.80
			0	-0.88	-0.50	-944.75	-536.79	4.8	4.80

Local Pressure Coefficient													Roof Wind Load (Pa)					
C_{pe}						C_{pi}	$(C_{pe} +/- C_{pi})$											
H1	H2	L1	L2	He	Le		H1	H2	L1	L2	He	Le	H1	H2	L1	L2	He	Le
-1.8	-0.88	-1.8	-1.4	-2	-2	-0.5	-1.3	-0.38	-1.3	-0.9	-1.5	-1.5	-1396	-408	-1396	-966	-1610	-1610
						0.5	-2.3	-1.38	-2.3	-1.9	-2.5	-2.5	-2469	-1482	-2469	-2040	-2684	-2684

Wind Load Along X Direction

$$V_x = 7.1\ kN$$

$$V_z = 51.6\ kN$$

Wind Load Along Y Direction

$$V_x = 26.6\ kN$$

<table>
<tr><th>ITEM</th><th>CALCULATION PROCEDURE</th><th>REFERENCE</th></tr>
<tr><td></td><td>$\boldsymbol{V_z = 33.18\ kN}$</td><td></td></tr>
<tr><td>STEP-4: Shear Check Calculation</td><td><u>Wall Resistance</u>

Wall resistance of each panel shall be the permissible wall capacity scaled by the duration factor for wind and seismic event.

$Allowable\ Wall\ Shear\ Capacity\ = (8\ kN/m)(C_{DF})$

$C_{DF} = 0.85$ (Instantaneous)

$Allowable\ Wall\ Shear\ Capacity\ = (8\ kN/m)(0.85)$

$Allowable\ Wall\ Shear\ Capacity\ = \boldsymbol{6.8\ kN/m}$ (Double Cladding)

$Allowable\ Wall\ Shear\ Capacity\ = \boldsymbol{3.4\ kN/m}$ (Single Cladding)

Providing cladding at both side of the wall gives a higher shear wall capacity. Note that for some instances where constant drying and wetting is anticipated, cladding shall be provided even if not structurally necessitated.

<u>Design Shear</u>

Seismic Base Shear :
V_{ex} = 17.62 kN
V_{ey} = 17.62 kN

Wind Base Shear :
V_{wx} = 7.10 kN
V_{wy} = 26.58 kN

$V_x = \mathbf{max}(V_{ex}, V_{wx})$
$\boldsymbol{V_x = 17.62\ kN}$

$V_y = \mathbf{max}(V_{ey}, V_{wy})$
$V_y = 26.\boldsymbol{58\ kN}$</td><td>3.7.3.4

Table 1</td></tr>
<tr><td></td><td>Calculation of total shear wall capacity is shown in the succeeding tables. The total shear wall capacity shall be at least the magnitude of the design shear load.</td><td></td></tr>
</table>

ITEM	CALCULATION PROCEDURE	REFERENCE
	(tables below)	
STEP-5: Overturning Check	End member check of each wall shall be performed to ensure stability of the entire structure against overturning. Individual walls are treated as vertical cantilever beam with compression and tension support at the bottom.	3.7.3.5

Storey 1 - (X - Direction)

Wall	L (m)	plastered sides	Le (m)	Shear Capacity (kN/M)	Wall Resistance (kN/m)
W-1	1.20	1	0.60	6.8	4.08
W-2	1.20	1	0.60	6.8	4.08
W-3	1.20	1	0.60	6.8	4.08
W-4	1.20	1	0.60	6.8	4.08
W-5	1.20	1	0.60	6.8	4.08
W-6	0.80	1	0.40	6.8	2.72
W-7	0.80	1	0.40	6.8	2.72
W-8	1.20	1	0.60	6.8	4.08
Total	**8.80**		**4.40**		**29.92**

Wall Resistance X - Direction = 29.92 kN > 17.62 kN OK!
Demand/Capacity Ratio = 0.59
Minimum Wall Length, Lmin = 2.59 m

Storey 1 - (Y - Direction)

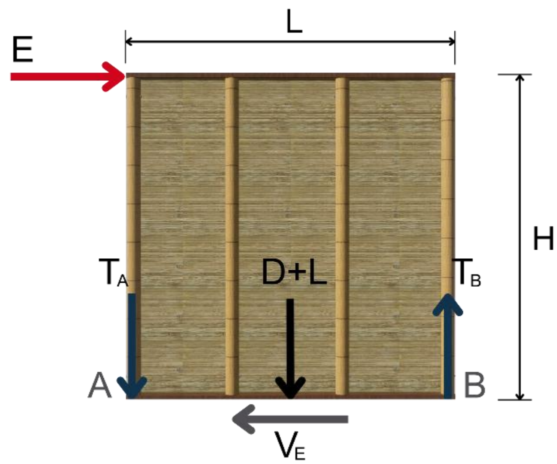
Wall	L (m)	plastered sides	Le (m)	Shear Capacity (kN/M)	Wall Resistance (kN/m)
W-A	1.20	2	1.20	6.8	8.16
W-B	1.20	2	1.20	6.8	8.16
W-C	1.20	2	1.20	6.8	8.16
W-D	0.80	2	0.80	6.8	5.44
W-E	1.20	2	1.20	6.8	8.16
W-F	1.20	2	1.20	6.8	8.16
W-G	1.20	2	1.20	6.8	8.16
Total	**8.00**		**8.00**		**54.40**

Wall Resistance Y - Direction = 54.40 kN > 26.58 kN OK!
Demand/Capacity Ratio = 0.49
Minimum Wall Length, Lmin = 3.91 m

Design Loads

ITEM	CALCULATION PROCEDURE	REFERENCE
	Loads are calculated for each wall considering the proportion of their length to the total length of wall resisting specific loading. *A. Dead Load (kN/m)* $$D_i = \frac{(\text{Wt. of wall } W_i)\ (1.2)}{L_{x_i}} + \frac{\text{Total Roof Dead Load}}{\sum L_{x_i} + \sum L_{y_i}}$$ *B. Live Load (kN/m)* $$L_i = \frac{\text{Roof Live Load}}{\sum L_{x_i} + \sum L_{y_i}}$$ *C. Seismic Load (kN)* $$E_i = \frac{(L_{x_i})(V_x)}{\sum L_{x_i}}$$ $$E_i = \frac{(L_{y_i})(V_y)}{\sum L_{y_i}}$$ *D. Lateral Wind Load (kN)* Along X $$W_{H-i} = \frac{(L_{x_i})(V_x)}{\sum L_{x_i}}$$ Along Y $$W_{H-i} = \frac{(L_{y_i})(V_y)}{\sum L_{y_i}}$$	
	E. Uplift Wind Load (kN) Along X	

ITEM	CALCULATION PROCEDURE	REFERENCE
	$$W_{H-i} = \frac{(L_{x_i})(F_{up})}{\sum L_{x_i} + \sum L_{y_i}}$$ Along Y $$W_{H-i} = \frac{(L_{y_i})(F_{up})}{\sum L_{x_i} + \sum L_{y_i}}$$ Allowable Capacities The allowable capacity of end members shall be determined as follows. When the capacity of one bamboo is insufficient to resist a reaction, the designer may use two end studs. *F. Tensile Capacity* $\text{Allowable Tensile Capacity} = (12.5\ \text{kN})(C_{DF})$ $\text{Allowable Tensile Capacity} = (12.5\ \text{kN})(0.85)$ $\text{Allowable Tensile Capacity} = \mathbf{10.625\ kN}$ *G. Compression Capacity* $\boldsymbol{f_c} = (\boldsymbol{f_{ik}})(\boldsymbol{C_R})(\boldsymbol{C_{DF}})(\boldsymbol{C_T})\left(\frac{\mathbf{1}}{\boldsymbol{FS_m}}\right)$ $\boldsymbol{f_c} = (28.6\ MPa)(0.90)(0.85)(1.0)\left(\frac{1}{2.0}\right)$ $\boldsymbol{f_c} = 10.9395\ MPa$	1.6.3
	End Bearing Capacity $\boldsymbol{P_b} = (\boldsymbol{C_{EB}})(\boldsymbol{f_c})(\boldsymbol{A})$ $C_{EB} = 0.80$ (for straight cuts bearing onto a flat surface)	4.1.7 3.3.7

ITEM	CALCULATION PROCEDURE	REFERENCE
	Area $\boldsymbol{A} = \left(\frac{\pi}{4}\right)[(\boldsymbol{D}^2 - (\boldsymbol{D} - 2\boldsymbol{\delta})^2)]$ $A = \frac{\pi\{[80 \text{ mm}]^2 - [(80 \text{ mm}) - (2 \times 13 \text{ mm})]^2\}}{4}$ $A = 2736.327 \text{ mm}^2$ $\boldsymbol{P_b} = (0.80)(10.9395\ MPa)(2736.327\ mm^2)\left(\frac{1\ kN}{1000\ N}\right)$ $\boldsymbol{P_b} = \boldsymbol{23.95\ kN}$ **<u>SEISMIC OVERTURNING CHECK</u>**  WALL ELEVATION *Note: Due to symmetry of each panel, lateral load may be checked for one direction of lateral load per axis.*	3.7.3.5
	Seismic Force: F_{roof} = 17.62 kN <u>Load Combination:</u> $LC1 = 0.7DL \pm EL$ $LC2 = DL + LL \pm EL$ **Along X - Direction**	2.2

ITEM	CALCULATION PROCEDURE	REFERENCE

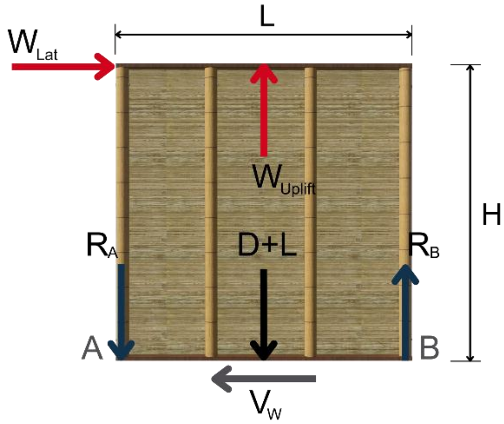
	A	B	C				F	G			
Wall Mark	Dead L, (kN/m)	Live L, (kN/m)	E, (kN)	Prevailing LC, (kN)		# of Poles	Allow. Force (kN)		D/C, Ratio		Remark
				R_A	R_B		Tension	Comp.	Tension	Comp.	
W-1	3.56	1.69	2.40	-3.91	8.56	1	-10.63	23.95	0.37	0.36	OK!
W-2	3.56	1.69	2.40	-3.91	8.56	1	-10.63	23.95	0.37	0.36	OK!
W-3	3.56	1.69	2.40	-3.91	8.56	1	-10.63	23.95	0.37	0.36	OK!
W-4	3.56	1.69	2.40	-3.91	8.56	1	-10.63	23.95	0.37	0.36	OK!
W-5	3.56	1.69	2.40	-3.91	8.56	1	-10.63	23.95	0.37	0.36	OK!
W-6	3.56	1.69	1.60	-4.41	7.51	1	-10.63	23.95	0.41	0.31	OK!
W-7	3.56	1.69	1.60	-4.41	7.51	1	-10.63	23.95	0.41	0.31	OK!
W-8	3.56	1.69	2.40	-2.96	7.85	1	-10.63	23.95	0.28	0.33	OK!

Along Y - Direction

	A	B	C				F	G			
Wall Mark	Dead L, (kN/m)	Live L, (kN/m)	E, (kN)	Prevailing LC, (kN)		# of Poles	Allow. Force (kN)		D/C, Ratio		Remark
				R_A	R_B		Tension	Comp.	Tension	Comp.	
W-A	6.38	1.69	2.64	-5.09	12.61	1	-10.63	23.95	0.48	0.53	OK!
W-B	5.55	1.69	2.64	-4.18	10.86	1	-10.63	23.95	0.39	0.45	OK!
W-C	6.38	1.69	2.64	-5.09	12.61	1	-10.63	23.95	0.48	0.53	OK!
W-D	5.97	1.69	1.76	-5.47	10.21	1	-10.63	23.95	0.52	0.43	OK!
W-E	5.55	1.69	2.64	-4.18	10.86	1	-10.63	23.95	0.39	0.45	OK!
W-F	6.38	1.69	2.64	-5.09	12.61	1	-10.63	23.95	0.48	0.53	OK!
W-G	5.97	1.69	2.64	-4.64	11.74	1	-10.63	23.95	0.44	0.49	OK!

WIND OVERTURNING CHECK — Reference: 3.7.3.5 2.2

ITEM	CALCULATION PROCEDURE	REFERENCE



WALL ELEVATION

Load Combination

$$LC1 = DL + LL \pm 0.8WL$$

$$LC2 = DL \pm WL$$

$$\mathrm{LC3} = 0.6DL \pm WL$$

Wind Force :

$F_{x(roof\text{-}lat)}$ = **7.10** kN $F_{y(roof\text{-}lat)}$ = **26.58** kN

$F_{x(roof\text{-}up)}$ = **51.60** kN $F_{y(roof\text{-}up)}$ = **33.20** kN

Along X - Direction

	A	B	D	E				F	G			
Wall Mark	Dead L, (kN/m)	Live L, (kN/m)	Lateral, W (kN)	Uplift, U (kN)	Prevailing LC, (kN)		# of Poles	Allow. Force (kN)		D/C, Ratio		Remark
					R_A	R_B		Tension	Comp.	Tension	Comp.	
W-1	3.56	1.69	0.97	3.69	-2.73	3.42	1	-10.63	23.95	0.26	0.14	OK!
W-2	3.56	1.69	0.97	3.69	-2.73	3.42	1	-10.63	23.95	0.26	0.14	OK!
W-3	3.56	1.69	0.97	3.69	-2.73	3.42	1	-10.63	23.95	0.26	0.14	OK!
W-4	3.56	1.69	0.97	3.69	-2.73	3.42	1	-10.63	23.95	0.26	0.14	OK!
W-5	3.56	1.69	0.97	3.69	-2.73	3.42	1	-10.63	23.95	0.26	0.14	OK!
W-6	3.56	1.69	0.64	2.46	-2.55	2.86	1	-10.63	23.95	0.24	0.12	OK!
W-7	3.56	1.69	0.64	2.46	-2.55	2.86	1	-10.63	23.95	0.24	0.12	OK!
W-8	3.56	1.69	0.97	3.69	-2.73	3.42	1	-10.63	23.95	0.26	0.14	OK!

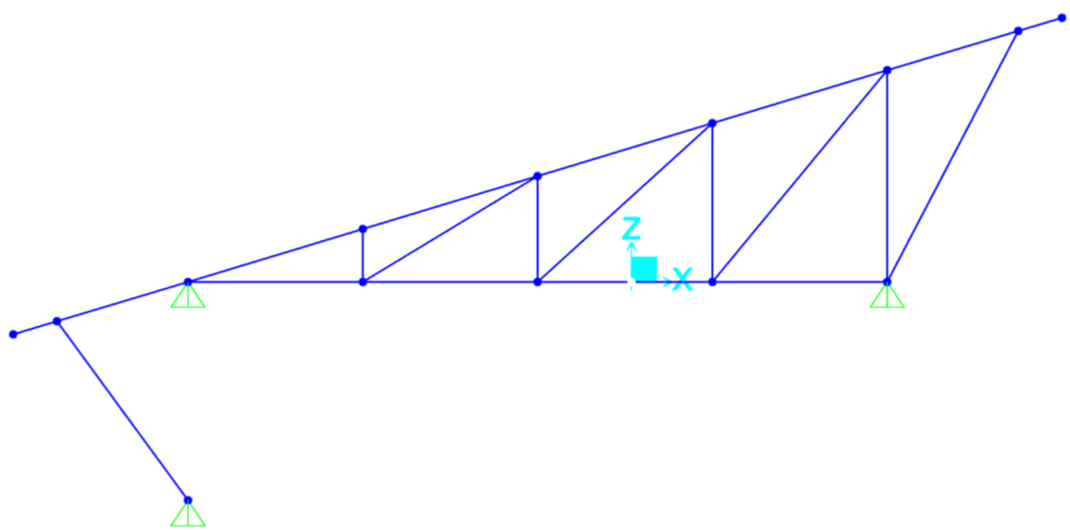
Along Y - Direction

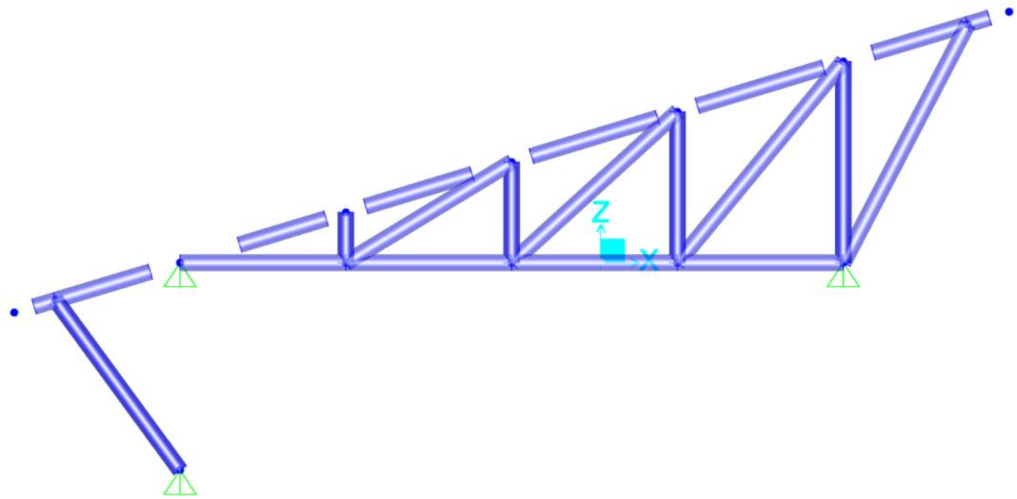
ITEM	CALCULATION PROCEDURE	REFERENCE

Wall Mark	Dead L, (kN/m)	Live L, (kN/m)	Lateral, W (kN)	Uplift, U (kN)	Prevailing LC, (kN)		# of Poles	Allow. Force (kN)		D/C, Ratio		Remark
					R_A	R_B		Tension	Comp.	Tension	Comp.	
W-A	6.38	1.69	3.99	2.37	-10.62	14.37	1	-10.63	23.95	1.00	0.60	OK!
W-B	5.55	1.69	3.99	2.37	-9.01	11.97	1	-10.63	23.95	0.85	0.50	OK!
W-C	6.38	1.69	3.99	2.37	-10.62	14.37	1	-10.63	23.95	1.00	0.60	OK!
W-D	5.97	1.69	2.66	1.58	-10.14	12.38	1	-10.63	23.95	0.95	0.52	OK!
W-E	5.55	1.69	3.99	2.37	-9.01	11.97	1	-10.63	23.95	0.85	0.50	OK!
W-F	6.38	1.69	3.99	2.37	-10.62	14.37	1	-10.63	23.95	1.00	0.60	OK!
W-G	5.97	1.69	3.99	2.37	-9.82	13.18	1	-10.63	23.95	0.92	0.55	OK!

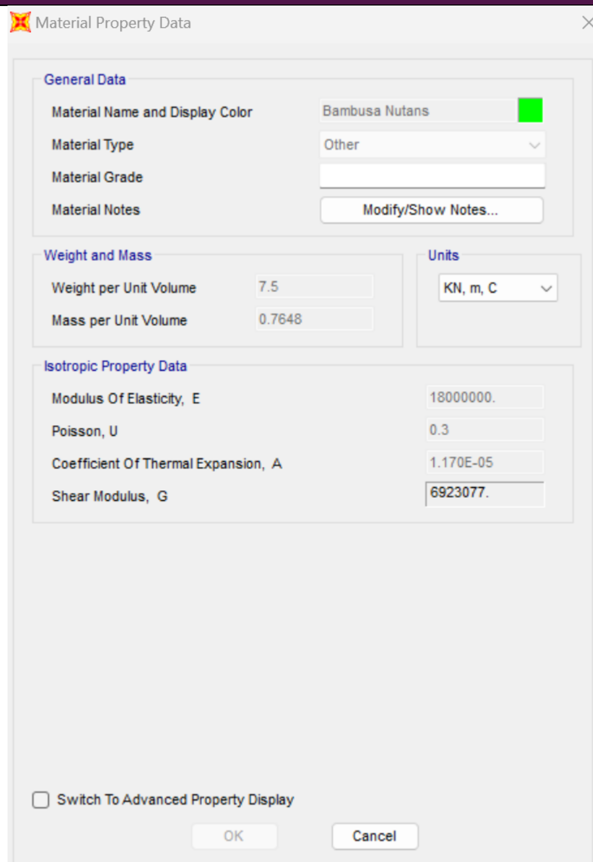
STEP-6: Roof Truss

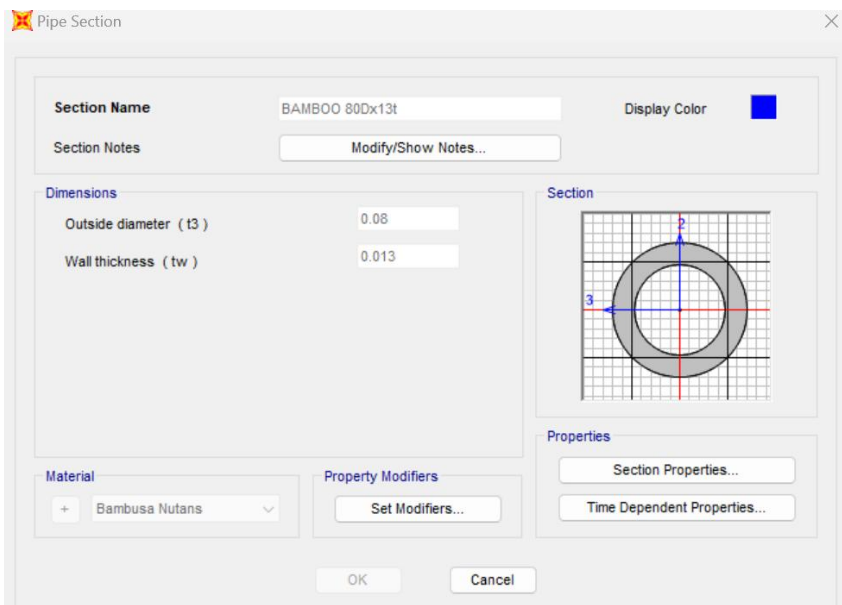
Truss is modelled using a software. Apparent loadings are applied, and node supports are provided to simulate the actual response of the roof framing when acted upon by the loads.



ITEM	CALCULATION PROCEDURE	REFERENCE
	 For the material, specifications of Bambusa Nutans are used as shown. Bamboo section used has a diameter of 80mm and thickness of 13 mm.	

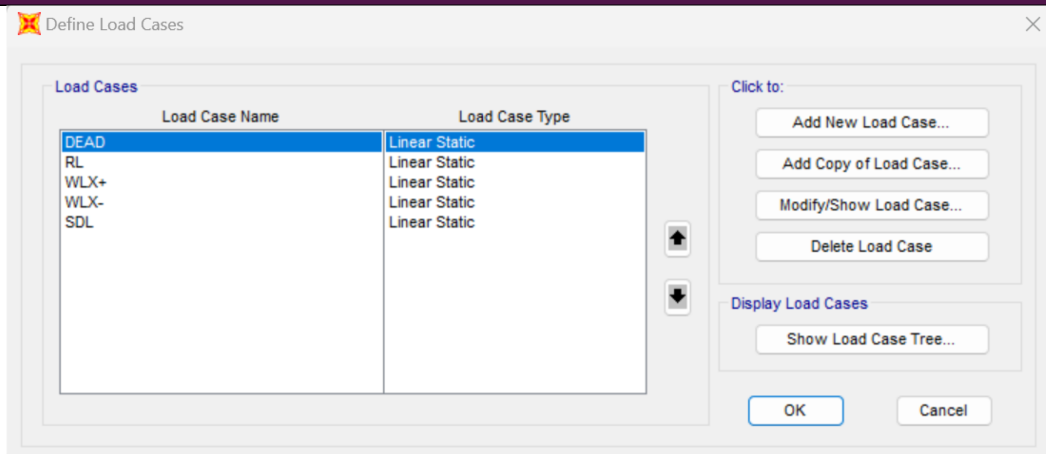
ITEM	CALCULATION PROCEDURE	REFERENCE



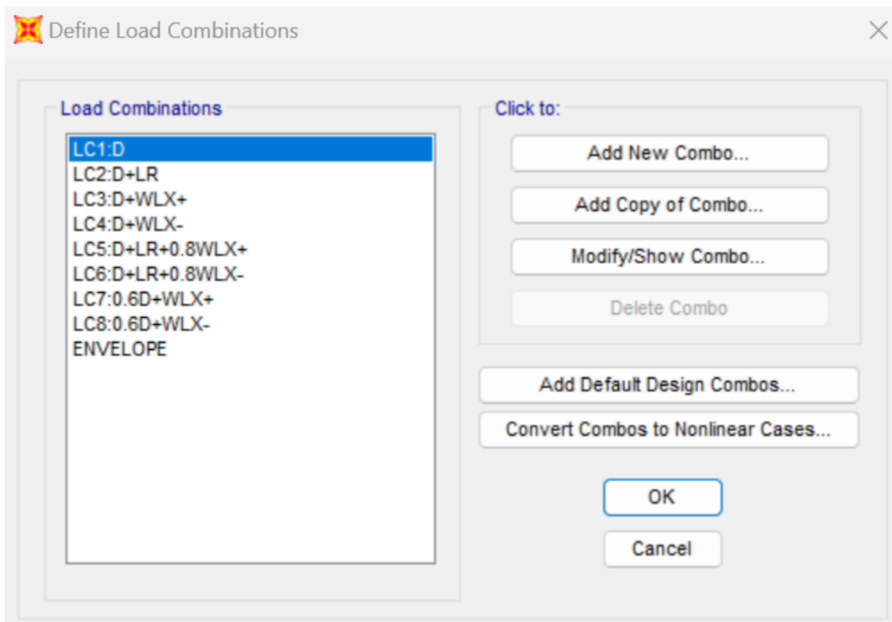


Load cases pertinent to the roofing system are defined as shown. Separate load case is defined for inward and outward wind load.

ITEM	CALCULATION PROCEDURE	REFERENCE



Load combinations are defined following section 2.2.



Truss Member Design

Section forces of truss members are extracted from the software to check if the capacity of bamboo for every limit state is adequate. For this sample, the two-culm top chord is checked for its adequacy.

Input Data Parameters

Bamboo Pole Dimensions and Properties:

Outside Diameter, d	=	80	mm	Modulus of Elasticity, $E_{0.5}$	=	13.2	GPa
Thickness, t	=	13	mm	Characteristic Bending Strength, f_{mk}	=	53.8	MPa
Length, L	=	1,150	mm	Characteristic Compressive Strength, f_{ck}	=	28.6	MPa
Effective Length Coeff.,K	=	1.0		Characteristic Tensile Strength, f_{tk}	=	44.5	MPa
Moment of Interia, I	=	1.9.E+06	mm^4	Characteristic Shear Strength, f_{vk}	=	4.15	MPa
Cross-Sectional Area, A	=	2,736.33	mm^2	Number of Culms, n	=	1	

ITEM	CALCULATION PROCEDURE	REFERENCE

Section Modulus, S	=	39,830.7 mm^3	b_{max}	=	17 mm

Design Modification Factors:

Load duration factor for capacity and strength, C_{DF} :			Load duration factor for modulus, C_{DE} :		
C_{DF} for Dead	=	0.55	C_{DE} for Dead	=	0.45
C_{DF} for Live	=	0.65	C_{DF} for Live	=	0.95
C_{DF} for Wind & Seismic	=	0.85	C_{DF} for Wind & Seismic	=	1.00
Redundancy factor, C_R	=	0.9	Material Factor of Safety, FS_m :		
Temperature Factor, C_T	=	1.0	FS_m for Bending & Compression	=	2
Service Class	=	2	FS_m for Shear	=	4

Capacity for each limit state and duration is calculated and tabulated. Load combinations are categorized depending on the duration of the load included in the combination.

Allowable Capacities

$$\boldsymbol{f_i = (f_{ik})\,(C_R)\,(C_T)\left(\frac{1}{FS_m}\right)}$$

		Permanent	Transient	Instantaneous
Allow. Comp. Strength Par. to fibers, f_c	=	7.0785	8.3655	10.9395
Allow. Tensile Strength Par. to fibers, f_t	=	11.01375	13.01625	17.02125
Allow. Bending Strength Par. to fibers, f_m	=	13.3155	15.7365	20.5785
Allow. Shear Strength Par. to fibers, f_v	=	0.5135625	0.6069375	0.7936875

Crushing Capacity — 3.6.3.2

$$F_{c,r,d} = f_{c,d} \sum A$$

Buckling Capacity — 3.6.3.3

$$F_{e,r,d} = \frac{n\pi^2 E_d I_{min} C_{bow}}{(K_L L)^2}$$

Compression Capacity — 3.6.3.1

$$F_{cc,r,d} = \frac{F_{c,r,d} + F_{e,r,d}}{1.6} - \sqrt{\left(\frac{F_{c,r,d} + F_{e,r,d}}{1.6}\right)^2 - \frac{F_{c,r,d}F_{e,r,d}}{0.8}}$$

Tension Capacity — 3.6.4

$$F_{t,r,d} = f_{t,d} \sum A$$

Moment Capacity — 3.5.2.1.1

ITEM	CALCULATION PROCEDURE	REFERENCE
	$M_{r,d} = f_{m,d}(\sum S)$	
	Shear Capacity	3.5.2.1.2
	$F_{v,r,d} = f_{v,d} \sum \frac{A}{2}$	
	Combined Axial and Flexural loads	3.6.5

For net axial compression:

$$\frac{F_{c,d}}{F_{cc,r,d}} + \frac{BM_d}{M_{r,d}} \leq 1.0$$

$$B = \left[1 - \frac{F_{c,d}}{F_{e,r,d}}\right]^{-1}$$

For net axial tension:

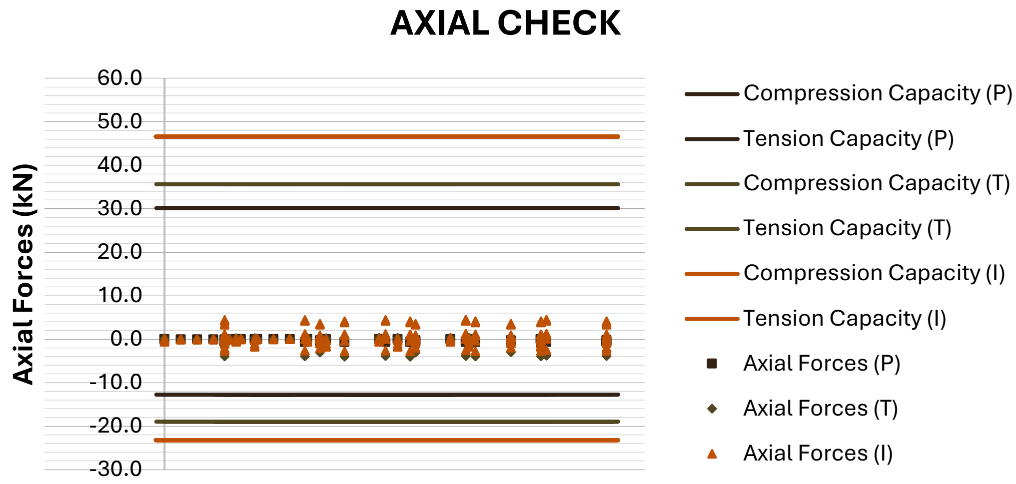
$$\frac{F_{t,d}}{F_{t,r,d}} + \frac{M_d}{M_{r,d}} \leq 1.0$$

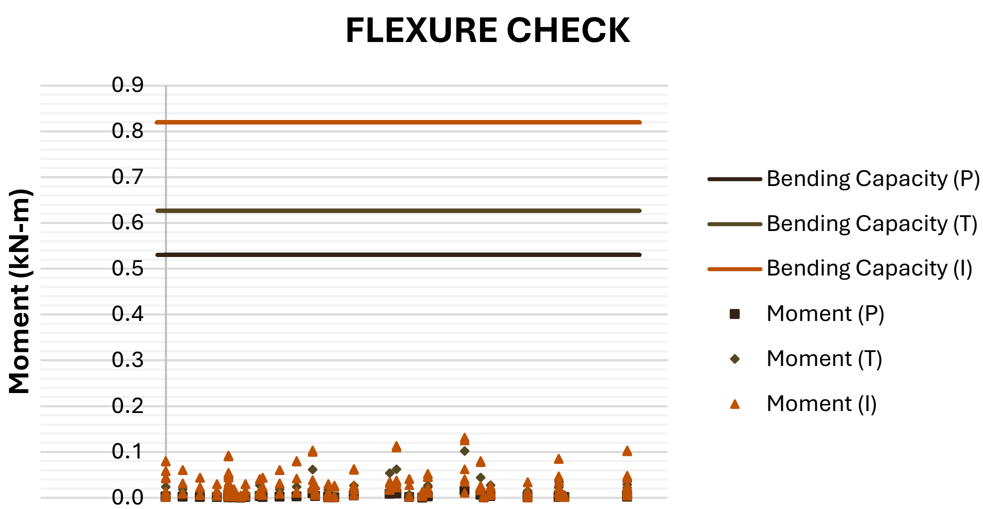
Allowable Capacities

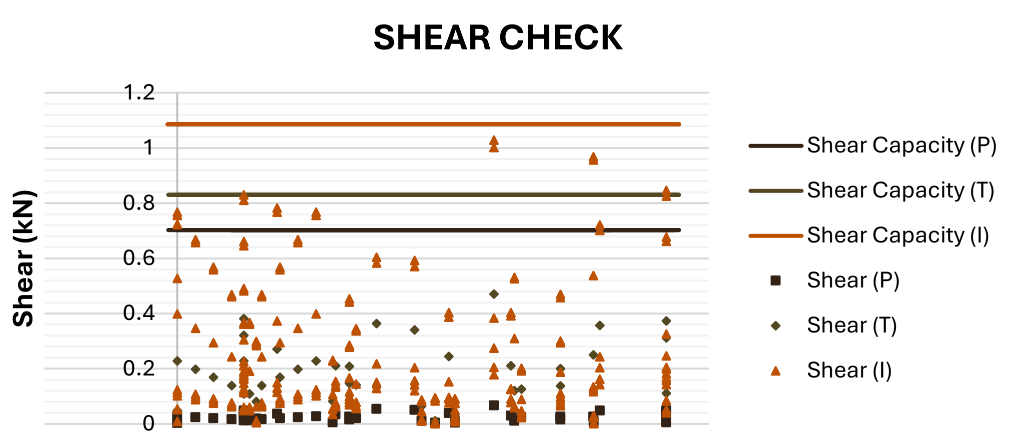
		Permanent	Transient	Instantaneous
Comp. Capacity (kN)	N_{cr}	-12.640	-18.888	-23.081
Crushing Capacity (kN)	P_c	19.369	22.891	29.934
Buckling Capacity (kN)	P_e	17.657	37.275	39.237
Tension Capacity (kN)	N_{tr}	30.137	35.617	46.576
Moment Capacity (kN-m)	M_r	0.530	0.627	0.820
Shear Capacity (kN-m)	V_r	0.703	0.830	1.086

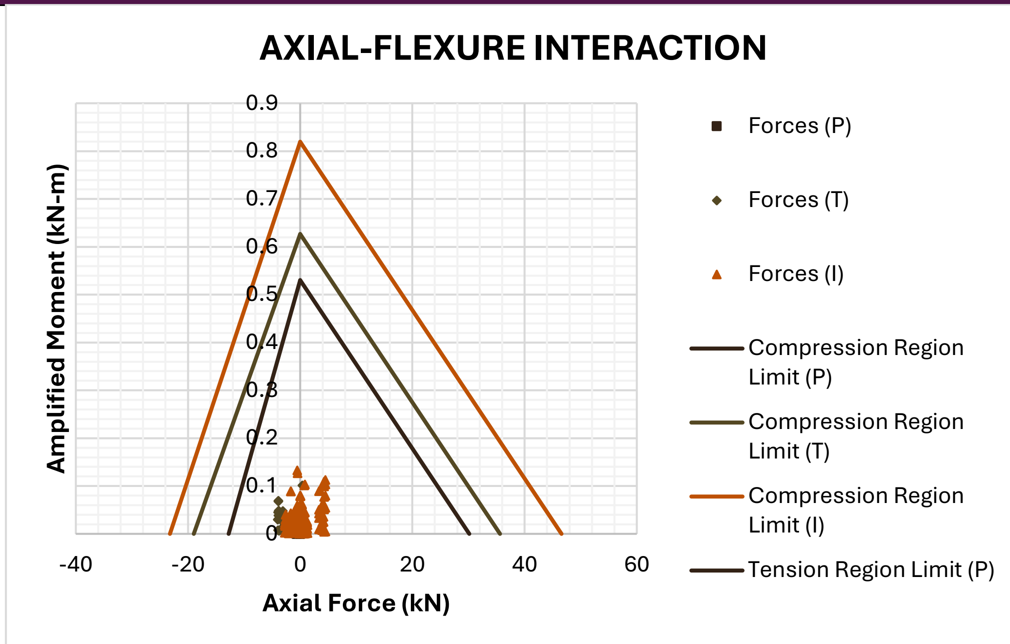
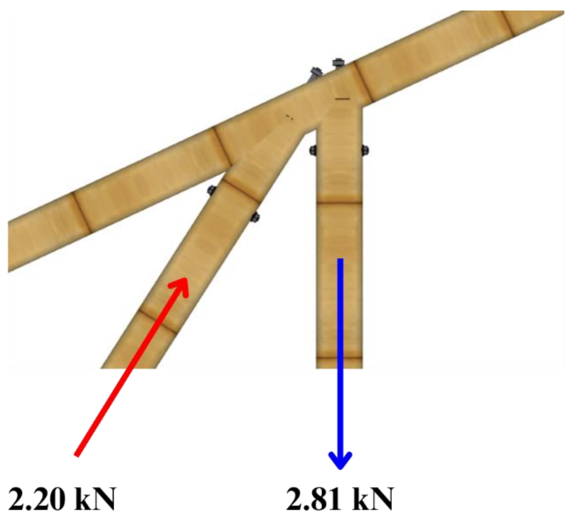
The internal forces are plotted in a graph together with the respective limit state capacity. The adequacy of the member is evaluated graphically based on the succeeding graphs.

ITEM	CALCULATION PROCEDURE	REFERENCE







ITEM	CALCULATION PROCEDURE	REFERENCE
		
STEP-7: Connection Design	**Fish Mouth Connection**  FROM WIND LOAD COMBINATION Due to Tension T-Connection $Demand = 2.81\ kN$ $Capacity = (3.4\ kN)(C_{DF})$	

ITEM	CALCULATION PROCEDURE	REFERENCE
	$Capacity = (3.4\ kN)(0.85)$ $Capacity = 2.89\ kN$ $DCR = \frac{2.81\ kN}{2.89\ kN}$ $DCR = 0.972 \therefore\ OK!$	
	Due to Compression $\boldsymbol{f_c} = (\boldsymbol{f_{ik}})\,(\boldsymbol{C_R})\,(\boldsymbol{C_{DF}})\,(\boldsymbol{C_T})\left(\frac{\boldsymbol{1}}{\boldsymbol{FS_m}}\right)$ $\boldsymbol{f_c} = (28.6\ MPa)(0.90)(0.85)(1.0)\left(\frac{1}{2.0}\right)$ $\boldsymbol{f_c} = 10.9395\ MPa$	
	$C_{EB} = 0.40$ (for fish − mouth connections bearing onto another piece of bamboo)	
	Area $\boldsymbol{A} = \left(\frac{\pi}{4}\right)[(\boldsymbol{D^2} - (\boldsymbol{D} - \boldsymbol{2\delta})^{\boldsymbol{2}})]$ $A = \frac{\pi\{[80\ mm]^2 - [(80\ mm) - (2 \times 13\ mm)]^2\}}{4}$ $A = 2736.327\ mm^2$	
	End Bearing Capacity $\boldsymbol{P_b} = (\boldsymbol{C_{EB}})\,(\boldsymbol{f_c})\,(\boldsymbol{A})$ $\boldsymbol{P_b} = (0.40)(10.9395\ MPa)(2736.327\ mm^2)\left(\frac{1\ kN}{1000\ N}\right)$ $\boldsymbol{P_b} = \mathbf{11.9736\ kN}$	
	$Demand = 2.20\ kN$ $Capacity = 11.9736\ kN$ $DCR = \frac{2.20\ kN}{11.9736\ kN}$ $DCR = 0.184 \therefore OK!$	
STEP-8: Purlin	Parameters	

<table>
<tr><th>ITEM</th><th>CALCULATION PROCEDURE</th><th>REFERENCE</th></tr>
<tr><td>Design</td><td>
Outside Diameter, D $= 80$ mm
Thickness, δ $= 13$ mm
Span Length, L $= 1575$ mm
Spacing, s $= 600$ mm
Moment of Inertia, I $= 1.6x10^6$ mm^4
Cross − Sectional Area, A $= 2739.33$ mm^2

Bamboo Unit Weight, γ $= 7.5$ kN/m^3
Section Modulus, S $= 39830.7$ mm^3

Modulus of Elasticity, $E_{0.05}$ $= 13000$ MPa
Characteristic Bending Strength, f_{mk} $= 53.8$ MPa
Characteristic Shear Strength, f_{vk} $= 4.15$ MPa
Number of Culms, n $= 1$
</td><td></td></tr>
<tr><td></td><td>
<u>Loadings</u>

Selfweight, W_D $= 0.020$ kN/m
Superimposed Dead Load, S_D $= 0.17$ kPa
Roof Live Load, L_r $= 0.75$ kPa
Windward Pressure, W_p $= 1.5$ kPa
Leeward Pressure, W_o $= -2.5$kPa
</td><td></td></tr>
<tr><td></td><td>
<u>Forces</u>

Uniform Load $= Ws$

Moment $= \frac{WL^2}{8}$
Shear $= \frac{WL}{2}$
</td><td></td></tr>
</table>

Load Combination	Uniform Load (kN/m)	Moment (kN-m)	Shear (kN)
LC1 = D	0.130	0.040	0.102
LC2 = D+LR	0.572	0.177	0.450
LC3 = D+WLX	1.030	0.319	0.811
LC4 = D-WLX	-1.370	-0.425	-1.079
LC5 = D+LR+0.8WLX	1.292	0.401	1.017
LC6 = D+LR-0.8WLX	-0.628	-0.195	-0.495
LC7 = 0.6D+WLX	0.973	0.302	0.766
LC8 = 0.6D-WLX	-1.427	-0.442	-1.124

<u>Allowable Capacities</u>

$$f_i = (f_{ik})\,(C_R)\,(C_T)\left(\frac{1}{FS_m}\right)$$

ITEM	CALCULATION PROCEDURE	REFERENCE
	Allowable Bending Strength Parallel to Fibers $f_m = (53.8\ MPa)\ (1.1)\ (1.0) \left(\frac{1}{2.0}\right)$ $f_m = 29.59\ MPa$	
	Allowable Shear Strength Parallel to Fibers $f_v = (4.15\ MPa)\ (1.1)\ (1.0) \left(\frac{1}{4.0}\right)$ $f_v = 1.14\ MPa$	
	Moment Capacity $M_r = (f_m)(C_{DF}) \left(\sum S\right)$ *Permanent* $M_r = (29.59\ MPa)(0.55)(39830.7\ \text{mm}^3)$ $M_r = 0.648\ kN - m$ *Transient* $M_r = (29.59\ MPa)(0.65)(39830.7\ \text{mm}^3)$ $M_r = 0.766\ kN - m$ *Instantaneous* $M_r = (29.59\ MPa)(0.85)(39830.7\ \text{mm}^3)$ $M_r = 1.001\ kN - m$	
	Shear Capacity $F_{v,r,d} = (f_{v,d})(C_{DF}) \left(\sum \frac{A}{2}\right)$ *Permanent* $F_{v,r,d} = (1.14\ MPa)(0.55) \left(\frac{2739.33\ \text{mm}^2}{2}\right) \left(\frac{1\ \text{kN}}{1000\ N}\right)$ $F_{v,r,d} = 0.858\ kN$ *Transient* $F_{v,r,d} = (1.14\ MPa)(0.65) \left(\frac{2739.33\ \text{mm}^2}{2}\right) \left(\frac{1\ \text{kN}}{1000\ N}\right)$ $F_{v,r,d} = 1.015\ kN$	

ITEM	CALCULATION PROCEDURE	REFERENCE
	Instantaneous $F_{v,r,d} = (1.14\ MPa)(0.85)\left(\frac{2739.33\ \text{mm}^2}{2}\right)\left(\frac{1\ \text{kN}}{1000\ N}\right)$ $F_{v,r,d} = 1.327\ kN$	
	Checking of DCR Bending	
	Shear	
	Deflection	
	For Dead Load $(EI)_d = (EI)_k\ (C_{DE})\ (C_T)$ $(EI)_d = (13000\ MPa)(1.6x10^6\ mm^4)\ (0.45)\ (1.0)$ $(EI)_d = 9.36x10^9\ N - mm^2$ $C_v = 0.5 + 0.05\left(\frac{a}{D}\right) \leq 1.0$ $C_v = 0.5 + 0.05\left(\frac{787.5\ mm}{80\ mm}\right) \leq 1.0$ $C_v = 0.542 \leq 1.0$ $C_v = 0.542$	

Bending

Load Combination	Demand (kN-m)	Capacity (kN-m)	DCR	Remark
LC1 = D	0.040	0.648	0.062	OK!
LC2 = D+LR	0.177	0.766	0.231	OK!
LC3 = D+WLX+	0.319	1.001	0.319	OK!
LC4 = D+WLX-	0.425	1.001	0.425	OK!
LC5 = D+LR+0.8WLX+	0.401	1.001	0.401	OK!
LC6 = D+LR+0.8WLX-	0.195	1.001	0.195	OK!
LC7 = 0.6D+WLX+	0.302	1.001	0.302	OK!
LC8 = 0.6D+WLX-	0.442	1.001	0.442	OK!

Shear

Load Combination	Demand (kN)	Capacity (kN)	DCR	Remark
LC1 = D	0.102	0.858	0.119	OK!
LC2 = D+LR	0.450	1.015	0.443	OK!
LC3 = D+WLX+	0.811	1.327	0.611	OK!
LC4 = D+WLX-	1.079	1.327	0.813	OK!
LC5 = D+LR+0.8WLX+	1.017	1.327	0.766	OK!
LC6 = D+LR+0.8WLX-	0.495	1.327	0.373	OK!
LC7 = 0.6D+WLX+	0.766	1.327	0.577	OK!
LC8 = 0.6D+WLX-	1.124	1.327	0.847	OK!

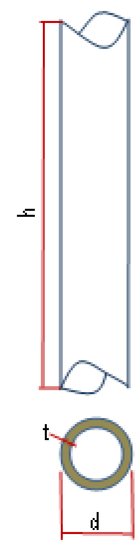
ITEM	CALCULATION PROCEDURE	REFERENCE
	$EI = (EI)_d\,(C_v)$ $EI = (9.36x10^9\ N - mm^2)\ (0.542)$ $EI = 5.07312x10^9\ N - mm^2$ $(\delta)_D = \frac{5W_D L^4}{384EI}$ $(\delta)_D = \frac{5(0.13\ kN/m)(1575\ mm)^4}{384(9.36x10^9\ N - mm^2)}$ $(\delta)_D = 1.113\ mm$	
	For Live Load $(EI)_d = (EI)_k\,(C_{DE})\,(C_T)$ $(EI)_d = (13000\ MPa)(1.6x10^6\ mm^4)\ (0.95)\ (1.0)$ $(EI)_d = 1.976x10^{10}\ N - mm^2$ $C_v = 0.5 + 0.05\left(\frac{a}{D}\right) \leq 1.0$ $C_v = 0.5 + 0.05\left(\frac{787.5\ mm}{80\ mm}\right) \leq 1.0$ $C_v = 0.542 \leq 1.0$ $C_v = 0.542$ $EI = (EI)_d\,(C_v)$ $EI = (1.976x10^{10}\ N - mm^2)\ (0.542)$ $EI = 1.071x10^{10}\ N - mm^2$ $(\delta)_L = \frac{5W_L L^4}{384EI}$ $(\delta)_L = \frac{5(0.45\ kN/m)(1575\ mm)^4}{384(1.071x10^{10}\ N - mm^2)}$ $(\delta)_L = 3.367\ mm$	
	Dead & Live Load $(\delta)_{D+L} = (\delta)_D + (\delta)_L$ $(\delta)_{D+L} = 1.113\ mm + 3.367\ mm$ $(\delta)_{D+L} = 4.48\ mm$	
	Allowable Deflection $(\delta)_{ALLOW} = \frac{L}{240}$ $(\delta)_{ALLOW} = \frac{1575mm}{240}$ $(\delta)_{ALLOW} = 6.5625\ mm$ $(\delta)_{D+L} \leq (\delta)_{ALLOW}\ \therefore OK!$	

ITEM	CALCULATION PROCEDURE	REFERENCE
STEP-9: Column Design		

Input Data Parameters

Bamboo Pole Dimensions and Properies:

Outside Diameter, d	=	80	mm	Allow. Bending Strength, F_b	=	24.21	MPa
Thickness, t	=	13	mm	Allow. Comp. Strength, F_c	=	12.87	MPa
Cross-Sectional Area, A	=	2,736.33	mm^2	Section Modulus, S	=	39,830.7	mm^3
Height, h	=	2,440	mm	Modulus of Elasticity, E_{05}	=	13	GPa
Spacing, s	=	1,600	mm	Radius of Gyration, r	=	24.13	mm
Moment of Interia, I	=	1.6.E+06	mm^4	Slendernes Ratio, λ	=	29.19	



Design Modification Factors:

Description	Dead Load	Live Load	Earthquake Load	Wind Load
Load Duration Factors, C_D	0.9	1.0	1.6	1.6
C_f	1.1			
C	0.8			
F_{CE}	12.55 MPa			
Ref. Comp. Design Value, F_{c^*}	12.74 MPa	14.16 MPa	22.65 MPa	22.65 MPa
Column Stability factor, C_p	0.69	0.65	0.47	0.47
F'_c	8.74 MPa	9.17 MPa	10.66 MPa	10.66 MPa
Axial Capacity, P_a	23.91 kN	25.10 kN	29.16 kN	29.16 kN

Capacity Check

Axial Capacity Check

Column Location	Tributary Area (m^2)	Loadings (kN)			Load Combinations						Remarks
		Dead	Live	$Wind_{(vert.)}$	D	D/C	D + L	D/C	D + L +W	D/C	
Interior	1.89	1.08	1.4175	2.64	1.08	0.0	2.5	0.1	5.1	0.2	OK!
Exterior	1.89	1.08	1.4175	-3.86	1.08	0.0	2.5	0.1	1.4	0.0	OK!

Bending Capacity Check

Column Location	Loading, kN/m	Bending Moment, kN-m	Bending Stress (Mpa)			Remarks
	$Wind_{(Hz.)}$		Allow. Bending Stress, F'_b	Actual bending Stress, f_b	D/C Ratio	
Exterior	1.60	1.19	42.61	29.89	0.70	OK!

Combined Axial and Bending Capacity

Column Location	Tributary Area (m^2)	Loadings (kN)			Load Combinations		Ncr, (N)	km	Demand Equation	Remarks
		Dead	$Wind_{(vert.)}$	$Wind_{(Hz.)}$	D	D + W				
Exterior	1.89	1.08	-3.86	1.60	1.08	-2.77	3.4.E+04	8.9.E-01	0.53	OK!

ITEM	CALCULATION PROCEDURE	REFERENCE
STEP-10: Wall Footing Design		

Parameters

Concrete Compressive Strength	f'_c	=	20	MPa
Min. Yield Strength of Main Bar	f_y	=	415	MPa
Min. Yield Strength of Temp. Bar	f_{yt}	=	415	MPa
Unit Weight of Concrete	γ_c	=	25	kN/m^3

ITEM	CALCULATION PROCEDURE	REFERENCE
	Unit Weight of Soil γ_{soil} = 18 kN/m[4] Allowable Soil Bearing Capacity q_{all} = 75 kPa Main Bar Diameter d_b = 10 mm Temp. Bar Diameter d_{bt} = 8 mm <u>Section Properties</u> Thickness of footing h = 100 mm Concrete Cover C_c = 75 mm Embedment Depth D = 457.2 mm Thickness of Wall t_{wall} = 150 mm <u>Loads</u> Superstructure loads are transformed into line loads along the length of wall footing. Dead = 8.769 kN/m Live = 1.71 kN/m Eq. = 6.270 kN/m Wind = 2.2187 kN/m <u>Serviceability Check</u> Base Pressure LC1 D = 8.769 kN/m LC2 D+L = 10.482 kN/m LC3 0.7D+E = 12.408 kN/m LC4 D+L+E = 16.752 kN/m LC5 D+L+0.8W = 12.257 kN/m LC6 D+W = 10.988 kN/m LC7 0.6D+W = 7.48 kN/m	
	$q_{max} = 16.752\ kPa\ (1 - m\ strip)$ Getting the required width of footing $b = \frac{q_{max}}{q_e}$	

ITEM	CALCULATION PROCEDURE	REFERENCE

$$b = \frac{16.752\ kN/m}{75\ kPa}$$

$$b = 0.223\ m$$

$$\boldsymbol{use\ b = 0.300\ m}$$

Strength Checks

Ultimate Base Pressure

U1	1.5D	=	13.154	kN/m
U2	1.5D+1.5L	=	15.724	kN/m
U3	1.2D+1.2L+0.6W	=	13.910	kN/m
U4	1.2D+1.2L+0.6E	=	16.341	kN/m
U5	1.2D+1.2L+1.2W	=	15.241	kN/m
U6	1.2D+1.2L+1.2E	=	20.103	kN/m
U7	1.5D+1.5W	=	16.482	kN/m
U8	1.5D+1.5E	=	22.559	kN/m

$$q_{u-max} = \frac{22.559\ kN/m}{0.3\ m}$$

$$q_{u-max} = 75.197\ kPa$$

Shear

Effective Depth, d

$$d = h - C_c - \frac{d_b}{2}c$$

$$d = 150\ mm - 75\ mm - \frac{10\ mm}{2}$$

$$d = 70\ mm$$

$$V_u = \left(\frac{b}{2} - \frac{t_{wall}}{4} - d\right) x\ q_{u-max}$$

$$V_u = \left(\frac{0.30\ m}{2} - \frac{0.10\ m}{4} - 0.07m\right) x\ 75.197\ kPa$$

$$V_u = 4.135\ kN$$

Concrete Shear Capacity

$$\phi V_c = \phi 0.17\sqrt{f'c}d(1000\ mm)$$

$$V_c = (0.75)(0.17)\left(\sqrt{20\ MPa}\right)(70\ mm)(1000\ mm)$$

$$V_c = 39.914\ kN$$

ITEM	CALCULATION PROCEDURE	REFERENCE
	$V_c \geq V_u$ ∴ FOOTING THICKNESS IS ADEQUATE <u>Flexure</u> Ultimate Moment $M_u = q_u x \left(\frac{b}{2} - \frac{t_{wall}}{4}\right) x \frac{\left(\frac{b}{2} - \frac{t_{wall}}{4}\right)}{2}$ $M_u = (75.197\ kPa)\left(\frac{0.30\ m}{2} - \frac{0.10\ m}{4}\right) x \frac{\left(\frac{0.30\ m}{2} - \frac{0.10\ m}{4}\right)}{2}$ $M_u = 0.5875\ kN - m$ $R_N = \frac{M_u}{\phi b d^2}$ $R_N = \frac{(0.5875\ kN - m)\left(\frac{1000\ N}{1\ kN}\right)\left(\frac{1000\ mm}{1\ m}\right)}{0.90(1000\ mm)(70\ mm)^2}$ $R_N = 0.1332\ MPa$ <u>Required Steel Ratio</u> $\rho_{req} = \frac{0.85f'c}{fy}\left(1-\sqrt{1-\frac{2R_n}{0.85f'c}}\right)$ $\rho_{req} = \frac{0.85(20\ MPa)}{415\ MPa}\left(1-\sqrt{1-\frac{2(0.1332\ MPa)}{0.85(20\ MPa)}}\right)$ $\rho_{req} = 0.00032$ Maximum Steel Ratio to ensure beyond transition region $\rho_{max} = \frac{0.85 f'c \beta_1}{fy}\left(\frac{3}{8}\right)$ $\rho_{max} = \frac{0.85(20\ MPa)(0.85)}{415\ MPa}\left(\frac{3}{8}\right)$ $\rho_{max} = 0.01305$ Minimum Steel Ratio $\rho_{min} = max\left(\frac{1.4}{fy}, \frac{\sqrt{f'c}}{4fy}\right)$	

ITEM	CALCULATION PROCEDURE	REFERENCE
	$\rho_{\min} = max\left[\frac{1.4}{415\ MPa}, \frac{\sqrt{20\ MPa}}{4(415\ MPa)}\right]$ $\rho_{\min} = max(0.00337, 0.0027)$ $\rho_{\min} = 0.00337$ Minimum Temperature Steel Ratio $\rho_{temp} = 0.002$ Provided Steel Ratio $\rho_{prov} = \max\left[\min\left(\frac{4}{3}\rho_{\text{req}}, \rho_{\min}, \rho_{max}\right), \rho_{temp}\right]$ $\rho_{prov} = \max[\min(0.0004, 0.00337, 0.0135), 0.002]$ $\rho_{prov} = 0.002$ Provided Steel (Transverse Bar) $A_s = \rho_{prov} bh$ $A_s = (0.002)(1000\ \ mm)(150\ mm)$ $A_s = 300\ mm^2$ Using 10-mm-diameter reinforcing bar $S_{req} = \frac{1000\ mm}{300\ mm^2}\left[\frac{\pi(10\ mm)^2}{4}\right]$ $S_{req} = 261.799\ mm\ \approx 250\ mm$ $\therefore \boldsymbol{use\ \emptyset 10\ mm\ transverse\ bar\ spaced\ at\ 250\ mm\ on\ center}$ Provided Steel (Longitudinal Bar) $A_s = \rho_{temp} bh$ $A_s = (0.002)(300\ \ mm)(150\ mm)$ $A_s = 90\ mm^2$ Using 12-mm-diameter reinforcing bar	

ITEM	CALCULATION PROCEDURE	REFERENCE
	$n = \frac{90\ mm^2}{\frac{\pi(12\ mm)^2}{4}}$ $n = 0.796\ pcs\ \approx 1\ pc$ $min_n = 3\ pcs$ $\therefore \boldsymbol{use\ 3 - \emptyset 12\ mm\ longitudinal\ bar}$	

A PROTOTYPE DRAWING OF

CEMENT BAMBOO FRAME TECHNOLOGY HOUSE

GENERAL NOTES:

1. Cement Bamboo Frame Technology(CBFT) and CGI sheet roofing is used in this design.
2. Dimensions are to be read only.
3. Change in dimensions shall be notified to the designer immediately.
4. The structural drawings shall be read in conjunction with architectural drawings. Discrepancies, if any, shall be reported to the designer.

5. BAMBOO

5.1. Bamboo species
Scientific name: Bambusa nutans cupulata
5.2. Aged 3 to 5 years old (before harvesting)- Optimal age for peak structural performance.
5.3. Dried bamboo below 19% moisture content.
5.4. Treated bamboo must be used for all the structural and non structural elements.
5.5. Bamboo culm diameter: min. 60mm (for purlins) to min 75mm (bamboo posts and rafters) or as per drawing whichever is maximum.
5.6. Select only straight portion from bamboo culm for construction. The curve on bamboo culm should not be more than 2% of its length.
5.7. The crack on bamboo culm passing through 2 nodes continuously shall be rejected.
5.8. Bamboo elements with evidence of insect infestation or fungus growth shall be rejected.
5.9. All bamboo connections on the plinth level shall be solidly filled with concrete grout with 1:3 mixture.
5.10. The plinth level shall be maintained to fit the vertical bamboo post evenly.
5.11. Fish-mouth connection shall be used.
5.12. Do not expose bamboo post to direct sun, moisture and rain.
5.13. The bamboo shall be cut at max. 200mm from the node.
5.14 For lapping, minimum lapping length should be 500mm
5.15 For bolting, minimum edge distance should be 100mm c/c and pitch distance should be 50mm c/c and not greater than 300mm c/c

6. FOUNDATION

6.1. The site should be free of organic material prior to leveling the soil.
6.2. No rock or similar irreducible material with a maximum dimension greater than 20cm shall be placed in fills.
6.3. Nylon string and stakes should be used to layout the foundation.
6.4. The foundation trench shall be of uniform width. The foundation bed shall be on the same level throughout the foundation in the flat area. The foundation size is different for perimeter wall and interior wall. Refer to the drawings.

7. FORMWORK

7.1. Formwork shall be of good quality, straight and unwarpped.
7.2. Forms shall be substantial and sufficiently tight to prevent leakage.
7.3. Forms shall be properly braced or tied together to maintain position and shape.
7.4. Immediately before new concrete is placed, all construction joints shall be wetted and standing water shall be removed.
7.5. Do not remove formwork and supports sooner than the times indicated below after casting the concrete:
Vertical ties and horizontal ring beams directly supported on walls: 24 hours.

8. REBAR & STEEL

8.1. Reinforcement shall be high strength deformed rebars with a yeild strength of atleast FY275 Mpa
8.2. Refer to structural drawing for placement and size of rebar.
8.3. Overlap for longitudinal rebar must be avoided. If in certain conditions overlapping cannot be avoided, the length of overlap must be no less than 60times diameter of longitudinal rebar.
8.4. Rebars shall be free from rust, grease or other materials likely to impair bond.
8.5. Not permanently bent.
8.6. Cross brace for Cement Bamboo Frame Technology wall shall be 5MM X 25MM flat bars.
8.7. Ø 7mm, 8mm and 10mm nut-bolts are used for connection in the designs. Refer to the drawing for nut-bolt connections. The nut-bolt or threaded bar shall be GI coated or painted before use.
8.8. Threading should typically be limited to the nut-bearing length of a fastener unless there's a specific reason to extend it.
8.9. For Nails - 1 ½" common wire nails spaced at 100 mm on center in staggered position into bamboo culms having a minimum wall thickness of 8 mm
8.10. Chicken wire mesh should be of at least 22 gauge and size of the mesh should be at least 25mm x 25mm
8.11. Normal screws, staples, or nails may be used to fix the chicken wire mesh in plaster work, taking care to not split the framing elements.
8.12. Clamps: Metallic straps or clamps should be provided to fit uniformly around the bamboo and should not damage it when tightened.
8.13. Clamps: All components of metallic clamping straps shall be corrosion resistant

10. ROOF

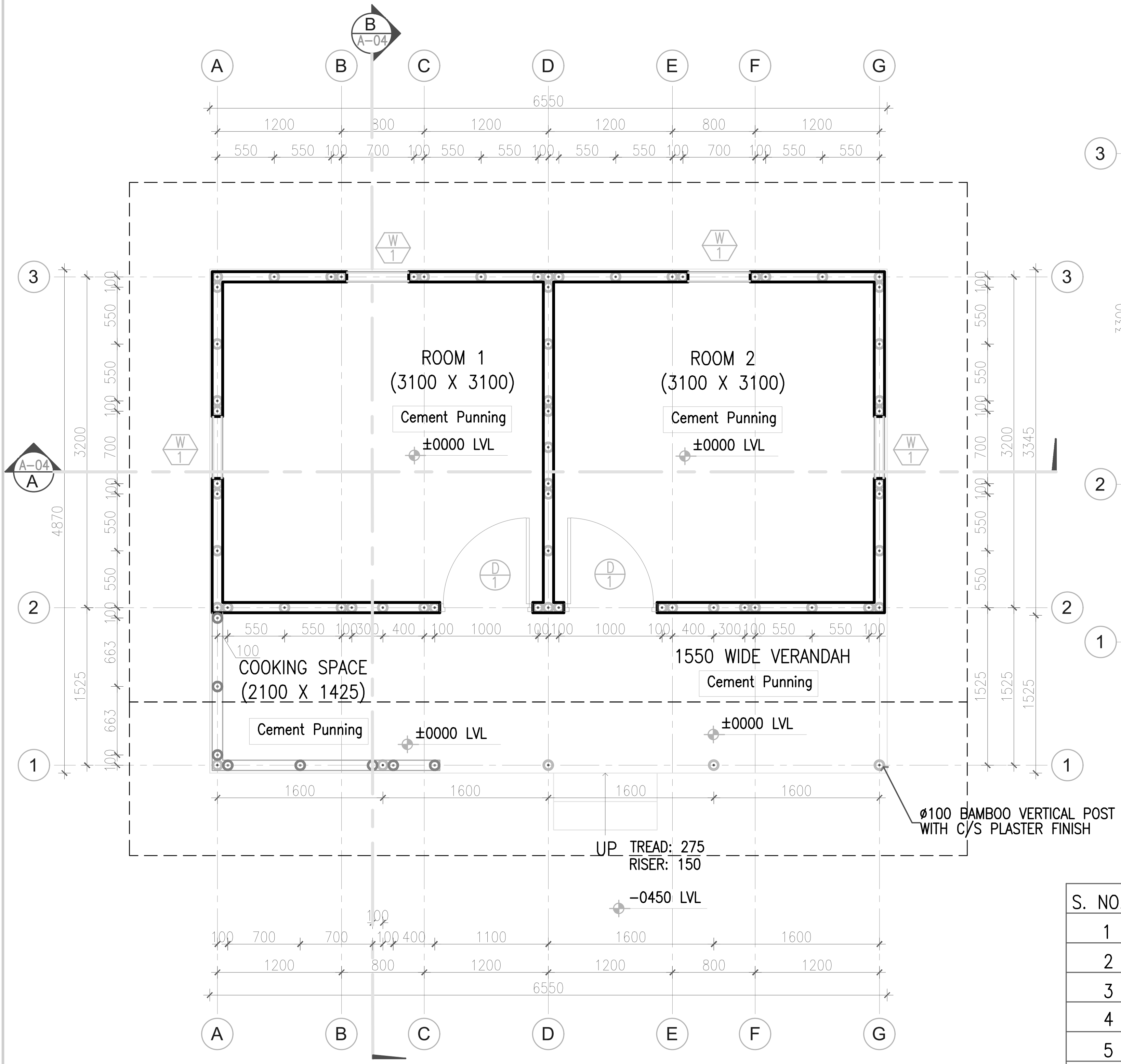
10.2. Coloured CGI sheet of 0.41 mm should be used.
10.3. Ridge sheet is same thickness as CGI.
10.4. CGI is bolted to the roof battens using J-hook.

9. CONCRETE

9.1. All RCC works shall use M20 (1:1.5:3) concrete and all PCC works shall use M15 concrete (1:2:4)
9.2. Cement : Portland Pozzolanic Cement (PPC), dry and unopened bags.
9.3. Sand : Should be clean and washed. Fine sand can be used for cement plaster and mortar, coarse for concrete.
9.4. Aggregate: Crushed, angular gravel less than 2cm in size for concrete.
9.5. Water: Potable water.
9.6. Ensure that the clear cover of 25mm is provided on all sides of the concrete.
9.7. At locations where concrete is cast or cement plaster is applied against masonry, surfaces shall be cleaned of foreign matter, and loose particles with a wire brush or by chipping, and shall be wet prior to placement of plaster or concrete.
9.8. Cement sand mix ratio for the grout infill should be at least 1:4 and recommended ratio is 1:2

GENERAL ABBREVIATIONS:

@	AT
&	AND
Ø	DIAMETER
C/C	CENTER TO CENTER
CGI	CORRUGATED GALVANIZED IRON
DIA	DIAMETER
DPC	DAMP PROOFING COURSE
EL	ELEVATION
FFL	FINISHED FLOOR LEVEL
GI	GALVANIZED IRON
GRD	GROUND
LVL	LEVEL
mm	MILLIMETER
NO.S	NUMBER
PCC	PLAIN CEMENT CONCRETE
RC	REINFORCED CONCRETE
RCC	REINFORCED CEMENT CONCRETE
SN	SERIAL NUMBER



GROUND FLOOR PLAN

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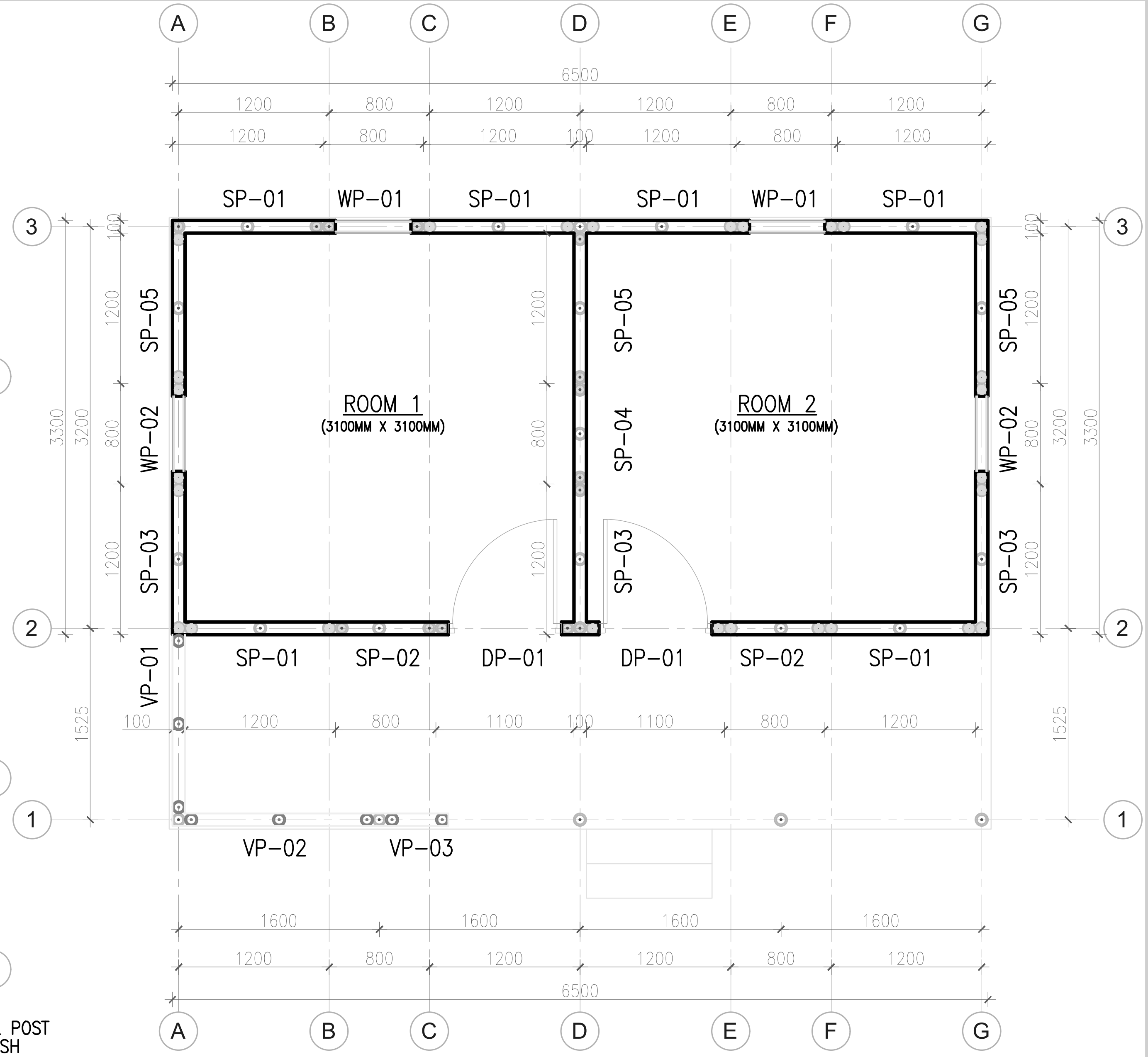


SCHEDULE OF PANELS

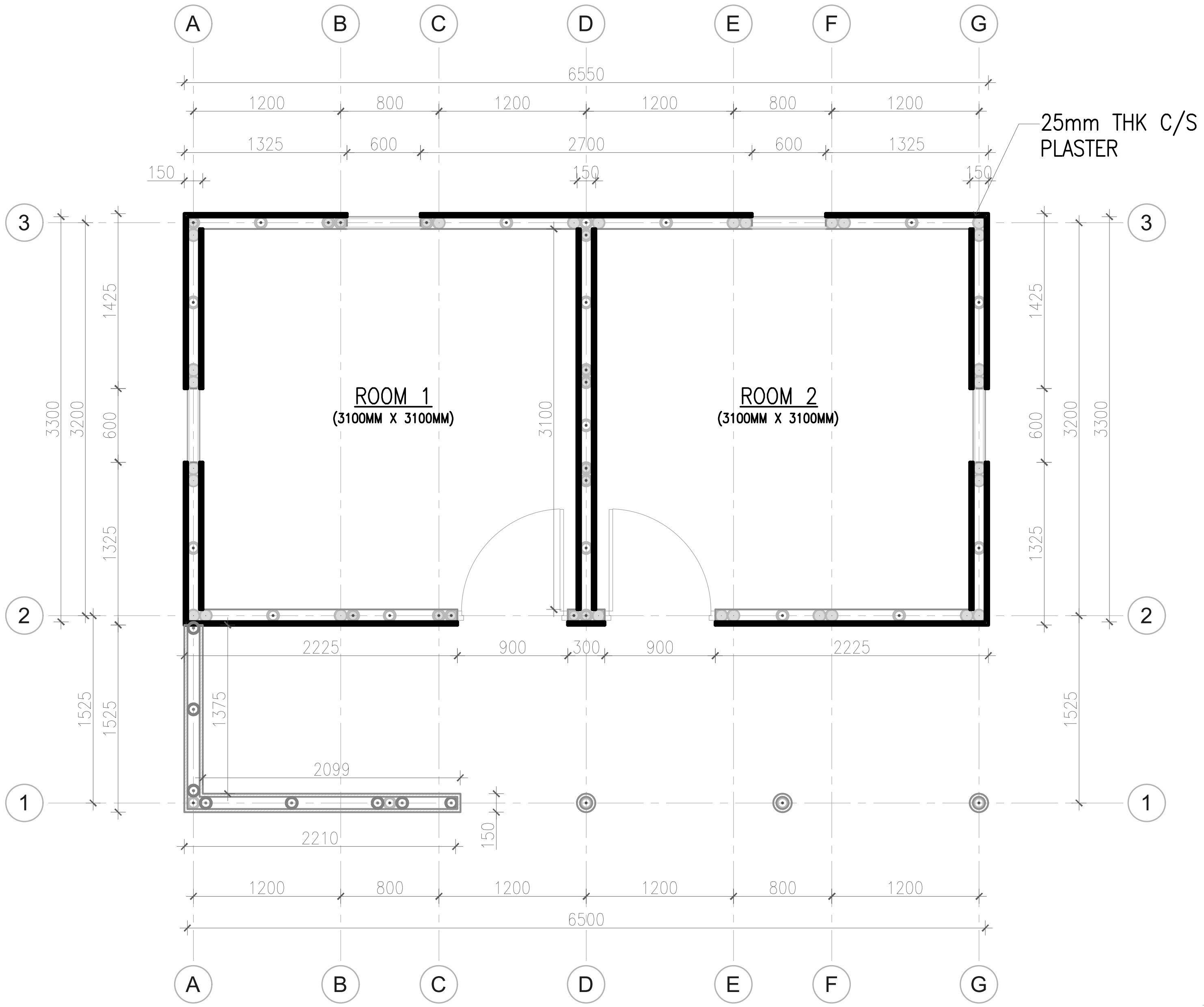
S. NO.	DESCRIPTION	SYMBOL	NO.
1	VERANDA PANEL 01	VP-01	1
2	VERANDA PANEL 02	VP-02	1
3	VERANDA PANEL 03	VP-03	1
4	SOLID PANEL 01	SP-01	6
5	SOLID PANEL 02	SP-02	2
6	SOLID PANEL 03	SP-03	3
7	SOLID PANEL 04	SP-04	1
8	SOLID PANEL 05	SP-05	3
9	WINDOW PANEL 01	WP-01	2
10	WINDOW PANEL 02	WP-02	2
11	DOOR PANEL 01	DP-01	2

SCHEDULE OF OPENINGS

S. NO.	DESCRIPTION	SYMBOL	SIZE	NO.	REMARKS
1	DOOR	D1	900 X 2100	2	
2	WINDOW	W1	600 X 1350	4	

WALL CONFIGURATION PLAN

SCALE: 1:50



MORTAR CLADDING KEY PLAN

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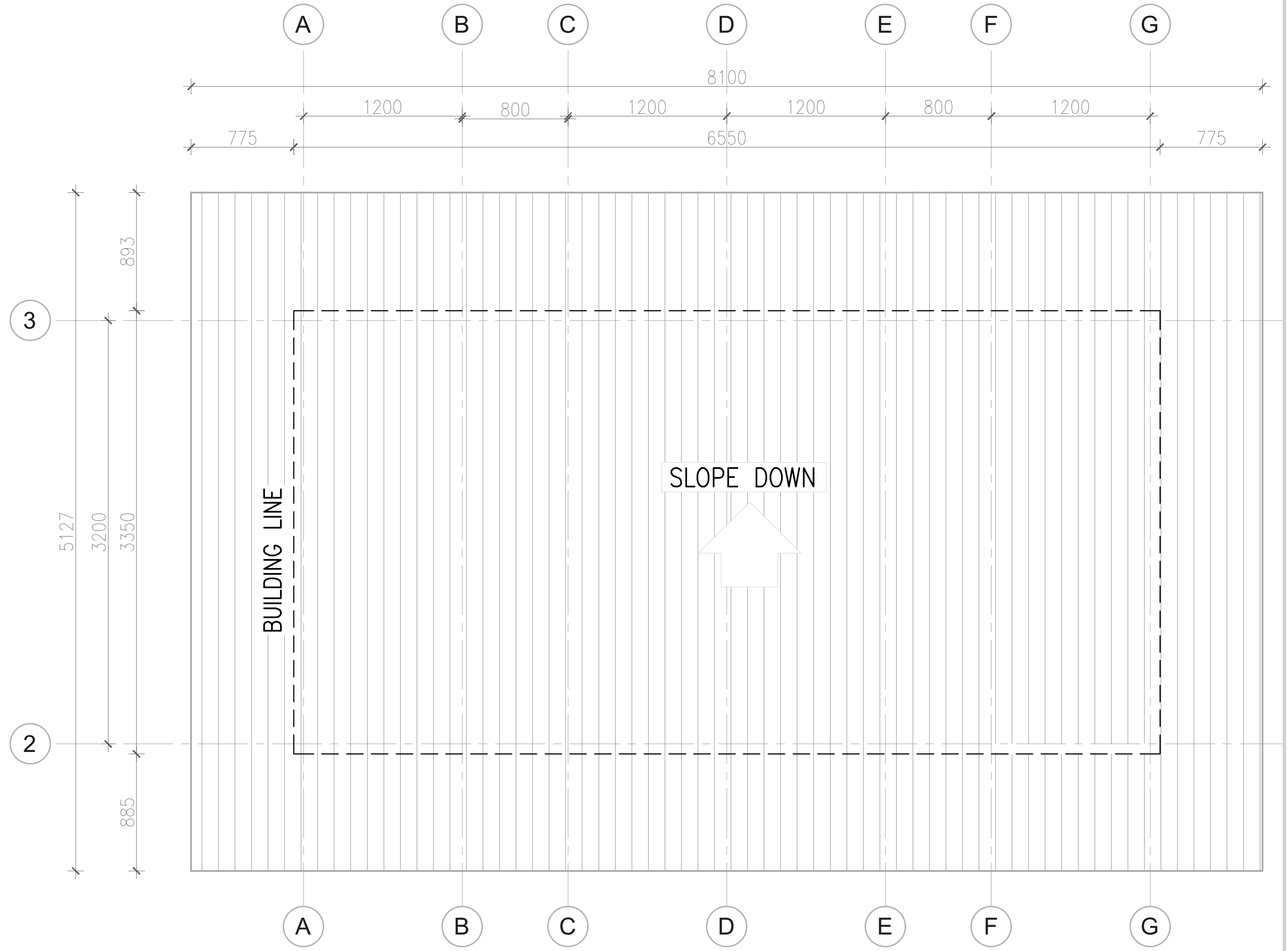

MAIN ROOF PLAN AT +4114MM LVL

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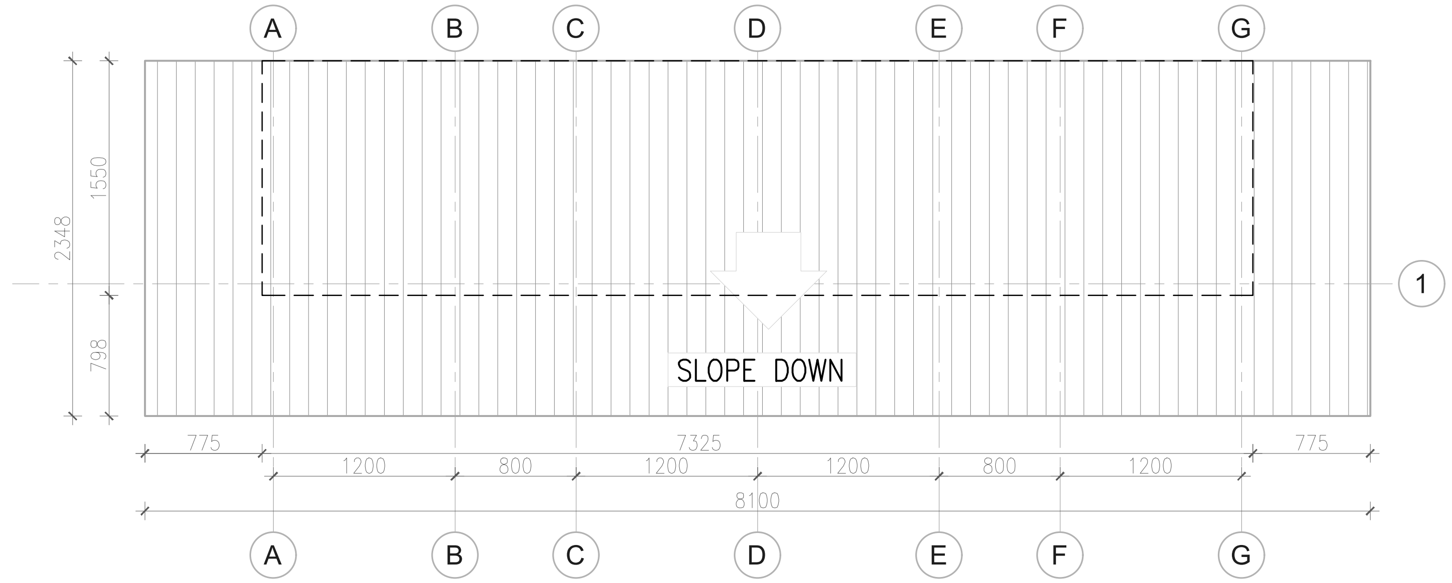

VERANDA ROOF PLAN

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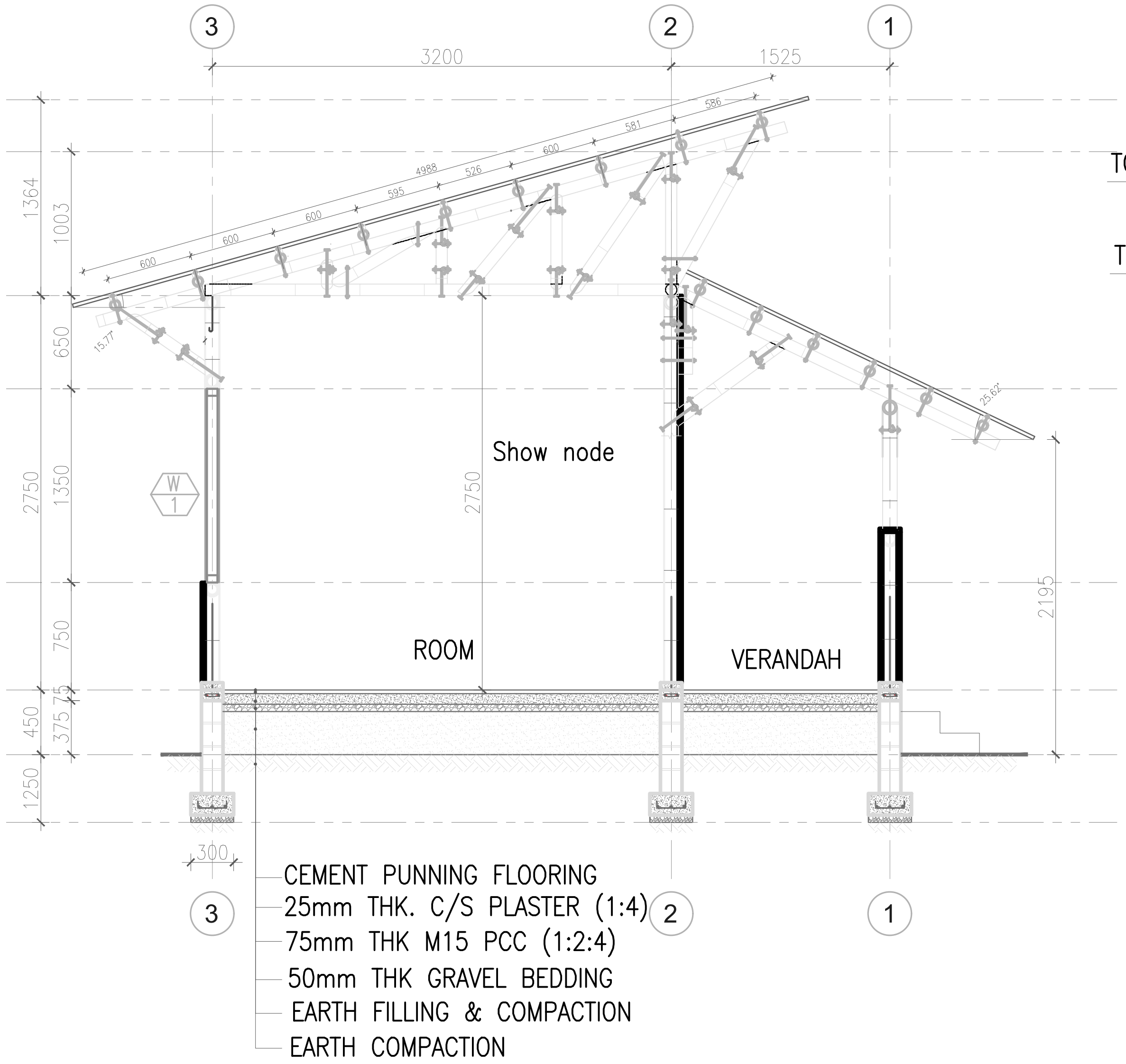

SECTION AT B

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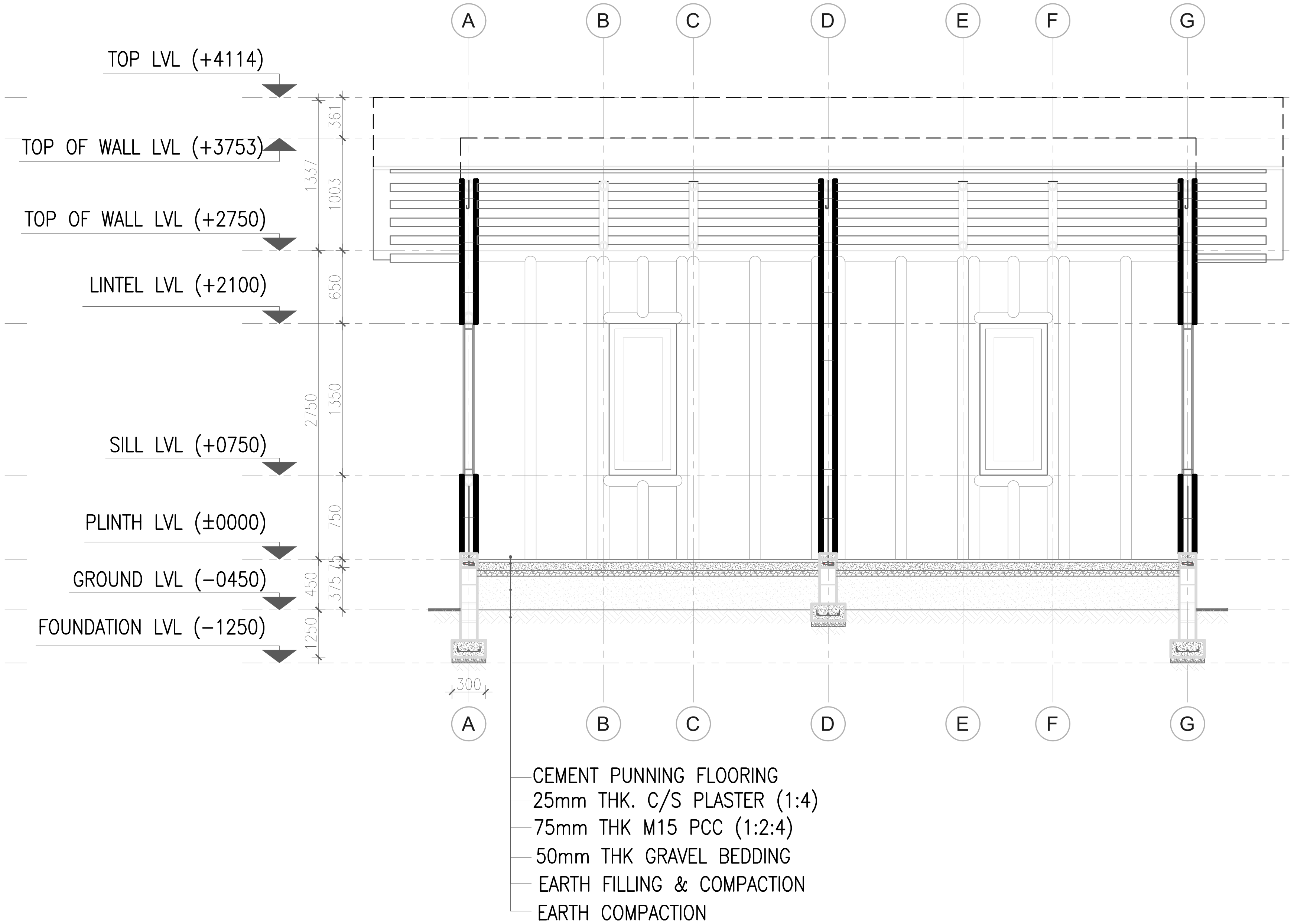
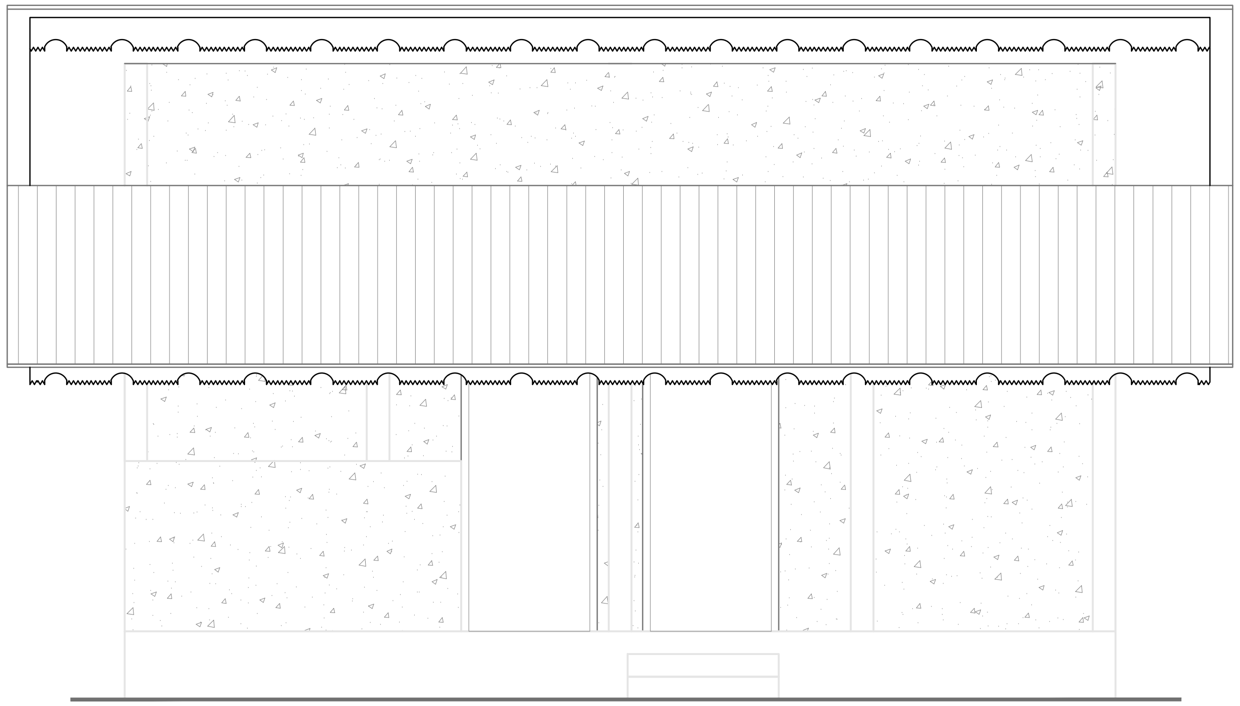


SECTION AT A



FRONT ELEVATION

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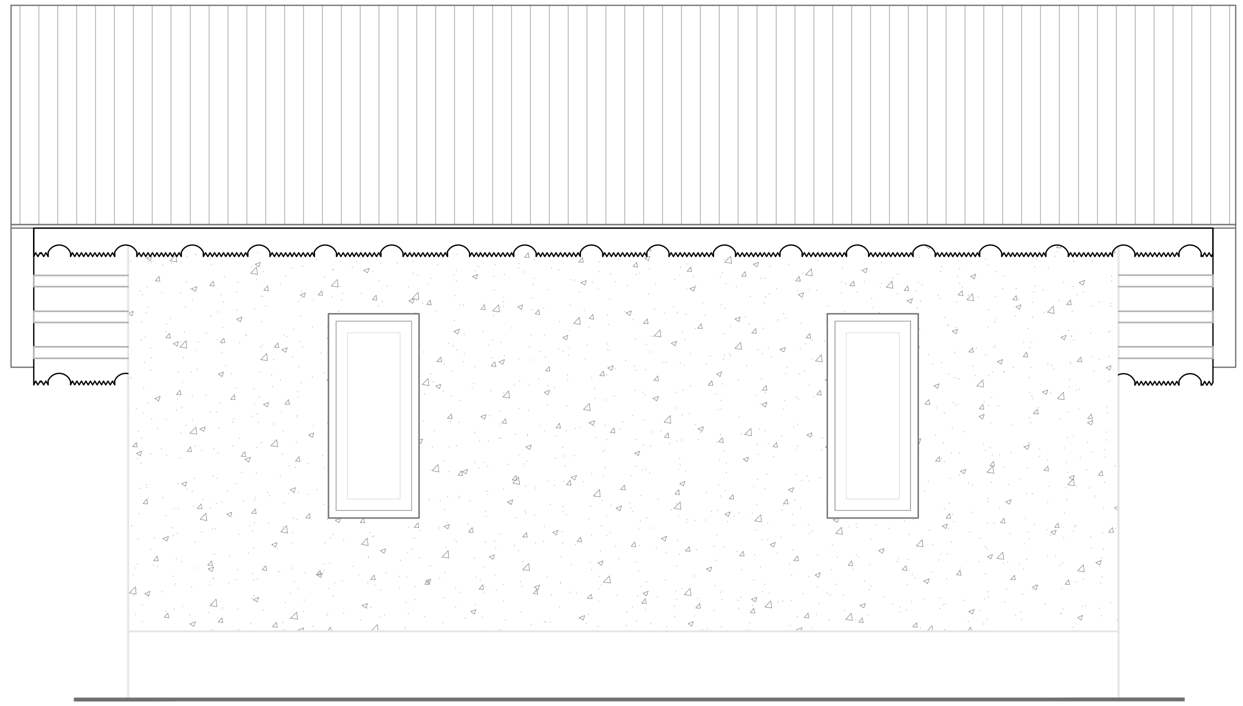

BACK ELEVATION

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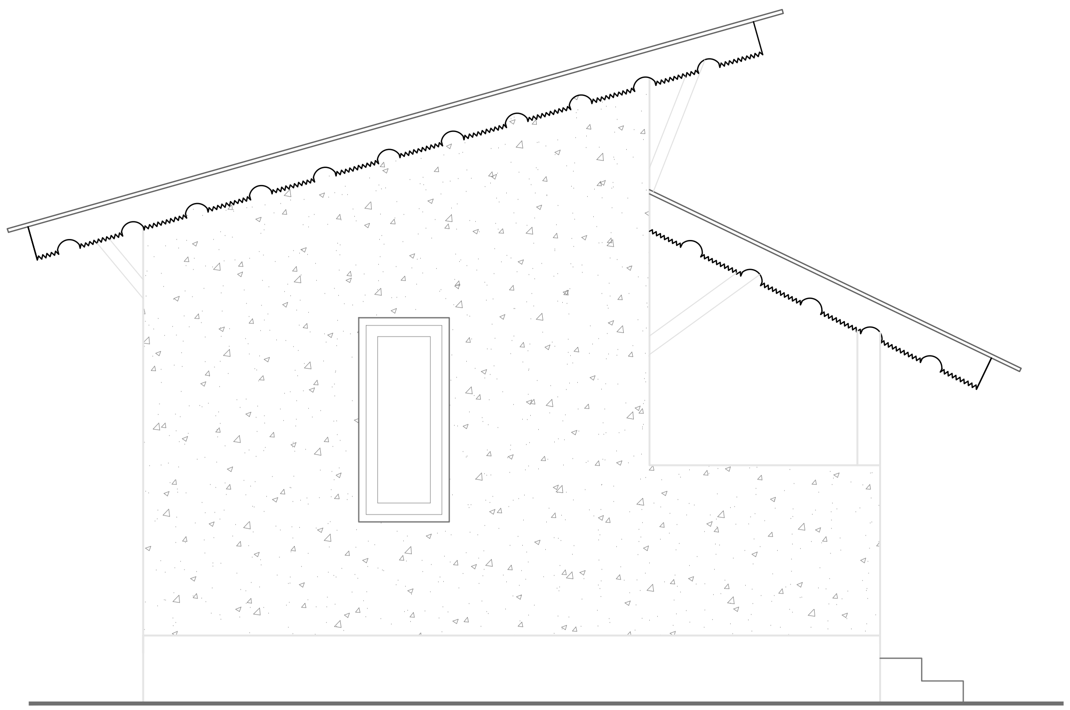

SIDE ELEVATION (LEFT)

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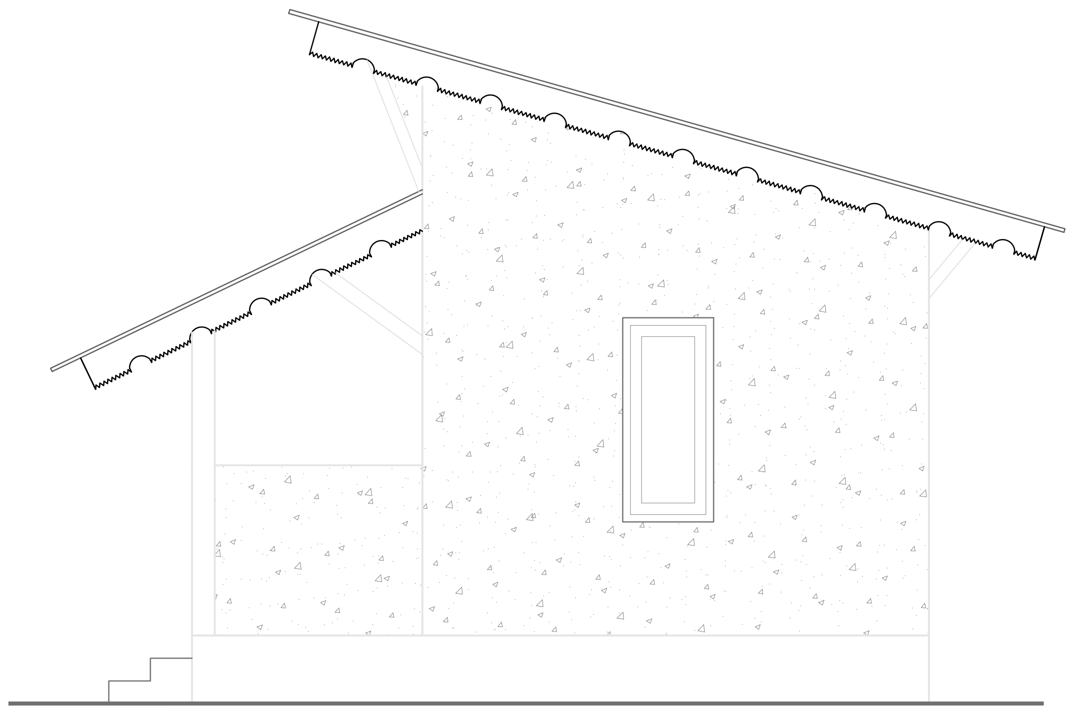

SIDE ELEVATION (RIGHT)

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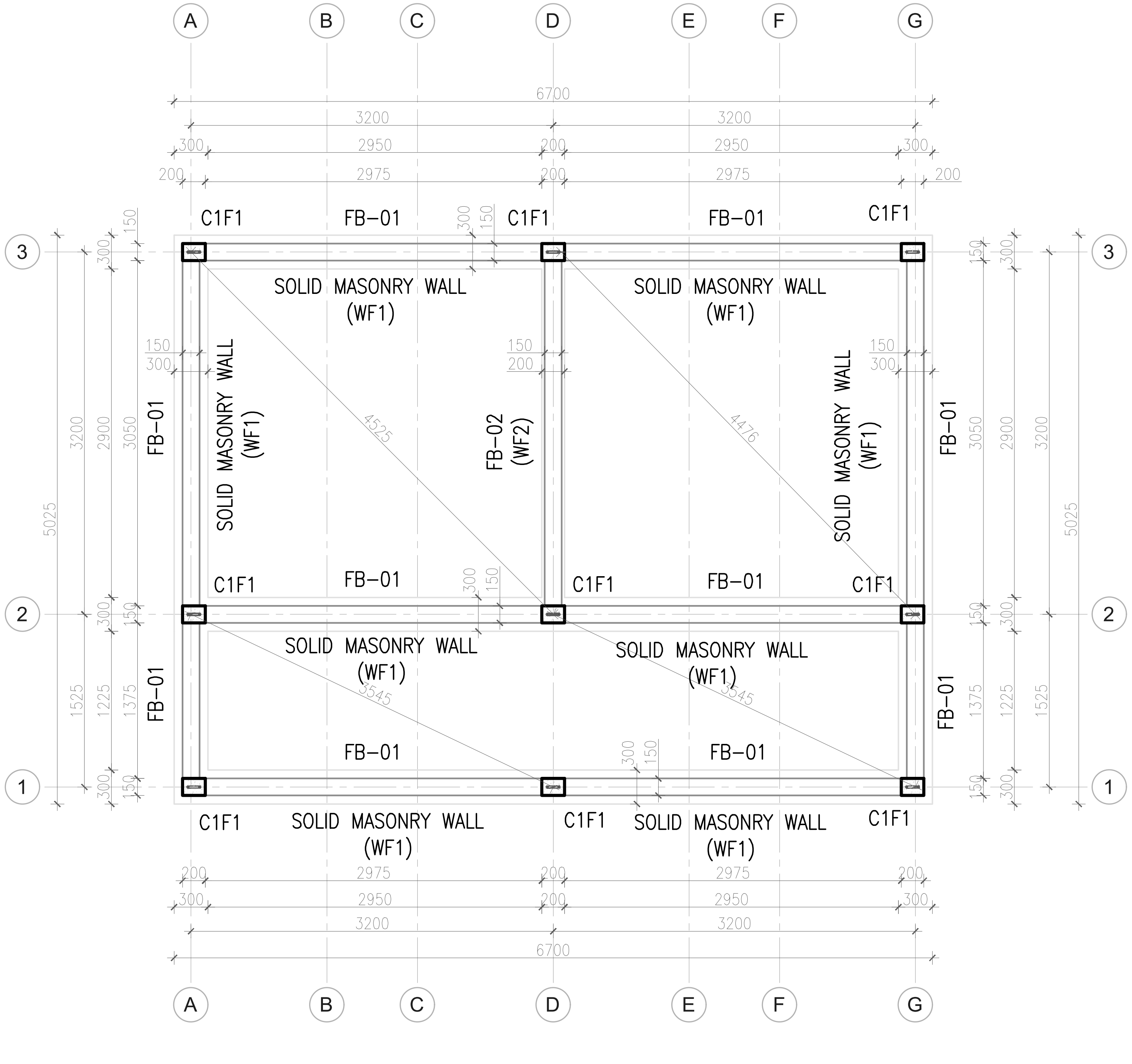
scale	1:50	sheet contents ALL SIDE ELEVATIONS
date	05/08/2025	

a-04

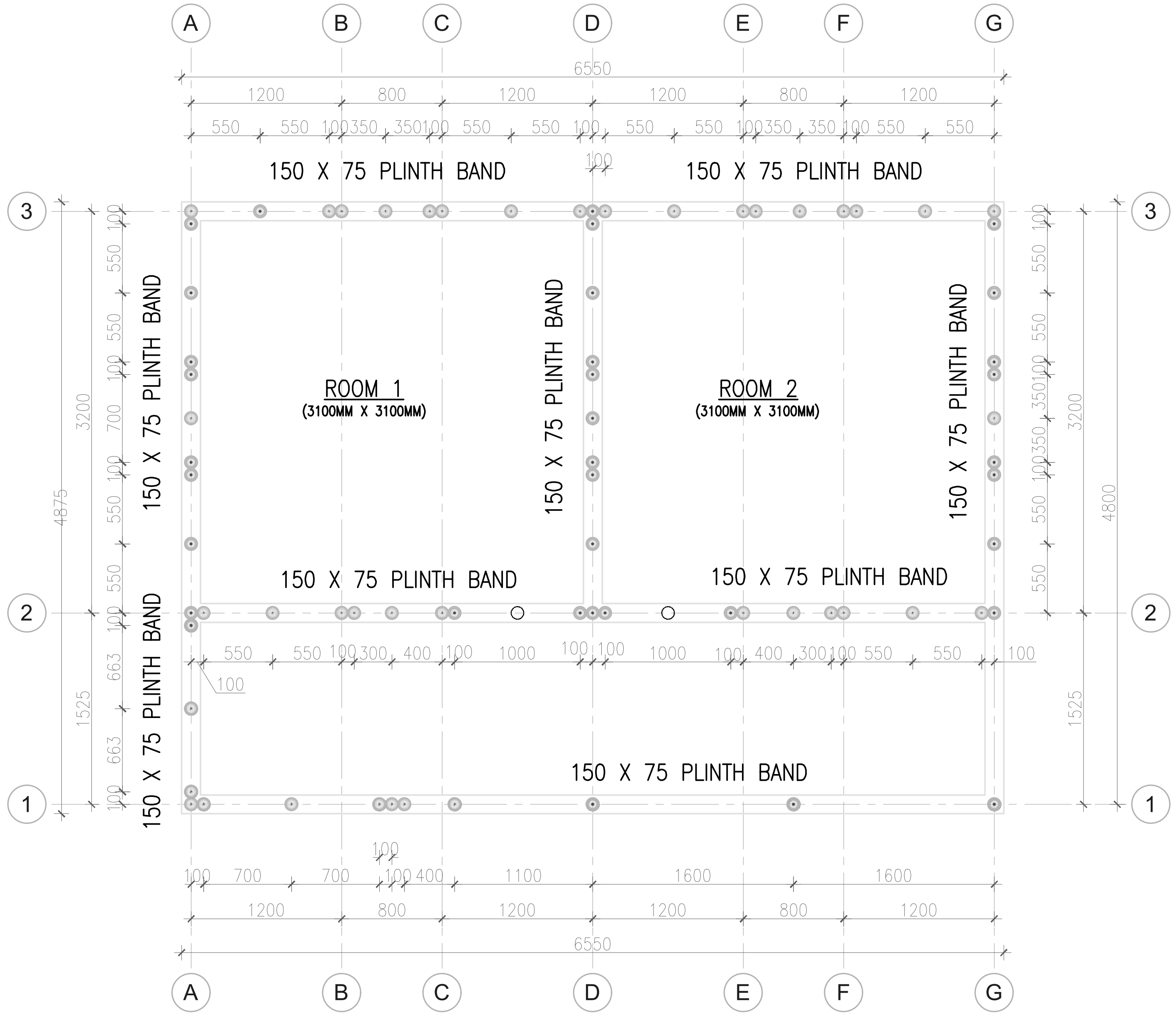
sheet

05 /14



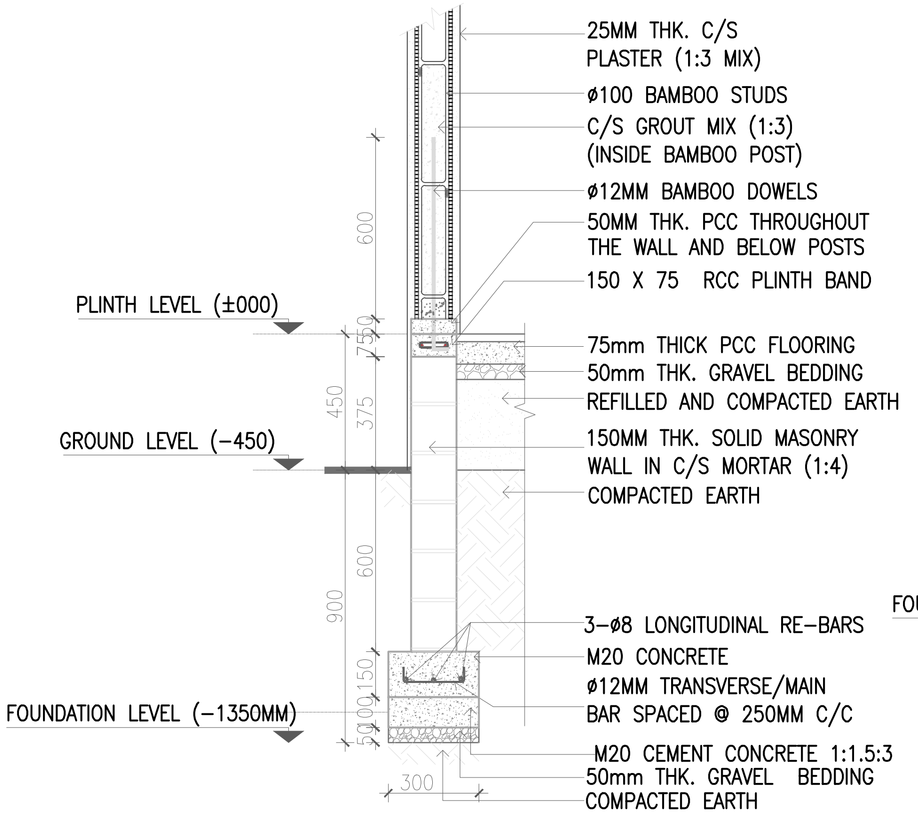
FOUNDATION AND PEDESTAL COLUMN PLAN

SCALE: 1: 50



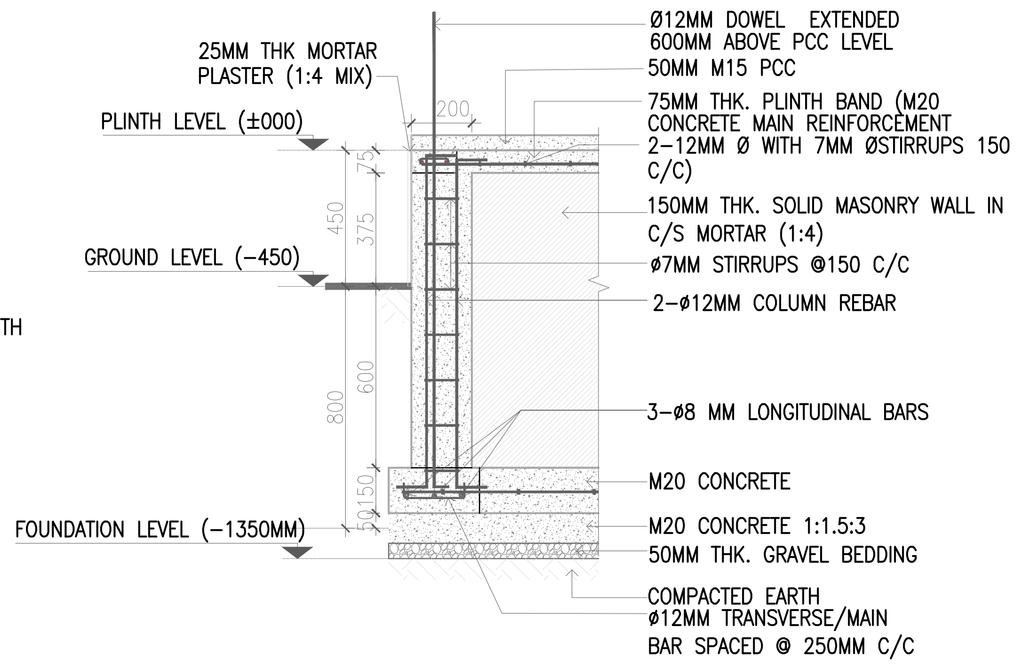
VERTICAL REBAR LOCATION PLAN

SCALE: 1:50



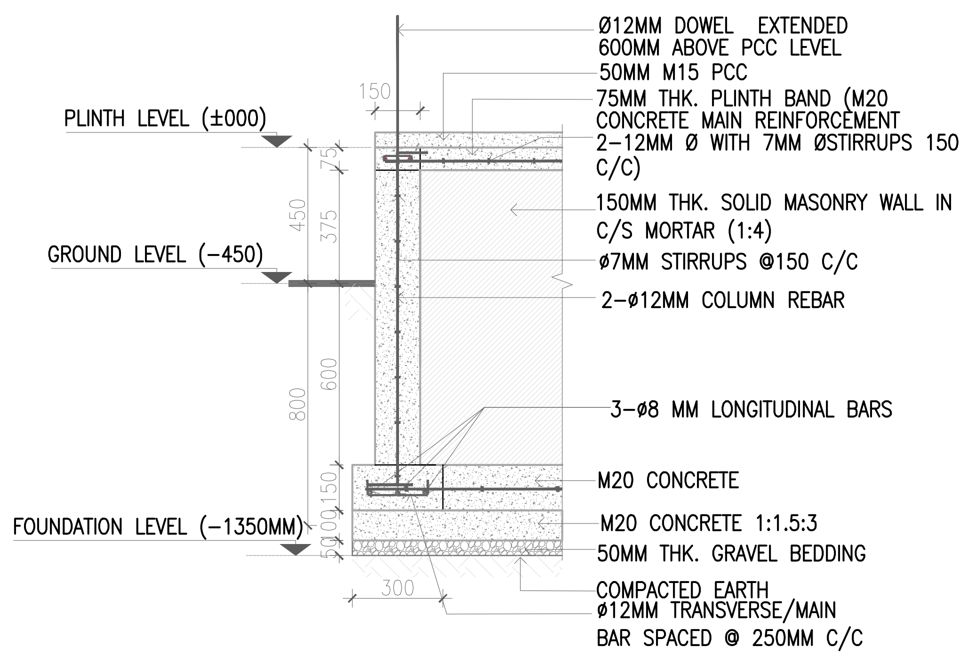
TYPICAL SECTION (EXTERIOR WALL FOOTING (WF-1))

SCALE: 1:25



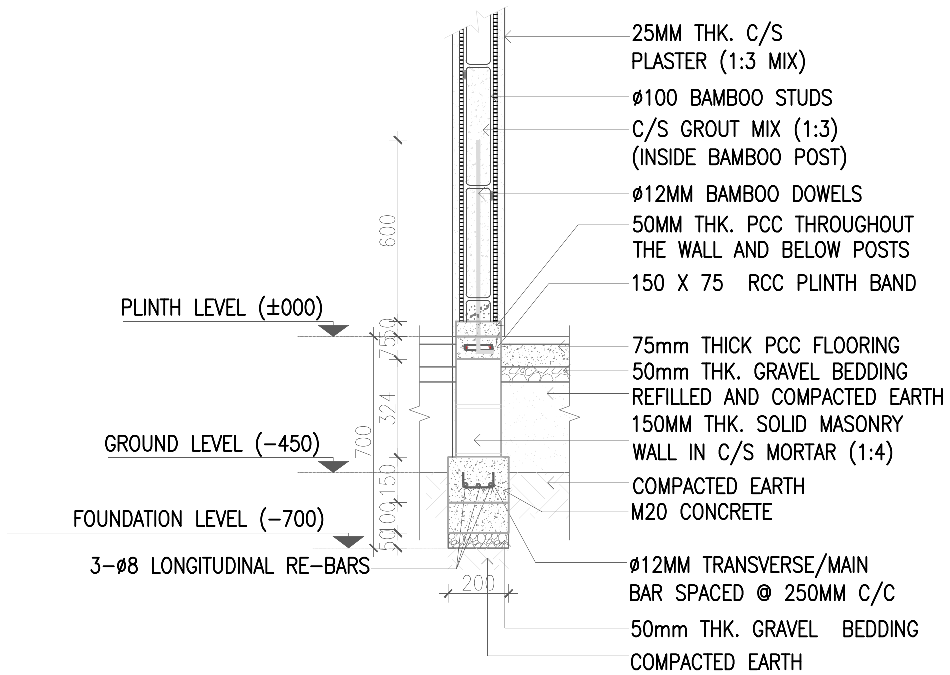
PEDESTAL COLUMN SECTION IN LONG DIRECTION
(EXTERIOR WALL FOOTING (WF-1))

SCALE: 1:25



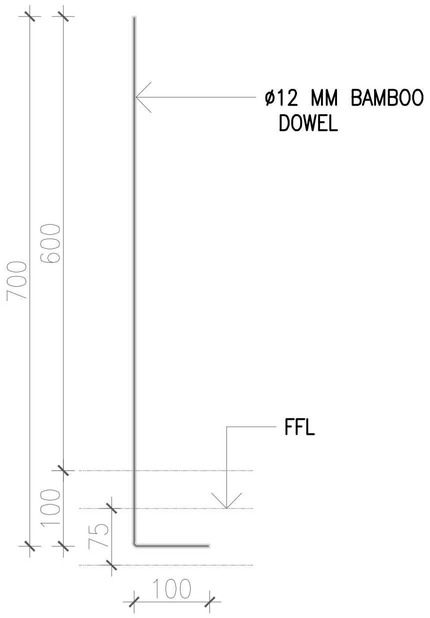
PEDESTAL COLUMN SECTION IN SHORT DIRECTION
(EXTERIOR WALL FOOTING (WF-1))

SCALE: 1:25



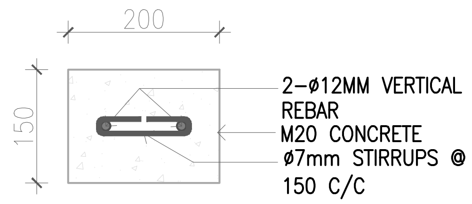
TYPICAL SECTION (INTERIOR WALL FOOTING (WF-2))

SCALE: 1:25



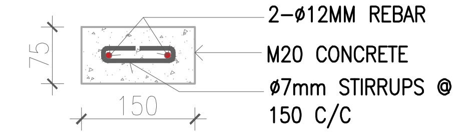
DOWEL BAR FOR BAMBOO POST

SCALE: 1:10



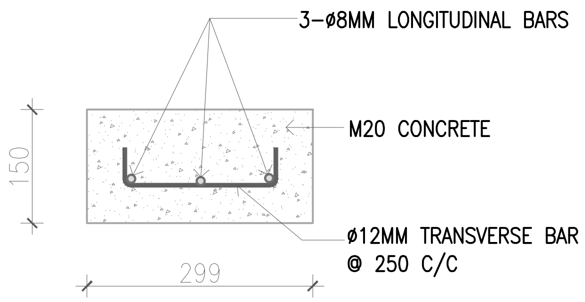
COLUMN (C1) SECTION

SCALE: 1:10



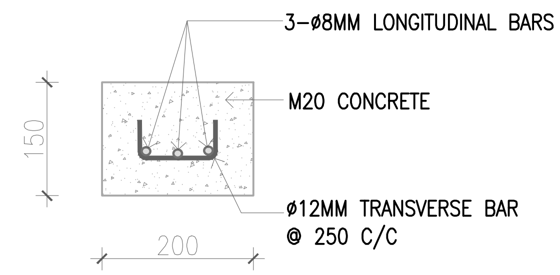
PLINTH BEAM SECTION

SCALE: 1:10



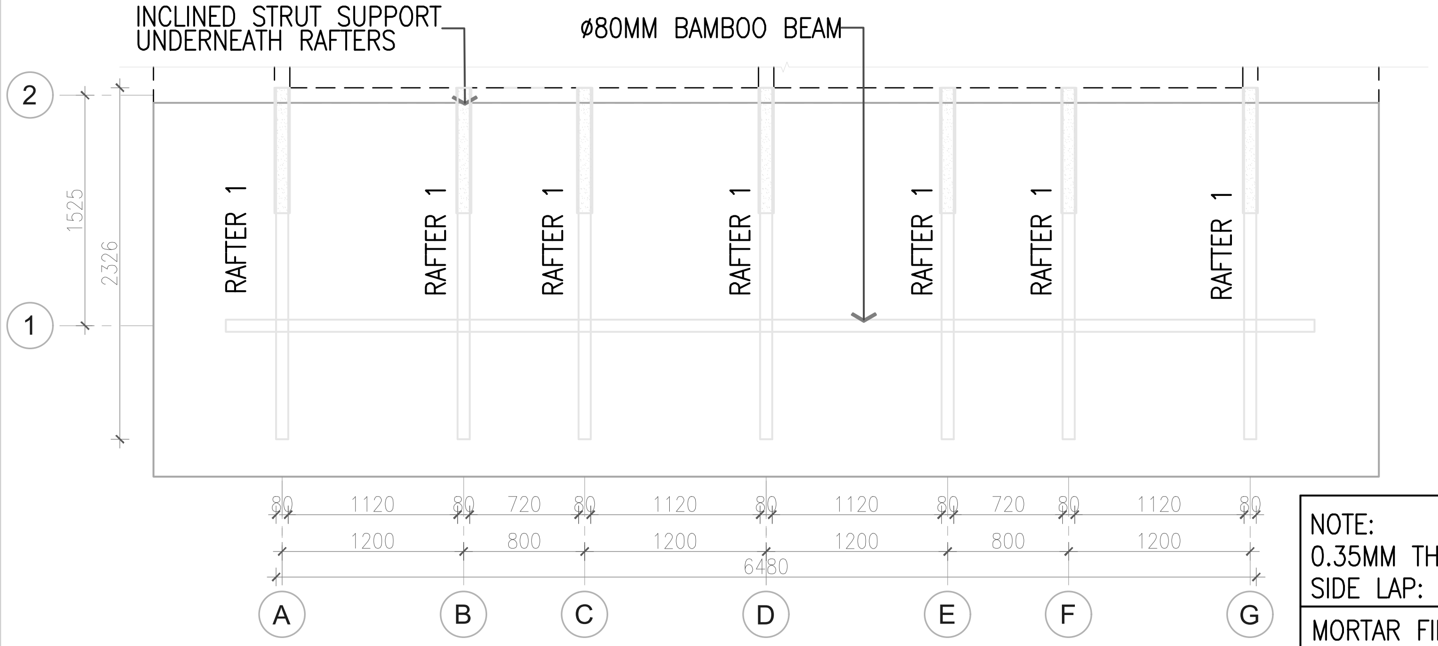
STRIP FOUNDATION (FB-01) SECTION

SCALE: 1:10



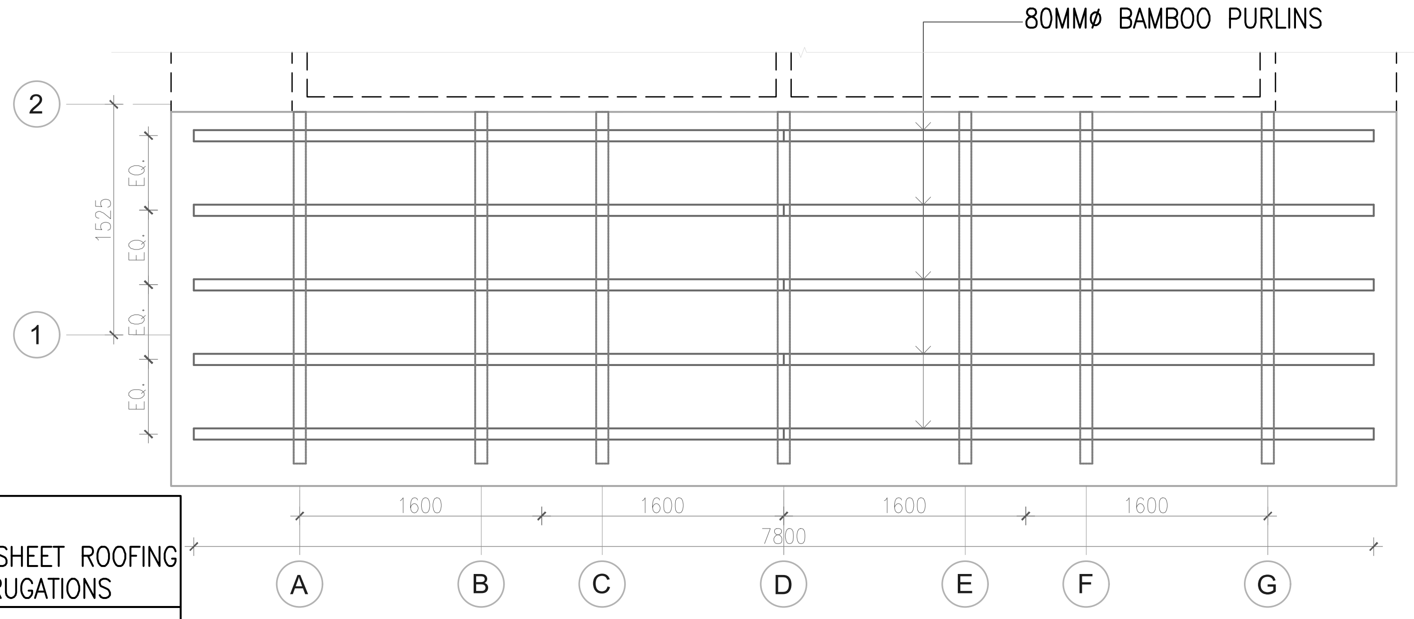
STRIP FOUNDATION (FB-02) SECTION

SCALE: 1:10



RAFTER 1 DETAILS (VERANDAH ROOF)

SCALE: 1:50



PURLINS DETAILS (VERANDAH ROOF)

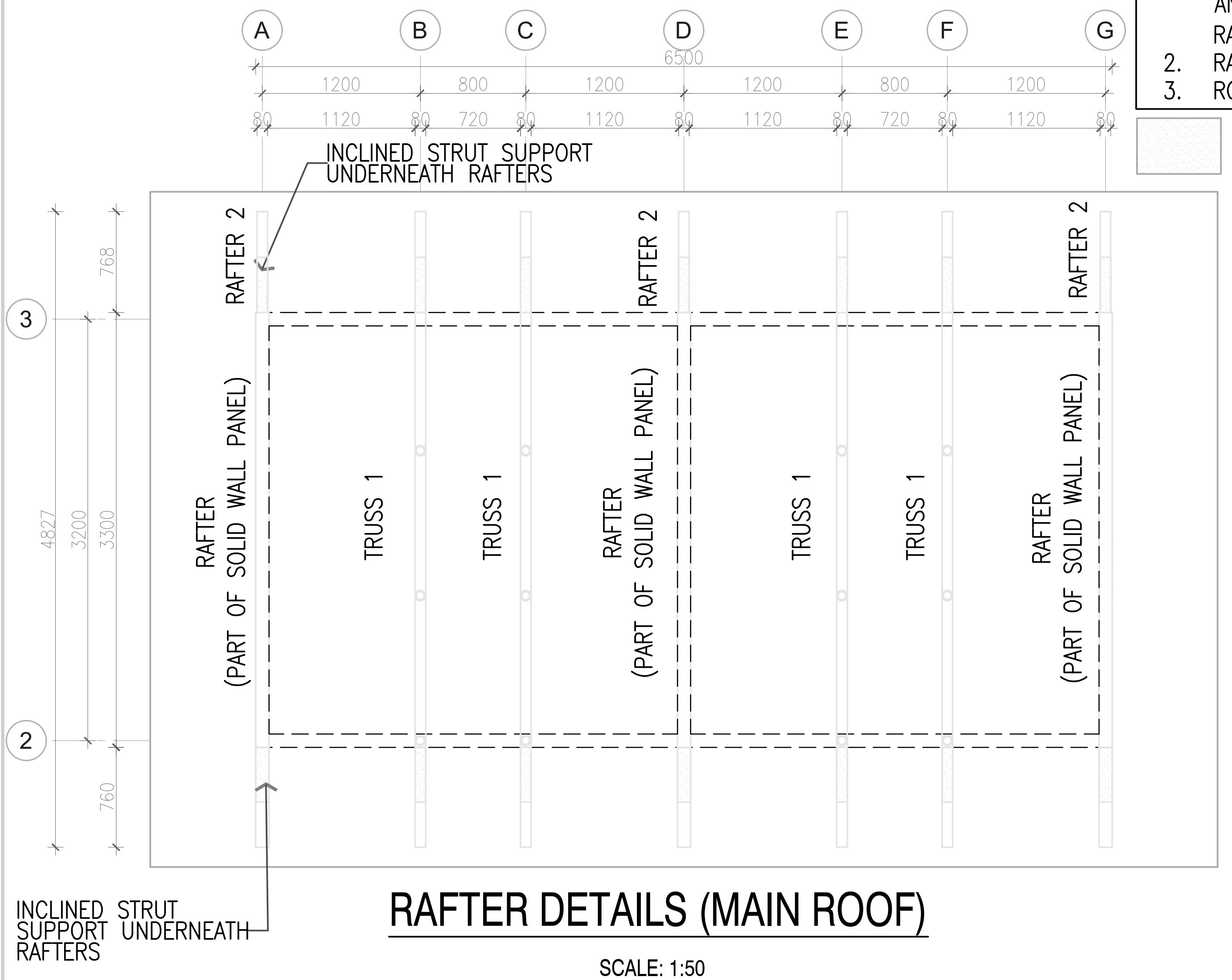
SCALE: 1:50

NOTE:
0.35MM THK CGI SHEET ROOFING
SIDE LAP: 2 CORRUGATIONS

MORTAR FILLING SHALL ONLY BE APPLIED TO THE FOLLOWING AREAS:

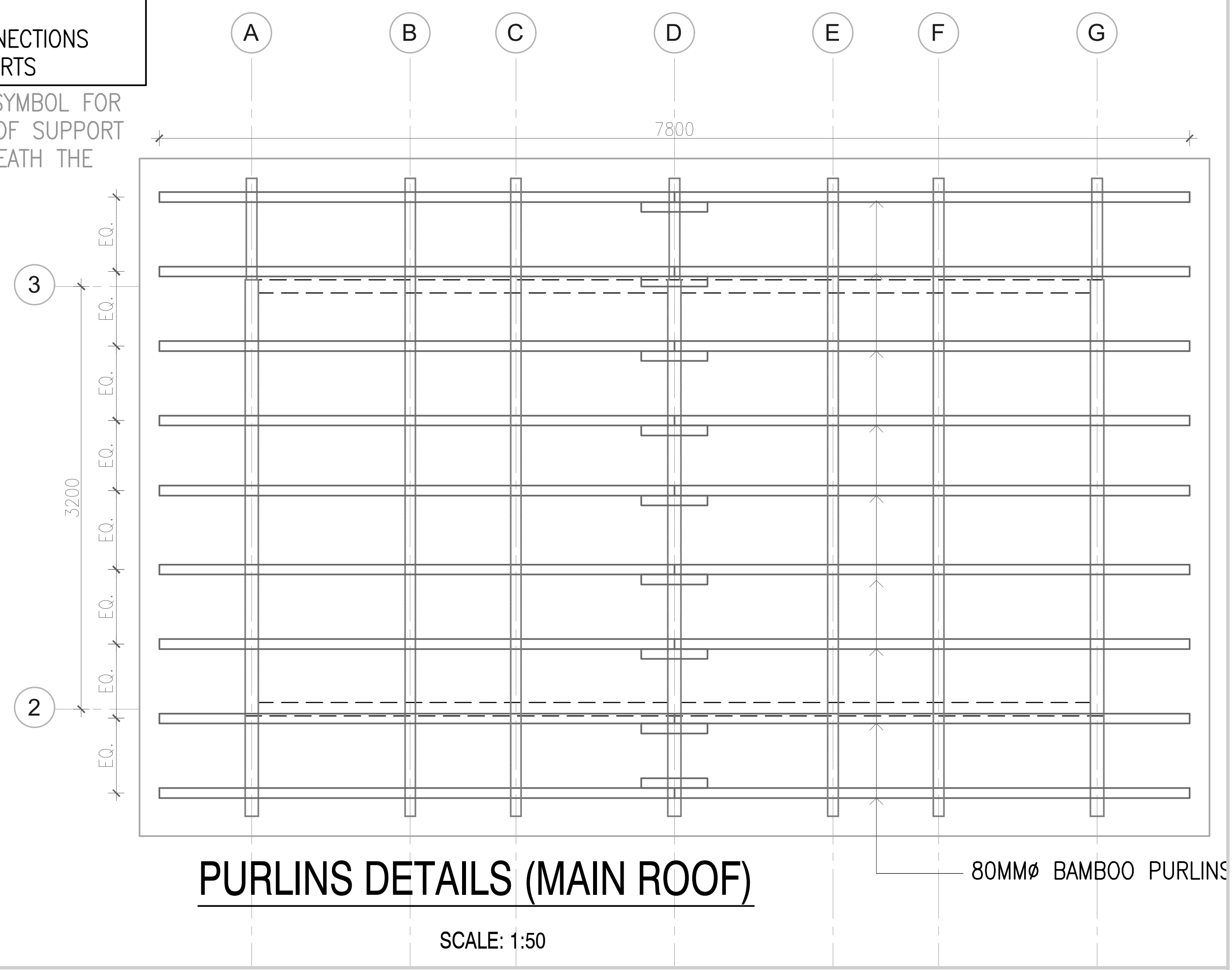
1. BAMBOO STUD; DOWEL AND CONNECTION TO RAFTER/S
2. RAFTER CONNECTIONS
3. ROOF SUPPORTS

HATCH SYMBOL FOR THE ROOF SUPPORT UNDERNEATH THE RAFTERS



RAFTER DETAILS (MAIN ROOF)

SCALE: 1:50



PURLINS DETAILS (MAIN ROOF)

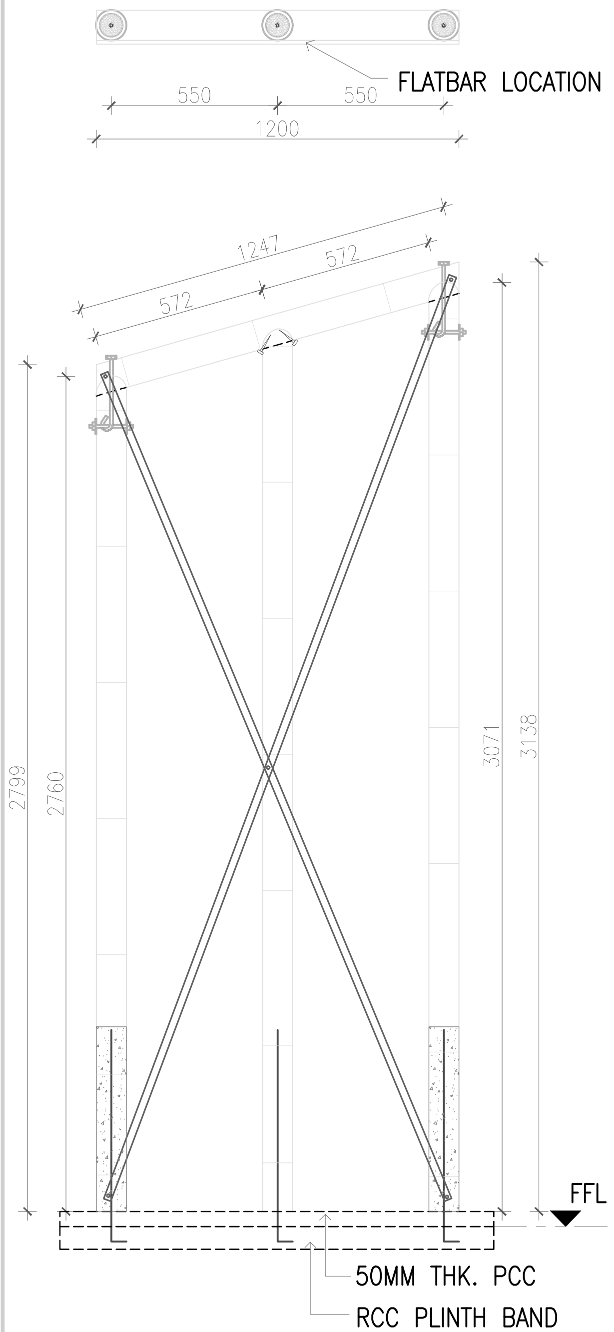
SCALE: 1:50

NOTES:

A.) TOP BAMBOO MEMBER & STUDS SHALL BE FIXED WITH FISHMOUTH CONNECTION USING Ø12MM J-BOLT & Ø12MM THREADED ROD PIN LOCK WITH PREPAINTED NUTS & WASHERS

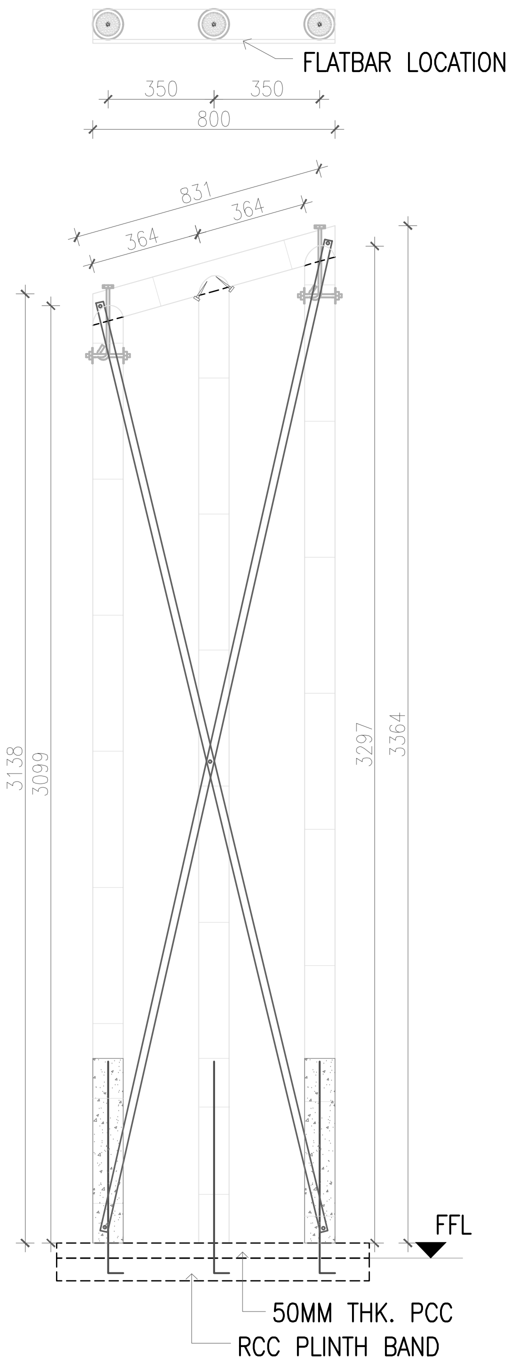
B.) JAMB TO STUD CONNECTION SHALL BE FIXED WITH 10MM THREADED ROD AND PREPAINTED NUTS & WASHERS

C.) INSTALLATION OF FLAT BARS ON THESE PANELS SHOULD BE ALWAYS BE OVER THE FACE TO BE PLASTERED AND FACING THE EXTERIOR



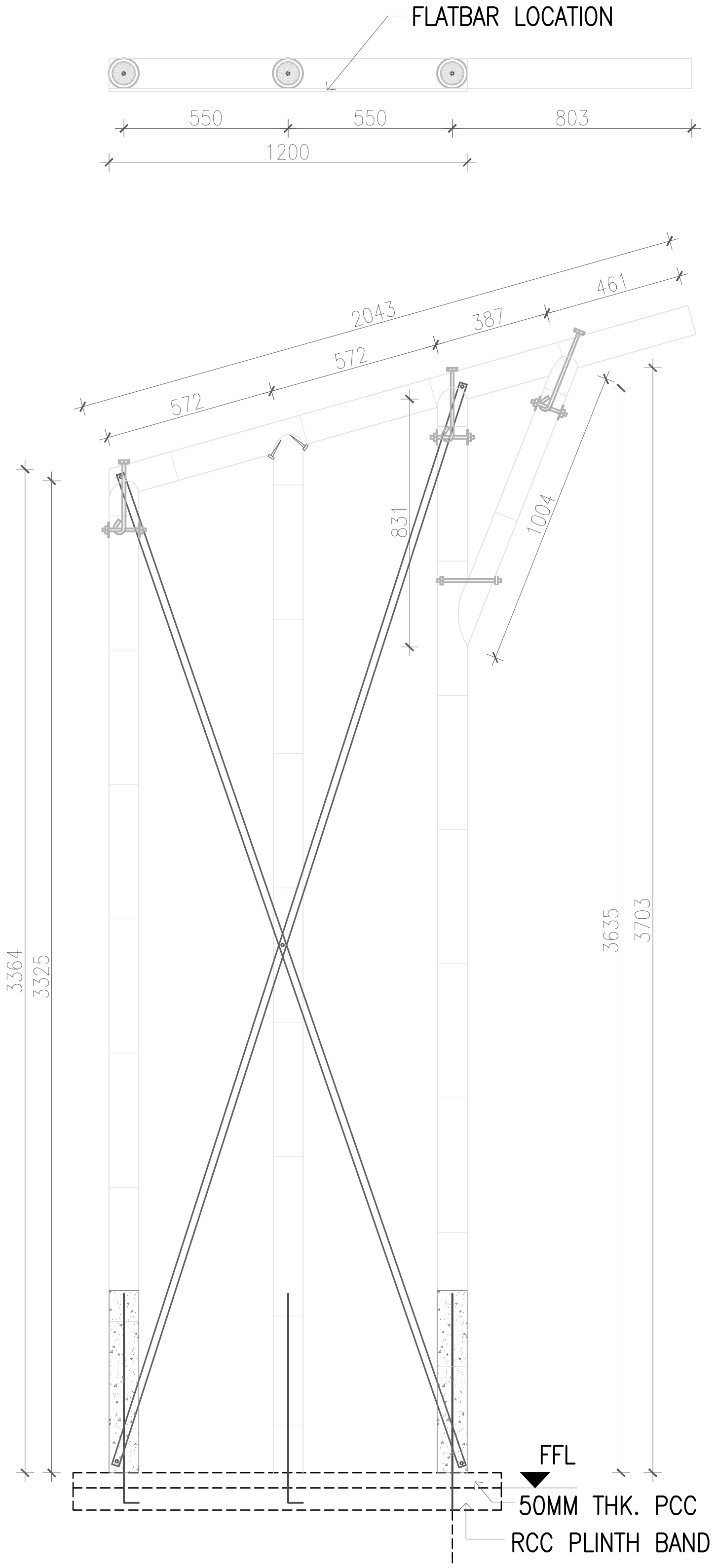
WALL PANEL 05 (SP-05)

SCALE: 1:25



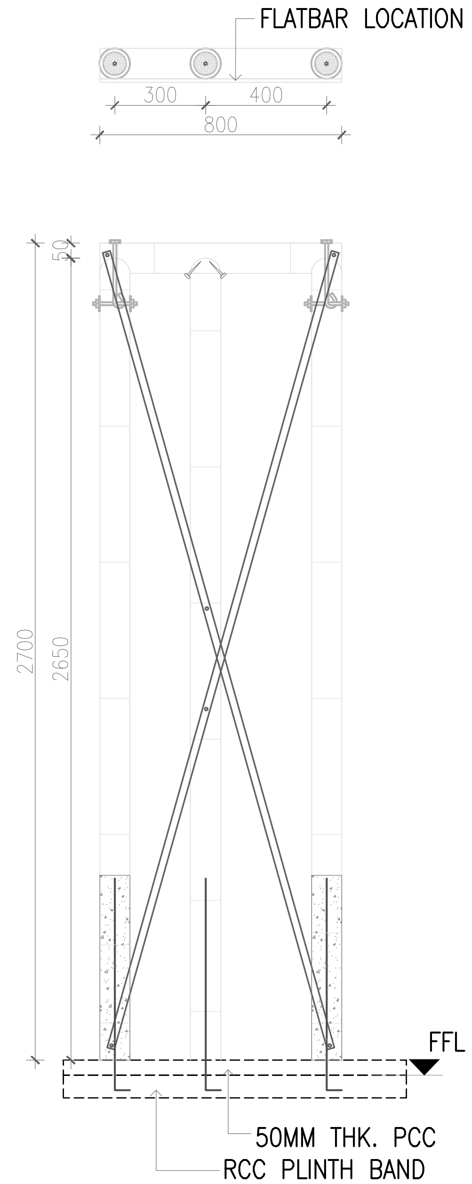
WALL PANEL 04 (SP-04)

SCALE: 1:25



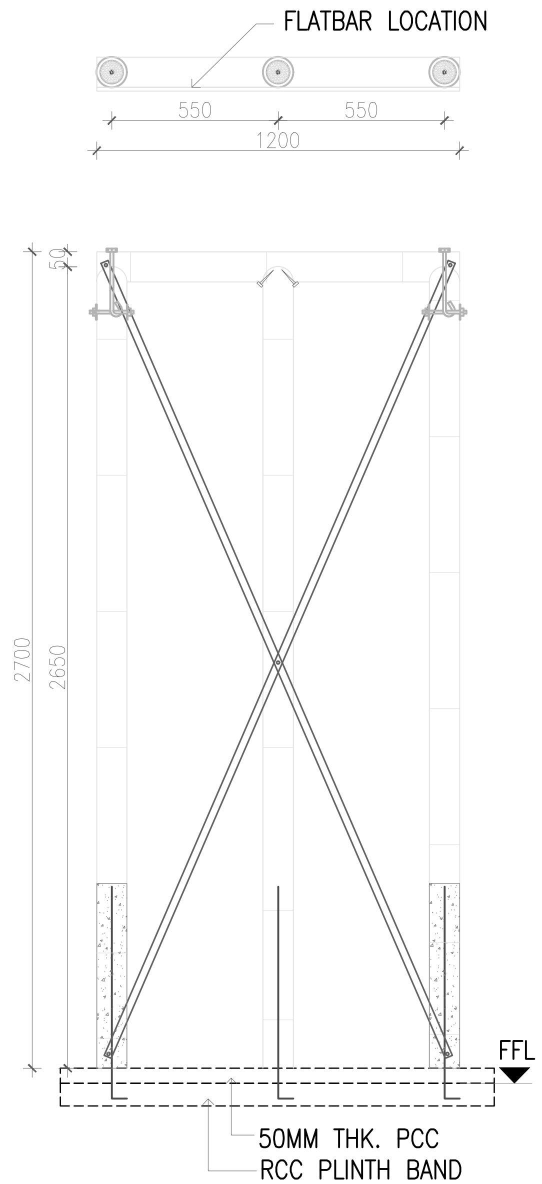
WALL PANEL 03 (SP-03)

SCALE: 1:25



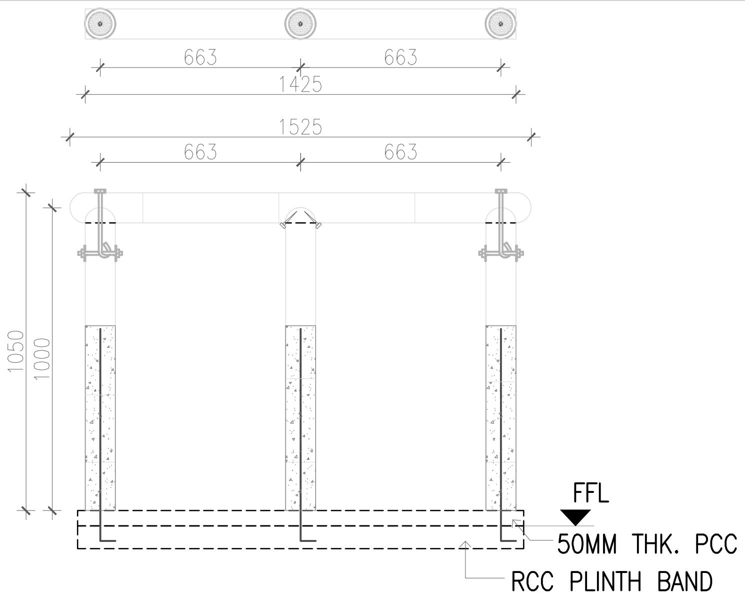
WALL PANEL 02 (SP-02)

SCALE: 1:25



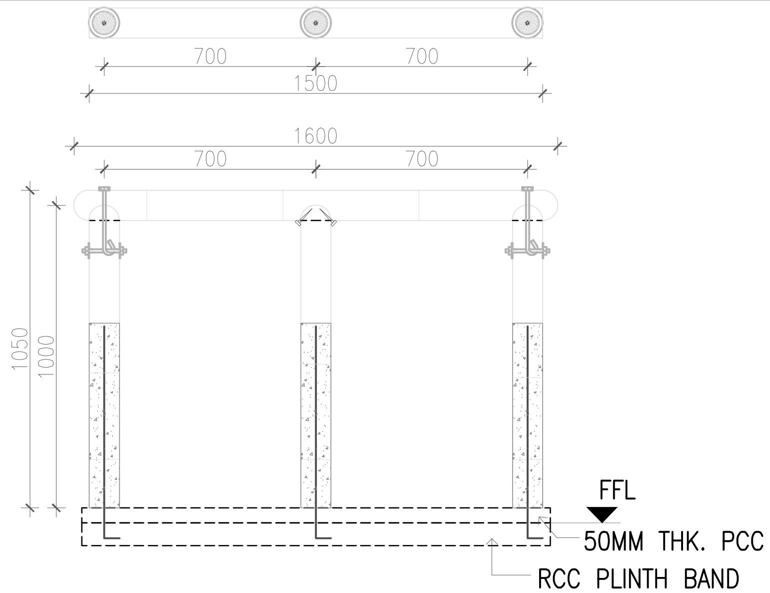
WALL PANEL 01 (SP-01)

SCALE: 1:25



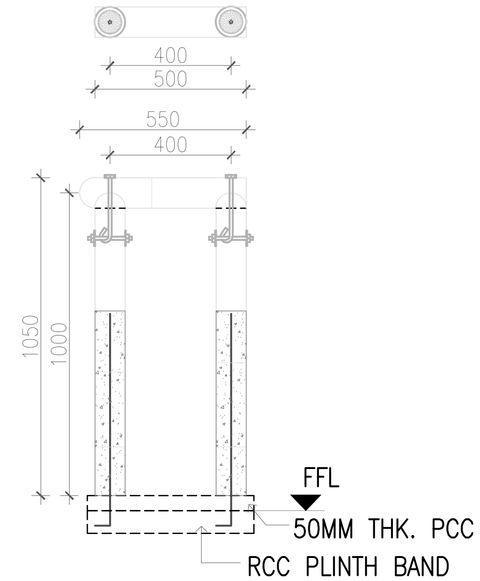
VERANDAH PANEL 01 (VP-01)

SCALE: 1:25



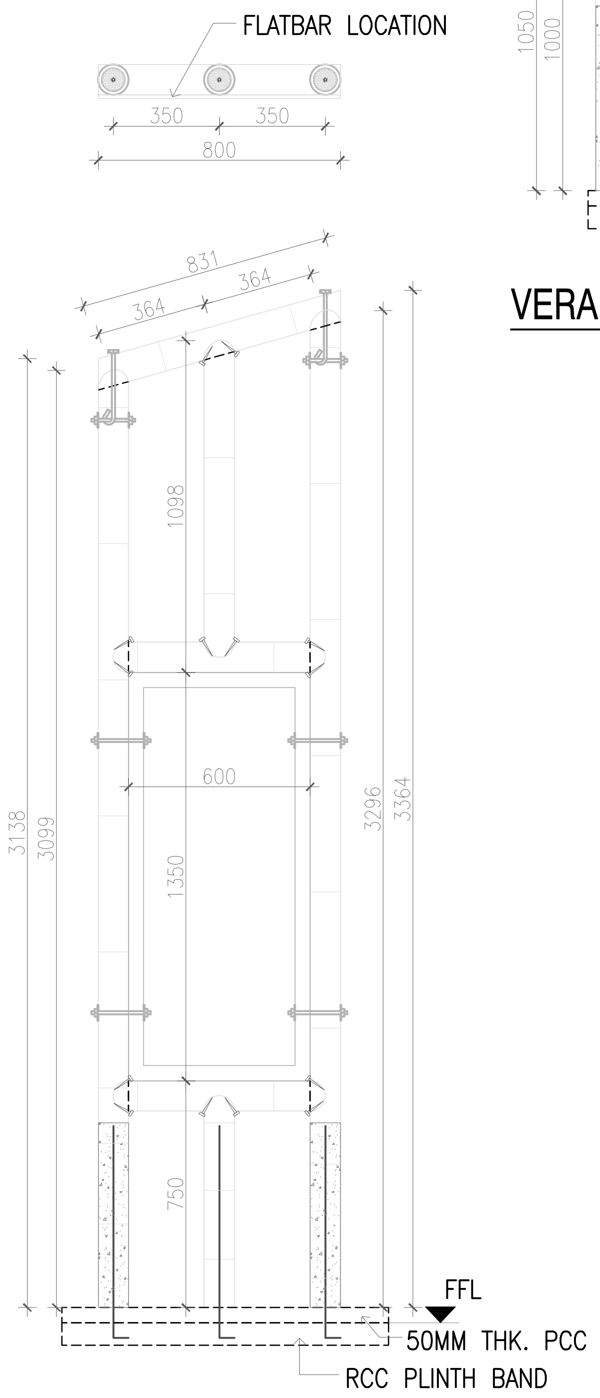
VERANDAH PANEL 02 (VP-02)

SCALE: 1:25



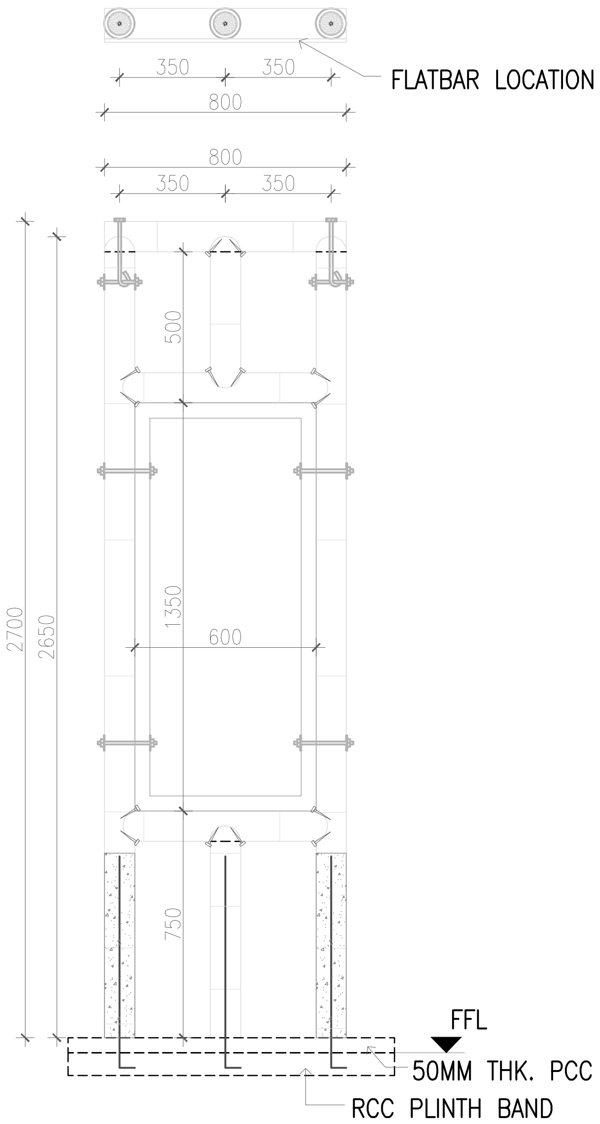
VERANDAH PANEL 03 (VP-03)

SCALE: 1:25



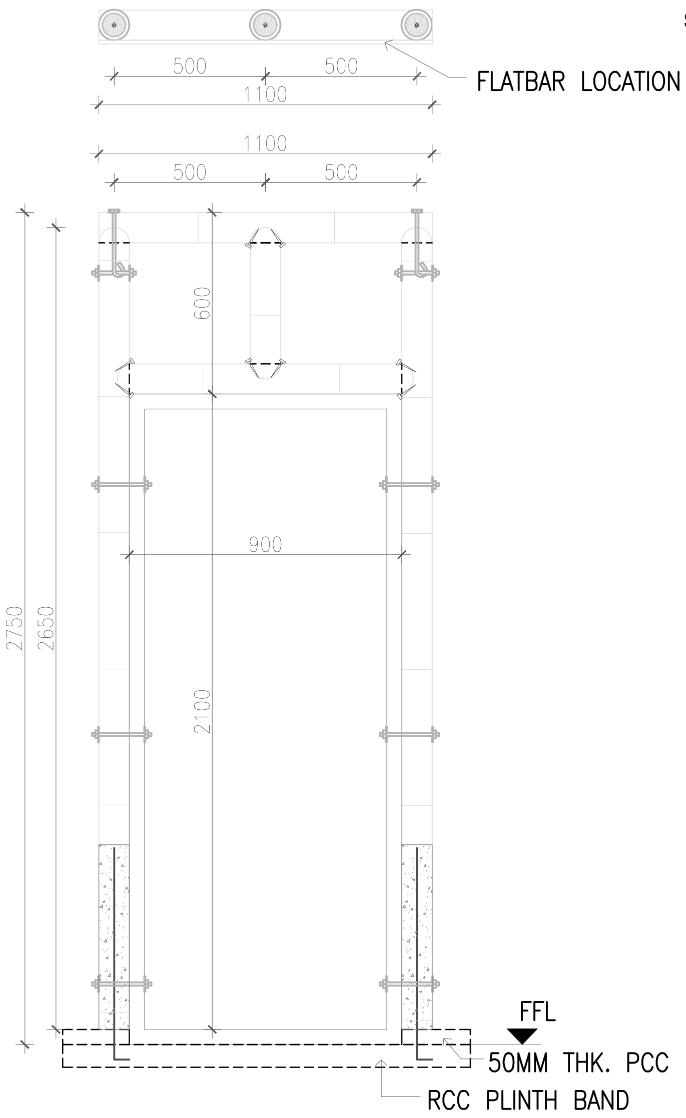
WINDOW PANEL 02 (WP-02)

SCALE: 1:25



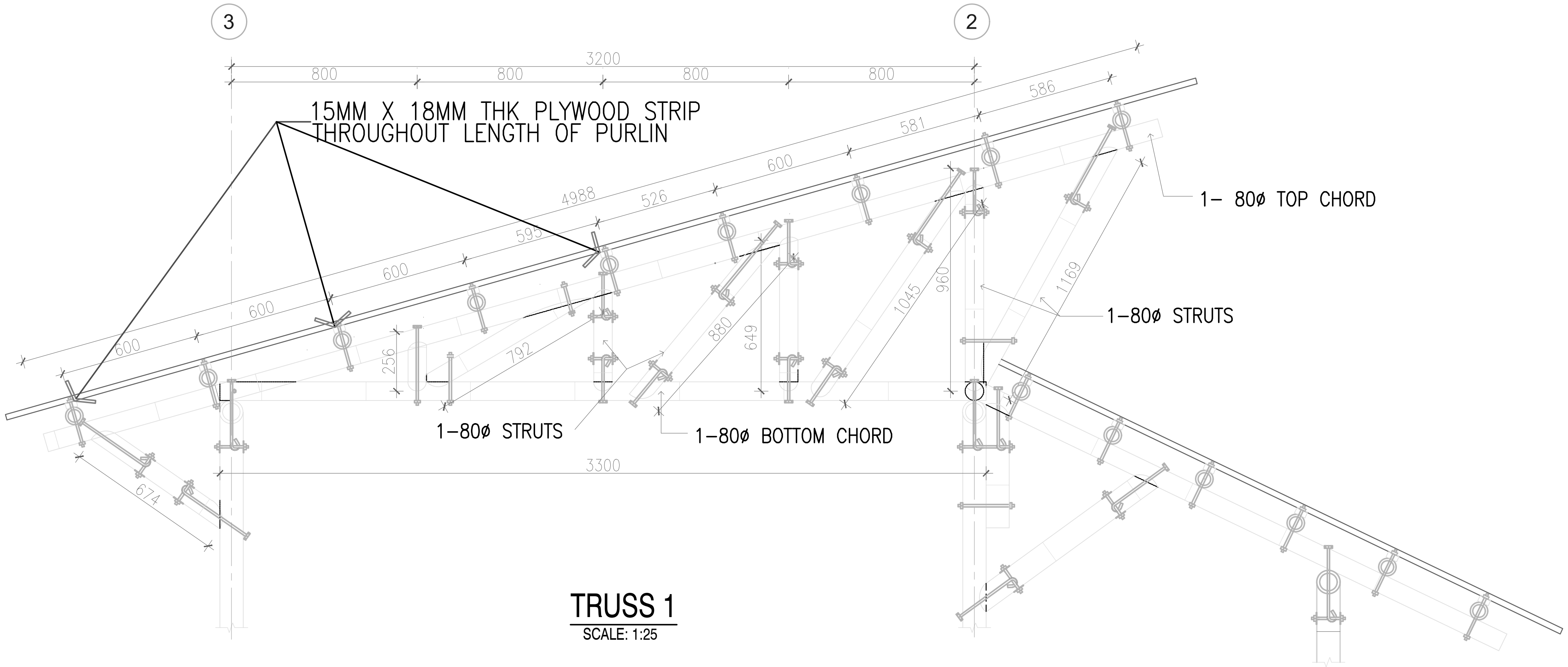
WINDOW PANEL 01 (WP-01)

SCALE: 1:25

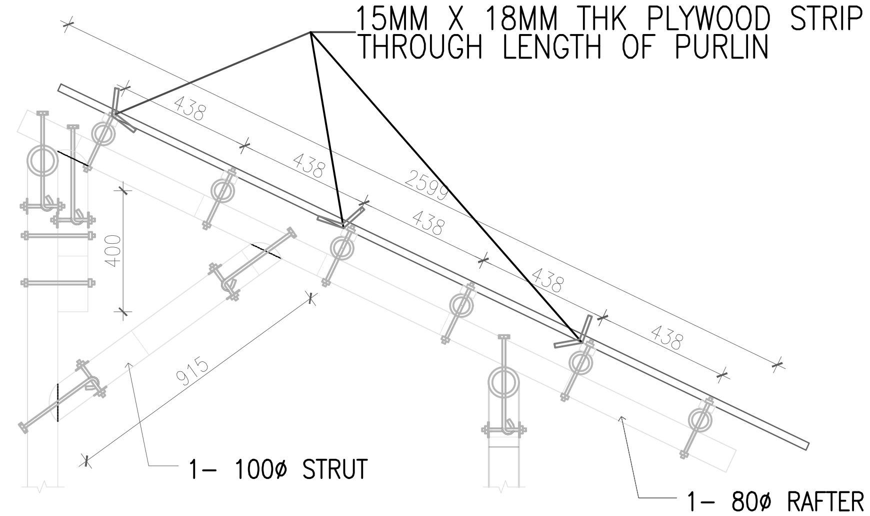


DOOR PANEL 01 (DP-01)

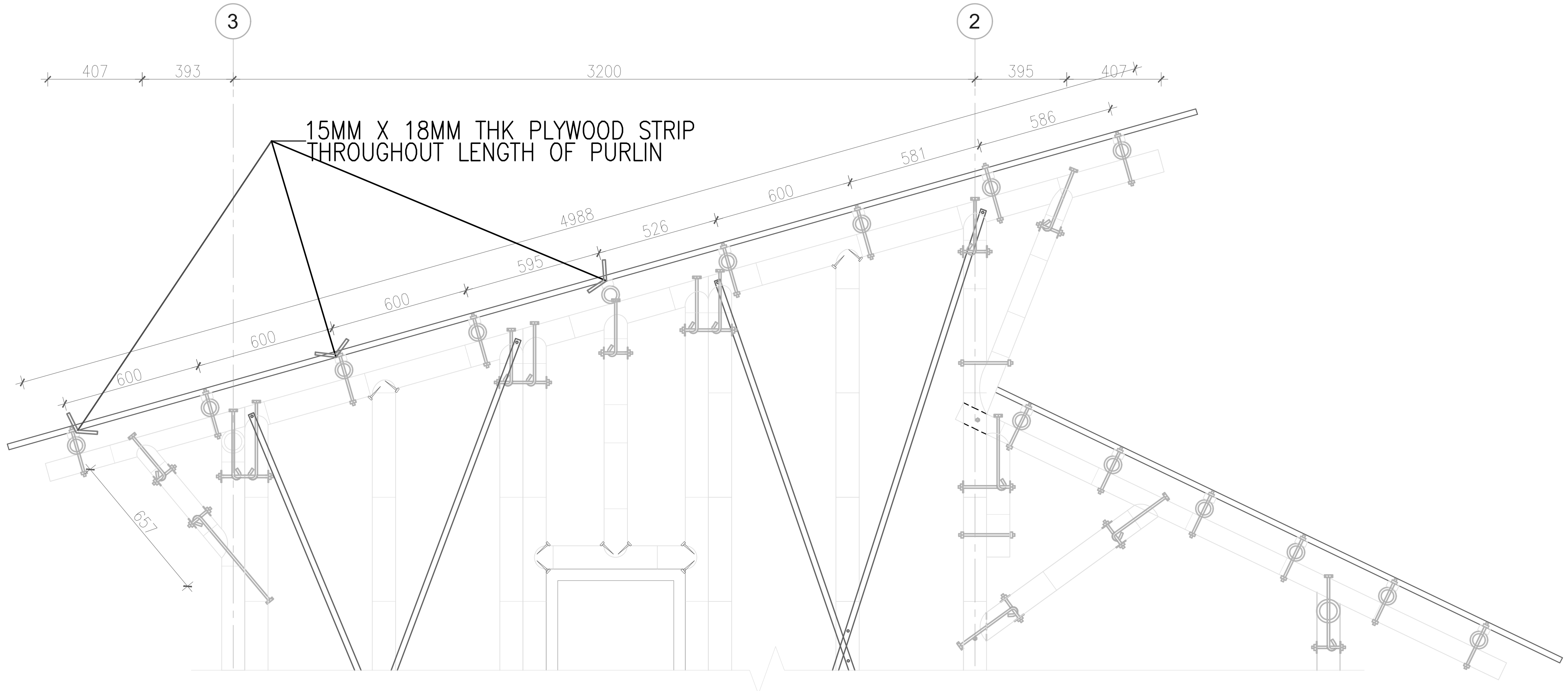
SCALE: 1:25



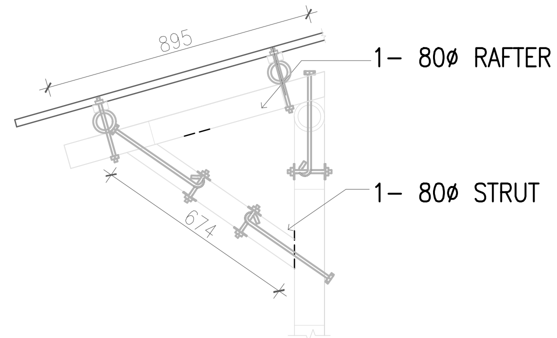
TRUSS 1
SCALE: 1:25



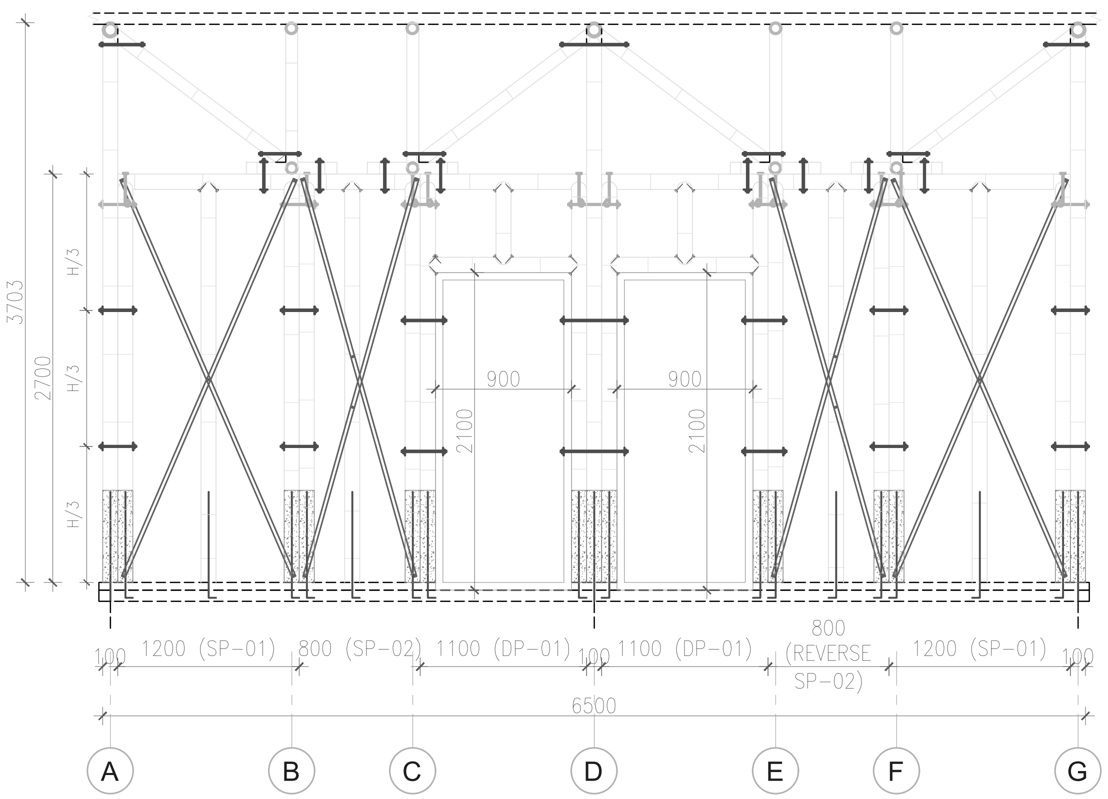
RAFTER 1 DETAIL
SCALE: 1:25



PRULIN-RAFTER CONNECTION DETAIL
SCALE: 1:25

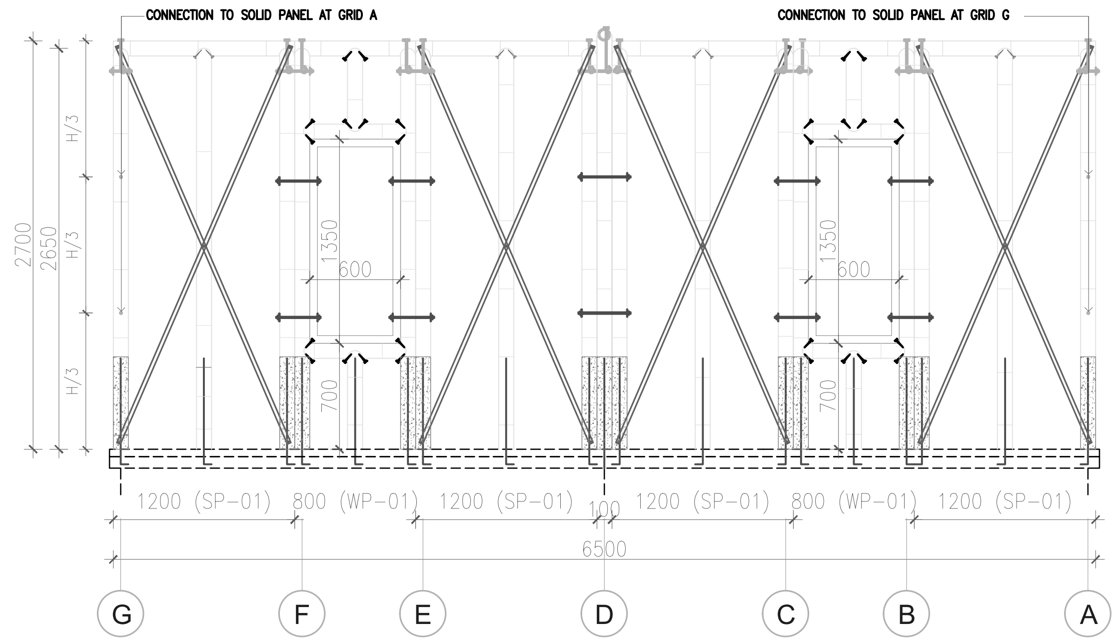


RAFTER 2 DETAIL
SCALE: 1:25



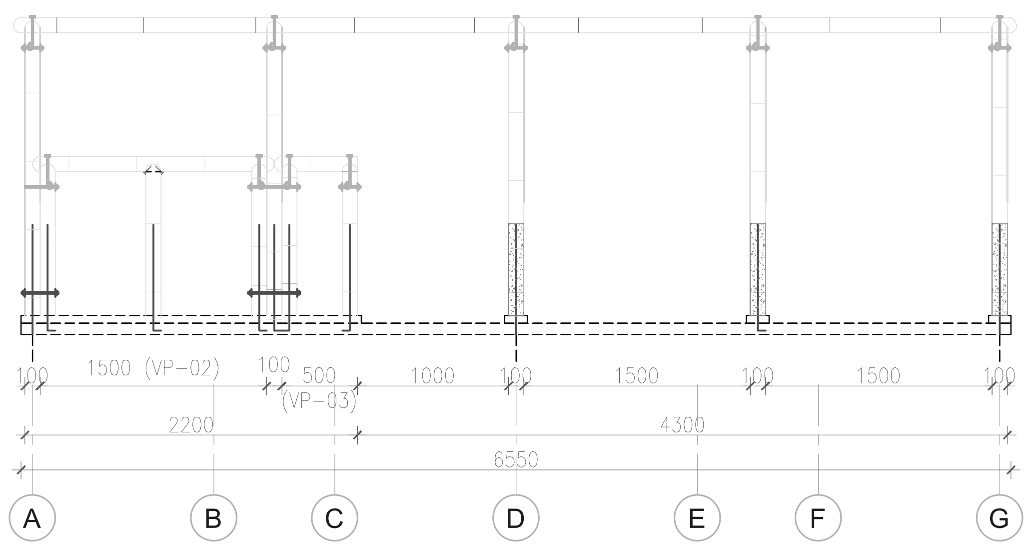
WALL PANEL SET AT GRID 2

SCALE: 1:50



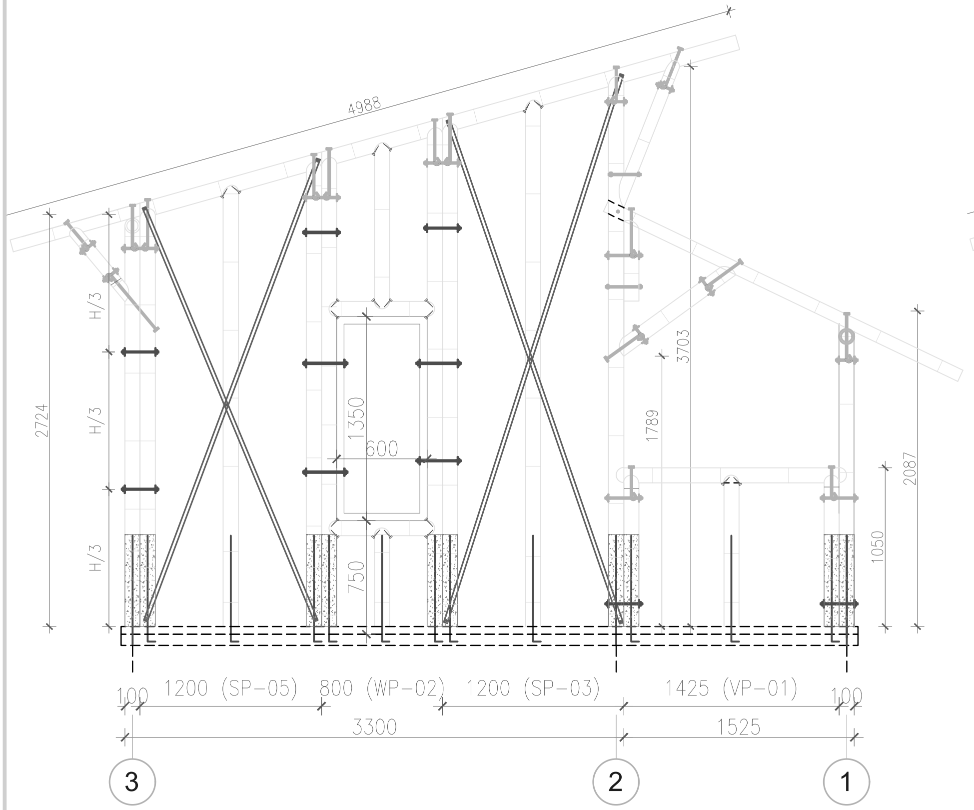
WALL PANEL SET AT GRID 3

SCALE: 1:50



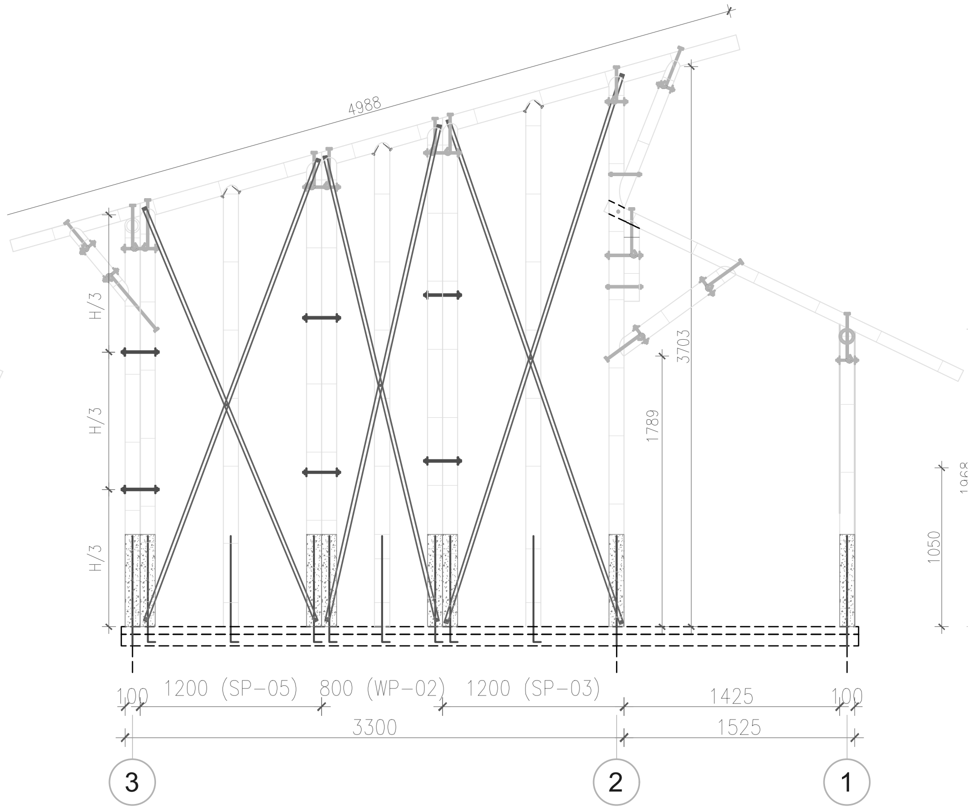
WALL PANEL SET AT GRID 1

SCALE: 1:50



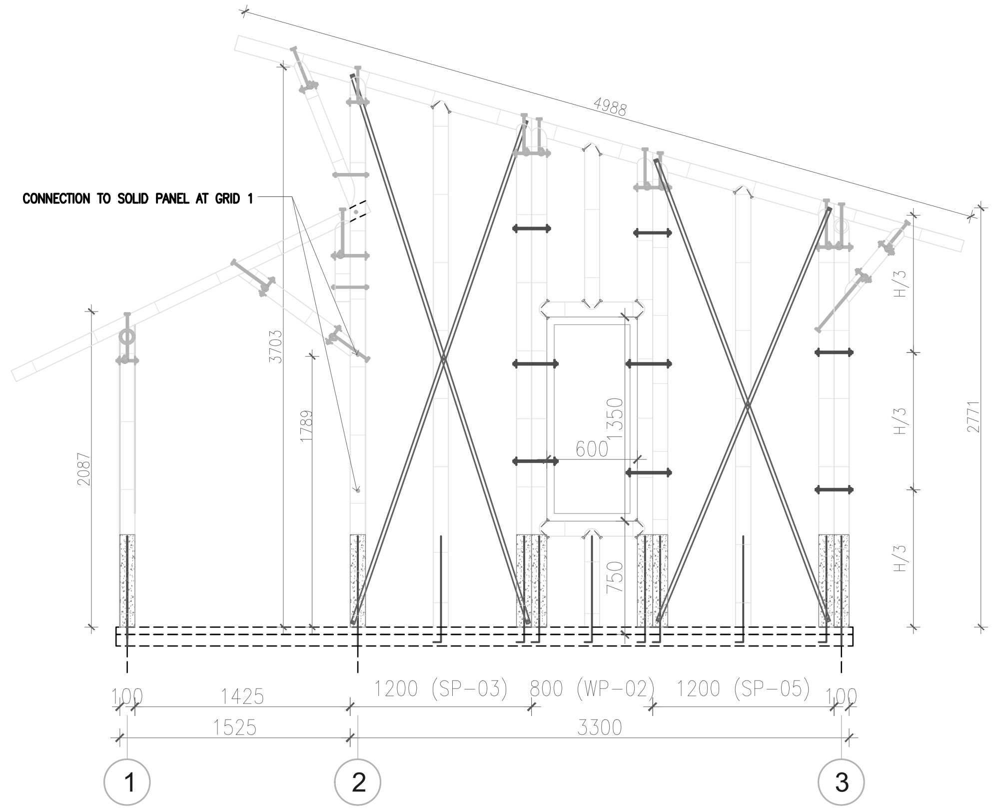
WALL PANEL SET AT GRID A

SCALE: 1:50



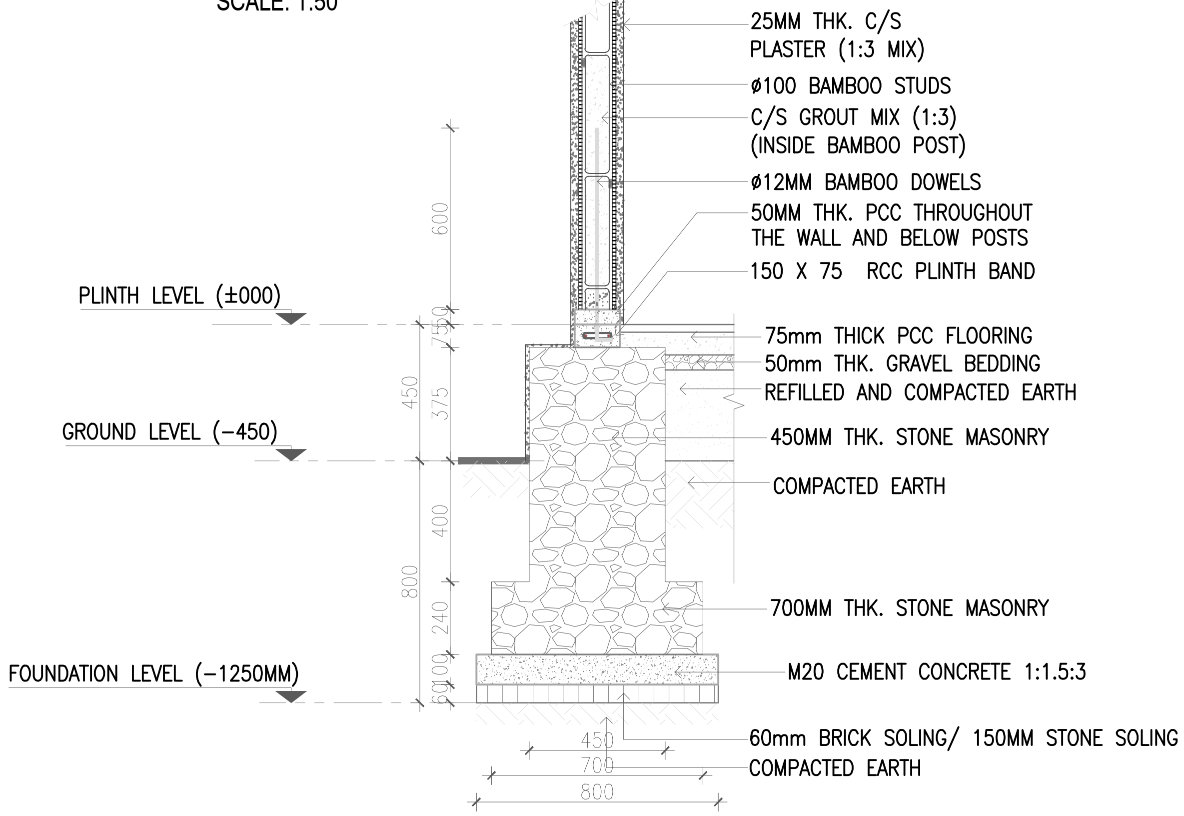
WALL PANEL SET AT GRID D

SCALE: 1:50



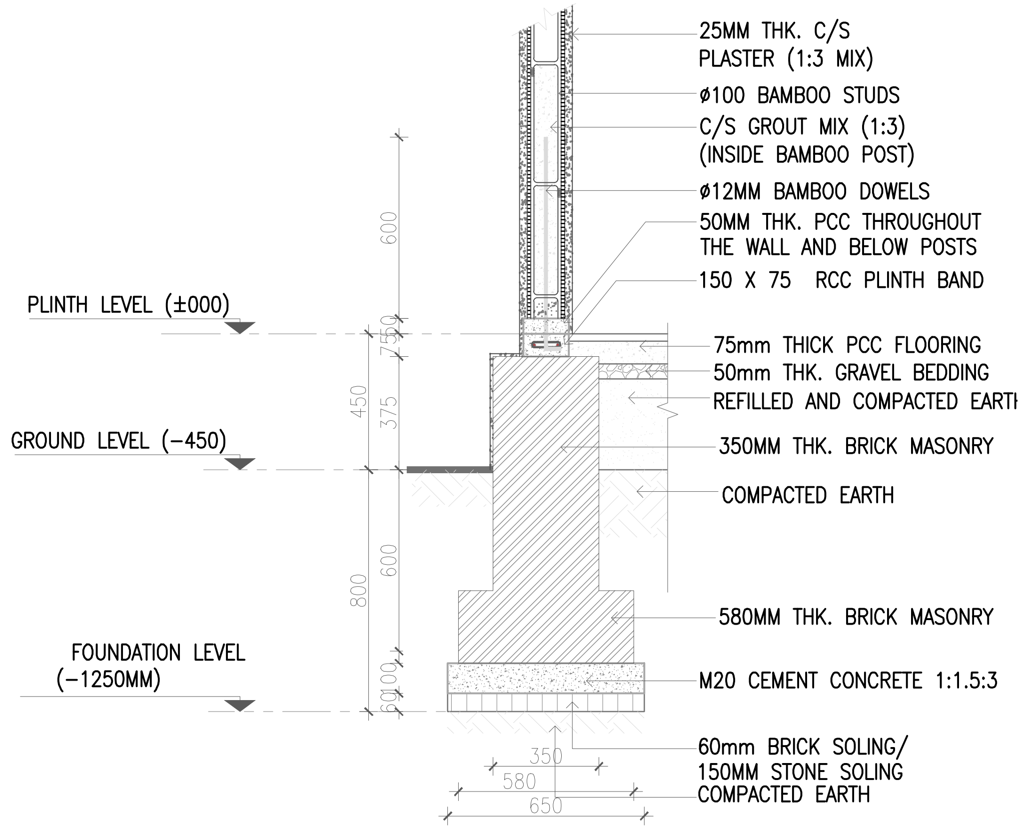
WALL PANEL SET AT GRID G

SCALE: 1:50



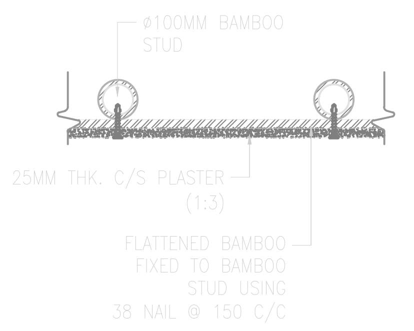
TYPICAL FOOTING SECTION - STONE MASONRY FOUNDATION

SCALE: 1:25



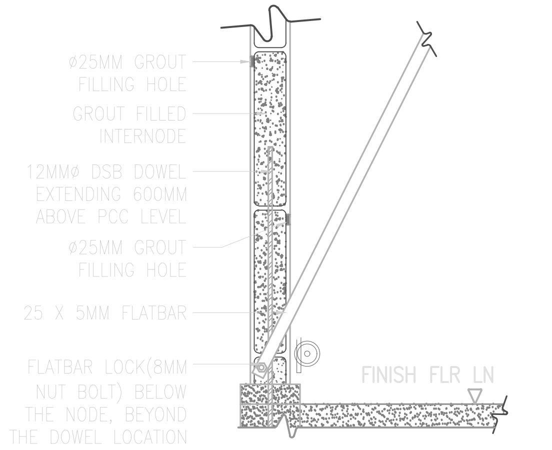
TYPICAL FOOTING SECTION - BRICK MASONRY FOUNDATION

SCALE: 1:25



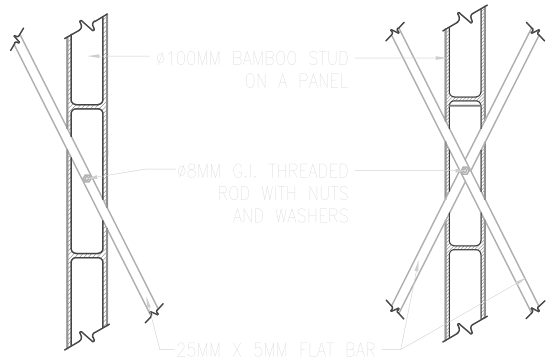
BAMBOO WALL CLADDING PLAN DETAIL

NOT IN SCALE



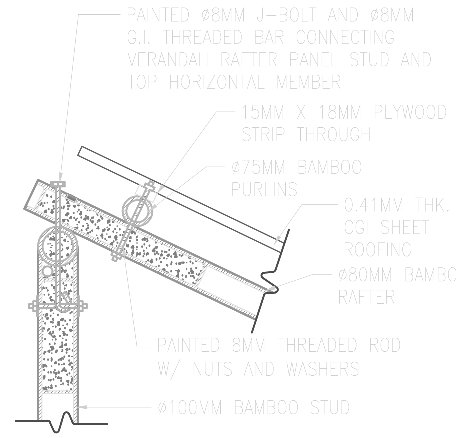
BAMBOO-FLATBAR CONNECTION DETAIL

NOT IN SCALE



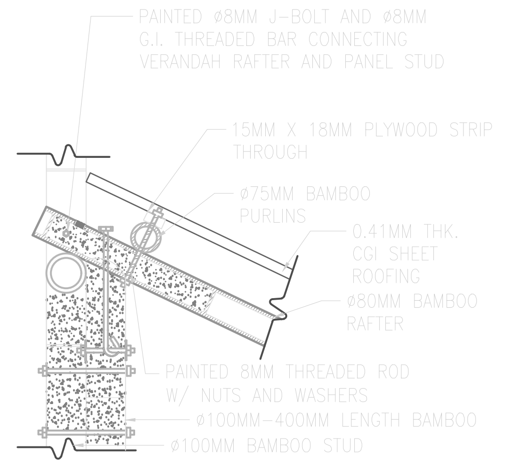
STUD-FLATBAR CONNECTION

NOT IN SCALE



STUD-VERANDAH RAFTER CONNECTION

NOT IN SCALE



STUD-VERANDAH RAFTER CONNECTION

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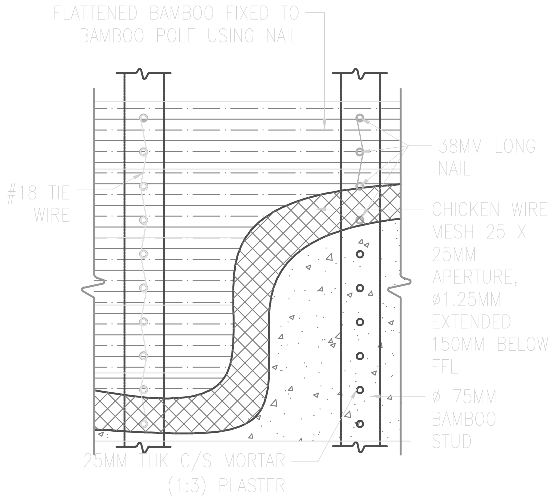
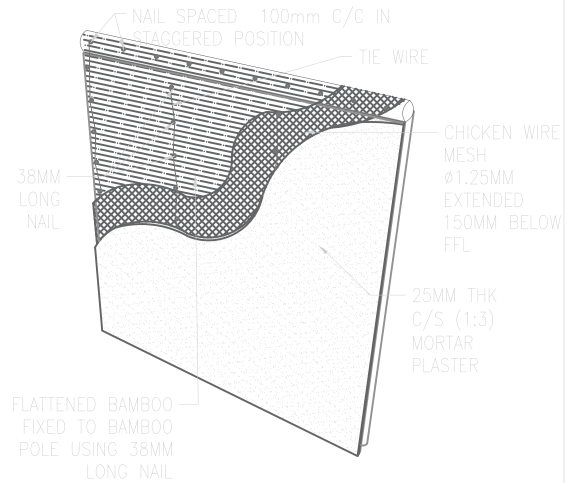


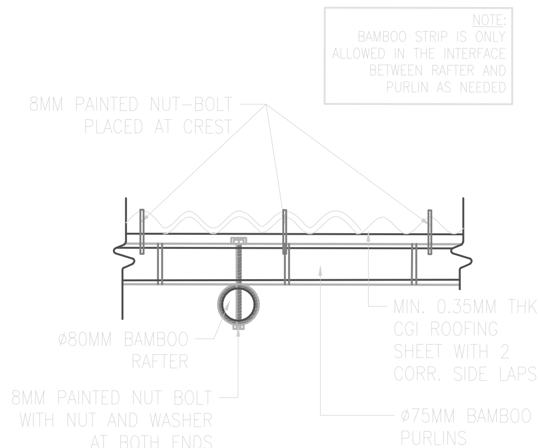
WALL CLADDING LAYER DETAIL # 1

NOT IN SCALE



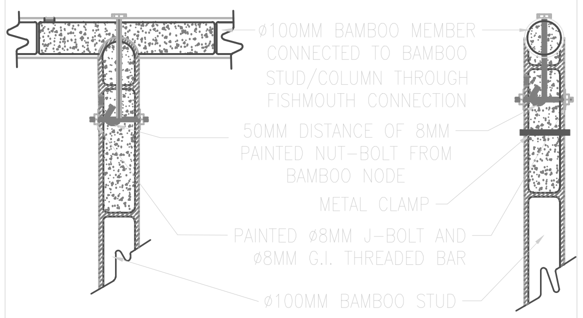
WALL CLADDING LAYER DETAIL # 2

NOT IN SCALE



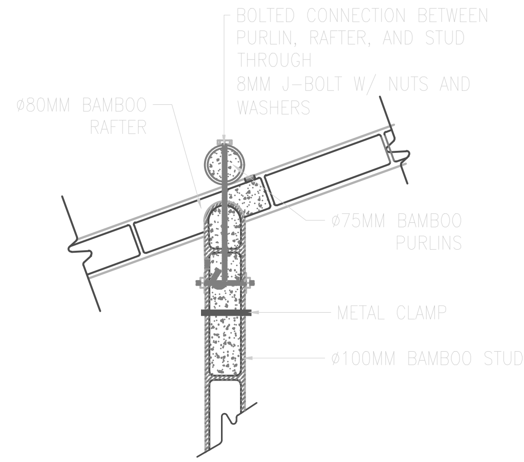
PURLIN-ROOFING CONNECTION

NOT IN SCALE



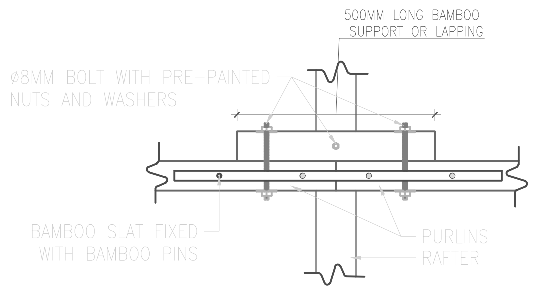
COLUMN/STUD-TOP MEMBER CONNECTION

NOT IN SCALE



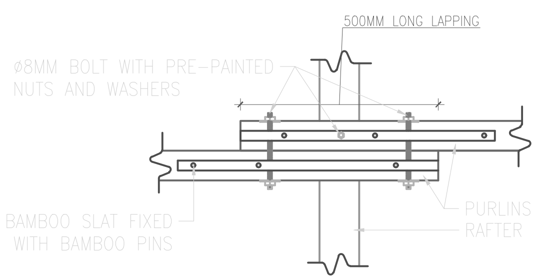
COLUMN/STUD-RAFTER-PURLIN CONNECTION

NOT IN SCALE



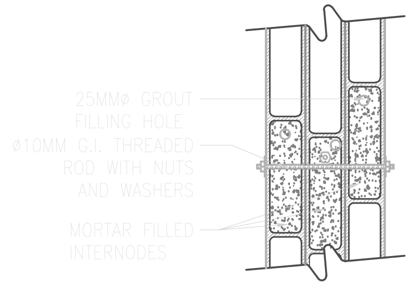
PURLIN LENGTHENING JOINT # 1

NOT IN SCALE



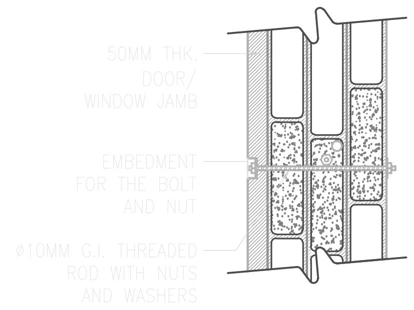
PURLIN LENGTHENING JOINT # 2

NOT IN SCALE



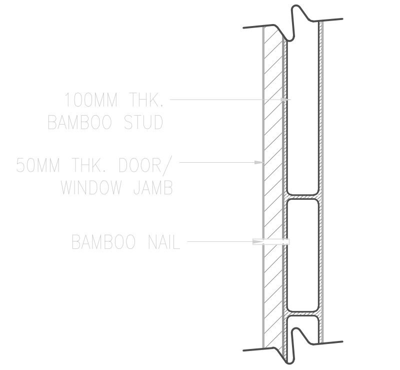
POLE CONNECTION DETAIL

NOT IN SCALE



POLE CONNECTION DETAIL

NOT IN SCALE



BAMBOO PIN-JAMB CONNECTION DETAIL

NOT IN SCALE

MANUAL FOR DESIGN OF BAMBOO STRUCTURES - 2025

Habitat for Humanity® Nepal

Government of Nepal
Ministry of Urban Development
Department of Urban Development and Building Construction