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Eurocode-Based Structural Design Methodology for a 275 kV Control Building in Battery Energy Storage Infrastructure

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Case study basis: Monk Fryston BESS, 275 kV Control Building, Civil Design Calculation

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ABSTRACT

The rapid deployment of battery energy storage systems (BESS) has created a demand for compact, resilient and serviceable control buildings capable of supporting high-voltage electrical infrastructure under stringent structural performance criteria. This paper presents a case-study-based structural design methodology for a 275 kV control building using the Eurocode framework. The study covers the development of design actions, structural idealisation of a steel portal-frame system, verification of primary and secondary steel members, stability bracing, serviceability control, and shallow pad foundation design on stiff clay. The methodology integrates permanent, imposed, snow, wind and accidental tie-force actions with member checks for strength, buckling and deflection. The foundation design is linked to geotechnical parameters, including soil density, undrained shear strength, friction angle and chemical exposure class. Results from the case study show that a rational hierarchy of structural modelling - global frame analysis for the primary system, component-level checks for beams/bracing, and geotechnical verification for foundations - provides an efficient design process for substation and BESS control buildings. The paper also highlights the importance of constructability, robustness, durability and confirmatory testing at formation level. The outcome is a practical publication-quality framework that can be adapted for similar high-voltage control buildings in energy transition projects.

Keywords: BESS control building; Eurocode; portal frame; steel design; pad foundation; wind loading; structural robustness; substation civil design.

INTRODUCTION

Control buildings used in high-voltage substations and BESS facilities are not ordinary industrial shelters. They accommodate protection, control, communication and auxiliary systems that support grid operation. Their structural design must therefore satisfy not only conventional strength and serviceability requirements, but also robustness, durability, operational access and buildability requirements. Failure or excessive deformation can affect electrical clearances, door operation, cable routes, panels, earthing interfaces and long-term maintenance access.

The case considered in this paper is a 275 kV control building associated with the Monk Fryston BESS project. The design report identifies a steel frame structure supported on concrete foundations, with the design based on architectural arrangement drawings, elevation information, external level strategy and site investigation/geotechnical reports. The governing design documents include BS EN 1990, BS EN 1991, BS EN 1992, BS EN 1993 and BS EN 1997, thereby forming a complete Eurocode route from actions and combinations to steel, concrete and geotechnical verification.

The purpose of this paper is to convert the project calculation workflow into a structured academic methodology suitable for an M.Tech structural engineering paper. The emphasis is on engineering reasoning: how loads are derived, how the structural model is idealised, how member checks are sequenced, and how foundation safety is connected to soil and durability data. Numerical values are presented as a case study, while the methodology remains applicable to other compact control buildings and modular substation structures.

CASE STUDY DESCRIPTION AND DESIGN BASIS

The structure is a steel-framed 275 kV control building with raised floor/operational floor areas, roof and wall cladding, landings, staircases, internal partitions and shallow concrete pad foundations. The design report uses a worst-case portal-frame bay width of 4.4 m, obtained from the tributary bay spacing of adjacent frames. Secondary members such as cold-rolled purlins, side rails and eaves beams are designed separately, while floor members, landing members and bracing are verified using member-specific checks.

Design item	Adopted data / criterion	Engineering significance
Structural form	Steel portal frame with secondary steel members	Efficient for short-to-medium-span control buildings and allows rapid construction.
Design life	50 years for concrete foundations	Requires durability classification and exposure-based concrete specification.
Soil model	Stiff clay; density 19 kN/m3; cu = 100 kN/m2; friction angle = 25 degrees	Supports shallow pad foundation design and checks for bearing, sliding and uplift.
Exposure class	ACEC AC-2, DC-2 concrete environment	Controls cement content, water/cement ratio and concrete durability.
Primary software workflow	CADS A3D for global portal frame; Tekla Tedds for components/foundations; Hi-Span for cold-rolled members	Provides a multi-level verification workflow rather than relying on a single black-box model.
Robustness action	75 kN accidental tie force for floor members	Improves structural integrity and load-path continuity.
Confirmatory check	Plate load testing at foundation formation level may be undertaken	Reduces geotechnical uncertainty before construction loading is committed.

The adopted approach reflects a common design philosophy for energy infrastructure: the global frame establishes load paths, while secondary members and connections are checked at a component level. This reduces over-conservatism and permits clearer traceability of engineering assumptions.

3. DESIGN ACTIONS AND LOAD DEVELOPMENT

Actions are developed in accordance with the Eurocode basis of structural design. Permanent actions include roof self-weight, raised/computer floor, PCC slab, walls and staircase/landing dead load. Variable actions include roof access or snow load, floor imposed loading, landing loading and staircase imposed loading. Wind actions are assessed for transverse and longitudinal directions, with different pressures applied to roof, walls and floor surfaces. Accidental tie forces are included for structural robustness.

Action category	Element	Value	Use in design
Permanent	Roof	0.3 kN/m2	Rafter and purlin gravity load.
Permanent	Total floor	3.4 kN/m2	Tributary load to central and edge floor beams.
Permanent	Walls	0.5 kN/m2	Direct load on portal columns and wind posts.
Variable	Roof	0.6 kN/m2	Governing of access/snow for roof design.
Variable	Floor	10.0 kN/m2	Dominant action for floor beam bending and deflection.
Variable	Landings	10.0 kN/m2	Landing beams, grating supports and landing column.
Variable	Staircases	2.5 kN/m2	Stair stringer and landing interface design.
Accidental	Floor members	75 kN tie force	Robustness and integrity requirement.

The roof direct load to the representative portal rafter is obtained by multiplying surface pressure by the effective bay width of 4.4 m, giving 1.32 kN/m permanent action, 2.64 kN/m variable action and -2.64 kN/m wind uplift. For the floor system, the 8.5 m tributary building width is split between edge and central beams. This produces central beam line loads of 14.45

kN/m permanent and 42.50 kN/m variable, and edge beam line loads of 7.23 kN/m permanent and 21.25 kN/m variable before transfer to the portal columns. This tributary-area method is simple, transparent and suitable for early-stage and detailed design validation.

4. METHODOLOGY

The design methodology follows a staged workflow. Each stage reduces uncertainty and transfers verified actions to the next stage. The process is summarised below.

Step	Process	Technical purpose
1	Establish design inputs	Collect layout, elevations, levels, geotechnical report, project design life and Eurocode references.
2	Define actions	Classify permanent, variable, wind, snow and accidental actions; convert area loads to line loads using tributary widths.
3	Global frame analysis	Model worst-case 4.4 m portal bay, apply ULS/SLS combinations and include equivalent horizontal forces for imperfections.
4	Member verification	Check primary and secondary beams for bending, shear, lateral torsional buckling and deflection under relevant load cases.
5	Stability system design	Resolve wind and equivalent horizontal forces into roof, wall and landing braces; design for tension/compression as appropriate.
6	Foundation design	Use column reactions and soil parameters to verify bearing, sliding, uplift, projection limits and durability specification.

A key feature of the methodology is separation of global stability from local component design. The portal frame is treated as the principal lateral and gravity load-resisting system, while secondary members are designed using their actual boundary conditions and loading. For example, an allowance for partial end fixity of long floor beams improves realism, because a purely simply supported assumption may create unnecessarily high mid-span bending and deflection effects. However, this assumption must be supported by robust connection detailing.

4.1 Structural Analysis Idealisation

The representative portal frame is selected from the worst effective bay width. Equivalent horizontal forces are applied to ultimate limit state combinations to represent frame imperfections. The load path is: roof and wall cladding transfer loads to purlins, side rails and eaves members; these transfer to rafters and columns; floor beams transfer vertical actions to portal columns; the portal frame transfers vertical and horizontal reactions to the foundations. This clear load path is essential for a defensible structural design paper because it links each numerical check to physical behaviour.

4.2 Bracing and Robustness

Wind bracing actions are obtained by resolving applied wind forces through brace geometry. For the roof brace, the force at eaves level is 7.8 kN and the brace angle is 37 degrees, producing a resolved brace force of 9.8 kN. The upper wall brace has a 53-degree angle and a resolved tension force of 13.0 kN, while the lower wall brace has a 26-degree angle and a resolved force of 20.0 kN. The landing brace is governed by equivalent horizontal force and is designed for 23.7 kN. These calculations demonstrate a rational conversion from global wind demand to axial design force in individual bracing members.

5. STEEL MEMBER VERIFICATION

Steel member design is performed in accordance with BS EN 1993. The selected sections are checked for cross-section class, shear resistance, bending resistance, buckling where relevant, and serviceability deflection. The calculations show that the principal members satisfy strength and deflection criteria. Several important checks are summarised below.

Member	Section	MEd / load	Resistance	Deflection / limit	Status
Central floor beam	UKB 406x178x60 S355	MEd 309.2 kNm; VEd 228 kN	MRd 425.8 kNm; VRd 709.1 kN	14.3 mm / 15.1 mm	Pass
Edge floor beam	UKB 305x165x54 S355	MEd 155.8 kNm; VEd 114.9 kN	MRd 300.4 kNm; VRd 544.3 kN	13.3 mm / 15.1 mm	Pass

Grating support	UKPFC 125x65x15 S355	MEd 8.4 kNm; VEd 13.7 kN	Mb,Rd 10.6 kNm; VRd 166.2 kN	3.47 mm / 6.8 mm	Pass
Side rail	Z17614	Design load 8.789 / -9.765 kN	Resistance 10.210 / 10.288 kN	UR 0.89	Pass
Roof purlin	Z15613	Design load 9.487 / -10.417 kN	Resistance 11.334 / 11.404 kN	UR 0.92	Pass
Eaves beam	E17020	Design load 8.834 kN	Resistance 13.765 kN	UR 0.81	Pass

The central floor beam is the most highly loaded floor element because it receives the larger tributary width. Its utilisation is controlled by both bending and deflection. Although the bending resistance is comfortably greater than the applied moment, the serviceability deflection is close to the L/360 limit. This demonstrates why serviceability often governs in raised-floor control buildings: even when steel strength is adequate, excessive deflection may affect equipment alignment, floor panels, door operation and cable interfaces.

The cold-rolled members show higher utilisation ratios, particularly under negative wind pressure and deflection. This is typical because purlins and rails are lightweight and optimised for envelope performance. Their design should therefore remain linked to final cladding, restraint and fixing arrangements. The results also show that global structural safety is not achieved by oversized primary members alone; secondary members and their restraint assumptions are equally important for envelope stability.

6. FOUNDATION AND DURABILITY DESIGN

The foundation design is based on shallow pad foundations in stiff clay. The adopted soil parameters are a density of 19 kN/m3, undrained shear strength of 100 kN/m2 and friction angle of 25 degrees. The design report also notes that nearby trees are outside the zone of influence for swelling or shrinkage, with a minimum foundation depth of 1.0 m below existing ground level. Plate load testing at formation level is recommended as a confirmatory check where required.

Foundation design aspect	Adopted result / criterion	Purpose
Concrete class	C30/37, normal weight	Provides adequate compressive strength for pad foundations.
Water/cement ratio	0.55 maximum	Controls durability for DC-2 chemical class.
Minimum cement content	320 kg/m3	Satisfies exposure and chemical attack requirements.
Sliding verification	H/RH,d = 0.048 for edge pad case	Shows horizontal resistance is much larger than applied action.
Plain concrete projection	600 mm projection vs 1079 mm permissible	Shows projection from column face is acceptable for plain concrete.

The foundation design is significant because the structure is relatively lightweight but may experience uplift and lateral load from wind. In such cases, bearing capacity alone is not sufficient; checks for sliding and uplift must be included. The design also considers durability through exposure classification and material specification. For electrical infrastructure, durability is a functional requirement because remedial work around energised assets can be costly and operationally disruptive.

7. DISCUSSION: ENGINEERING INTERPRETATION

The case study demonstrates that the design of a control building is governed by a combination of structural, geotechnical and operational criteria. The primary frame must be adequate for gravity and wind actions, but the floor system must also limit deflection to protect electrical equipment interfaces. The foundations must resist vertical reactions and lateral actions while providing durability in the ground environment. Bracing design must provide a direct and inspectable load path for longitudinal wind and equivalent horizontal forces.

A notable strength of the workflow is traceability. Each design action is developed from a clearly stated surface load, tributary width or brace geometry. Each software output is supported by engineering assumptions such as restraint condition, steel grade, effective length, load duration and serviceability limit. For academic presentation, this traceability is valuable because it shows not only that the structure passed, but why it passed.

For future research or advanced M.Tech work, the methodology could be extended by comparing alternative structural systems, such as braced frames versus portal frames, reinforced concrete raft foundations versus pad foundations, or modular control-room units versus site-assembled steel frames. A sensitivity study could also be conducted on wind pressure, floor imposed load, soil shear strength, foundation embedment and secondary member restraint. Such studies would convert the design calculation into a broader optimisation problem involving cost, embodied carbon, construction speed and reliability.

8. COMPLETE DESIGN PROCESS FOR SIMILAR BESS CONTROL BUILDINGS

A complete design process should begin with a data validation register. The civil designer should list all received drawings, geotechnical documents, electrical equipment interfaces, access requirements and assumptions. Missing data should be recorded as design risks rather than silently assumed. For example, final cladding weight, restraint to cold-rolled members, cable trench openings, door reactions and equipment plinth penetrations can change the structural demand or connection detailing.

After data validation, the designer should establish load zoning. Roof, floor, wall, landing, staircase and equipment zones should be mapped directly on the general arrangement. The advantage of this approach is that every calculation can be traced to a physical area on the building. Tributary widths should be marked for edge beams, central beams, rafters and columns. Where a software model is used, hand-derived line loads should be retained as independent checks.

The global frame analysis should then be carried out for ultimate and serviceability combinations. Ultimate combinations verify collapse resistance, while serviceability combinations verify deflection, usability and equipment compatibility. For control buildings, serviceability is especially important because sensitive electrical panels, floor systems and cable entries may be affected by movement long before steel strength is exhausted.

The design should proceed from primary members to secondary members and connections. Primary beams and columns form the main load path; purlins, side rails and eaves beams stabilise the envelope; bracing members deliver longitudinal stability; baseplates and anchors transfer force into concrete; foundations distribute the loads into the soil. This sequential verification prevents a common mistake in design submissions: proving the main frame while leaving secondary support or foundation assumptions unclear.

The final stage should be design assurance. This includes checking software input units, reviewing load combinations, confirming section grades, comparing reactions against foundation input, checking drawing consistency, and identifying construction-stage requirements such as plate load testing or hold points at foundation formation. A publication or thesis paper should include these assurance steps because they show engineering judgement beyond numerical output.

9. RESEARCH CONTRIBUTION, LIMITATIONS AND FUTURE SCOPE

The main contribution of this study is the conversion of a project calculation package into a generalised structural design framework for high-voltage BESS control buildings. The framework is practical because it keeps the project data, load derivation, global analysis, member checks and foundation verification in one logical chain. It is also academically useful because it demonstrates how Eurocode provisions are applied to a real energy-infrastructure building rather than to an idealised textbook frame.

The limitations are also important. The paper is based on calculation outputs and design assumptions available from the project report. It does not include a full independent finite element model, measured dynamic response, construction tolerances, detailed connection drawings or cost/carbon optimisation. The results should therefore be interpreted as a design methodology case study, not as a replacement for project-specific checking by a chartered/qualified structural engineer.

Future work may include parametric comparison of portal frames and braced frames, optimisation of steel tonnage, embodied-carbon assessment, probabilistic treatment of soil parameters, and sensitivity analysis of wind uplift and floor imposed loading. Such extensions would strengthen the academic value of the study and make it suitable for journal publication in structural engineering, industrial infrastructure or sustainable energy systems.

CONCLUSIONS

- The Eurocode-based workflow provides a complete and reliable framework for designing high-voltage BESS control buildings, covering actions, steel member design, foundation design and robustness.

- The representative 4.4 m portal-frame bay is an efficient modelling approach because it captures the worst tributary loading while keeping the global model manageable and transparent.
- Floor beam deflection is a critical serviceability consideration for control buildings; therefore, the design should not be assessed on strength alone.
- Bracing calculations demonstrate the importance of resolving global wind actions into member axial forces using actual brace geometry.
- Foundation verification must include bearing, sliding, uplift and durability, supported by geotechnical data and, where necessary, confirmatory plate load testing.
- The proposed methodology is suitable for academic publication as a practical case-study framework for structural design of energy infrastructure buildings.

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