

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

Project Title	Job No.
Discipline Structural	File Ref.
Review Date	Reviewer
Project Stage	Circulation

Abbreviations

ES = Every Storey	MARD = Model and Analysis Results Display	Legend	<input type="checkbox"/>
BA = Building Analysis	APP = Analysis Post-Processing	Pass	√
STAGE = Building Analysis [Staged Building Analysis]	DAS = Differential (Elastic, Creep, Shrinkage) Axial Shortening Not Applicable	Fail	X
FEFA = FE Floor Analysis	VIM = Active Windows Settings → Visual Interrogation		NA
	CBAFE = Combination of Building Analysis and the FE Based Gravity Load Chase Down		

Building SLS Load (MN) | Undecomposed | BA | CBAFE | BA+CBAFE Foundation

Checklist Inclusions and Exclusions

EQ Checks Included	Wall / Column Nodal Loads and Live Load Reduction Checks Included	Hinged Beam Checks Included
Wall / Column Clear Height, Effective Height and Base Support Checks Included	Transferred Wall / Column on Transfer Beam / Slab Checks Included	
Section Properties, Torsion and Horizontal Framing Checks Included	Method of Slab Analysis, Beam Load Application and Frame Analysis Checks Included	
Redundant Slab, Beam and Wall / Column Analysis and Design Checks Included	Rare Slab, Beam and Wall / Column Analysis and Design Checks Included	
Pad Footing Checks Included	Strip Footing Checks Included	Raft / Piled Raft Footing Checks Included
		Pile Footing Checks Included

Note that in this document, the terms steel, rebar and reinforcement refer to steel reinforcement bars associated with RC or PT construction, whilst the term tendon refers to tendons associated with PT construction.

ITEM	CONTENT	✓	
1.0	COMPANY STANDARD TEMPLATE CHECKS		
1.1	General		
1.11	Company standard template used → Housing-EQ <input type="checkbox"/> Housing-NoEQ <input type="checkbox"/> MultiStorey-EQ <input type="checkbox"/> MultiStorey-NoEQ <input type="checkbox"/>	<input type="checkbox"/>	
1.12	Date of release of company standard template.	<input type="checkbox"/>	
1.2	Variations to Company Standard Template		
1.21	VIM → Materials → check default and storey specific concrete and steel/tendon grade for slab/beam/wall/column/foundation. Run → BA → Model Options Tab → Stiffnesses Sub-Tab → check k_1 and k_j are 1.00 (i.e. uncracked) for Class 1 PT or Class 2 PT and 0.50 (i.e. cracked) for RC or Class 3 PT.	C C C C C $k_1=0.50, k_j=0.50$	<input type="checkbox"/>
1.22	Braced/unbraced wall/column.	Braced	<input type="checkbox"/>
1.23	Maximum beam/wall/column rebar diameter.	T32/T32/T40	<input type="checkbox"/>
1.24	Adoption of (unique) design links at beam supports.	Adopted	<input type="checkbox"/>
1.25	Beam section cuts (span only – once for every beam or once for every axis).	Span, once every beam	<input type="checkbox"/>
1.26	RigidZones Maximum or RigidZones None.	RigidZones None	<input type="checkbox"/>
1.27	Compatibility torsion ($k_j=1.0$ BA, 1.0 CBAFE) for transfer / edge beams for Class 1 PT or Class 2 PT. Compatibility torsion ($k_j=0.5$ BA, 1.0 CBAFE) for transfer / edge beams for RC or Class 3 PT.	$k_j=0.5$ BA, 1.0 CBAFE	<input type="checkbox"/>
1.28	Foundation load combinations G+Q load factor (1.00, 1.02, 1.05, 1.10).	1.00	<input type="checkbox"/>
1.29	Etcetera.		<input type="checkbox"/>
1.3	Variations to Material Properties		
1.31	For RC models with EQ loads stabilised by moment frames or (framed) tubes, as per capacity design concepts of BS EN1998-1 (i.e. the optimum location and sequence of attainment of member capacity with the attainment of primary seismic beam plastic moment capacity prior to the attainment of primary seismic column plastic moment capacity), for simplicity, the steel reinforcement strength of primary seismic column longitudinal bars should be reduced with respect to the steel reinforcement strength of primary seismic beam longitudinal bars by the following factors: - Capacity Design Concepts (Optimum Location and Sequence of Attainment of Member Capacity)		<input type="checkbox"/>

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

ITEM	CONTENT	√																				
	<table border="1" style="width: 100%; border-collapse: collapse; background-color: #f2f2f2;"> <thead> <tr style="background-color: #004a7c; color: white;"> <th style="width: 20%;">Ductility Class</th> <th style="width: 20%;">Element</th> <th style="width: 20%;">BS EN1998-1 Clause</th> <th style="width: 40%;">ProtaStructure Representation</th> </tr> </thead> <tbody> <tr> <td rowspan="2">Ductility Class Medium (DCM) and Ductility Class High (DCH)</td> <td>Primary Seismic Beam</td> <td rowspan="2" style="text-align: center;">cl.4.4.2.3 $\Sigma M_{Rc} \geq 1.3 \Sigma M_{Rb}$</td> <td>Maintain longitudinal bar strength grade at f_y</td> </tr> <tr> <td>Primary Seismic Column</td> <td>Reduce longitudinal bar strength grade to $f_y / 1.3$</td> </tr> </tbody> </table>	Ductility Class	Element	BS EN1998-1 Clause	ProtaStructure Representation	Ductility Class Medium (DCM) and Ductility Class High (DCH)	Primary Seismic Beam	cl.4.4.2.3 $\Sigma M_{Rc} \geq 1.3 \Sigma M_{Rb}$	Maintain longitudinal bar strength grade at f_y	Primary Seismic Column	Reduce longitudinal bar strength grade to $f_y / 1.3$	√										
Ductility Class	Element	BS EN1998-1 Clause	ProtaStructure Representation																			
Ductility Class Medium (DCM) and Ductility Class High (DCH)	Primary Seismic Beam	cl.4.4.2.3 $\Sigma M_{Rc} \geq 1.3 \Sigma M_{Rb}$	Maintain longitudinal bar strength grade at f_y																			
	Primary Seismic Column		Reduce longitudinal bar strength grade to $f_y / 1.3$																			
1.32	<p>For RC models with EQ loads stabilised by moment frames or (framed) tubes, as per capacity design concepts of BS EN1998-1 (i.e. the favourable mechanism of deformation with the primary seismic beam and primary seismic column elemental attainment of ductile plastic moment capacity prior to elemental attainment of brittle shear capacity), for simplicity, the steel reinforcement strength of primary seismic beam and primary seismic column shear links should be reduced with respect to the steel reinforcement strength of primary seismic beam and primary seismic column longitudinal bars by the following factors: -</p> <table border="1" style="width: 100%; border-collapse: collapse; background-color: #f2f2f2;"> <thead> <tr style="background-color: #004a7c; color: white;"> <th colspan="4" style="text-align: center;">Capacity Design Concepts (Favourable Mechanism of Deformation)</th> </tr> <tr style="background-color: #004a7c; color: white;"> <th style="width: 20%;">Ductility Class</th> <th style="width: 20%;">Element</th> <th style="width: 20%;">BS EN1998-1 Clause</th> <th style="width: 40%;">ProtaStructure Representation</th> </tr> </thead> <tbody> <tr> <td rowspan="2">Ductility Class Medium (DCM)</td> <td>Primary Seismic Beam</td> <td>cl.5.4.2.2 $\gamma_{Rd} = 1.0$</td> <td rowspan="2" style="text-align: center;">Reduce shear link strength grade to $f_{yv} / 1.1$</td> </tr> <tr> <td>Primary Seismic Column</td> <td>cl.5.4.2.3 $\gamma_{Rd} = 1.1$</td> </tr> <tr> <td rowspan="2">Ductility Class High (DCH)</td> <td>Primary Seismic Beam</td> <td>cl.5.5.2.1 $\gamma_{Rd} = 1.2$</td> <td rowspan="2" style="text-align: center;">Reduce shear link strength grade to $f_{yv} / 1.3$</td> </tr> <tr> <td>Primary Seismic Column</td> <td>cl.5.5.2.2 $\gamma_{Rd} = 1.3$</td> </tr> </tbody> </table>	Capacity Design Concepts (Favourable Mechanism of Deformation)				Ductility Class	Element	BS EN1998-1 Clause	ProtaStructure Representation	Ductility Class Medium (DCM)	Primary Seismic Beam	cl.5.4.2.2 $\gamma_{Rd} = 1.0$	Reduce shear link strength grade to $f_{yv} / 1.1$	Primary Seismic Column	cl.5.4.2.3 $\gamma_{Rd} = 1.1$	Ductility Class High (DCH)	Primary Seismic Beam	cl.5.5.2.1 $\gamma_{Rd} = 1.2$	Reduce shear link strength grade to $f_{yv} / 1.3$	Primary Seismic Column	cl.5.5.2.2 $\gamma_{Rd} = 1.3$	□
Capacity Design Concepts (Favourable Mechanism of Deformation)																						
Ductility Class	Element	BS EN1998-1 Clause	ProtaStructure Representation																			
Ductility Class Medium (DCM)	Primary Seismic Beam	cl.5.4.2.2 $\gamma_{Rd} = 1.0$	Reduce shear link strength grade to $f_{yv} / 1.1$																			
	Primary Seismic Column	cl.5.4.2.3 $\gamma_{Rd} = 1.1$																				
Ductility Class High (DCH)	Primary Seismic Beam	cl.5.5.2.1 $\gamma_{Rd} = 1.2$	Reduce shear link strength grade to $f_{yv} / 1.3$																			
	Primary Seismic Column	cl.5.5.2.2 $\gamma_{Rd} = 1.3$																				
2.0	ARCHITECTURAL DESIGN INTENT CHECKS																					
2.1	General																					
2.11	File → Model/File Import → External Reference Drawing → check consistency of wall/column positions (ES).	□																				
2.12	File → Model/File Import → External Reference Drawing → check consistency of slab/beam drops (ES).	□																				
2.13	File → Model/File Import → External Reference Drawing → check consistency of slab edges and openings (ES).	□																				
2.14	Storeys → Edit Storey → check storey heights, h (mm) including stump depth ($h_{st01} >$ deepest beam to ensure correct wall/column base shears) and Foundation Depth, i.e. thickness of foundation (pad, strip, raft or pile cap).	□																				
2.15	Storeys → Edit Storey → check total building height, H _T (mm).	□																				
3.0	FRAMING AND LOADING CHECKS																					
3.1	Framing Intent																					
3.11	<p>Check floor framing intent (i.e. simple support, continuous, cantilever) is visually comprehensible. Check staircase framing intent (i.e. longitudinal, transverse, stiffener) is visually comprehensible. Check joint scheme (contraction, expansion, settlement and sway joints) is visually comprehensible. Check frame sizes → VIM → Slab Thickness / Beam Sections / Wall Thickness / Column Sections → check slab thickness / beam sections / wall thickness / column sections → compare: -</p> <p>(i) slab sizes w.r.t. span to depth ratios (30 RC, 40 PT), ULS bending stress $M_{ULS}/bh^2 \approx 1N/mm^2 \ll 5N/mm^2$, ProtaStructure analytical slab strips and FEFA deflections, with M_{ULS} checked based on 1.4 x tributary width x (15.0-25.0kPa) x L²/12,</p> <p>(ii) beam sizes w.r.t. span to depth ratios (20 RC, 30 PT), ULS shear stress $V_{ULS}/bh \approx 3N/mm^2 \ll 5N/mm^2$ and ULS bending stress $M_{ULS}/bh^2 \approx 3N/mm^2 \ll 5N/mm^2$ and FEFA deflections, with M_{ULS} and V_{ULS} checked based on 1.4 x tributary width x (15.0-25.0kPa) x L²/12 and 1.4 x tributary width x (15.0-25.0kPa) x L/2, respectively with $A_{s,prov} \approx 3000$. M_{ULS} (kNm) / d (mm),</p> <p>(iii) shear wall #A sizes w.r.t. scheme design ratios (for 0.4% steel, $A_c \approx F_{ULS} / [15@C35; 17@C40; 19@C45; 21@C50; 23@C55; 25@C60]$ #B effectively equalising axial stress at every level to cater for DAS #C) and shear wall detailing capacity tables, with F_{ULS} checked based on 1.4 x tributary area x no. of storeys x (15.0-25.0kPa) #D,</p> <p>(iv) transfer beam sizes w.r.t. ULS shear stress $V_{ULS}/bh \approx 3N/mm^2 \ll 5N/mm^2$ and ULS bending stress $M_{ULS}/bh^2 \approx 3N/mm^2 \ll 5N/mm^2$, ULS punching shear transfer column face stress $V_{eff}/ud \approx 4N/mm^2 \ll 5N/mm^2$ (applicable when transfer beam width > column width), deep beam design #E1 and CBAFE deflections, with $M_{ULS} = F_{ULS}.L/4$ and $V_{ULS} = F_{ULS}/2$ #F1 computed from F_{ULS} checked based on 1.4 x tributary area x no. of storeys x (15.0-25.0kPa) #D,</p> <p>(v) transfer slab sizes w.r.t. ULS shear stress $V_{ULS}/bh @ 1.0d \approx 1.0N/mm^2 [RC]$ to $1.5N/mm^2 [PT]$ $\ll 5N/mm^2$ and ULS bending stress $M_{ULS}/bh^2 \approx 1.5N/mm^2 [RC]$ to $2.5N/mm^2 [PT]$ $\ll 5N/mm^2$, ULS punching shear transfer column (or transfer column head where applicable) and transferred walls/columns</p>	□																				

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

ITEM	CONTENT	✓
	<p>face stress $V_{eff}/ud \approx 4N/mm^2 \ll 5N/mm^2$, ULS punching shear transfer column (or transfer column head where applicable) and transferred walls/columns first perimeter stress $V_{eff}/ud @ 1.5d \approx 0.6N/mm^2$ [RC] to $1.0N/mm^2$ [PT], deep beam design #E2 and CBAFE deflections, with $M_{ULS} = F_{ULS} \cdot L/4$ and $V_{ULS} = F_{ULS}/2$ #F2 computed from F_{ULS} checked based on 1.4 x tributary area x no. of storeys x (15.0-25.0kPa) #D,</p> <p>(vi) column #A sizes w.r.t. scheme design ratios (for 2.0% steel, $A_c \approx F_{ULS} / [20@C35; 22@C40; 24@C45; 26@C50; 28@C55; 30@C60]$ #B effectively equalising axial stress at every level to cater for DAS #C), with F_{ULS} checked based on 1.4 x tributary area x no. of storeys x (15.0-25.0kPa) #D,</p> <p>(vii) lateral stability frame size and extent w.r.t. scheme design ratios (height / 10) whilst confirming the braced/unbraced wall/column conditions based on the lateral stability system, the Moment Ratio Check and/or the Sway Susceptibility Check (NHF / wind: non-sway with $Q/1.4 \leq 0.05$ and sway with $Q/1.4 \leq 0.25$ with default stiffness parameters; EQ: non-sway with $q \cdot Q/0.7 \leq 0.05$ and sway with $q \cdot Q/0.7 \leq 0.25$ with default stiffness parameters),</p> <p>(viii) lateral stability frame size and extent w.r.t. lateral stability base shear magnitude distribution #G and lateral stability base moment magnitude distribution #H, and</p> <p>(ix) lateral stability frame size and extent w.r.t. lateral deflections to NHF / wind #I ($\delta_{total}/2 \leq H_{total}/500$ and $\Delta\delta_{storey,I}/2 \leq h_{storey,I}/500$ with default stiffness parameters) and EQ #I ($q \cdot \delta_{total} \leq H_{total}/250$ and $q \cdot \Delta\delta_{storey,I} \leq h_{storey,I}/250$ (with fundamental period $T_1/\sqrt{2}$) with default stiffness parameters), (ES).</p> <p>#A: Note check wall/column for $Len \geq 1$, correctness of duplicate storeys and perform Building Model Check.</p> <p>#B: Note check Column Capacity Analyses Table for ULS axial stress F_{ULS}/A_c (BA / CBAFE) and % steel $\ll 2\%$ (shear wall vertical steel % limit for avoidance of through-thickness links)/5% (column vertical steel % limit).</p> <p>#C: Note check MARD (BA/STAGE) for DAS and MARD (BA/STAGE) for lateral deflection (sway) of the building due to DL+SDL+LL+PT. The SLS load combination inherently includes the effects of differential (elastic, creep, shrinkage) axial shortening. Staged construction analysis may be performed to reduce the magnitude of the effects of differential (elastic, creep, shrinkage) axial shortening.</p> <p>#D: Note check MARD animated deflections for spurious members whilst ensuring gradual wall/column axial load increment and check Column Forces Listing for minimal discrepancy between BA and CBAFE wall/column axial load take down by ensuring minimal differential beam support (i.e. wall/column point) settlement (due to DAS and differential transfer floor deflection) in MARD and FEFA !. The ULS load combinations inherently include the effects of differential (elastic, creep, shrinkage) axial shortening. Staged construction analysis may be performed to reduce the magnitude of the effects of differential (elastic, creep, shrinkage) axial shortening.</p> <p>#E1: Note check (a) transfer beam / transferred wall strut and tie truss analogy design for the transferred wall (acting as the diagonal compression element with the provision of horizontal steel equivalent to $1/4$ of the required vertical steel) and transfer beam (acting as the tension element with the provision of rebar of $0.95f_y \cdot A_{s,prov}$ to resist $F_{ULS}/4$ over the transfer beam depth of span/3), (b) transfer beam deep beam design with $A_{s,prov} \approx 3800 \cdot M_{ULS} \text{ (kNm)} / h \text{ (mm)}$, (c) transfer beam longitudinal shear within web and between web and flanges and (d) transfer beam torsion design.</p> <p>#E2: Note check (a) transfer slab / transferred wall strut and tie truss analogy design for the transferred wall (acting as the diagonal compression element with the provision of horizontal steel equivalent to $1/4$ of the required vertical steel) and transfer slab (acting as the tension element with the provision of rebar of $0.95f_y \cdot A_{s,prov}$ to resist $F_{ULS}/4$ over the transfer slab depth of span/3), (b) transfer slab deep beam design with $A_{s,prov} \approx 3800 \cdot M_{ULS} \text{ (kNm)} / h \text{ (mm)}$ and (c) transfer slab longitudinal shear within web.</p> <p>#F1: Note check MARD and FEFA for minimal discrepancy between BA and CBAFE transfer beam bending moments by ensuring minimal differential transfer beam support (i.e. wall/column point) settlement (due to DAS) !. The ULS load combinations inherently include the effects of differential (elastic, creep, shrinkage) axial shortening. Staged construction analysis may be performed to reduce the magnitude of the effects of differential (elastic, creep, shrinkage) axial shortening.</p> <p>#F2: Note check MARD and FEFA for minimal discrepancy between BA and CBAFE transfer slab bending moments by ensuring minimal differential transfer slab support (i.e. wall/column point) settlement (due to DAS) !. The ULS load combinations inherently include the effects of differential (elastic, creep, shrinkage) axial shortening. Staged construction analysis may be performed to reduce the magnitude of the effects of differential (elastic, creep, shrinkage) axial shortening.</p> <p>#G: Note check Column Capacity Analyses Table for ULS shear stress $\tau = V_{ULS}/A_c \approx 3N/mm^2$ (based on nominal link provision for vertical elements loaded to $40\%f_{cu}$ at ULS i.e. the capacity for a 0.4% steel reinforced vertical element) $\ll 5N/mm^2$ for all stability base shear resisting elements i.e. shear walls above transfer and shear walls / mega columns below transfer.</p> <p>#H: Note ensure no foundation uplift.</p> <p>#I: Note check on-plan torsional twist due to NHF, wind and EQ loads.</p>	

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

ITEM	CONTENT	√
3.2	Slab Loads	
3.21	VIM → Slab Live Loads → check slab LL (ES).	<input type="checkbox"/>
3.22	VIM → Slab Additional Dead Loads → check slab SDL (ES).	<input type="checkbox"/>
3.23	3D Visualisation → check slab point, line and partial patch loading visually (ES).	<input type="checkbox"/>
3.3	Beam Loads	
3.31	VIM → Beam Wall Loads → check internal cladding load (ES).	<input type="checkbox"/>
3.32	VIM → Beam Wall Loads → check external cladding load (ES).	<input type="checkbox"/>
3.33	VIM → Beams with User Defined Loads → check beams with user defined loads (ES).	<input type="checkbox"/>
3.4	Wall/Column Loads	
3.41	Active Windows Settings → Columns Plan Display Tab → Display Analysis Results Subsection → select Nodal Loads to check sign (negative downwards) and magnitude of wall/column nodal loads (ES). Alternatively, VIM → Column Nodal Loads → check sign (negative downwards) and magnitude of wall/column nodal loads (ES).	<input type="checkbox"/>
3.5	Lateral Loads	
3.51	Run → BA → Pre-Analysis Tab → Project Parameters and Loading Subsection → Storey Loads and Parameters → check wind loads (ES).	<input type="checkbox"/>
3.52	Run → BA → Pre-Analysis Tab → Project Parameters and Loading Subsection → Seismic Parameters → check EQ spectra. Run → BA → Pre-Analysis Tab → Project Parameters and Loading Subsection → Storey Loads and Parameters → check EQ loads (ES).	<input type="checkbox"/>
3.6	Imposed Load Reduction	
3.61	Storeys → Edit Storey → check Imposed Load Reduction. Note that live load reduction option must also be checked on the Loading Combinations table for applicability.	<input type="checkbox"/>
3.7	Load Combination Cases	
3.71	Note for EQ ULS load combination cases, if required by cl.4.3.3.5.2 BS EN1998-1 i.e. if a_{vg} is greater than 0.25g, then the vertical component of the seismic action will need to be incorporated as follows: - $1.0DL+1.0SDL+\psi_{2i}LL+HYP\pm 1.0EQ_x\pm 0.3EQ_y\pm 0.3EQ_z$ $1.0DL+1.0SDL+\psi_{2i}LL+HYP\pm 0.3EQ_x\pm 1.0EQ_y\pm 0.3EQ_z$ by enhancing G to $G+0.3EQ_z$ where EQ_z is the total EQ base shear in Z and G is DL+SDL, and for $1.0DL+1.0SDL+\psi_{2i}LL+HYP\pm 0.3EQ_x\pm 0.3EQ_y\pm 1.0EQ_z$ by enhancing G to $G+1.0EQ_z$ where EQ_z is the total EQ base shear in Z and G is DL+SDL. Note for EQ SLS load combination cases, if required by cl.4.3.3.5.2 BS EN1998-1 i.e. if a_{vg} is greater than 0.25g, then the vertical component of the seismic action will need to be incorporated as follows: - $1.0DL+1.0SDL+\psi_{2i}LL+PT\pm 1.0EQ_x\pm 0.3EQ_y\pm 0.3EQ_z$ $1.0DL+1.0SDL+\psi_{2i}LL+PT\pm 0.3EQ_x\pm 1.0EQ_y\pm 0.3EQ_z$ by enhancing G to $G+0.3EQ_z$ where EQ_z is the total EQ base shear in Z and G is DL+SDL, and for $1.0DL+1.0SDL+\psi_{2i}LL+PT\pm 0.3EQ_x\pm 0.3EQ_y\pm 1.0EQ_z$ by enhancing G to $G+1.0EQ_z$ where EQ_z is the total EQ base shear in Z and G is DL+SDL. Note effectively both the DL+SDL and LL components within the dynamic weight W is lumped into the enhanced load factor for G.	<input type="checkbox"/>
3.72	Note for EQ ULS load combination cases, as required by cl.6.4.3.4 BS EN1990, the combination coefficient for variable action, ψ_{2i} will need to be recalculated as per T.A1.1 BS EN1990. $1.0DL+1.0SDL+\psi_{2i}LL+HYP\pm 1.0EQ_x$ $1.0DL+1.0SDL+\psi_{2i}LL+HYP\pm 1.0EQ_y$ $1.0DL+1.0SDL+\psi_{2i}LL+HYP\pm 1.0EQ_x\pm 0.3EQ_y\pm 0.3EQ_z$ $1.0DL+1.0SDL+\psi_{2i}LL+HYP\pm 0.3EQ_x\pm 1.0EQ_y\pm 0.3EQ_z$ $1.0DL+1.0SDL+\psi_{2i}LL+HYP\pm 0.3EQ_x\pm 0.3EQ_y\pm 1.0EQ_z$ Note for EQ SLS load combination cases, as required by cl.6.4.3.4 BS EN1990, the combination coefficient for variable action, ψ_{2i} will need to be recalculated as per T.A1.1 BS EN1990. $1.0DL+1.0SDL+\psi_{2i}LL+PT\pm 1.0EQ_x$ $1.0DL+1.0SDL+\psi_{2i}LL+PT\pm 1.0EQ_y$ $1.0DL+1.0SDL+\psi_{2i}LL+PT\pm 1.0EQ_x\pm 0.3EQ_y\pm 0.3EQ_z$ $1.0DL+1.0SDL+\psi_{2i}LL+PT\pm 0.3EQ_x\pm 1.0EQ_y\pm 0.3EQ_z$ $1.0DL+1.0SDL+\psi_{2i}LL+PT\pm 0.3EQ_x\pm 0.3EQ_y\pm 1.0EQ_z$	<input type="checkbox"/>
4.0	BOUNDARY CONDITION CHECKS	
4.1	Beam/Column Releases	
4.11	Member → Member Tables → Beam/Column Table → check Hinge = None (ES).	<input type="checkbox"/>
4.12	Check beams on corbels are defined with hinged ends (ES).	<input type="checkbox"/>
4.13	Check stepped secondary beams across primary beams are defined with hinged ends for steps of a dimension greater than the width of the primary beam (ES).	<input type="checkbox"/>

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

ITEM	CONTENT	✓																		
4.14	Check beams of depths significantly larger than the thickness of the supporting wall (orientated perpendicular to the longitudinal beam direction) e.g. basement retaining wall or lift core wall and beams of widths significantly larger than the thickness of the supporting wall (orientated parallel to the longitudinal beam direction) are defined with hinged ends with a nominal 50% of span steel defined at the hinged supports (ES).	<input type="checkbox"/>																		
4.2	Wall/Column Clear Height																			
4.21	<table border="1" style="width: 100%; border-collapse: collapse; margin-bottom: 10px;"> <thead> <tr style="background-color: #004a7c; color: white;"> <th colspan="3" style="text-align: center;">Wall/Column Clear Height Calculation</th> </tr> <tr style="background-color: #004a7c; color: white;"> <th style="width: 33%;">Item</th> <th style="width: 33%;">Wall Clear Height</th> <th style="width: 33%;">Column Clear Height</th> </tr> </thead> <tbody> <tr> <td style="text-align: center;">Beam Depths h-bot</td> <td style="text-align: center;">Not Included</td> <td style="text-align: center;">Included #^A</td> </tr> <tr> <td style="text-align: center;">Beam Drops or Elevation h-top (Method 1 – Insignificant Drops)</td> <td style="text-align: center;">Not Included</td> <td style="text-align: center;">Included #^B</td> </tr> <tr> <td style="text-align: center;">Beam Drops or Elevation del z (Method 2 – Significant Drops)</td> <td style="text-align: center;">Included only if a corresponding del z definition is specified for the wall in the particular storey and the storey above</td> <td style="text-align: center;">Included only if a corresponding del z definition is specified for the column in the particular storey and the storey above</td> </tr> <tr> <td style="text-align: center;">Multiple Storey Wall/Column Spans</td> <td style="text-align: center;">Included only if the number of storeys that the wall spans is specified in Len (Storey) #^C</td> <td style="text-align: center;">Included only if the number of storeys that the column spans is specified in Len (Storey) #^C</td> </tr> </tbody> </table> <p>#A: Note that +ve h-bot (i.e. downwards) is recognized in the clear height calculation for columns in the particular storey, however -ve h-bot (i.e. upwards) is not recognized in the clear height calculation for columns in the particular storey. #B: Note that +ve h-top (i.e. upwards) is recognized in the clear height calculation for columns in the storey above, however -ve h-top (i.e. downwards) is not recognized in the clear height calculation for columns in the storey above. #C: Member → Member Tables → Wall/Column Table → check Len (Storey) = 1, 2, 3 etc., noting that only walls/columns that are strutted/tied in both directions may be considered Len (Storey) = 1 (ES). Struts/ties should be capable of resisting 2.5% of the design ultimate vertical load that the wall/column is designed to carry at the point of lateral support as stipulated by cl.3.9.2.3 BS8110-1. Note that the struts/ties should be at least 1/10th of the stiffness of the columns, i.e. $\Sigma I_{beam}/L_{beam} \geq 0.10[\Sigma I_{column}/L_{column}]$ to be effective as suggested by cl.2.5.4 BS8110-2 and is to be fully restrained by a horizontal diaphragm (floor slab, note that flat slab also constitutes a horizontal diaphragm), failing which the summation of beam stiffnesses of at least 1/10th of the summation of column stiffnesses is mandatory.</p>	Wall/Column Clear Height Calculation			Item	Wall Clear Height	Column Clear Height	Beam Depths h-bot	Not Included	Included # ^A	Beam Drops or Elevation h-top (Method 1 – Insignificant Drops)	Not Included	Included # ^B	Beam Drops or Elevation del z (Method 2 – Significant Drops)	Included only if a corresponding del z definition is specified for the wall in the particular storey and the storey above	Included only if a corresponding del z definition is specified for the column in the particular storey and the storey above	Multiple Storey Wall/Column Spans	Included only if the number of storeys that the wall spans is specified in Len (Storey) # ^C	Included only if the number of storeys that the column spans is specified in Len (Storey) # ^C	<input type="checkbox"/>
Wall/Column Clear Height Calculation																				
Item	Wall Clear Height	Column Clear Height																		
Beam Depths h-bot	Not Included	Included # ^A																		
Beam Drops or Elevation h-top (Method 1 – Insignificant Drops)	Not Included	Included # ^B																		
Beam Drops or Elevation del z (Method 2 – Significant Drops)	Included only if a corresponding del z definition is specified for the wall in the particular storey and the storey above	Included only if a corresponding del z definition is specified for the column in the particular storey and the storey above																		
Multiple Storey Wall/Column Spans	Included only if the number of storeys that the wall spans is specified in Len (Storey) # ^C	Included only if the number of storeys that the column spans is specified in Len (Storey) # ^C																		
4.22	<table border="1" style="width: 100%; border-collapse: collapse; margin-bottom: 10px;"> <thead> <tr style="background-color: #004a7c; color: white;"> <th colspan="3" style="text-align: center;">Recognition of Len (Storey) ≥ 2 Wall/Column As Beam Supports for Beams Not on the Wall/Column Defined Storey</th> </tr> <tr style="background-color: #004a7c; color: white;"> <th style="width: 33%;">Item</th> <th style="width: 33%;">BA</th> <th style="width: 33%;">FEFA</th> </tr> </thead> <tbody> <tr> <td style="text-align: center;">Wall (Mid-Pier Model)</td> <td style="text-align: center;">Not Recognized</td> <td style="text-align: center;">Not Recognized</td> </tr> <tr> <td style="text-align: center;">Wall (FE Shell Model)</td> <td style="text-align: center;">Recognized</td> <td style="text-align: center;">Not Recognized</td> </tr> <tr> <td style="text-align: center;">Column</td> <td style="text-align: center;">Recognized</td> <td style="text-align: center;">Not Recognized</td> </tr> </tbody> </table>	Recognition of Len (Storey) ≥ 2 Wall/Column As Beam Supports for Beams Not on the Wall/Column Defined Storey			Item	BA	FEFA	Wall (Mid-Pier Model)	Not Recognized	Not Recognized	Wall (FE Shell Model)	Recognized	Not Recognized	Column	Recognized	Not Recognized	<input type="checkbox"/>			
Recognition of Len (Storey) ≥ 2 Wall/Column As Beam Supports for Beams Not on the Wall/Column Defined Storey																				
Item	BA	FEFA																		
Wall (Mid-Pier Model)	Not Recognized	Not Recognized																		
Wall (FE Shell Model)	Recognized	Not Recognized																		
Column	Recognized	Not Recognized																		
4.3	Wall/Column Effective Length Factor																			
4.31	<p>Building → Parameters → Lateral Drift Tab → check Braced for walls/columns in a lateral stability system (ES): -</p> <ul style="list-style-type: none"> (i) that exist in a coupled shear wall (minor plane only) / outrigger frame (outrigger columns only) / (framed) tube flange / (framed) tube web (minor plane only) lateral stability system (cl.3.8.1.5 BS8110-1), and (ii) that have a total (of all walls/columns in question) gross stiffness ≤ 1/12th of the total gross stiffness of the bracing elements resisting lateral movement of that storey (cl.6.2.5 ACI 318-14), and (iii) that exhibit a total (of all walls/columns in question) magnitude of shear force and bending moment (excluding the bending moment back-calculated by multiplying the push-pull axial forces of the walls/columns at the frame extremity) based on the Moment Ratio Check ≤ 1/12th of the total magnitude of shear force and bending moment (including ditto) of the bracing elements resisting lateral movement of that storey (inferred from cl.6.2.5 ACI 318-14), and (iv) that are within a sway storey (exhibiting $Q \leq 0.25$ or $\lambda \geq 4.0$) based on the Sway Susceptibility Check but with elastic second-order analysis / P-Δ analysis / lateral loads (wind, EQ) amplification with the amplified sway factor, $m = \lambda/(\lambda-1)$ performed (cl.6.2.6 and cl.R6.7.1.2 ACI 318-14), or (albeit unconservatively) (v) that are within a non-sway storey (exhibiting $Q \leq 0.05$ or $\lambda \geq 20$) based on the Sway Susceptibility Check (based on cl.6.6.4.3(b) ACI 318-14). <p>Note that for significant buildings, based on a (vertical load take down, base lateral load distribution and lateral drift verified) CSI.Etabs model, a first principle eigenvalue buckling analysis should be performed to confirm the global building buckling characteristics (requiring $\lambda \geq 4.0$ to cl.R6.2.6 ACI 318-14 and to verify the value for m in $m = \lambda/(\lambda-1)$) and local mega column buckling characteristics ((requiring $\lambda \geq 1$)).</p>	<input type="checkbox"/>																		
4.32	<p>Building → Parameters → Lateral Drift Tab → check Unbraced for walls/columns in a lateral stability system (ES): -</p> <ul style="list-style-type: none"> (i) that exist in a coupled shear wall (major plane only) / moment frame / outrigger frame (except 	<input type="checkbox"/>																		

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

ITEM	CONTENT	√
	<p>outrigger columns) / (framed) tube web (major plane only) lateral stability system (cl.3.8.1.5 BS8110-1), or</p> <p>(ii) that have a total (of all walls/columns in question) gross stiffness > 1/12th of the total gross stiffness of the bracing elements resisting lateral movement of that storey (cl.6.2.5 ACI 318-14), or</p> <p>(iii) that exhibit a total (of all walls/columns in question) magnitude of shear force or bending moment (excluding the bending moment back-calculated by multiplying the push-pull axial forces of the walls/columns at the frame extremity) based on the Moment Ratio Check > 1/12th of the total magnitude of shear force or bending moment (including ditto) of the bracing elements resisting lateral movement of that storey (inferred from cl.6.2.5 ACI 318-14), and (albeit unconservatively)</p> <p>(iv) that are within a sway storey (exhibiting $Q > 0.05$ or $\lambda < 20$) based on the Sway Susceptibility Check (based on cl.6.6.4.3(b) ACI 318-14).</p> <p>Note that for significant buildings, based on a (vertical load take down, base lateral load distribution and lateral drift verified) CSI.Etabs model, a first principle eigenvalue buckling analysis should be performed to confirm the global building buckling characteristics (requiring $\lambda \geq 4.0$ to cl.R6.2.6 ACI 318-14 and to verify the value for m in $m = \lambda/(\lambda-1)$) and local mega column buckling characteristics ((requiring $\lambda \geq 1$).</p>	√
4.33	<p>Run → Column Section Design → Design Tab → Interactive Design → Slenderness Tab → check manually Edited Bracing for walls/columns in structures with transferred lateral stability (e.g. braced shear wall residential block on an unbraced moment frame car park podium, noting that should the car park podium floors be constructed in flat slabs instead of in beams and slabs, the unbraced mega columns beneath the transfer floor would effectively resist a primary stability base shear induced vierendeel moment over its height from the transfer floor to a base level that can effectively transfer the stability base shear into the foundations unless, and as highly recommended, a certain proportion of the existing shear walls are continued below the transfer floor to the foundations or if new shear walls are introduced below the transfer floor, yielding a scenario akin to the core and outrigger form of stability whereby the stability base moment is resolved into axial forces into the then braced (provided cl.6.2.5 and conservatively cl.6.6.4.3(b) ACI 318-14 are satisfied for a non-sway storey) mega columns and the stability base shear is transferred by the transfer floor diaphragm to the shear walls beneath the transfer floor into the foundations; note that even if the car park podium floors were constructed in beams and slabs, it is likely that the stability base shear will migrate to the usually stiffer shear walls if they are provided; note that a ULS shear stress check should be done on all stability base shear resisting elements) (ES).</p>	<input type="checkbox"/>
4.4	Wall/Column Base Support Conditions	
4.41	<p>Member → Member Tables → Wall/Column Table → Support Type → check User-Defined (Member → Support Type Definitions → introduce lateral and rotational flexibility): -</p> <p>Pad, Strip, Raft, Piled Raft Foundations</p> <ul style="list-style-type: none"> - Introduce lateral flexibility in both directions in accordance with soil stiffness. - Introduce zero rotational flexibility in both planes. <p>Piled Foundations (with Dropped or Integrated Pile Caps)</p> <ul style="list-style-type: none"> - Introduce lateral flexibility in both directions in accordance with soil stiffness. - Introduce rotational flexibility in both planes for single-pile pile caps and one plane for double-pile pile caps. 	<input type="checkbox"/>
4.42	Check stepped foundations levels relative to St00 (e.g. general pile cap level compared to the lift pit pile cap level) defined with +ve del z (bot) upwards in the St01 wall/column definitions.	<input type="checkbox"/>
4.43	Check stepped foundations levels relative to St0i where $i \geq 1$ defined with +ve del z (bot) upwards and Support Types defined in St0i+1 wall/column definitions (Member → Member Tables → Wall/Column Table → Support Type → check User-Defined Support) noting that user-defined support types are defined in Member → Support Type Definitions. Alternatively, wall/column definitions at St0i+1 where $i \geq 1$ may be defined with Len (Storey) ≥ 2 and +ve del z (bot) upwards defined to extend beyond the storey height(s).	<input type="checkbox"/>
5.0	MODELLING CHECKS	
5.1	General	
5.11	Check all elements (with the allowable exception of columns) modelled with their insertion lines/points closest to their centroid (ES).	<input type="checkbox"/>
5.12	<p>Check that secondary beam spans break at primary beam crossings and that primary beam spans break at wall/column crossings (ES).</p> <p>Check that offset beams (which are secondary beams that frame into the beam in question within the footprint of the wall/column) are avoided as far as it is practical so as to prevent the potential error message "analysis moment and moment calculated using the diagrams not matching" in the RigidZones None case (ES).</p> <p>Check that beam insertion points do not project through and beyond the column insertion points (ES).</p> <p>Check that user defined point loads are not applied at the extreme tip of cantilever beams but slightly inset so as to prevent the error message "analysis moment and moment calculated using the diagrams not matching" (ES).</p>	<input type="checkbox"/>
5.13	<p>Check 3D Visualisation for accuracy of modelling in particular: -</p> <ul style="list-style-type: none"> • slab and beam drops and soffit continuity (ES). • avoidance of voids in beam wall loading (ES). • consistency of inter-storey wall/column setting out (ES). • check skeletal FE model (Run → BA → Post Analysis → MARD) for rigid beams erroneously interconnecting 	<input type="checkbox"/>

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

ITEM	CONTENT	✓																										
	different stories (ES). <ul style="list-style-type: none"> multi-storey (Len (Storey) > 1) wall/column element spans, noting that only walls/columns that are strutted/tied in both directions may be considered Len (Storey) = 1 (ES). employment of FE Shell Model idealisation instead of the Mid-Pier idealisation for long walls whereby the effect of shear lag may be prominent (ES). 	<input checked="" type="checkbox"/>																										
5.14	Member → Member Tables → Slab Table → check Slab Does Not Contribute to Floor Diaphragm for all dropped slabs, inclined slabs, slabs near inclined walls/columns and conservatively slabs near basement retaining walls to ensure that the stability base shear is resisted by the walls/columns supporting the superstructure (ES).	<input type="checkbox"/>																										
5.15	Check all cantilever beams are manually marked as such (to enable the correct cantilever reinforcement detailing and the correct deflection assessment based on cantilever span / depth ratios), the option to <i>"automatically mark all cantilever beams"</i> should not be used with the existence of non-prismatic beams as they will be incorrectly marked as such (ES).	<input type="checkbox"/>																										
5.16	Check all duplicate storeys share the same storey height (only beneath for the BA method and both above and beneath for the CBAFE method) with their parent storey to ensure that wall/column clear heights are accurately calculated. If Len (Storey) > 1 is adopted for wall/column definitions, then the above requirement is to be likewise extended to multiple storeys. Check all duplicate storeys share the same wall/column dimensions (both above and beneath for the CBAFE method) with their parent storey to ensure correct load take down.	<input type="checkbox"/>																										
5.2	Section and Material Properties																											
5.21	<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr style="background-color: #004a7c; color: white;"> <th colspan="3" style="text-align: center;">% Reduction in Rigidity in BA ^{#A}</th> </tr> <tr style="background-color: #004a7c; color: white;"> <th style="width: 30%;">Action</th> <th style="width: 35%;">Slab/Beam</th> <th style="width: 35%;">Wall/Column</th> </tr> </thead> <tbody> <tr> <td style="background-color: #004a7c; color: white; text-align: center;">ULS DL, SDL, LL (V) ^{#B}</td> <td style="background-color: #004a7c; color: white;"> Class 1 PT or Class 2 PT 50%{EA} Uncracked, Creep 50%{EI} Uncracked, Creep 50%{GA_s} Uncracked, Creep 50%{GJ} Uncracked, Creep k_E=1.0, k_I=1.0, k_J=1.0, k_A=1.0 [2.0 x Default Parameters] </td> <td rowspan="3" style="background-color: #004a7c; color: white; text-align: center;"> Class 1 PT, Class 2 PT, RC or Class 3 PT 50%{EA} Uncracked, Creep 50%{EI} Uncracked, Creep 50%{GA_s} Uncracked, Creep 50%{GJ} Uncracked, Creep k_E=1.0, k_I=1.0, k_J=1.0, k_A=1.0 [Default Parameters] </td> </tr> <tr> <td style="background-color: #004a7c; color: white; text-align: center;">ULS NHF (H) ^{#B}</td> <td style="background-color: #004a7c; color: white;"> 50%{EI} Uncracked, Creep 50%{GA_s} Uncracked, Creep 50%{GJ} Uncracked, Creep k_E=1.0, k_I=1.0, k_J=1.0, k_A=1.0 [2.0 x Default Parameters] </td> </tr> <tr> <td style="background-color: #004a7c; color: white; text-align: center;">ULS Wind (H) ^{#B}</td> <td style="background-color: #004a7c; color: white;"> 50%{EI} Uncracked, Creep 50%{GA_s} Uncracked, Creep 50%{GJ} Uncracked, Creep k_E=1.0, k_I=1.0, k_J=1.0, k_A=1.0 [2.0 x Default Parameters] </td> </tr> <tr> <td style="background-color: #004a7c; color: white; text-align: center;">SLS DL, SDL, LL (V) ^{#C}</td> <td style="background-color: #004a7c; color: white;"> RC or Class 3 PT 50%{EA} Uncracked, Creep 25%{EI} Cracked, Creep 50%{GA_s} Uncracked, Creep 25%{GJ} Cracked, Creep k_E=1.0, k_I=0.5, k_J=0.5, k_A=1.0 [Default Parameters] </td> <td style="background-color: #004a7c; color: white; text-align: center;"> 50%{EI} Cracked, Creep 50%{GA_s} Uncracked, Creep 50%{GJ} Cracked, Creep k_E=1.0, k_I=0.5, k_J=0.5, k_A=1.0 [Default Parameters] </td> </tr> <tr> <td style="background-color: #004a7c; color: white; text-align: center;">ULS EQ (H) ^{#B, #F}</td> <td style="background-color: #004a7c; color: white;"> Class 1 PT or Class 2 PT 50%{EA} Uncracked, Creep 50%{EI} Uncracked, Creep 50%{GA_s} Uncracked, Creep 50%{GJ} Uncracked, Creep k_E=1.0, k_I=1.0, k_J=1.0, k_A=1.0 [2.0 x Default Parameters] </td> <td style="background-color: #004a7c; color: white; text-align: center;"> Class 1 PT, Class 2 PT, RC or Class 3 PT 50%{EA} Uncracked, Creep 25%{EI} Cracked, Creep 50%{GA_s} Uncracked, Creep 25%{GJ} Cracked, Creep k_E=1.0, k_I=0.5, k_J=0.5, k_A=1.0 [~0.5 x Default Parameters] </td> </tr> <tr> <td style="background-color: #004a7c; color: white; text-align: center;">SLS NHF (H) ^{#C, #D}</td> <td style="background-color: #004a7c; color: white;"> Class 1 PT or Class 2 PT 100%{EA} Uncracked, No Creep 100%{EI} Uncracked, No Creep 100%{GA_s} Uncracked, No Creep 100%{GJ} Uncracked, No Creep k_E=2.0, k_I=1.0, k_J=1.0, k_A=1.0 [4.0 x Default Parameters] </td> <td rowspan="3" style="background-color: #004a7c; color: white; text-align: center;"> Class 1 PT, Class 2 PT, RC or Class 3 PT 100%{EA} Uncracked, No Creep 100%{EI} Uncracked, No Creep 100%{GA_s} Uncracked, No Creep 100%{GJ} Uncracked, No Creep k_E=2.0, k_I=1.0, k_J=1.0, k_A=1.0 [2.0 x Default Parameters] </td> </tr> <tr> <td style="background-color: #004a7c; color: white; text-align: center;">SLS Wind (H) ^{#C, #D}</td> <td style="background-color: #004a7c; color: white;"> 100%{EI} Uncracked, No Creep 100%{GA_s} Uncracked, No Creep 100%{GJ} Uncracked, No Creep k_E=2.0, k_I=1.0, k_J=1.0, k_A=1.0 [4.0 x Default Parameters] </td> </tr> <tr> <td style="background-color: #004a7c; color: white; text-align: center;">SLS Vibration (H) ^{#C, #D}</td> <td style="background-color: #004a7c; color: white;"> RC or Class 3 PT 100%{EA} Uncracked, No Creep 50%{EI} Cracked, No Creep 100%{GA_s} Uncracked, No Creep 50%{GJ} Cracked, No Creep k_E=2.0, k_I=0.5, k_J=0.5, k_A=1.0 [2.0 x Default Parameters] </td> </tr> </tbody> </table>	% Reduction in Rigidity in BA ^{#A}			Action	Slab/Beam	Wall/Column	ULS DL, SDL, LL (V) ^{#B}	Class 1 PT or Class 2 PT 50%{EA} Uncracked, Creep 50%{EI} Uncracked, Creep 50%{GA _s } Uncracked, Creep 50%{GJ} Uncracked, Creep k _E =1.0, k _I =1.0, k _J =1.0, k _A =1.0 [2.0 x Default Parameters]	Class 1 PT, Class 2 PT, RC or Class 3 PT 50%{EA} Uncracked, Creep 50%{EI} Uncracked, Creep 50%{GA _s } Uncracked, Creep 50%{GJ} Uncracked, Creep k _E =1.0, k _I =1.0, k _J =1.0, k _A =1.0 [Default Parameters]	ULS NHF (H) ^{#B}	50%{EI} Uncracked, Creep 50%{GA _s } Uncracked, Creep 50%{GJ} Uncracked, Creep k _E =1.0, k _I =1.0, k _J =1.0, k _A =1.0 [2.0 x Default Parameters]	ULS Wind (H) ^{#B}	50%{EI} Uncracked, Creep 50%{GA _s } Uncracked, Creep 50%{GJ} Uncracked, Creep k _E =1.0, k _I =1.0, k _J =1.0, k _A =1.0 [2.0 x Default Parameters]	SLS DL, SDL, LL (V) ^{#C}	RC or Class 3 PT 50%{EA} Uncracked, Creep 25%{EI} Cracked, Creep 50%{GA _s } Uncracked, Creep 25%{GJ} Cracked, Creep k _E =1.0, k _I =0.5, k _J =0.5, k _A =1.0 [Default Parameters]	50%{EI} Cracked, Creep 50%{GA _s } Uncracked, Creep 50%{GJ} Cracked, Creep k _E =1.0, k _I =0.5, k _J =0.5, k _A =1.0 [Default Parameters]	ULS EQ (H) ^{#B, #F}	Class 1 PT or Class 2 PT 50%{EA} Uncracked, Creep 50%{EI} Uncracked, Creep 50%{GA _s } Uncracked, Creep 50%{GJ} Uncracked, Creep k _E =1.0, k _I =1.0, k _J =1.0, k _A =1.0 [2.0 x Default Parameters]	Class 1 PT, Class 2 PT, RC or Class 3 PT 50%{EA} Uncracked, Creep 25%{EI} Cracked, Creep 50%{GA _s } Uncracked, Creep 25%{GJ} Cracked, Creep k _E =1.0, k _I =0.5, k _J =0.5, k _A =1.0 [~0.5 x Default Parameters]	SLS NHF (H) ^{#C, #D}	Class 1 PT or Class 2 PT 100%{EA} Uncracked, No Creep 100%{EI} Uncracked, No Creep 100%{GA _s } Uncracked, No Creep 100%{GJ} Uncracked, No Creep k _E =2.0, k _I =1.0, k _J =1.0, k _A =1.0 [4.0 x Default Parameters]	Class 1 PT, Class 2 PT, RC or Class 3 PT 100%{EA} Uncracked, No Creep 100%{EI} Uncracked, No Creep 100%{GA _s } Uncracked, No Creep 100%{GJ} Uncracked, No Creep k _E =2.0, k _I =1.0, k _J =1.0, k _A =1.0 [2.0 x Default Parameters]	SLS Wind (H) ^{#C, #D}	100%{EI} Uncracked, No Creep 100%{GA _s } Uncracked, No Creep 100%{GJ} Uncracked, No Creep k _E =2.0, k _I =1.0, k _J =1.0, k _A =1.0 [4.0 x Default Parameters]	SLS Vibration (H) ^{#C, #D}	RC or Class 3 PT 100%{EA} Uncracked, No Creep 50%{EI} Cracked, No Creep 100%{GA _s } Uncracked, No Creep 50%{GJ} Cracked, No Creep k _E =2.0, k _I =0.5, k _J =0.5, k _A =1.0 [2.0 x Default Parameters]	<input type="checkbox"/>
% Reduction in Rigidity in BA ^{#A}																												
Action	Slab/Beam	Wall/Column																										
ULS DL, SDL, LL (V) ^{#B}	Class 1 PT or Class 2 PT 50%{EA} Uncracked, Creep 50%{EI} Uncracked, Creep 50%{GA _s } Uncracked, Creep 50%{GJ} Uncracked, Creep k _E =1.0, k _I =1.0, k _J =1.0, k _A =1.0 [2.0 x Default Parameters]	Class 1 PT, Class 2 PT, RC or Class 3 PT 50%{EA} Uncracked, Creep 50%{EI} Uncracked, Creep 50%{GA _s } Uncracked, Creep 50%{GJ} Uncracked, Creep k _E =1.0, k _I =1.0, k _J =1.0, k _A =1.0 [Default Parameters]																										
ULS NHF (H) ^{#B}	50%{EI} Uncracked, Creep 50%{GA _s } Uncracked, Creep 50%{GJ} Uncracked, Creep k _E =1.0, k _I =1.0, k _J =1.0, k _A =1.0 [2.0 x Default Parameters]																											
ULS Wind (H) ^{#B}	50%{EI} Uncracked, Creep 50%{GA _s } Uncracked, Creep 50%{GJ} Uncracked, Creep k _E =1.0, k _I =1.0, k _J =1.0, k _A =1.0 [2.0 x Default Parameters]																											
SLS DL, SDL, LL (V) ^{#C}	RC or Class 3 PT 50%{EA} Uncracked, Creep 25%{EI} Cracked, Creep 50%{GA _s } Uncracked, Creep 25%{GJ} Cracked, Creep k _E =1.0, k _I =0.5, k _J =0.5, k _A =1.0 [Default Parameters]	50%{EI} Cracked, Creep 50%{GA _s } Uncracked, Creep 50%{GJ} Cracked, Creep k _E =1.0, k _I =0.5, k _J =0.5, k _A =1.0 [Default Parameters]																										
ULS EQ (H) ^{#B, #F}	Class 1 PT or Class 2 PT 50%{EA} Uncracked, Creep 50%{EI} Uncracked, Creep 50%{GA _s } Uncracked, Creep 50%{GJ} Uncracked, Creep k _E =1.0, k _I =1.0, k _J =1.0, k _A =1.0 [2.0 x Default Parameters]	Class 1 PT, Class 2 PT, RC or Class 3 PT 50%{EA} Uncracked, Creep 25%{EI} Cracked, Creep 50%{GA _s } Uncracked, Creep 25%{GJ} Cracked, Creep k _E =1.0, k _I =0.5, k _J =0.5, k _A =1.0 [~0.5 x Default Parameters]																										
SLS NHF (H) ^{#C, #D}	Class 1 PT or Class 2 PT 100%{EA} Uncracked, No Creep 100%{EI} Uncracked, No Creep 100%{GA _s } Uncracked, No Creep 100%{GJ} Uncracked, No Creep k _E =2.0, k _I =1.0, k _J =1.0, k _A =1.0 [4.0 x Default Parameters]	Class 1 PT, Class 2 PT, RC or Class 3 PT 100%{EA} Uncracked, No Creep 100%{EI} Uncracked, No Creep 100%{GA _s } Uncracked, No Creep 100%{GJ} Uncracked, No Creep k _E =2.0, k _I =1.0, k _J =1.0, k _A =1.0 [2.0 x Default Parameters]																										
SLS Wind (H) ^{#C, #D}	100%{EI} Uncracked, No Creep 100%{GA _s } Uncracked, No Creep 100%{GJ} Uncracked, No Creep k _E =2.0, k _I =1.0, k _J =1.0, k _A =1.0 [4.0 x Default Parameters]																											
SLS Vibration (H) ^{#C, #D}	RC or Class 3 PT 100%{EA} Uncracked, No Creep 50%{EI} Cracked, No Creep 100%{GA _s } Uncracked, No Creep 50%{GJ} Cracked, No Creep k _E =2.0, k _I =0.5, k _J =0.5, k _A =1.0 [2.0 x Default Parameters]																											

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

ITEM	CONTENT	√
SLS EQ (H) #C, #D, #F	<p style="text-align: center;">Class 1 PT or Class 2 PT 100%{EA} Uncracked, No Creep 100%{EI} Uncracked, No Creep 100%{GA_s} Uncracked, No Creep 100%{GJ} Uncracked, No Creep k_E=2.0, k_I=1.0, k_J=1.0, k_A=1.0 [4.0 x Default Parameters]</p> <hr style="border: 1px solid black;"/> <p style="text-align: center;">RC or Class 3 PT 100%{EA} Uncracked, No Creep 50%{EI} Cracked, No Creep 100%{GA_s} Uncracked, No Creep 50%{GJ} Cracked, No Creep k_E=2.0, k_I=0.5, k_J=0.5, k_A=1.0 [2.0 x Default Parameters]</p>	
ULS Sway Susceptibility (NHF) (H) #E	<p style="text-align: center;">Class 1 PT or Class 2 PT 100%{EA} Uncracked, No Creep 70%{EI} Uncracked, No Creep 100%{GA_s} Uncracked, No Creep 70%{GJ} Uncracked, No Creep k_E=2.0, k_I=0.7, k_J=0.7, k_A=1.0 [~2.8 x Default Parameters]</p> <hr style="border: 1px solid black;"/> <p style="text-align: center;">RC or Class 3 PT 100%{EA} Uncracked, No Creep 35%{EI} Cracked, No Creep 100%{GA_s} Uncracked, No Creep 35%{GJ} Cracked, No Creep k_E=2.0, k_I=0.35, k_J=0.35, k_A=1.0 [~1.4 x Default Parameters]</p>	
ULS Sway Susceptibility (Wind) (H) #E	<p style="text-align: center;">Class 1 PT or Class 2 PT 100%{EA} Uncracked, No Creep 70%{EI} Uncracked, No Creep 100%{GA_s} Uncracked, No Creep 70%{GJ} Uncracked, No Creep k_E=2.0, k_I=0.7, k_J=0.7, k_A=1.0 [~2.8 x Default Parameters]</p> <hr style="border: 1px solid black;"/> <p style="text-align: center;">RC or Class 3 PT 100%{EA} Uncracked, No Creep 35%{EI} Cracked, No Creep 100%{GA_s} Uncracked, No Creep 35%{GJ} Cracked, No Creep k_E=2.0, k_I=0.35, k_J=0.35, k_A=1.0 [~1.4 x Default Parameters]</p>	
ULS Sway Susceptibility (EQ) (H) #E, #F	<p style="text-align: center;">Class 1 PT or Class 2 PT 100%{EA} Uncracked, No Creep 70%{EI} Uncracked, No Creep 100%{GA_s} Uncracked, No Creep 70%{GJ} Uncracked, No Creep k_E=2.0, k_I=0.7, k_J=0.7, k_A=1.0 [~2.8 x Default Parameters]</p> <hr style="border: 1px solid black;"/> <p style="text-align: center;">RC or Class 3 PT 100%{EA} Uncracked, No Creep 35%{EI} Cracked, No Creep 100%{GA_s} Uncracked, No Creep 35%{GJ} Cracked, No Creep k_E=2.0, k_I=0.35, k_J=0.35, k_A=1.0 [~1.4 x Default Parameters]</p>	

#A: These values of k_E, k_I, k_J and k_A within the table are formulated based on the premise that the elastic modulus, E value has been reduced to account for creep effects as the default. The reduction to the elastic modulus, E of 0.50 for typical office / residential buildings as stipulated by cl.14.5.2 of Report 110 Design of RC Flat Slabs to BS8100 (CIRIA) pp.34 is adopted.

#B: RC or Class 3 PT stiffness values for ULS design governed by 1.00I_g (wall, column) and 0.50I_g (slab) of TR.64 Guide to the Design and Construction of RC Flat Slabs (The Concrete Society) pp.31 and by cl.14.5.4 of Report 110 Design of RC Flat Slabs to BS8100 (CIRIA) pp.35 are adopted. The RC or Class 3 PT ratio of relative stiffness for ULS design between (wall, column) : (slab, beam) elements of 1.00 : 0.50 is also suggested by cl.6.6.3.1.1 ACI 318-14, i.e. in 0.70 : 0.35 although the stiffness reduction factor 0.70 is not adopted here as would have a somewhat negligible effect on the ULS effects. Creep on the other hand is included for ULS effects to cater for the additional effects generated by differential (elastic, creep, shrinkage) axial shortening of walls/columns.

#C: RC or Class 3 PT stiffness values for SLS design governed by 0.70I_g (wall, column), 0.35I_g (beam) and 1.00A_g (beam, wall, column) of cl.6.6.3.1.1 ACI 318-14 together with a 1.4 multiplier stipulated within cl.6.6.3.2.2 ACI 318-14 resulting in 1.00I_g (wall, column), 0.50I_g (beam) and 1.00A_g (beam, wall, column) are adopted. Similar RC or Class 3 PT stiffness values for SLS design of 1.00I_g (wall, column) and 0.50I_g (slab) are also suggested by TR.64 Guide to the Design and Construction of RC Flat Slabs (The Concrete Society) pp.31 and by cl.14.5.4 of Report 110 Design of RC Flat Slabs to BS8100 (CIRIA) pp.35.

#D: The elastic modulus, E value incorporating creep effects is still adopted for ULS NHF / ULS wind / ULS EQ as part of the ULS load combination cases involving vertical loads (even though wind / EQ are short-term phenomena), as the effect of which is deemed negligible as the ratio of stiffness between (wall, column) and (slab, beam) elements is similar to their ratio of stiffness without incorporating creep effects. On the other hand, for SLS NHF / SLS wind / SLS EQ / SLS vibration design, the elastic modulus, E without incorporating creep effects is employed.

#E: RC or Class 3 PT stiffness values for ULS design governed by 0.70I_g (wall, column), 0.35I_g (beam) and 1.00A_g (beam, wall, column) of cl.6.6.3.1.1 ACI 318-14 are adopted. Further, it is given in cl.R6.6.4.3 ACI 318-14 that if the lateral load deflections of the frame are calculated using service loads and the service load moments of inertia given in cl.6.6.3.2.2, it is permissible to calculate Q using 1.2 times the sum of the service gravity loads, the service load story shear, and 1.4 times the first order service load story deflections.

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

ITEM	CONTENT	√																														
	#F: Note that in certain circumstances, it may be deemed more appropriate to employ cracked 0.50I _g (wall, column) stiffness properties for ULS EQ or SLS EQ effects due to the large displacements involved as suggested by T.9.1 of the Manual for the Seismic Design of Steel and Concrete Buildings to EC8 (IStructE) pp.61.	<input type="checkbox"/>																														
5.22	Member → Member Tables → Slab Table → check cover 25mm internal and 40mm external (e.g. ground, podium deck, swimming pool, water tank, roof) (ES).	<input type="checkbox"/>																														
5.23	Run → BA → Model Options Tab → Stiffnesses Sub-Tab → check Torsional Stiffness Factor (i.e. the torsional constant factor) = { 0.01 Class 1 PT or Class 2 PT 0.01 RC or Class 3 PT } and uncheck Consider Beam Torsional Stiffnesses in FEFA for models without equilibrium torsional beams.	<input type="checkbox"/>																														
5.24	Run → BA → Model Options Tab → Stiffnesses Sub-Tab → check Torsional Stiffness Factor (i.e. the torsional constant factor) = { 1.00 Class 1 PT or Class 2 PT 0.50 RC or Class 3 PT } and check Consider Beam Torsional Stiffnesses in FEFA for models with equilibrium torsional beams (e.g. curved beams and straight beams that frame eccentrically to columns (especially heavily loaded beams in transfer floors)). Torsional stiffness may also be considered for: - (i) heavily loaded straight transfer beams, and (ii) straight edge beams in regular buildings experiencing significant compatibility torsion .	<input type="checkbox"/>																														
5.25	<table border="1" style="width: 100%; border-collapse: collapse; background-color: #f2f2f2;"> <thead> <tr> <th colspan="3">Equilibrium and Compatibility Torsion</th> </tr> <tr> <th style="width: 35%;">Scenario</th> <th style="width: 30%;">Equilibrium Torsion</th> <th style="width: 35%;">Compatibility Torsion</th> </tr> </thead> <tbody> <tr> <td>Straight (Between Columns) Continuous Primary Beams</td> <td style="text-align: center;">Not Generated</td> <td style="text-align: center;">Generated</td> </tr> <tr> <td>Facetted (Between Columns) Continuous Primary Beams</td> <td style="text-align: center;">Generated</td> <td style="text-align: center;">Generated</td> </tr> <tr> <td>Curved (Between Columns) Continuous Primary Beams</td> <td style="text-align: center;">Generated</td> <td style="text-align: center;">Generated</td> </tr> </tbody> </table>	Equilibrium and Compatibility Torsion			Scenario	Equilibrium Torsion	Compatibility Torsion	Straight (Between Columns) Continuous Primary Beams	Not Generated	Generated	Facetted (Between Columns) Continuous Primary Beams	Generated	Generated	Curved (Between Columns) Continuous Primary Beams	Generated	Generated	<input type="checkbox"/>															
Equilibrium and Compatibility Torsion																																
Scenario	Equilibrium Torsion	Compatibility Torsion																														
Straight (Between Columns) Continuous Primary Beams	Not Generated	Generated																														
Facetted (Between Columns) Continuous Primary Beams	Generated	Generated																														
Curved (Between Columns) Continuous Primary Beams	Generated	Generated																														
5.26	For models with EQ loads stabilised by moment frames, as per the requirements of BS EN1998-1, the following geometrical constraints need to be achieved: - (a) as per cl.5.4.1.2.1 and cl.5.5.1.2.1, primary seismic beam eccentricity, $e \leq$ column orthogonal dim, $b_c / 4$ (DCM, DCH) primary seismic beam width, $b_w \leq$ min {column orthogonal dim, $b_c +$ beam depth, $h_w, 2b_c$ } (DCM, DCH) primary seismic beam width, $b_w \geq 200$ mm (DCH) (b) as per cl.5.4.1.2.2 and cl.5.5.1.2.2, primary seismic column width, $h_c \geq$ (column clear height, $l_d / 2$) / 10 (DCM, DCH) primary seismic column width, $h_c \geq 250$ mm (DCH)	<input type="checkbox"/>																														
5.27	For models with EQ loads stabilised by stability walls, as per the requirements of BS EN1998-1, the following geometrical constraints need to be achieved: - (a) as per cl.5.4.1.2.3 and cl.5.5.1.2.3, ductile wall thickness, $b_{wo} \geq$ max {150mm, clear storey height, $h_s / 20$ } (DCM, DCH) (b) as per cl.5.4.3.4.2 and cl.5.5.3.4.5, ductile wall boundary element requirements (DCM, DCH)	<input type="checkbox"/>																														
5.3	Element Horizontal Framing																															
5.31	<table border="1" style="width: 100%; border-collapse: collapse; background-color: #f2f2f2;"> <thead> <tr> <th colspan="5">Requirement of Element to Frame Horizontally (Within the Same Storey) onto Element Insertion Point / Line (or Simply Within the Element Footprint on Plan)</th> </tr> <tr> <th style="width: 15%;">Element</th> <th style="width: 20%;">Slab</th> <th style="width: 20%;">Beam</th> <th style="width: 20%;">Wall</th> <th style="width: 25%;">Column</th> </tr> </thead> <tbody> <tr> <td>Slab</td> <td style="text-align: center;">N/A</td> <td style="text-align: center;">Required #^A</td> <td style="text-align: center;">Required #^B</td> <td style="text-align: center;">Required #^C</td> </tr> <tr> <td>Beam</td> <td style="text-align: center;">N/A</td> <td style="text-align: center;">Required #^D</td> <td style="text-align: center;">Not Required #^E</td> <td style="text-align: center;">Not Required #^E</td> </tr> <tr> <td>Wall</td> <td style="text-align: center;">N/A</td> <td style="text-align: center;">N/A</td> <td style="text-align: center;">Required #^F</td> <td style="text-align: center;">Required #^F</td> </tr> <tr> <td>Column</td> <td style="text-align: center;">N/A</td> <td style="text-align: center;">N/A</td> <td style="text-align: center;">N/A</td> <td style="text-align: center;">N/A</td> </tr> </tbody> </table> <p>#^A: Check slab insertion lines frame onto beam insertion lines (ES). #^B: Check slab insertion lines frame onto wall insertion lines (ES). #^C: Check slab insertion lines frame onto (or through) column insertion points (ES). #^D: Check secondary beam insertion lines frame onto primary beam insertion lines (ES). #^E: Check primary beam insertion lines need only frame onto footprint of wall/column (ES). #^F: Check wall insertion lines frame onto wall/column insertion lines/points (ES). Note that in all cases above, no element may frame through the other element (but instead only onto element insertion point/line or within the element footprint), unless specifically denoted otherwise.</p>	Requirement of Element to Frame Horizontally (Within the Same Storey) onto Element Insertion Point / Line (or Simply Within the Element Footprint on Plan)					Element	Slab	Beam	Wall	Column	Slab	N/A	Required # ^A	Required # ^B	Required # ^C	Beam	N/A	Required # ^D	Not Required # ^E	Not Required # ^E	Wall	N/A	N/A	Required # ^F	Required # ^F	Column	N/A	N/A	N/A	N/A	<input type="checkbox"/>
Requirement of Element to Frame Horizontally (Within the Same Storey) onto Element Insertion Point / Line (or Simply Within the Element Footprint on Plan)																																
Element	Slab	Beam	Wall	Column																												
Slab	N/A	Required # ^A	Required # ^B	Required # ^C																												
Beam	N/A	Required # ^D	Not Required # ^E	Not Required # ^E																												
Wall	N/A	N/A	Required # ^F	Required # ^F																												
Column	N/A	N/A	N/A	N/A																												
5.32	<table border="1" style="width: 100%; border-collapse: collapse; background-color: #f2f2f2;"> <thead> <tr> <th style="width: 15%;">Element</th> <th style="width: 40%;">Method 1 (Insignificant Drops)</th> <th style="width: 45%;">Method 2 (Significant Drops)</th> </tr> </thead> <tbody> <tr> <td>Slab</td> <td style="text-align: center;">Defining drops -ve downwards (and elevation</td> <td style="text-align: center;">Defining drops by -ve del z downwards (and elevation +ve del z upwards) or by defining planes and setting the plane definition</td> </tr> </tbody> </table>	Element	Method 1 (Insignificant Drops)	Method 2 (Significant Drops)	Slab	Defining drops -ve downwards (and elevation	Defining drops by -ve del z downwards (and elevation +ve del z upwards) or by defining planes and setting the plane definition	<input type="checkbox"/>																								
Element	Method 1 (Insignificant Drops)	Method 2 (Significant Drops)																														
Slab	Defining drops -ve downwards (and elevation	Defining drops by -ve del z downwards (and elevation +ve del z upwards) or by defining planes and setting the plane definition																														

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

ITEM	CONTENT				✓
		+ve upwards) in Rel.Level	of the member		
	Beam	Defining drops -ve h-top downwards (and elevation +ve h-top upwards)	Defining drops / inclination by -ve del z (I) and del z (J) downwards (and elevation +ve del z (I) and del z (J) upwards) or by defining planes and setting the plane definition of the member		
	Wall	N/A	Defining drops by -ve del z (I,top) and del z (J,top) downwards (and elevation +ve del z (I,top) and del z (J,top) upwards) or by defining planes and setting the plane definition of the member		
	Column	N/A	Defining drops by -ve del z (top) downwards (and elevation +ve del z (top) upwards) or by defining planes and setting the plane definition of the member		
5.4	Element Vertical Framing				
5.41	Requirement of Element to Frame Vertically (Between Storeys) onto Element Insertion Point / Line (or Simply Within the Element Footprint on Plan)				
	Element	Slab	Beam	Wall	Column
	Slab	N/A	N/A	N/A	N/A
	Beam	N/A	N/A	N/A	N/A
	Wall	Not Required #A	Required #B2	Required #B1, #C	Required #B1
	Column	Not Required #D	Required #E	Not Required #F	Not Required #F
	<p>#A: Check wall insertion lines need only frame onto footprint of transfer slab (ES).</p> <p>#B1: Check wall insertion lines frame onto transfer column insertion points. Manually perform the strut and tie truss analogy design for the transferred wall and the transferred wall bearing stress check to $0.40f_{cu}$ at supports (over the minimum of the length of the support or $0.2 \times$ clear span, ref. CIRIA Guide 2 and thickness of the transferred wall) for the transferred wall (ES).</p> <p>#B2: Check wall insertion lines frame onto transfer beam insertion lines. Manually perform the strut and tie truss analogy design for the transferred wall (acting as the diagonal compression element) and transfer beam (acting as the tension element). Manually perform the deep beam design for the transfer beam. (ES).</p> <p>#C: Check wall insertion lines frame onto wall insertion lines (ES).</p> <p>#D: Check column insertion points need only frame onto footprint of transfer slab (ES).</p> <p>#E: Check column insertion points frame onto transfer beam insertion lines (ES).</p> <p>#F: Check column insertion points need only frame onto footprint of wall/column (ES).</p>				<input type="checkbox"/>
5.42	Check employment of FE Shell Model (with mesh size being reduced until convergence of the wall axial forces and bending moments) idealisation instead of the Mid-Pier idealisation for transferred walls at the transfer level for a greater distribution of load and the realistic adoption of the wall contribution to the load transfer.				<input type="checkbox"/>
5.43	Check for transferred walls framing across multiple transfer walls / transfer columns / transfer beams along the same axis that the FE Shell Model idealisation instead of the Mid-Pier idealisation is used as the latter will not distribute the load over the multiple transfer elements but instead concentrate the load on potentially a single transfer element. If the Mid-Pier idealisation is to be used nevertheless, then the transferred walls need to be split at all supporting transfer beam to wall/column interfaces so as to generate the correct loading distribution.				<input type="checkbox"/>
5.44	Check transfer wall / transfer beam and transferred wall are modelled with their insertion lines at their centroids and coincident with each other as beam torsions due to any relative offset will not be generated as beam rigid links are not created. Check transfer column / transfer beam and transferred column are modelled with their insertion lines / points coincident with each other, however the transferred column insertion points need not be at their centroids as beam torsions due to any relative offset will be generated as beam rigid links are created.				<input type="checkbox"/>
5.45	Modelling of Transferred Walls				
	Transfer Wall	Transfer Wall/ Column #C	Rigid Zones	Overlap #A	Remark
	Wall #B	Wall #B	None	No Overlap	<ul style="list-style-type: none"> • Correct flexible representation of transfer beam bending moment and shear force effects • Correct RC rebar arrangement – no manual elongation of rebar and link required (rebar linking across wall required)
	Wall #B	Column	None	No Overlap	<ul style="list-style-type: none"> • Correct flexible representation of transfer beam bending moment and shear force effects • Correct RC rebar arrangement – no manual elongation of rebar and link required (rebar linked across column)
	Wall #B	Wall #B	None #D	Full / Partial	<ul style="list-style-type: none"> • Correct rigid representation of transfer beam bending moment and shear force effects
					<input type="checkbox"/>

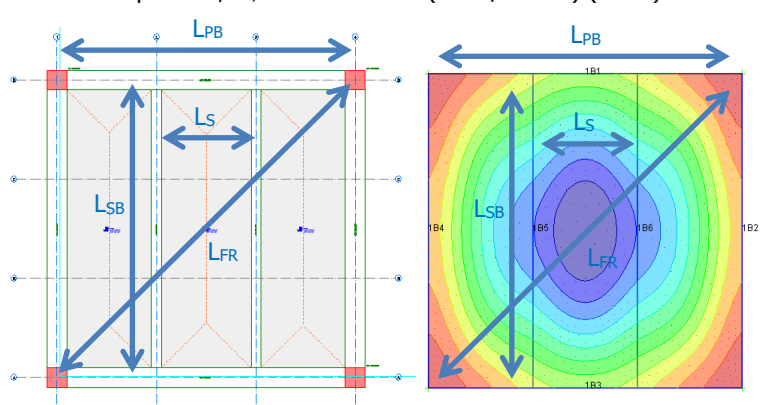
FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

ITEM	CONTENT				√				
				Overlap	<ul style="list-style-type: none"> Incorrect RC rebar arrangement – manual elongation of rebar and link required (rebar linking across wall required) 				
	Wall #B	Column	None	Full / Partial Overlap	<ul style="list-style-type: none"> Correct rigid representation of transfer beam bending moment and shear force effects Correct RC rebar arrangement – no manual elongation of rebar and link required (rebar linked across column) 				
	Wall #B	Wall #B	Max	No Overlap	<ul style="list-style-type: none"> Correct flexible representation of transfer beam bending moment and shear force effects Correct RC rebar arrangement – no manual elongation of rebar and link required (rebar linking across wall required) 				
	Wall #B	Column	Max	No Overlap	<ul style="list-style-type: none"> Correct flexible representation of transfer beam bending moment and shear force effects Correct RC rebar arrangement – no manual elongation of rebar and link required (rebar linked across column) 				
	Wall #B	Wall #B	Max #D	Full / Partial Overlap	<ul style="list-style-type: none"> Incorrect representation of transfer beam bending moment and shear force effects 				
	Wall #B	Column	Max	Full / Partial Overlap	<ul style="list-style-type: none"> Incorrect representation of transfer beam bending moment and shear force effects 				
	<p>#A: Overlap refers to overlap between transferred wall and transfer wall/column.</p> <p>#B: Wall may refer to either Mid-Pier wall or FE Shell Model wall. For FE Shell Model walls, smaller shell mesh sizes should be investigated until convergence of the maximum support shear force effects on transfer beams.</p> <p>#C: With regards to the wall/column effective length calculation, the clear height computation for walls does not incorporate the reduction due to the depth of the incoming beam(s) whilst the clear height computation for columns does incorporate the reduction due to the depth of the incoming beam(s).</p> <p>#D: Check for models with transferred walls overlapping with transfer walls/columns, specify RigidZones as None in BA (and for consistency Exclude Column Sections in FEFA) to avoid the error message "analysis moment and moment calculated using the diagrams not matching" considering that the detailing is based upon the <i>Diagram Moments</i>. As an alternative to specifying RigidZones as Maximum, specify walls instead of columns to effectively model columns with rigid beam arms.</p>								
5.5	Housekeeping								
5.51	Edit → Re-Label Members → re-label all slabs and beams independently between storeys.				<input type="checkbox"/>				
5.52	Edit → Re-Label Members → re-label all walls and columns consistently between storeys.				<input type="checkbox"/>				
5.6	Model Integrity								
5.61	Run → BA → Analysis Tab → Building Model Check Subsection → Building Model Check.				<input type="checkbox"/>				
5.62	Edit → Move Members to Axes → Start.				<input type="checkbox"/>				
6.0	METHOD OF ANALYSIS CHECKS								
6.1	Method of Slab Analysis and Design								
6.11	Method of Slab Analysis and Design		Method 1		Method 2		<input type="checkbox"/>		
			Conventional Codified BS8110 Coefficients Method		Full Finite Element Method Design Method				
			Slab Loads		Uniform loads			Uniform, patch, line or point loads	
			Slab Openings		Not Supported			Supported	
			Irregular Floor Plates		Not Supported			Supported	
	Flat Slabs		Not Supported		Supported				
6.2	Method of Application of Slab Loads onto Beams								
6.21	Method of Load Application onto Beams		Method 1		Method 2		<input type="checkbox"/>		
			Yield Line Method		Finite Element Method				
			Slab Loads		Uniform loads			Uniform, patch, line or point loads	
			Slab Openings		Not Supported			Supported	
	Irregular Floor Plates		Not Supported		Supported				
6.3	Method of Frame Analysis								
6.31	Vertical Load Functional Framing and Lateral Load Stability Scheme		Method of Frame Analysis			<input type="checkbox"/>			
			Method 1	Method 2					

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

ITEM	CONTENT	√																																						
	<table border="1" style="width: 100%; border-collapse: collapse; text-align: center;"> <thead> <tr style="background-color: #0056b3; color: white;"> <th colspan="2"></th> <th style="width: 25%;">BA</th> <th style="width: 25%;">CBAFE</th> </tr> </thead> <tbody> <tr> <td style="width: 40%;">Beam-Column with Shear Wall</td> <td></td> <td>Supported</td> <td>Supported</td> </tr> <tr> <td>Beam-Column as Moment Frame</td> <td></td> <td>Supported</td> <td>Supported</td> </tr> <tr> <td>Flat Slab-Column with Shear Wall</td> <td></td> <td>Supported (Meshed Slabs) ^{#A}</td> <td>Supported ^{#A}</td> </tr> <tr> <td>Flat Slab-Column as Moment Frame</td> <td></td> <td>Supported (Meshed Slabs) ^{#B}</td> <td>Supported (Support Band) ^{#B}</td> </tr> </tbody> </table> <p>#A: Check flat slab / flat transfer slab analysis undertaken with Method 1 (meshed slabs) or Method 2 with lateral loads being resisted by shear walls. #B: Check flat slab / flat transfer slab analysis undertaken with Method 1 (meshed slabs) with lateral loads being resisted by flat slab / flat transfer slab and columns moment frames or Method 2 as a workaround with Support Band type concealed beams and columns moment frames.</p>			BA	CBAFE	Beam-Column with Shear Wall		Supported	Supported	Beam-Column as Moment Frame		Supported	Supported	Flat Slab-Column with Shear Wall		Supported (Meshed Slabs) ^{#A}	Supported ^{#A}	Flat Slab-Column as Moment Frame		Supported (Meshed Slabs) ^{#B}	Supported (Support Band) ^{#B}	√																		
		BA	CBAFE																																					
Beam-Column with Shear Wall		Supported	Supported																																					
Beam-Column as Moment Frame		Supported	Supported																																					
Flat Slab-Column with Shear Wall		Supported (Meshed Slabs) ^{#A}	Supported ^{#A}																																					
Flat Slab-Column as Moment Frame		Supported (Meshed Slabs) ^{#B}	Supported (Support Band) ^{#B}																																					
6.32	<table border="1" style="width: 100%; border-collapse: collapse; text-align: center;"> <thead> <tr style="background-color: #0056b3; color: white;"> <th colspan="7">Transferred Beam/Slab on Transferred Wall/Column on Transfer Beam/Slab</th> </tr> <tr style="background-color: #0056b3; color: white;"> <th colspan="2" rowspan="3">Method of Frame Analysis</th> <th colspan="3">ULS and SLS Effects on Transferred</th> <th colspan="2">ULS and SLS Effects on Transfer</th> </tr> <tr style="background-color: #0056b3; color: white;"> <th colspan="2">Beam or Wall/Column</th> <th rowspan="2">Slab</th> <th colspan="2">Beam</th> <th rowspan="2">Slab</th> </tr> <tr style="background-color: #0056b3; color: white;"> <th>Beam or Wall/Column</th> <th>Slab in Vicinity</th> <th>Beam</th> <th>Slab in Vicinity</th> </tr> </thead> <tbody> <tr> <td style="width: 5%; text-align: center;">1</td> <td style="width: 15%; text-align: center;">BA</td> <td>Supported ^{#A, #B}</td> <td>Supported (Meshed Slabs) ^{#A, #B}</td> <td>Supported (Meshed Slabs) ^{#A, #B}</td> <td>Supported ^{#C}</td> <td>Supported (Meshed Slabs) ^{#D}</td> </tr> <tr> <td style="text-align: center;">2</td> <td style="text-align: center;">CBAFE</td> <td>Not Supported ^{#A}</td> <td>Not Supported</td> <td>Not Supported</td> <td>Supported ^{#C}</td> <td>Supported ^{#D}</td> </tr> </tbody> </table> <p>#A: Check that the envelope effects of both Method 1 (meshed slabs) and Method 2 are used in the design of transferred beams, transferred slabs in vicinity, transferred slabs and transferred walls/columns, noting that Method 1 (meshed slabs) supports the effects of differential support settlement on superstructure beams, superstructure slabs in vicinity and superstructure slabs supported on walls/columns on transfer beams or transfer slabs (meshed slabs) or due to DAS of adjacent walls/columns. Note that the actual results (which can be predicted by a staged construction analysis) fall in between the effects produced by the two methods. The ULS load combinations inherently include the effects of differential (elastic, creep, shrinkage) axial shortening. Staged construction analysis may be performed to reduce the magnitude of the effects of differential (elastic, creep, shrinkage) axial shortening. #B: Check that Method 1 (with a meshed transfer slab) or Method 1 (with Support Band type concealed beams workaround for the transfer slab) is adopted to cater for the effects of differential support settlement of transferred beams, transferred slabs in vicinity, transferred slabs and transferred walls/columns on transfer slabs. #C: Check that Method 2 is used to evaluate the effects on the transfer beams as Method 2 does not allow for the flexibility of the transfer beam resulting in larger action effects (forces, moments) on the transfer beam. #D: Check that Method 2 is used to evaluate the effect of walls/columns on transfer slabs and on slabs in the vicinity of walls/columns on transfer beams as Method 2 does not allow for the flexibility of the transfer slab / transfer beam resulting in larger action effects (forces, moments) on the transfer slab / slabs in the vicinity of transfer beams.</p>	Transferred Beam/Slab on Transferred Wall/Column on Transfer Beam/Slab							Method of Frame Analysis		ULS and SLS Effects on Transferred			ULS and SLS Effects on Transfer		Beam or Wall/Column		Slab	Beam		Slab	Beam or Wall/Column	Slab in Vicinity	Beam	Slab in Vicinity	1	BA	Supported ^{#A, #B}	Supported (Meshed Slabs) ^{#A, #B}	Supported (Meshed Slabs) ^{#A, #B}	Supported ^{#C}	Supported (Meshed Slabs) ^{#D}	2	CBAFE	Not Supported ^{#A}	Not Supported	Not Supported	Supported ^{#C}	Supported ^{#D}	□
Transferred Beam/Slab on Transferred Wall/Column on Transfer Beam/Slab																																								
Method of Frame Analysis		ULS and SLS Effects on Transferred			ULS and SLS Effects on Transfer																																			
		Beam or Wall/Column		Slab	Beam		Slab																																	
		Beam or Wall/Column	Slab in Vicinity		Beam	Slab in Vicinity																																		
1	BA	Supported ^{#A, #B}	Supported (Meshed Slabs) ^{#A, #B}	Supported (Meshed Slabs) ^{#A, #B}	Supported ^{#C}	Supported (Meshed Slabs) ^{#D}																																		
2	CBAFE	Not Supported ^{#A}	Not Supported	Not Supported	Supported ^{#C}	Supported ^{#D}																																		
6.33	<table border="1" style="width: 100%; border-collapse: collapse; text-align: center;"> <thead> <tr style="background-color: #0056b3; color: white;"> <th colspan="3">Method of Frame Analysis</th> </tr> <tr style="background-color: #0056b3; color: white;"> <th style="width: 30%;">Item</th> <th style="width: 35%;">Method 1</th> <th style="width: 35%;">Method 2</th> </tr> <tr style="background-color: #0056b3; color: white;"> <th colspan="2"></th> <th style="text-align: center;">CBAFE</th> </tr> </thead> <tbody> <tr> <td>Effect of Continuity on Beam Loading Tributary ^{#A}</td> <td>Supported (Meshed Slabs)</td> <td>Supported</td> </tr> <tr> <td>Effect of Flat Slabbing in Beam-Column Vertical Load Functional Framing</td> <td>Supported (Meshed Slabs)</td> <td>Supported</td> </tr> <tr> <td>Pattern Loading</td> <td>Supported</td> <td>Not Supported</td> </tr> <tr> <td>Effect of Slabs in Resisting Torsion of Beams</td> <td>Supported (Meshed Slabs)</td> <td>Supported</td> </tr> </tbody> </table> <p>#A: Check that Method 1 (meshed slabs) or Method 2 is used when there exist long cantilevers as the adoption of Method 1 (unmeshed slabs) together with either method of load application onto beams (i.e. the yield line method or the finite element method) would significantly underestimate the loading on the beam adjacent to the cantilever. This is so because the methods of load application onto beams replace the beams with a line of fully fixed supports, thus resulting in both internal and edge beams attracting load according to their loading tributary without any consideration of continuity.</p>	Method of Frame Analysis			Item	Method 1	Method 2			CBAFE	Effect of Continuity on Beam Loading Tributary ^{#A}	Supported (Meshed Slabs)	Supported	Effect of Flat Slabbing in Beam-Column Vertical Load Functional Framing	Supported (Meshed Slabs)	Supported	Pattern Loading	Supported	Not Supported	Effect of Slabs in Resisting Torsion of Beams	Supported (Meshed Slabs)	Supported	□																	
Method of Frame Analysis																																								
Item	Method 1	Method 2																																						
		CBAFE																																						
Effect of Continuity on Beam Loading Tributary ^{#A}	Supported (Meshed Slabs)	Supported																																						
Effect of Flat Slabbing in Beam-Column Vertical Load Functional Framing	Supported (Meshed Slabs)	Supported																																						
Pattern Loading	Supported	Not Supported																																						
Effect of Slabs in Resisting Torsion of Beams	Supported (Meshed Slabs)	Supported																																						
7.0	SLAB ANALYSIS AND DESIGN CHECKS																																							
7.1	General																																							

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

ITEM	CONTENT	✓															
7.11	In RC models, check sufficiency of number of slab strips in orthogonal directions to fully mesh slab with rebar (ES). In PT models, check sufficiency of number of slab strips in orthogonal directions to fully mesh slab with tendons (and rebar) (ES).	<input type="checkbox"/>															
7.2	Conventional Codified BS8110 Coefficients Method																
7.21	Select all slabs → Right-click → Set Slab Types Automatically to facilitate choice of bending and shear coefficients based on the conventional codified BS8110 coefficients method of slab analysis in RC models (ES). Run → Slab Analysis and Design → check sufficiency of rebar at all conventional slab strips in RC models (ES).	<input type="checkbox"/>															
7.3	Full FE Method Design Method																
7.31	Run → FEFA → check Stiffness Factors (i.e. EI) for slab and beam are 1.00 (i.e. uncracked) for Class 1 PT or Class 2 PT and 0.50 (i.e. cracked) for RC or Class 3 PT (ES).	<input type="checkbox"/>															
7.32	<table border="1" style="width: 100%; border-collapse: collapse; text-align: center;"> <thead> <tr style="background-color: #333; color: white;"> <th colspan="3">Positive and Negative Moment Factors for FEFA Effects</th> </tr> <tr> <th></th> <th>Positive Moment Factor</th> <th>Negative Moment Factor</th> </tr> </thead> <tbody> <tr> <td>(Less conservative) elasto-plastic slab design (assuming conditions of cl.3.5.2.3 BS8110-1 satisfied)</td> <td>1.2</td> <td>0.8</td> </tr> <tr> <td>(More conservative) elastic slab design (assuming conditions of cl.3.5.2.3 BS8110-1 satisfied)</td> <td>1.0</td> <td>1.0</td> </tr> <tr> <td>(More conservative) elastic slab design with equivalent pattern loading (assuming conditions of cl.3.5.2.3 BS8110-1 not satisfied)</td> <td>1.2</td> <td>1.0</td> </tr> </tbody> </table>	Positive and Negative Moment Factors for FEFA Effects				Positive Moment Factor	Negative Moment Factor	(Less conservative) elasto-plastic slab design (assuming conditions of cl.3.5.2.3 BS8110-1 satisfied)	1.2	0.8	(More conservative) elastic slab design (assuming conditions of cl.3.5.2.3 BS8110-1 satisfied)	1.0	1.0	(More conservative) elastic slab design with equivalent pattern loading (assuming conditions of cl.3.5.2.3 BS8110-1 not satisfied)	1.2	1.0	<input type="checkbox"/>
Positive and Negative Moment Factors for FEFA Effects																	
	Positive Moment Factor	Negative Moment Factor															
(Less conservative) elasto-plastic slab design (assuming conditions of cl.3.5.2.3 BS8110-1 satisfied)	1.2	0.8															
(More conservative) elastic slab design (assuming conditions of cl.3.5.2.3 BS8110-1 satisfied)	1.0	1.0															
(More conservative) elastic slab design with equivalent pattern loading (assuming conditions of cl.3.5.2.3 BS8110-1 not satisfied)	1.2	1.0															
7.33	Run → FEFA → APP → check animated deflections for modelling accuracy (ES).	<input type="checkbox"/>															
7.34	<p>PT Tendon Modelling Check tendons based on prestress force and eccentricity required for load balancing and prestress force for average precompression (ES).</p> <p>RC or PT Deflection Checks Run → FEFA → APP → check $T S = DL + PT$ deflections $\leq \{[span/500 \text{ to } span/350].C_1, 20mm\}$ (ES). Run → FEFA → APP → check $SLS = DL + SDL + LL + PT$ deflections $\leq [span/250].C_1$ (ES). Run → FEFA → APP → check $k_c.(DL + SDL) + LL + k_{c,PT}.PT$ deflections $\leq \{[span/500 \text{ to } span/350].C_1, 20mm\}$, note the creep term also includes the total (elastic, creep, shrinkage) axial shortening of the one storey in question (ES). Run → FEFA → APP → check $k_c.(DL + SDL) + LL + k_{c,PT}.PT$ deflections at façade beams $\leq \{[span/1000].C_1, 20mm\}$, note the creep term also includes the total (elastic, creep, shrinkage) axial shortening of the one storey in question (ES). Note $C_1 = \{0.8 \text{ for flanged beams, } 10.0/span(m) \text{ for spans } > 10.0m, 0.9 \text{ for flat slabs}\}$. Note deflection criteria to cl.3.4.6.3 and cl.3.4.6.4 BS8110-1 and cl.3.2.1.1 and cl.3.2.1.2 BS8110-2. Note creep factor, k_c calculated from equating $0.5.(1-0.4)DL + 1.0SDL = k_c.(DL + SDL)$ based on multiplying factor 0.5 for the total DL creep deflection component (as opposed to the instantaneous deflection component) to (1-0.4) for the remaining 60% component of DL creep deflection after 1 month (cl.7.3 BS8110-2), giving $k_c = [0.3DL + 1.0SDL] / [DL + SDL]$. Note likewise creep factor, $k_{c,PT}$ calculated as $(1-0.5/K_{LT}.K_{ST}).(1-0.4) = 0.2625$.</p> <div style="display: flex; align-items: center;">  <div style="border: 1px solid blue; padding: 10px; margin-left: 20px;"> <p style="color: blue;">L_s : slab deflection check</p> <p style="color: blue;">L_{sB} : secondary beam deflection check</p> <p style="color: blue;">L_{pB} : primary beam deflection check</p> <p style="color: blue;">L_{FR} : frame (column to column) deflection check</p> </div> </div> <p>In RC models, note if necessary, the simulation of the beneficial effect of additional reinforcement in controlling deflections can be made by factoring down the exhibited deflections by the ratio of the modified span / effective depth to the ratio of the basic span / effective depth (cantilever 7.0, simply supported 20.0, continuous 26.0) (ES).</p>	<input type="checkbox"/>															
7.35	PT Tendon Modelling Check tendons based on prestress force and eccentricity required for load balancing and prestress force for average precompression (ES).	<input type="checkbox"/>															

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

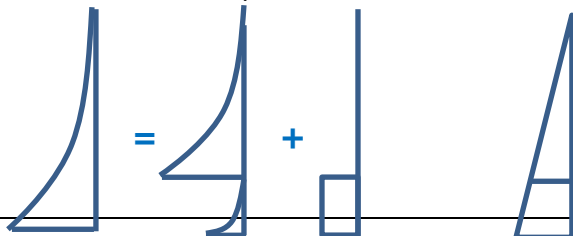
ITEM	CONTENT	√
	<p>RC or PT Design Strip Support Lines, RC or PT Design Strip Tributaries and RC or PT Design Strip Design Sections Frequency Check design strip support lines in X/Y directions (ES). Check design strip tributaries in X/Y directions and design strip design sections frequency for RC (column and middle design strip) or PT (full tributary width design strip) (ES).</p> <p>FE Analysis Method RC Analysis and Design Run → FEFA → APP → check RC analysis and design in X/Y directions (ES) → check ULS bending effects $M_{ULS,E/E}$, note w.o./w. the differential (elastic, creep, shrinkage) axial shortening of adjacent supports. → check ULS shear effects $V_{ULS,E/E}$, note w.o./w. the differential (elastic, creep, shrinkage) axial shortening of adjacent supports.</p> <p>RC Design Strip Design Sections FE Analysis Method Integration of Effects Analysis and RC Design Strip Design Sections Design Run → FEFA → APP → check design strip design sections RC analysis and design in X/Y directions (ES) → check ULS bending effects $M_{ULS,E/E}$ based on $1.4 \times$ tributary width $\times (15.0-25.0\text{kPa}) \times L^2/12$, note w.o./w. the differential (elastic, creep, shrinkage) axial shortening of adjacent supports. → check ULS shear effects $V_{ULS,E/E}$ based on $1.4 \times$ tributary width $\times (15.0-25.0\text{kPa}) \times L/2$, note w.o./w. the differential (elastic, creep, shrinkage) axial shortening of adjacent supports. → check rebar areas (to resist ULS bending) required $\{As(d)1, As(d)2\}$, noting minimum steel. → check ULS shear capacity, V_u is greater than ULS shear effects $V_{ULS,E/E}$ together with the associated required shear links $A_{sv,req}/S$. Run → Slab Analysis and Design → check sufficiency of rebar (to resist ULS bending) at all FE slab strips (ES).</p> <p>FE Analysis Method PT Analysis and Design Run → FEFA → APP → check PT analysis and design in X/Y directions (ES) → check TLS/SLS bending effects $M_{TLS/SLS,E/E} + M_{TLS/SLS,E/L}$ are minimal. → check ULS bending effects $M_{ULS,E/E} + M_{ULS,S/E}$, note w.o./w. the differential (elastic, creep, shrinkage) axial shortening of adjacent supports. Note by convention, +ve bending moment is sagging and -ve bending moment is hogging (<i>consistent</i> with ProtaStructure). → check TLS/SLS average precompression 0.7-2.5N/mm² for slab and 2.5-4.5N/mm² for beam. → check TLS top stress $f'_{min,t} \leq f'_t \leq f'_{max,t}$ BM: $-1.0 \leq f'_t \leq 0.50f_{ci}$ [CL1] $-0.36\sqrt{f_{ci}} \leq f'_t \leq 0.50f_{ci}$ [CL2] $-0.25f_{ci} \leq f'_t \leq 0.50f_{ci}$ [CL3] FS: $-1.0 \leq f'_t \leq 0.24f_{ci}$ [CL1] $-0.36\sqrt{f_{ci}} \leq f'_t \leq 0.24f_{ci}$ [CL2] $-0.45\sqrt{f_{ci}} \leq f'_t \leq 0.24f_{ci}$ [CL3] → check TLS bottom stress $f'_{min,b} \leq f'_b \leq f'_{max,b}$ BM: $-1.0 \leq f'_b \leq 0.50f_{ci}$ [CL1] $-0.36\sqrt{f_{ci}} \leq f'_b \leq 0.50f_{ci}$ [CL2] $-0.25f_{ci} \leq f'_b \leq 0.50f_{ci}$ [CL3] FS: $-1.0 \leq f'_b \leq 0.33f_{ci}$ [CL1] $-0.36\sqrt{f_{ci}} \leq f'_b \leq 0.33f_{ci}$ [CL2] $-0.45\sqrt{f_{ci}} \leq f'_b \leq 0.33f_{ci}$ [CL3] → check SLS top stress $f_{min,t} \leq f_t \leq f_{max,t}$ BM: $-0.0 \leq f_t \leq 0.33f_{cu}$ [CL1] $-0.36\sqrt{f_{cu}} \leq f_t \leq 0.33f_{cu}$ [CL2] $-<.....> \leq f_t \leq 0.33f_{cu}$ [CL3] FS: $-0.0 \leq f_t \leq 0.33f_{cu}$ [CL1] $-0.36\sqrt{f_{cu}} \leq f_t \leq 0.33f_{cu}$ [CL2] $-0.45\sqrt{f_{cu}} \leq f_t \leq 0.33f_{cu}$ [CL3] Note $-<.....> = \text{MAX} \{-0.25f_{cu}, (0.7-1.1) \cdot (-0.58\sqrt{f_{cu}} \text{ to } -0.82\sqrt{f_{cu}}) - 4\text{N/mm}^2/1.0\%\}$. → check SLS bottom stress $f_{min,b} \leq f_b \leq f_{max,b}$ BM: $-0.0 \leq f_b \leq 0.40f_{cu}$ [CL1] $-0.36\sqrt{f_{cu}} \leq f_b \leq 0.40f_{cu}$ [CL2] $-<.....> \leq f_b \leq 0.40f_{cu}$ [CL3] FS: $-0.0 \leq f_b \leq 0.24f_{cu}$ [CL1] $-0.36\sqrt{f_{cu}} \leq f_b \leq 0.24f_{cu}$ [CL2] $-0.45\sqrt{f_{cu}} \leq f_b \leq 0.24f_{cu}$ [CL3] Note $-<.....> = \text{MAX} \{-0.25f_{cu}, (0.7-1.1) \cdot (-0.58\sqrt{f_{cu}} \text{ to } -0.82\sqrt{f_{cu}}) - 4\text{N/mm}^2/1.0\%\}$. Note by convention, +ve stress is compressive and -ve stress is tensile (<i>consistent</i> with ProtaStructure).</p> <p>PT Design Strip Design Sections FE Analysis Method Integration of Effects Analysis and PT Design Strip Design Sections Design Run → FEFA → APP → check design strip design sections PT analysis and design in X/Y directions (ES) → check $T S = DL + PT$ deflections $\leq \{[\text{span}/500 \text{ to } \text{span}/350].C_1, 20\text{mm}\}$. → check $S S = DL + SDL + LL + PT$ deflections $\leq [\text{span}/250].C_1$. → check $k_c \cdot (DL + SDL) + LL + k_{c,PT} \cdot PT$ deflections $\leq \{[\text{span}/500 \text{ to } \text{span}/350].C_1, 20\text{mm}\}$, note the creep term also includes the total (elastic, creep, shrinkage) axial shortening of the one storey in question. → check $k_c \cdot (DL + SDL) + LL + k_{c,PT} \cdot PT$ deflections at façade beams $\leq \{[\text{span}/1000].C_1, 20\text{mm}\}$, note the creep term also includes the total (elastic, creep, shrinkage) axial shortening of the one storey in question. Note $C_1 = \{0.8 \text{ for flanged beams, } 10.0/\text{span(m)} \text{ for spans } > 10.0\text{m}, 0.9 \text{ for flat slabs}\}$. Note deflection criteria to cl.3.4.6.3 and cl.3.4.6.4 BS8110-1 and cl.3.2.1.1 and cl.3.2.1.2 BS8110-2. Note creep factor, k_c calculated from equating $0.5 \cdot (1-0.4)DL + 1.0SDL = k_c \cdot (DL + SDL)$ based on multiplying factor 0.5 for the total DL creep deflection component (as opposed to the instantaneous deflection component) to (1-0.4) for the remaining 60%</p>	

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

ITEM	CONTENT	√
	<p>component of DL creep deflection after 1 month (cl.7.3 BS8110-2), giving $k_c = [0.3DL + 1.0SDL] / [DL + SDL]$. Note likewise creep factor, $k_{c,PT}$ calculated as $(1 - 0.5/K_{LT} \cdot K_{ST}) \cdot (1 - 0.4) = 0.2625$.</p> <p>→ check percentage of DL+SDL load balancing is approximately 70-100%.</p> <p>→ check TLS/SLS bending effects $M_{TLS/SLS,E/E} + M_{TLS/SLS,E/L}$ are minimal.</p> <p>→ check ULS bending effects $M_{ULS,E/E} + M_{ULS,S/E}$ based on $1.4 \times$ tributary width $\times (15.0 - 25.0 \text{ kPa}) \times L^2/12$ and hyperstatic effects, note w.o./w. the differential (elastic, creep, shrinkage) axial shortening of adjacent supports.</p> <p>Note by convention, +ve bending moment is sagging and -ve bending moment is hogging (<i>consistent</i> with ProtaStructure).</p> <p>→ check TLS/SLS shear effects $V_{TLS/SLS,E/E} + V_{TLS/SLS,E/L}$ are minimal.</p> <p>→ check ULS shear effects $V_{ULS,E/E} + V_{ULS,S/E}$ based on $1.4 \times$ tributary width $\times (15.0 - 25.0 \text{ kPa}) \times L/2$ and hyperstatic effects, note w.o./w. the differential (elastic, creep, shrinkage) axial shortening of adjacent supports.</p> <p>Note an arbitrary sign convention adopted for shear force (<i>consistent</i> with ProtaStructure).</p> <p>→ check TLS/SLS average precompression $0.7 - 2.5 \text{ N/mm}^2$ for slab and $2.5 - 4.5 \text{ N/mm}^2$ for beam.</p> <p>→ check TLS top stress $f'_{min,t} \leq f'_t \leq f'_{max,t}$ BM: $-1.0 \leq f'_t \leq 0.50f_{ci}$ [CL1] $-0.36\sqrt{f_{ci}} \leq f'_t \leq 0.50f_{ci}$ [CL2] $-0.25f_{ci} \leq f'_t \leq 0.50f_{ci}$ [CL3] FS: $-1.0 \leq f'_t \leq 0.24f_{ci}$ [CL1] $-0.36\sqrt{f_{ci}} \leq f'_t \leq 0.24f_{ci}$ [CL2] $-0.45\sqrt{f_{ci}} \leq f'_t \leq 0.24f_{ci}$ [CL3] </p> <p>→ check TLS bottom stress $f'_{min,b} \leq f'_b \leq f'_{max,b}$ BM: $-1.0 \leq f'_b \leq 0.50f_{ci}$ [CL1] $-0.36\sqrt{f_{ci}} \leq f'_b \leq 0.50f_{ci}$ [CL2] $-0.25f_{ci} \leq f'_b \leq 0.50f_{ci}$ [CL3] FS: $-1.0 \leq f'_b \leq 0.33f_{ci}$ [CL1] $-0.36\sqrt{f_{ci}} \leq f'_b \leq 0.33f_{ci}$ [CL2] $-0.45\sqrt{f_{ci}} \leq f'_b \leq 0.33f_{ci}$ [CL3] </p> <p>→ check SLS top stress $f_{min,t} \leq f_t \leq f_{max,t}$ BM: $-0.0 \leq f_t \leq 0.33f_{cu}$ [CL1] $-0.36\sqrt{f_{cu}} \leq f_t \leq 0.33f_{cu}$ [CL2] $-<.....> \leq f_t \leq 0.33f_{cu}$ [CL3] FS: $-0.0 \leq f_t \leq 0.33f_{cu}$ [CL1] $-0.36\sqrt{f_{cu}} \leq f_t \leq 0.33f_{cu}$ [CL2] $-0.45\sqrt{f_{cu}} \leq f_t \leq 0.33f_{cu}$ [CL3] Note $-<.....> = \text{MAX} \{-0.25f_{cu}, (0.7 - 1.1) \cdot (-0.58\sqrt{f_{cu}} \text{ to } -0.82\sqrt{f_{cu}}) - 4 \text{ N/mm}^2 / 1.0\%$.</p> <p>→ check SLS bottom stress $f_{min,b} \leq f_b \leq f_{max,b}$ BM: $-0.0 \leq f_b \leq 0.40f_{cu}$ [CL1] $-0.36\sqrt{f_{cu}} \leq f_b \leq 0.40f_{cu}$ [CL2] $-<.....> \leq f_b \leq 0.40f_{cu}$ [CL3] FS: $-0.0 \leq f_b \leq 0.24f_{cu}$ [CL1] $-0.36\sqrt{f_{cu}} \leq f_b \leq 0.24f_{cu}$ [CL2] $-0.45\sqrt{f_{cu}} \leq f_b \leq 0.24f_{cu}$ [CL3] Note $-<.....> = \text{MAX} \{-0.25f_{cu}, (0.7 - 1.1) \cdot (-0.58\sqrt{f_{cu}} \text{ to } -0.82\sqrt{f_{cu}}) - 4 \text{ N/mm}^2 / 1.0\%$.</p> <p>Note by convention, +ve stress is compressive and -ve stress is tensile (<i>consistent</i> with ProtaStructure).</p> <p>→ check rebar areas (to resist SLS tensile stress) required $\{A_s(d)1, A_s(d)2\}$, noting minimum steel.</p> <p>→ check ULS moment capacity, M_u is greater than ULS bending effects $M_{ULS,E/E} + M_{ULS,S/E}$.</p> <p>→ check ULS shear capacity, V_u is greater than ULS shear effects $V_{ULS,E/E} + V_{ULS,S/E}$ together with the associated required shear links $A_{sv,req}/S$.</p> <p>Run → Slab Analysis and Design → check sufficiency of rebar (to resist SLS tensile stress) at all FE slab strips (ES).</p>	
RC or PT Method of Slab Detailing		
RC or PT Method of Slab Detailing		
<p>Method 1: Automatic Specification of Reinforcement Bars #A</p>	<p>Automatic specification of (top and bottom) reinforcement bars based on slab strips setting Slab Design Settings → Steel Bars → Min Steel Bar Size T10 (i.e. smallest available rebar diameter), Bar Spacing 100mm Min to 250mm Max and Steel Bar Spacing Step 25mm. Note in this method, only the 1/3rd span hogging regions will be automatically reinforced, manual addition required for top steel throughout.</p>	
<p>Method 2: Semi-Automatic Specification of Reinforcement Mesh / Bars #A</p>	<p>Automatic specification of (top) reinforcement mesh / bars based on slab strips setting Slab Design Settings → Steel Bars → Min Steel Bar Size T6, Bar Spacing 100mm Min to 200mm Max, Steel Bar Spacing Step 100mm and subsequent manual equivalent mesh substitution (where possible). Note in this method, only the 1/3rd span hogging regions will be automatically reinforced, manual addition required for top steel throughout. Manual specification of (bottom) reinforcement mesh / bars based on FEFA rebar areas required $\{A_s(d)1, A_s(d)2\}$ for slab panels (Method 3).</p>	
<p>Method 3: Manual Specification of Reinforcement Mesh / Bars #B</p>	<p>Manual specification of (top) reinforcement mesh / bars based on FEFA rebar areas required $\{A_s(d)1, A_s(d)2\}$ for slab panels. Note in this method, since it is a manual method, either only the 1/3rd span hogging regions may be reinforced or alternatively top steel may be provided throughout. Manual specification of (bottom) reinforcement mesh / bars based on FEFA rebar areas required $\{A_s(d)1, A_s(d)2\}$ for slab panels.</p>	
<p>#A: Applicable for both the Conventional Codified BS8110 Coefficients Method and the Full FEM Design method. #B: Applicable for only the Full FEM Design method.</p>		
RC or PT Analysis and Design Summary Report		
<p>Check design strip design sections forces (ES). Check design strip design sections rebar (ES).</p>		

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

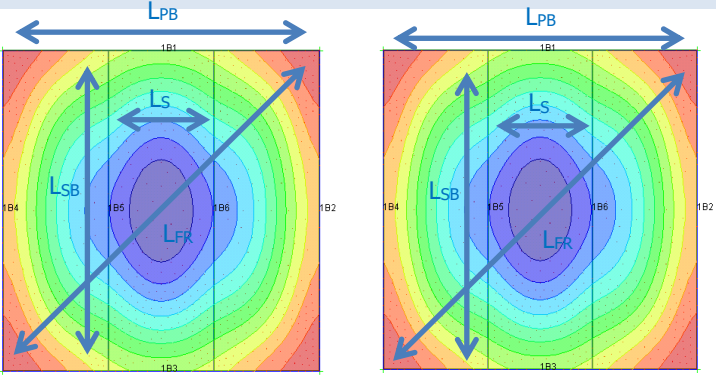
ITEM	CONTENT	√
	Check design strip design sections moment capacities (ES). Check design strip design sections dimensions (ES). Check design strip design sections geometry (ES). Check tendon and rebar plans (ES).	<input checked="" type="checkbox"/>
7.36	Manually check ULS shear stresses and shear design at beam/wall supports of heavily loaded slabs (ES).	<input type="checkbox"/>
7.37	Run → Column Punching Check → check ULS punching shear at wall/column supports of flat slabs together with the associated required shear links $A_{sv,req}$ (ES).	<input type="checkbox"/>
8.0	BEAM AND WALL/COLUMN ANALYSIS AND DESIGN CHECKS	
8.1	Building Analysis Method	
8.11	Run → BA → Post Analysis → MARD → check skeletal FE model correctly discretises the sectional model by checking animated deflections for modelling accuracy ensuring that all primary beams do frame onto their supporting columns (also displaying the primary beam ULS bending moments for clarity) (ES).	<input type="checkbox"/>
8.12	Run → BA → Post Analysis → MARD → check $ T_{LS} = DL + PT $ deflections $\leq \{[span/500 \text{ to } span/350].C_1, 20mm\}$ (ES). Run → BA → Post Analysis → MARD → check $SLS = DL + SDL + LL + PT$ deflections $\leq [span/250].C_1$ (ES). Run → BA → Post Analysis → MARD → check $k_c.(DL + SDL) + LL + PT$ deflections $\leq \{[span/500 \text{ to } span/350].C_1, 20mm\}$ (ES). Run → BA → Post Analysis → MARD → check $k_c.(DL + SDL) + LL + PT$ deflections at façade beams $\leq \{[span/1000].C_1, 20mm\}$ (ES). Note $C_1 = \{0.8 \text{ for flanged beams, } 10.0/span(m) \text{ for spans } > 10.0m, 0.9 \text{ for flat slabs}\}$. Note deflection criteria to cl.3.4.6.3 and cl.3.4.6.4 BS8110-1 and cl.3.2.1.1 and cl.3.2.1.2 BS8110-2. Note creep factor, k_c calculated from equating $0.5.(1-0.4)DL + 1.0SDL = k_c.(DL + SDL)$ based on multiplying factor 0.5 for the total DL creep deflection component (as opposed to the instantaneous deflection component) to (1-0.4) for the remaining 60% component of DL creep deflection after 1 month (cl.7.3 BS8110-2), giving $k_c = [0.3DL + 1.0SDL] / [DL + SDL]$.	<input type="checkbox"/>
8.13	Run → BA → Post Analysis → MARD → check magnitude and shape of ULS effects (axial forces, shear forces, bending moments, torsional moments) (ES).	<input type="checkbox"/>
8.14	Run → BA → Post Analysis → MARD → perform the Moment Ratio Check to comprehend the building primary lateral stability elements by both - (i) comparing the relative magnitude of the coupled shear wall / moment frame / outrigger frame / tube (shear mode) equivalent global bending moment (back-calculated by multiplying the push-pull axial forces of the walls/columns at the frame extremity with the frame extremity lever arm, noting that the effectiveness of the coupling beams / moment beams / outrigger beams / (framed) tube web spandrel beams in contributing to the base moment resisting lateral stability is measured from the existence of significant push-pull axial forces in the walls/columns at the frame extremity, from the existence of significant local zig-zag bending moments in the walls/columns (except outrigger columns and tube flange columns) or from the existence of significant zig-zag bending moments in the coupling beams / moment beams / outrigger beams / (framed) tube web spandrel beams themselves) with the magnitude of the shear wall (bending mode) cumulative bending moment (exhibited as cumulative bending moments in the shear walls or as push-pull axial forces within the flanges of flanged shear walls) from lateral loads only (noting that the summation of which shall match the stability base moment) (ES), and (ii) comparing the relative magnitude of the summation of the coupled shear wall / moment frame / outrigger frame (except outrigger columns) / (framed) tube (except tube flange columns) wall/column (shear mode) shear forces (which cause the local zig-zag bending moments in the walls/columns, noting that the effectiveness of the coupling beams / moment beams / outrigger beams / (framed) tube web spandrel beams in contributing to the base shear resisting lateral stability is measured from the existence of significant shear forces in the walls/columns (except outrigger columns and tube flange columns) or from the existence of significant shear forces in the coupling beams / moment beams / outrigger beams / (framed) tube web spandrel beams themselves) with the magnitude of the shear wall (bending mode) cumulative shear force from lateral loads only (noting that the summation of which shall match the stability base shear) (ES). Note that the effect to the stability base moment and stability base shear of a transfer floor (defined as a horizontal level at which the more extensive vertical elements on plan become discontinuous on elevation ensuing in less extensive vertical elements on plan) is firstly , the resolution of the stability base moment at the transfer level to constant push-pull axial forces in the walls/columns at the transfer frame extremity (somewhat akin to the effect of an outrigger) below the transfer level and secondly , the redistribution of stability base shear to different stability elements.	<input type="checkbox"/>



FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

ITEM	CONTENT	√
	<div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"> Stability Base Moment (MNm) </div> <div style="text-align: center;"> Stability Base Shear (MN) </div> </div>	
8.15	<p>Run → BA/STAGE → Post Analysis → MARD → and Run → FEFA → APP → check differential beam support SLS settlement (i.e. SLS settlement at the wall/column points) due to DAS of adjacent walls/columns (as a result of non-uniform column sections areas or non-uniform axial loading due to say differing building heights) and/or due to uneven flexibility of transfer beams below $\leq \text{span}/400$ (ES). Note that significant differential beam support (i.e. wall/column point) settlement is also characterised by a significant lateral deflection (sway) of the building due to DL+SDL+LL+PT alone to the side undergoing greater elastic shortening or to the side supported by walls/columns on more flexible transfer beams (thus check for lateral movement of the floor plate on plan due to DL+SDL+LL+PT alone is $\leq \text{span}/500$). The SLS load combination inherently includes the effects of differential (elastic, creep, shrinkage) axial shortening. Staged construction analysis may be performed to reduce the magnitude of the effects of differential (elastic, creep, shrinkage) axial shortening. Finally, significant differential beam support (i.e. wall/column point) settlement is also characterised by large discrepancies in the load take down, transfer beam bending moments and the higher levels beam bending moments predicted between the BA and CBAFE methods of frame analysis. The ULS load combinations inherently include the effects of differential (elastic, creep, shrinkage) axial shortening. Staged construction analysis may be performed to reduce the magnitude of the effects of differential (elastic, creep, shrinkage) axial shortening. Since it is difficult to reduce elastic shortening significantly, a better strategy is to limit the DAS by designing all walls/columns to the same axial stress level, maintain long clear spans between different structural types, i.e. between lightly-loaded cores and shear walls on the one hand and heavily loaded columns on the other or introduce settlement joints / pour strips between areas subject to large DAS (ES).</p>	<input type="checkbox"/>
8.16	Manually check that the bending moment design, ultimate shear force (ultimate shear stress) check and shear force design of beams with incoming offset beams (i.e. secondary beams that frame into the beam in question within the footprint of the wall/column) with a physical width that protrudes beyond the wall/column footprint is sufficiently enhanced (ES).	<input type="checkbox"/>
8.17	Manually check beams (especially heavily loaded beams / transfer beams) with widths larger than the supporting wall/column width for ultimate shear and design shear within a beam width equal to the supporting wall/column width, notwithstanding the reverse analogy to multi column footing foundation shear design where the full width of the footing beam contributes to the ultimate and design shear capacity. These beams need also be manually checked for ULS punching shear (ES).	<input type="checkbox"/>
8.18	Manually check ULS shear stresses and shear design at transferred walls on transfer beams.	<input type="checkbox"/>
8.19	Manually check ULS punching shear at transferred walls/columns on transfer beams.	<input type="checkbox"/>
8.2	Combination of Building Analysis and the FE Based Gravity Load Chase Down Method	
8.21	<p>Run → FEFA (CBAFE) → check (uncracked) Stiffness Factors (i.e. EI) for (transfer) slab and (transfer) beam are $(2/3^{\text{rd}}) \cdot (1.00) \approx 0.66$ for Class 1 PT or Class 2 PT, note the further $2/3^{\text{rd}}$ reduction factor applied to simulate the additional deflection due to creep to storage loading instead of normal loading (i.e. creep coefficient, $\phi=2$ for storage loading instead of $\phi=1$ for normal loading).</p> <p>Run → FEFA (CBAFE) → check (cracked) Stiffness Factors (i.e. EI) for (transfer) slab and (transfer) beam are $(2/3^{\text{rd}}) \cdot (0.50) \approx 0.32$ for RC or Class 3 PT, note the further $2/3^{\text{rd}}$ reduction factor applied to simulate the additional deflection due to creep to storage loading instead of normal loading (i.e. creep coefficient, $\phi=2$ for storage loading instead of $\phi=1$ for normal loading).</p>	<input type="checkbox"/>
8.22	<p>PT Tendon Modelling Check tendons based on prestress force and eccentricity required for load balancing and prestress force for average precompression.</p> <p>RC or PT Deflection Checks Run → FEFA (CBAFE) → APP → check $\text{TLS} = \text{DL} + \text{PT}$ deflections $\leq \{[\text{span}/500 \text{ to } \text{span}/350].C_1, 20\text{mm}\}$. Run → FEFA (CBAFE) → APP → check $\text{SLS} = \text{DL} + \text{SDL} + \text{LL} + \text{PT}$ deflections $\leq [\text{span}/250].C_1$. Run → FEFA (CBAFE) → APP → check $k_c \cdot (\text{DL} + \text{SDL}) + \text{LL} + k_{c,PT} \cdot \text{PT}$ deflections $\leq \{[\text{span}/500 \text{ to } \text{span}/350].C_1, 20\text{mm}\}$, note the creep term also includes the total (elastic, creep, shrinkage) axial shortening of the one storey in question. Run → FEFA (CBAFE) → APP → check $k_c \cdot (\text{DL} + \text{SDL}) + \text{LL} + k_{c,PT} \cdot \text{PT}$ deflections at façade beams $\leq \{[\text{span}/1000].C_1, 20\text{mm}\}$, note the creep term also includes the total (elastic, creep, shrinkage) axial shortening of the one storey in question.</p> <p>Note deflections above refer to deflections of all transfer slabs and slabs in the vicinity of transfer beams. Note $C_1 = \{0.8 \text{ for flanged beams, } 10.0/\text{span(m)} \text{ for spans } > 10.0\text{m, } 0.9 \text{ for flat slabs}\}$. Note deflection criteria to cl.3.4.6.3 and cl.3.4.6.4 BS8110-1 and cl.3.2.1.1 and cl.3.2.1.2 BS8110-2. Note creep factor, k_c calculated from equating $(1-0.32) \cdot (1-0.4) \text{DL} + 1.0\text{SDL} = k_c \cdot (\text{DL} + \text{SDL})$ based on multiplying factor $(1-0.32)$ for the total DL creep deflection component (as opposed to the instantaneous deflection component) to $(1-0.4)$ for the remaining 60% component of DL creep deflection after 1 month (cl.7.3 BS8110-2), giving $k_c = [0.4\text{DL} + 1.0\text{SDL}] / [\text{DL} + \text{SDL}]$. Note likewise creep factor, $k_{c,PT}$ calculated as $(1-0.32/K_{LT} \cdot K_{ST}) \cdot (1-0.4) = 0.375$.</p>	<input type="checkbox"/>

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

ITEM	CONTENT	✓
	 <div data-bbox="1015 286 1390 600" style="border: 1px solid blue; padding: 5px;"> <p>L_S : slab deflection check</p> <p>L_{SB} : secondary beam deflection check</p> <p>L_{PB} : primary beam deflection check</p> <p>L_{FR} : frame (column to column) deflection check</p> </div>	✓
8.23	<p>In RC models, note if necessary, the simulation of the beneficial effect of additional reinforcement in controlling deflections can be made by factoring down the exhibited deflections by the ratio of the modified span / effective depth to the ratio of the basic span / effective depth (cantilever 7.0, simply supported 20.0, continuous 26.0).</p> <p>Note here that in the following subsection, slab refers to transfer slab and slabs in the vicinity of transfer beams and beam refers to transfer beam.</p> <p>PT Tendon Modelling Check tendons based on prestress force and eccentricity required for load balancing and prestress force for average precompression.</p> <p>RC or PT Design Strip Support Lines, RC or PT Design Strip Tributaries and RC or PT Design Strip Design Sections Frequency Check design strip support lines in X/Y directions. Check design strip tributaries in X/Y directions and design strip design sections frequency for RC (column and middle design strip) or PT (full tributary width design strip).</p> <p>FE Analysis Method RC Analysis and Design Run → FEFA (CBAFE) → APP → check RC analysis and design in X/Y directions → check ULS bending effects $M_{ULS,E/E}$, note w.o./w. the differential (elastic, creep, shrinkage) axial shortening of adjacent supports. → check ULS shear effects $V_{ULS,E/E}$, note w.o./w. the differential (elastic, creep, shrinkage) axial shortening of adjacent supports.</p> <p>RC Design Strip Design Sections FE Analysis Method Integration of Effects Analysis and RC Design Strip Design Sections Design Run → FEFA (CBAFE) → APP → check design strip design sections RC analysis and design in X/Y directions → check ULS bending effects $M_{ULS,E/E}$ based on $1.4 \times \text{tributary width} \times (15.0-25.0\text{kPa}) \times L^2/12$, note w.o./w. the differential (elastic, creep, shrinkage) axial shortening of adjacent supports. → check ULS shear effects $V_{ULS,E/E}$ based on $1.4 \times \text{tributary width} \times (15.0-25.0\text{kPa}) \times L/2$, note w.o./w. the differential (elastic, creep, shrinkage) axial shortening of adjacent supports. → check rebar areas (to resist ULS bending) required $\{A_s(d)1, A_s(d)2\}$, noting minimum steel. → check ULS shear capacity, V_u is greater than ULS shear effects $V_{ULS,E/E}$ together with the associated required shear links $A_{sv,req}/S$. Run → FEFA (CBAFE) → Run → Slab Analysis and Design → check sufficiency of rebar (to resist ULS bending) at all FE slab strips.</p> <p>FE Analysis Method PT Analysis and Design Run → FEFA (CBAFE) → APP → check PT analysis and design in X/Y directions → check TLS/SLS bending effects $M_{TLS/SLS,E/E} + M_{TLS/SLS,E/L}$ are minimal. → check ULS bending effects $M_{ULS,E/E} + M_{ULS,S/E}$, note w.o./w. the differential (elastic, creep, shrinkage) axial shortening of adjacent supports. Note by convention, +ve bending moment is sagging and -ve bending moment is hogging (<i>consistent</i> with ProtaStructure). → check TLS/SLS average precompression 0.7-2.5N/mm² for slab and 2.5-4.5N/mm² for beam. → check TLS top stress $f'_{min,t} \leq f'_t \leq f'_{max,t}$ BM: $-1.0 \leq f'_t \leq 0.50f_{ci}$ [CL1] $-0.36\sqrt{f_{ci}} \leq f'_t \leq 0.50f_{ci}$ [CL2] $-0.25f_{ci} \leq f'_t \leq 0.50f_{ci}$ [CL3] FS: $-1.0 \leq f'_t \leq 0.24f_{ci}$ [CL1] $-0.36\sqrt{f_{ci}} \leq f'_t \leq 0.24f_{ci}$ [CL2] $-0.45\sqrt{f_{ci}} \leq f'_t \leq 0.24f_{ci}$ [CL3] → check TLS bottom stress $f'_{min,b} \leq f'_b \leq f'_{max,b}$ BM: $-1.0 \leq f'_b \leq 0.50f_{ci}$ [CL1] $-0.36\sqrt{f_{ci}} \leq f'_b \leq 0.50f_{ci}$ [CL2] $-0.25f_{ci} \leq f'_b \leq 0.50f_{ci}$ [CL3] FS: $-1.0 \leq f'_b \leq 0.33f_{ci}$ [CL1] $-0.36\sqrt{f_{ci}} \leq f'_b \leq 0.33f_{ci}$ [CL2] $-0.45\sqrt{f_{ci}} \leq f'_b \leq 0.33f_{ci}$ [CL3] </p>	□

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

ITEM	CONTENT	✓
	<p>→ check SLS top stress $f_{min,t} \leq f_t \leq f_{max,t}$ BM: $-0.0 \leq f_t \leq 0.33f_{cu}$ [CL1] $-0.36\sqrt{f_{cu}} \leq f_t \leq 0.33f_{cu}$ [CL2] $-\dots \leq f_t \leq 0.33f_{cu}$ [CL3] FS: $-0.0 \leq f_t \leq 0.33f_{cu}$ [CL1] $-0.36\sqrt{f_{cu}} \leq f_t \leq 0.33f_{cu}$ [CL2] $-0.45\sqrt{f_{cu}} \leq f_t \leq 0.33f_{cu}$ [CL3] Note $-\dots = \text{MAX} \{-0.25f_{cu}, (0.7-1.1) \cdot (-0.58\sqrt{f_{cu}} \text{ to } -0.82\sqrt{f_{cu}}) - 4N/mm^2/1.0\%$.</p> <p>→ check SLS bottom stress $f_{min,b} \leq f_b \leq f_{max,b}$ BM: $-0.0 \leq f_b \leq 0.40f_{cu}$ [CL1] $-0.36\sqrt{f_{cu}} \leq f_b \leq 0.40f_{cu}$ [CL2] $-\dots \leq f_b \leq 0.40f_{cu}$ [CL3] FS: $-0.0 \leq f_b \leq 0.24f_{cu}$ [CL1] $-0.36\sqrt{f_{cu}} \leq f_b \leq 0.24f_{cu}$ [CL2] $-0.45\sqrt{f_{cu}} \leq f_b \leq 0.24f_{cu}$ [CL3] Note $-\dots = \text{MAX} \{-0.25f_{cu}, (0.7-1.1) \cdot (-0.58\sqrt{f_{cu}} \text{ to } -0.82\sqrt{f_{cu}}) - 4N/mm^2/1.0\%$.</p> <p>Note by convention, +ve stress is compressive and -ve stress is tensile (<i>consistent</i> with ProtaStructure).</p> <p>PT Design Strip Design Sections FE Analysis Method Integration of Effects Analysis and PT Design Strip Design Sections Design</p> <p>Run → FEFA (CBAFE) → APP → check design strip design sections PT analysis and design in X/Y directions</p> <p>→ check T_{LS} = DL+PT deflections ≤ {[span/500 to span/350].C₁, 20mm}.</p> <p>→ check SLS=DL+SDL+LL+PT deflections ≤ [span/250].C₁.</p> <p>→ check k_c.(DL+SDL)+LL+k_{c,PT}.PT deflections ≤ {[span/500 to span/350].C₁, 20mm}, note the creep term also includes the total (elastic, creep, shrinkage) axial shortening of the one storey in question.</p> <p>→ check k_c.(DL+SDL)+LL+k_{c,PT}.PT deflections at façade beams ≤ {[span/1000].C₁, 20mm}, note the creep term also includes the total (elastic, creep, shrinkage) axial shortening of the one storey in question.</p> <p>Note C₁ = {0.8 for flanged beams, 10.0/span(m) for spans > 10.0m, 0.9 for flat slabs}. Note deflection criteria to cl.3.4.6.3 and cl.3.4.6.4 BS8110-1 and cl.3.2.1.1 and cl.3.2.1.2 BS8110-2. Note creep factor, k_c calculated from equating 0.5.(1-0.4)DL+1.0SDL=k_c.(DL+SDL) based on multiplying factor 0.5 for the total DL creep deflection component (as opposed to the instantaneous deflection component) to (1-0.4) for the remaining 60% component of DL creep deflection after 1 month (cl.7.3 BS8110-2), giving k_c=[0.3DL+1.0SDL]/[DL+SDL]. Note likewise creep factor, k_{c,PT} calculated as (1-0.32/K_{LT}.K_{ST}). (1-0.4)=0.375.</p> <p>→ check percentage of DL+SDL load balancing is approximately 70-100%.</p> <p>→ check TLS/SLS bending effects M_{TLS/SLS,E/E}+M_{TLS/SLS,E/L} are minimal.</p> <p>→ check ULS bending effects M_{ULS,E/E}+M_{ULS,S/E} based on 1.4 x tributary width x (15.0-25.0kPa) x L²/12 and hyperstatic effects, note w.o./w. the differential (elastic, creep, shrinkage) axial shortening of adjacent supports.</p> <p>Note by convention, +ve bending moment is sagging and -ve bending moment is hogging (<i>consistent</i> with ProtaStructure).</p> <p>→ check TLS/SLS shear effects V_{TLS/SLS,E/E}+V_{TLS/SLS,E/L} are minimal.</p> <p>→ check ULS shear effects V_{ULS,E/E}+V_{ULS,S/E} based on 1.4 x tributary width x (15.0-25.0kPa) x L/2 and hyperstatic effects, note w.o./w. the differential (elastic, creep, shrinkage) axial shortening of adjacent supports.</p> <p>Note an arbitrary sign convention adopted for shear force (<i>consistent</i> with ProtaStructure).</p> <p>→ check TLS/SLS average precompression 0.7-2.5N/mm² for slab and 2.5-4.5N/mm² for beam.</p> <p>→ check TLS top stress $f'_{min,t} \leq f'_t \leq f'_{max,t}$ BM: $-1.0 \leq f'_t \leq 0.50f_{ci}$ [CL1] $-0.36\sqrt{f_{ci}} \leq f'_t \leq 0.50f_{ci}$ [CL2] $-0.25f_{ci} \leq f'_t \leq 0.50f_{ci}$ [CL3] FS: $-1.0 \leq f'_t \leq 0.24f_{ci}$ [CL1] $-0.36\sqrt{f_{ci}} \leq f'_t \leq 0.24f_{ci}$ [CL2] $-0.45\sqrt{f_{ci}} \leq f'_t \leq 0.24f_{ci}$ [CL3] </p> <p>→ check TLS bottom stress $f'_{min,b} \leq f'_b \leq f'_{max,b}$ BM: $-1.0 \leq f'_b \leq 0.50f_{ci}$ [CL1] $-0.36\sqrt{f_{ci}} \leq f'_b \leq 0.50f_{ci}$ [CL2] $-0.25f_{ci} \leq f'_b \leq 0.50f_{ci}$ [CL3] FS: $-1.0 \leq f'_b \leq 0.33f_{ci}$ [CL1] $-0.36\sqrt{f_{ci}} \leq f'_b \leq 0.33f_{ci}$ [CL2] $-0.45\sqrt{f_{ci}} \leq f'_b \leq 0.33f_{ci}$ [CL3] </p> <p>→ check SLS top stress $f_{min,t} \leq f_t \leq f_{max,t}$ BM: $-0.0 \leq f_t \leq 0.33f_{cu}$ [CL1] $-0.36\sqrt{f_{cu}} \leq f_t \leq 0.33f_{cu}$ [CL2] $-\dots \leq f_t \leq 0.33f_{cu}$ [CL3] FS: $-0.0 \leq f_t \leq 0.33f_{cu}$ [CL1] $-0.36\sqrt{f_{cu}} \leq f_t \leq 0.33f_{cu}$ [CL2] $-0.45\sqrt{f_{cu}} \leq f_t \leq 0.33f_{cu}$ [CL3] Note $-\dots = \text{MAX} \{-0.25f_{cu}, (0.7-1.1) \cdot (-0.58\sqrt{f_{cu}} \text{ to } -0.82\sqrt{f_{cu}}) - 4N/mm^2/1.0\%$.</p> <p>→ check SLS bottom stress $f_{min,b} \leq f_b \leq f_{max,b}$ BM: $-0.0 \leq f_b \leq 0.40f_{cu}$ [CL1] $-0.36\sqrt{f_{cu}} \leq f_b \leq 0.40f_{cu}$ [CL2] $-\dots \leq f_b \leq 0.40f_{cu}$ [CL3] FS: $-0.0 \leq f_b \leq 0.24f_{cu}$ [CL1] $-0.36\sqrt{f_{cu}} \leq f_b \leq 0.24f_{cu}$ [CL2] $-0.45\sqrt{f_{cu}} \leq f_b \leq 0.24f_{cu}$ [CL3] Note $-\dots = \text{MAX} \{-0.25f_{cu}, (0.7-1.1) \cdot (-0.58\sqrt{f_{cu}} \text{ to } -0.82\sqrt{f_{cu}}) - 4N/mm^2/1.0\%$.</p> <p>Note by convention, +ve stress is compressive and -ve stress is tensile (<i>consistent</i> with ProtaStructure).</p> <p>→ check rebar areas (to resist SLS tensile stress) required {As(d)1, As(d)2}, noting minimum steel.</p> <p>→ check ULS moment capacity, M_u is greater than ULS bending effects M_{ULS,E/E}+M_{ULS,S/E}.</p> <p>→ check ULS shear capacity, V_u is greater than ULS shear effects V_{ULS,E/E}+V_{ULS,S/E} together with the associated required shear links A_{sv,req}/S.</p> <p>Run → FEFA (CBAFE) → Run → Slab Analysis and Design → check sufficiency of rebar (to resist SLS tensile stress) at all FE slab strips.</p>	✓
8.24	<p>Note here that in the following subsection, slab refers to transfer slab and slabs in the vicinity of transfer beams and beam refers to transfer beam.</p> <p>RC or PT Analysis and Design Summary Report</p>	□

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

ITEM	CONTENT	✓
	<p>Check design strip design sections forces. Check design strip design sections rebar. Check design strip design sections moment capacities. Check design strip design sections dimensions. Check design strip design sections geometry. Check tendon and rebar plans.</p>	<input checked="" type="checkbox"/>
8.25	Manually check ULS shear stresses and shear design at beam/wall supports of transfer slabs.	<input type="checkbox"/>
8.26	Run → FEFA (CBAFE) → Run → Column Punching Check → check ULS punching shear at wall/column supports of transfer slabs together with the associated required shear links $A_{sv,req}$.	<input type="checkbox"/>
8.27	Manually check ULS shear stresses and shear design at transferred walls on transfer slabs.	<input type="checkbox"/>
8.28	Manually check ULS punching shear at transferred walls/columns on transfer slabs.	<input type="checkbox"/>
8.3	FE Model III-Conditioning	
8.31	<p>Building Analysis Method Run → BA → Analysis Tab → Axial Load Comparison Report → check consistency between the applied undecomposed slab loads (Table 1), applied decomposed slab loads (Table 2) and the reactions presented in the column / wall axial loads (Table 3).</p> <p>Combination of Building Analysis and the FE Based Gravity Load Chase Down Method Run → BA → Analysis Tab → Axial Load Comparison Report → check consistency between the applied undecomposed slab loads (Table 1) and the reactions presented in the FE analysis column / wall axial loads (Table 4).</p>	<input type="checkbox"/>
8.4	Load Take Down	
8.41	Run → BA → Analysis Tab → Axial Load Comparison Report → check SLS load $\approx 15.0\text{-}25.0\text{kPa}$ for typical concrete and 10.0kPa for typical steel residential and commercial buildings (ES). Note check load take down calculation for BA / CBAFE .	<input type="checkbox"/>
8.42	<p>Run → BA → Post Analysis → MARD → filtering out beams to only show walls/columns, check Axial Load in all walls/columns to visually inspect the sensibility of the load take down, e.g. only compression loads in walls/column, no zero loads to ensure no erroneous unattached walls/columns and no tension loads to ensure no erroneous hanging walls/columns.</p> <p>St01 → Active Windows Settings → Columns Plan Display Tab → Display Analysis Results Subsection → enable display of Axial Load, Moment and Shear Force for appropriate Loading Combinations to visually display Bottom loading effects, noting that directions 1 and 2 refer to the local axes (i.e. axis direction 1 and 2, respectively) → check Axial Load (ensuring no uplift) for all walls/columns and Axial Load (ensuring no uplift), Moment and Shear Force for stability walls/columns (ES but primarily above the transfer floor and foundations). In addition for EQ combination cases, EQ base shear force for foundations to be calculated with the lateral and vertical EQ loads in the EQ combination cases enhanced by the overstrength and multiplicative factors, $\gamma_{Rd,\Omega}$ as per cl.4.4.2.6 BS EN1998-1. Note perform load take down calculation and likewise foundation SLS load combinations reporting for BA / CBAFE.</p>	<input type="checkbox"/>
8.5	Sway Susceptibility (NHF, Wind, EQ)	
8.51	<p>Run → BA → Reports Tab → check Sway Classification Report $Q \leq 0.05$ for $\lambda \geq 20$ for BA / CBAFE, else amplify lateral loads (wind, EQ) with the amplified sway factor, $m = \lambda/(\lambda-1)$ to a maximum of $m = 1.33$ corresponding to $Q \leq 0.25$ and $\lambda \geq 4.0$ as the limit of linearity of the static analysis (cl.R6.2.6 ACI 318-14).</p> <ul style="list-style-type: none"> ULS sway susceptibility to NHF / wind load combinations should be analysed with modified default stiffness parameters {Class 1 PT or Class 2 PT slab/beam: $k_E=2.0, k_I=0.7, k_J=0.7$; RC or Class 3 PT slab/beam: $k_E=2.0, k_I=0.35, k_J=0.35$; wall/column: $k_E=2.0, k_I=0.7, k_J=0.7$} and other lateral load combinations (EQ) deleted. ULS sway susceptibility to EQ load combinations should be analysed with modified default stiffness parameters {Class 1 PT or Class 2 PT slab/beam: $k_E=2.0, k_I=0.7, k_J=0.7$; RC or Class 3 PT slab/beam: $k_E=2.0, k_I=0.35, k_J=0.35$; wall/column: $k_E=2.0, k_I=0.35, k_J=0.35$} and other lateral load combinations (NHF, wind) deleted. Further, the lateral EQ displacements from the SLS EQ load combinations are to be enhanced by the adopted behaviour factor, q as per cl.4.3.4 BS EN1998-1. 	<input type="checkbox"/>
8.6	Lateral Deflections / Torsional Twist	
8.61	Run → BA → Reports Tab → Post-Analysis Checks Report → optionally check total building lateral deflections to NHF , $\delta_{total} \leq H_{total}/500$ and relative storey drift, $\Delta\delta_{storey,I} \leq h_{storey,I}/500$ (ES). NHF load combinations should be analysed with modified default stiffness parameters {Class 1 PT or Class 2 PT slab/beam: $k_E=2.0, k_I=1.0, k_J=1.0$; RC or Class 3 PT slab/beam: $k_E=2.0, k_I=0.5, k_J=0.5$; wall/column: $k_E=2.0, k_I=1.0, k_J=1.0$ }, NHF load factors reset to 1.0 , other lateral load combinations (wind, EQ) deleted and as a last resort adopting flanged beam sections in lieu of rectangular beam sections.	<input type="checkbox"/>
8.62	Run → BA → Post Analysis → MARD → optionally check on-plan torsional twist due to NHF indicating if the offset between the centre of gravity / mass and centre of stiffness is $\leq \text{span}/500$ (ES). NHF load combinations should be analysed with modified default stiffness parameters {Class 1 PT or Class 2 PT slab/beam: $k_E=2.0, k_I=1.0, k_J=1.0$; RC or Class 3 PT slab/beam: $k_E=2.0, k_I=0.5, k_J=0.5$; wall/column: $k_E=2.0, k_I=1.0, k_J=1.0$ }, NHF load factors reset to 1.0 , other lateral load combinations (wind, EQ) deleted and as a last resort adopting flanged	<input type="checkbox"/>

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

ITEM	CONTENT	√
	beam sections in lieu of rectangular beam sections.	
8.63	Run → BA → Reports Tab → Storey Displacements Report → check total building lateral deflections to wind , $\delta_{total} \leq H_{total}/500$ and relative storey drift, $\Delta\delta_{storey,I} \leq h_{storey,I}/500$ (ES) to cl.3.2.2.2 BS8110-2. SLS wind load combinations should be analysed with modified default stiffness parameters {Class 1 PT or Class 2 PT slab/beam: $k_E=2.0, k_I=1.0, k_J=1.0$; RC or Class 3 PT slab/beam: $k_E=2.0, k_I=0.5, k_J=0.5$; wall/column: $k_E=2.0, k_I=1.0, k_J=1.0$ }, wind load factors reset to 1.0, other lateral load combinations (NHF, EQ) deleted and as a last resort adopting flanged beam sections in lieu of rectangular beam sections.	<input type="checkbox"/>
8.64	Run → BA → Post Analysis → MARD → check on-plan torsional twist due to wind indicating if the offset between the centre of elevation and centre of stiffness is $\leq \text{span}/500$ (ES). SLS wind load combinations should be analysed with modified default stiffness parameters {Class 1 PT or Class 2 PT slab/beam: $k_E=2.0, k_I=1.0, k_J=1.0$; RC or Class 3 PT slab/beam: $k_E=2.0, k_I=0.5, k_J=0.5$; wall/column: $k_E=2.0, k_I=1.0, k_J=1.0$ }, wind load factors reset to 1.0, other lateral load combinations (NHF, EQ) deleted and as a last resort adopting flanged beam sections in lieu of rectangular beam sections.	<input type="checkbox"/>
8.65	Run → BA → Reports Tab → Storey Displacements Report → check total building lateral deflections to EQ , $v.q.\delta_{total} \leq H_{total}/250$ and relative storey drift, $v.q.\Delta\delta_{storey,I} \leq h_{storey,I}/250$ (ES) as per cl.4.4.3.2 BS EN1998-1. SLS EQ load combinations should be analysed with modified default stiffness parameters {Class 1 PT or Class 2 PT slab/beam: $k_E=2.0, k_I=1.0, k_J=1.0$; RC or Class 3 PT slab/beam: $k_E=2.0, k_I=0.5, k_J=0.5$; wall/column: $k_E=2.0, k_I=0.5, k_J=0.5$ } and other lateral load combinations (NHF, wind) deleted. Further, the lateral EQ displacements from the SLS EQ load combinations are to be enhanced by the adopted behaviour factor, q as per cl.4.3.4 BS EN1998-1.	<input type="checkbox"/>
8.66	Run → BA → Post Analysis → MARD → check on-plan torsional twist due to EQ indicating if the offset between the centre of gravity / mass and centre of stiffness is $\leq \text{span}/500$ (ES). SLS EQ load combinations should be analysed with modified default stiffness parameters {Class 1 PT or Class 2 PT slab/beam: $k_E=2.0, k_I=1.0, k_J=1.0$; RC or Class 3 PT slab/beam: $k_E=2.0, k_I=0.5, k_J=0.5$; wall/column: $k_E=2.0, k_I=0.5, k_J=0.5$ } and other lateral load combinations (NHF, wind) deleted. Further, the lateral EQ displacements from the SLS EQ load combinations are to be enhanced by the adopted behaviour factor, q as per cl.4.3.4 BS EN1998-1.	<input type="checkbox"/>
8.7	Beam Design	
8.71	VIM → Design Status → check design status of RC beams (ES). Check design status of PT beam design strips design sections (ES).	<input type="checkbox"/>
8.72	In RC models, Run → Beam Reinforcement Design → Storey Beams → Design Tab → Beam Design (Batch Mode) → Calculate for BA / CBAFE → check Messages for failed beams, especially in shear (ES). In PT models, check beam design strip design sections tendons (and rebar) design for BA / CBAFE (ES).	<input type="checkbox"/>
8.73	In RC models, for common beam details in all duplicate storeys, the function Run → Beam Reinforcement Design → Storey Beams → Design Tab → Copy Steel Bars to Clipboard and Paste Steel Bars from Clipboard (applied onto the user-selected duplicate beams using Shift + Select) is used. Alternatively, select Run → Beam Reinforcement Design → Storey Beams → Grouping Tab → Automatic Grouping → Group Beam Axes Vertically. For common beam details between similar beams within the storey, the function Run → Beam Reinforcement Design → Storey Beams → Design Tab → Copy Steel Bars to Clipboard and Paste Steel Bars from Clipboard (applied onto the user-selected similar beams using Shift + Select) is used. Alternatively, select Run → Beam Reinforcement Design → Storey Beams → Grouping Tab → Automatic Grouping → Group Beam Axes Within Floor (ES). In PT models, check common beam details in all duplicate storeys and between similar beams within the storey (ES).	<input type="checkbox"/>
8.74	In RC models, Run → Beam Reinforcement Design → Storey Beams → Design Tab → Beam Capacity Reports → check % steel $\ll 4\%$ and design shear stress $\approx 3N/mm^2 \ll 5N/mm^2$ for BA / CBAFE (ES including duplicate storeys). In PT models, check design shear stress $\approx 3N/mm^2 \ll 5N/mm^2$ for BA / CBAFE (ES including duplicate storeys).	<input type="checkbox"/>
8.75	In RC models, Run → Beam Reinforcement Design → Storey Beams → Design Tab → Beam Design Report → check beam detailed design report for BA / CBAFE (ES including duplicate storeys). In PT models, check beam detailed design report for BA / CBAFE (ES including duplicate storeys).	<input type="checkbox"/>
8.76	In RC and PT models, manually perform ULS longitudinal shear check within web and between web and flanges for heavily loaded transfer beams if ULS shear stresses are greater than those stipulated on T.5.5 BS8110-1 for BA / CBAFE . Manually perform deep beam design for the transfer beam should the span to depth ratio be ≤ 2.0 simply-supported or 2.5 continuous (CIRIA Guide 2). Manually perform strut and tie truss analogy design for the transferred wall (acting as the diagonal compression element) and transfer beam (acting as the tension element).	<input type="checkbox"/>
8.77	In RC models, manually check compliance to the deflection criteria for non-prismatic beams by recalculating the actual span / depth ratio based on the total beam span instead of the segmented beam span for BA / CBAFE (ES).	<input type="checkbox"/>
8.78	Building RC and PT beam final comprehensive design check (ES) #A	
8.781	BA → check design → % steel $\ll 4\%$ → $\tau \approx 3 \ll 5N/mm^2$ →	<input type="checkbox"/>

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

ITEM	CONTENT	√
8.782	CBAFE → check design → % steel << 4% → $\tau \approx 3 \ll 5\text{N/mm}^2$ →	<input type="checkbox"/>
	#A Note for models with EQ loads, ULS EQ load combinations should be analysed on models with the following modified default stiffness parameters {Class 1 PT or Class 2 PT slab/beam: $k_E=1.0, k_I=1.0, k_J=1.0$; RC or Class 3 PT slab/beam: $k_E=1.0, k_I=0.5, k_J=0.5$; wall/column: $k_E=1.0, k_I=0.5, k_J=0.5$ }.	
8.79	Manual modification of RC and PT beam detailing as follows: - (a) incorporation of outer perimeter torsion links at heavily loaded transfer beam sections. (b) elongation of rebar and links for the portions of transfer beam beneath transferred walls. (c) inclusion of additional shear links / hooks for very wide beams to satisfy the 150mm maximum spacing requirement of cl.3.12.7.2 BS8110-1 noting that maximum number of closed shear links in ProtaStructure is 3 (ES). (d) appropriate enhancement to non-prismatic beams (ES). (e) search for single rebar specification, e.g. 1T12, 1T16, 1T20, 1T25, 1T32 or 1T40 within the beam dxfs (ES). (f) for models with EQ loads stabilised by moment frames, enhancement to the primary seismic beam maximum link spacing, s should be provided based on cl.5.4.3.1.2 BS EN1998-1 (DCM) which states $s = \min \{\text{beam depth} / 4; 24 \times \text{link diameter}; 225\text{mm}; 8 \times \text{longitudinal bar diameter}\}$ and cl.5.5.3.1.3 BS EN1998-1 (DCH) which states $s = \min \{\text{beam depth} / 4; 24 \times \text{link diameter}; 175\text{mm}; 6 \times \text{longitudinal bar diameter}\}$ (ES).	<input type="checkbox"/>
8.8	Wall/Column Design	
8.81	VIM → Design Status → check design status of walls/columns (ES).	<input type="checkbox"/>
8.82	Run → Column Section Design → Design Tab → Column Design (Batch Mode) → Design for both frame analysis methods and both column design theories , i.e. BA + cl.3.8.4.5 BS8110-1 theory, BA + biaxial bending theory, CBAFE + cl.3.8.4.5 BS8110-1 theory and CBAFE + biaxial bending theory → check Messages for failed walls/columns, especially for insufficient section (ES). Note that the cl.3.8.4.5 BS8110-1 theory is more conservative (less economic) compared to the biaxial bending theory.	<input type="checkbox"/>
8.83	Run → Column Section Design → Design Tab → Steel Standardisation → check reinforcement only increases down the building and decreases up the building (in general). Alternatively, for common column details between certain storeys, the function Run → Column Section Design → Design Tab → Copy Steel Bars to Clipboard and Paste Steel Bars from Clipboard (applied onto the user-selected certain columns using Shift + Select) is used.	<input type="checkbox"/>
8.84	Run → Column Section Design → Design Tab → Copy Steel Bars to Clipboard and Paste Steel Bars from Clipboard (applied onto the user-selected similar columns using Shift + Select) for common column details between similar columns within the storey (ES).	<input type="checkbox"/>
8.85	Run → Column Section Design → Design Tab → Column Capacity Analyses → check % steel for walls (i.e. sections without through-thickness shear links) << 2% and design shear stress $\approx 3\text{N/mm}^2 \ll 5\text{N/mm}^2$ for both frame analysis methods and both column design theories , i.e. BA + cl.3.8.4.5 BS8110-1 theory, BA + biaxial bending theory, CBAFE + cl.3.8.4.5 BS8110-1 theory and CBAFE + biaxial bending theory (ES).	<input type="checkbox"/>
8.86	Run → Column Section Design → Design Tab → Column Capacity Analyses → check % steel for columns (i.e. sections with through-thickness shear links) << 5% and design shear stress $\approx 3\text{N/mm}^2 \ll 5\text{N/mm}^2$ for both frame analysis methods and both column design theories , i.e. BA + cl.3.8.4.5 BS8110-1 theory, BA + biaxial bending theory, CBAFE + cl.3.8.4.5 BS8110-1 theory and CBAFE + biaxial bending theory (ES).	<input type="checkbox"/>
8.87	Run → Column Section Design → Design Tab → Column Design Report → wall/column detailed design report → search for {< 15.0 or > 15.0} for walls/columns that are to be correctly defined as braced and {< 10.0 or > 10.0} for walls/columns that are to be correctly defined as unbraced (ES).	<input type="checkbox"/>
8.88	Building wall/column final comprehensive design check (ES) ^{#B, #C}	
8.881	BA → BS8110-1 theory → check design → % steel << 2%/5% ^{#A} → $\tau \approx 3 \ll 5\text{N/mm}^2$ →	<input type="checkbox"/>
8.882	BA → biaxial bending theory → check design → % steel << 2%/5% ^{#A} → $\tau \approx 3 \ll 5\text{N/mm}^2$ →	<input type="checkbox"/>
8.883	CBAFE → BS8110-1 theory → check design → % steel << 2%/5% ^{#A} → $\tau \approx 3 \ll 5\text{N/mm}^2$ →	<input type="checkbox"/>
8.884	CBAFE → biaxial bending theory → check design → % steel << 2%/5% ^{#A} → $\tau \approx 3 \ll 5\text{N/mm}^2$ →	<input type="checkbox"/>
	#A Note for models with EQ loads stabilised by moment frames, the maximum primary seismic column % steel is 4%, not 5%. #B Note for models with EQ loads, ULS EQ load combinations should be analysed on models with the following modified default stiffness parameters {Class 1 PT or Class 2 PT slab/beam: $k_E=1.0, k_I=1.0, k_J=1.0$; RC or Class 3 PT slab/beam: $k_E=1.0, k_I=0.5, k_J=0.5$; wall/column: $k_E=1.0, k_I=0.5, k_J=0.5$ }. #C Note enhance walls/columns as appropriate for accidental loads (e.g. car park vehicular impact loads) and as disproportionate collapse key elements.	
8.89	Manual modification of wall/column detailing as follows: - (a) manual addition of nominal through-thickness links in column-like vertical elements detailed as walls (ES). (b) for models with EQ loads stabilised by moment frames, enhancement to the primary seismic column maximum link spacing, s should be provided based on cl.5.4.3.2.2 BS EN1998-1 (DCM) which states $s = \min \{\text{minimum column dimension excluding cover and half link diameter} / 2; 175\text{mm}; 8 \times \text{longitudinal bar diameter}\}$ and cl.5.5.3.2.2 BS EN1998-1 (DCH) which states $s = \min \{\text{minimum column dimension excluding cover and half link diameter} / 3; 125\text{mm}; 6 \times \text{longitudinal bar diameter}\}$ (ES).	<input type="checkbox"/>
9.0	FOUNDATION CHECKS	

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

ITEM	CONTENT	✓
9.1	General	
9.11	Settings → Foundation Design Settings → check Allowable Soil Stress Ultimate Strength Factor = $(1.4DL+1.4SDL+1.6LL)/(DL+SDL+LL)$, 1.4 being conservative.	<input type="checkbox"/>
9.2	Pad Footing	
9.21	Right-click → Insert Pad Base → check Footing Depth, Surcharge Height and Allowable Stress of Soil. Note perform load take down calculation for BA / CBAFE for all load combinations.	<input type="checkbox"/>
9.22	Structure Tree dialog → right-click Pad & Pile Bases → Print Pad and Pile Base Results (All Bases) → Pad/Pile Footing Results for a detailed design check of all pad footings for BA / CBAFE for all load combinations.	<input type="checkbox"/>
9.3	Strip Footing	
9.31	Building → Parameters → Foundations Tab → check allowable stress of soil (kPa). Building → Parameters → Foundations Tab → check coefficient of subgrade reaction (kN/m ³).	<input type="checkbox"/>
9.32	Right-click → Insert Strip Footing → check range of Subgrade Coefficients, Footing Width and Footing Depth. Note perform load take down calculation for BA / CBAFE for all load combinations.	<input type="checkbox"/>
9.33	Structure Tree dialog → right-click Strip Footings → Print Strip Footing Results (All Footings) → Strip Footing Results for a detailed design check of all strip footings for BA / CBAFE for all load combinations.	<input type="checkbox"/>
9.34	Run → Beam Reinforcement Design → Foundation Beams → Design Tab → Beam Design Report → check (strip footing) beam detailed design report for BA / CBAFE for all load combinations.	<input type="checkbox"/>
9.4	Raft / Piled Raft Footing	
9.41	Building → Parameters → Foundations Tab → check allowable stress of soil (kPa). Building → Parameters → Foundations Tab → check coefficient of subgrade reaction (kN/m ³). Right-click → check pile SWL and vertical Pile Spring Coefficient. Ensure no uniformly distributed SDL or LL on the raft / piled raft as this will not translate into bending or shear effects on the raft / piled raft, instead employ point loads with their spacing distributed to depict reality.	<input type="checkbox"/>
9.42	Run → FE Raft Foundation Analysis → choosing <i>not to</i> Ignore Bearing Capacity of Soil → check raft / piled raft. Note perform load take down calculation for BA / CBAFE for all load combinations.	<input type="checkbox"/>
9.43	Run → FE Raft Foundation Analysis → APP → check SLS rotations $\leq 1/250$ to BS8110-2 cl.3.2.1.1 (note that since the Stiffness Factors (i.e. factor for bending rigidity EI) for (raft strip) beam and (raft) slab elements cannot be set to $(2/3)^{rd}$, $(0.50) \approx 0.32$ (the further $2/3^{rd}$ reduction factor applied to simulate the additional deflection due to creep to storage loading instead of normal loading (i.e. creep coefficient, $\phi=2$ for storage loading instead of $\phi=1$ for normal loading)), adopt a criterion of $1/750$ instead). Note perform load take down calculation for BA / CBAFE for all load combinations. Run → FE Raft Foundation Analysis → APP → check SLS tilt $\leq 1/400$ (note that tilt is unaffected by E and I values but instead is dependent only on the loading magnitude and distribution and the soil stiffness). Note perform load take down calculation for BA / CBAFE for all load combinations.	<input type="checkbox"/>
	<div style="border: 1px solid blue; padding: 5px; margin-top: 10px;"> <p>L_s : (raft) slab deflection check</p> <p>L_{SB} : secondary (raft strip) beam deflection check</p> <p>L_{PB} : primary (raft strip) beam deflection check</p> <p>L_{FR} : frame (column to column) deflection check</p> </div>	<input type="checkbox"/>
	Note if necessary, the simulation of the beneficial effect of additional reinforcement in controlling deflections can be made by factoring down the exhibited deflections by the ratio of the modified span / effective depth to the ratio of the basic span / effective depth (cantilever 7.0, simply supported 20.0, continuous 26.0).	
9.44	Run → FE Raft Foundation Analysis → APP → check rebar areas required $\{As(d)1, As(d)2\}$, noting minimum steel. Run → Slab Analysis and Design → check sufficiency of rebar at all slab strips. Note perform load take down calculation for BA / CBAFE for all load combinations.	<input type="checkbox"/>
9.45	Run → FE Raft Foundation Analysis → APP → check soil pressure. Note perform load take down calculation for BA / CBAFE for all load combinations.	<input type="checkbox"/>
9.46	Manually check raft ULS shear stresses and shear design at beam/wall framing. Note perform load take down calculation for BA / CBAFE for all load combinations.	<input type="checkbox"/>
9.47	Run → Column Punching Check → check raft ULS punching shear at wall/column framing. Note perform load take down calculation for BA / CBAFE for all load combinations.	<input type="checkbox"/>

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

ITEM	CONTENT	√
9.48	Run → Beam Reinforcement Design → Foundation Beams → Design Tab → Beam Design Report → check (raft strip) beam detailed design report for BA / CBAFE for all load combinations.	<input type="checkbox"/>
9.49	VIM → Pile Capacity Status → check factored pile forces (ensuring no tension due to uplift) against the factored pile capacity (especially for stability walls attracting significant moments obscuring the obvious adequacy of the pile group capacity). Note perform load take down calculation for BA / CBAFE for all load combinations.	<input type="checkbox"/>
9.5	Pile Footing	
9.51	Right-click → Insert Pile Cap → check pile SWL, Pile Size, vertical pile Spring Coefficient, Pile Cap Depth and Surcharge Height. Note perform load take down calculation for BA / CBAFE for all load combinations.	<input type="checkbox"/>
9.52	Structure Tree dialog → right-click Pad & Pile Bases → Print Pad and Pile Base Results (All Bases) → Pad/Pile Footing Results for a detailed design check of all pile footings for BA / CBAFE for all load combinations.	<input type="checkbox"/>
9.53	Note for pile caps with complex geometries (i.e. more than 4 pile pile-groups), employ the concepts of piled raft analysis and design choosing to Ignore the Bearing Capacity of Soil and incorporating the soil surcharge loads into the (pile cap) slab superimposed dead loads.	<input type="checkbox"/>
10.0	QUANTITY CHECKS	
10.1	General	
10.11	File → Quantity Extraction Tables → Concrete Quantity Extractions Table → check estimate of the concrete volume (m ³). File → Quantity Extraction Tables → Formwork Quantity Table → check estimate of the formwork area (m ²). Run → ProtaDetails → check estimate of the steel / tendon quantity (kg).	<input type="checkbox"/>
10.12	In RC or PT models, check concrete quantity to typical concrete equivalent floor thicknesses (m ³ /10 ³ m ²) → 250-500. In RC or PT models, check formwork quantity to typical formwork rates (m ² /m ²) → 1.5-2.5. In RC models, check rebar quantity to typical rebar tonnages (kg/m ³) → one-way or two-way slabs 75-100, flat slabs 125-175, transfer slabs 150-350, beams 125-250, transfer beams 150-350, walls 100, columns 150-300, pile caps 150-200. In PT models, check tendon quantity to typical tendon tonnages (kg/m ³) → slabs 20-25, transfer slabs 20-25, beams 40-50. In PT models, check rebar quantity to typical rebar tonnages (kg/m ³) → slabs 20-35, transfer slabs 40-70, beams 40-70.	<input type="checkbox"/>

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

Appendix A: PT Permissible Stress

Permissible Stress [N/mm ²] [BS8110, TR.43]						
	Serviceability Class 1 No Flexural Tensile Stresses		Serviceability Class 2 Flexural Tensile Stresses, Uncracked (No Visible Cracking)		Serviceability Class 3 Flexural Tensile Stresses, Cracked	
	Top	Bottom	Top	Bottom	Top	Bottom
TLS comp $f'_{max,t/b}$	$0.50 f_{ci} \text{ #A1}$ $0.24 f_{ci} \text{ #A2}$	$0.50 f_{ci} \text{ #A1}$ $0.33 f_{ci} \text{ #A2}$	$0.50 f_{ci} \text{ #A1}$ $0.24 f_{ci} \text{ #A2}$	$0.50 f_{ci} \text{ #A1}$ $0.33 f_{ci} \text{ #A2}$	$0.50 f_{ci} \text{ #A1}$ $0.24 f_{ci} \text{ #A2}$	$0.50 f_{ci} \text{ #A1}$ $0.33 f_{ci} \text{ #A2}$
TLS tensile $f'_{min,t/b}$	-1.0 #B	-1.0 #B	$-0.36 \sqrt{f_{ci}} \text{ #B}$	$-0.36 \sqrt{f_{ci}} \text{ #B}$	$-0.25 f_{ci} \text{ #B1}$ $-0.45 \sqrt{f_{ci}} \text{ #B2}$	$-0.25 f_{ci} \text{ #B1}$ $-0.45 \sqrt{f_{ci}} \text{ #B2}$
SLS comp $f'_{max,t/b}$	$0.33 f_{cu} \text{ #C1}$ $0.33 f_{cu} \text{ #C2}$	$0.40 f_{cu} \text{ #C1}$ $0.24 f_{cu} \text{ #C2}$	$0.33 f_{cu} \text{ #C1}$ $0.33 f_{cu} \text{ #C2}$	$0.40 f_{cu} \text{ #C1}$ $0.24 f_{cu} \text{ #C2}$	$0.33 f_{cu} \text{ #C1}$ $0.33 f_{cu} \text{ #C2}$	$0.40 f_{cu} \text{ #C1}$ $0.24 f_{cu} \text{ #C2}$
SLS tensile $f'_{min,t/b}$	-0.0 #D	-0.0 #D	$-0.36 \sqrt{f_{cu}} \text{ #D}$	$-0.36 \sqrt{f_{cu}} \text{ #D}$	$-\langle \dots \rangle \text{ #D1}$ $-0.45 \sqrt{f_{cu}} \text{ #D2}$	$-\langle \dots \rangle \text{ #D1}$ $-0.45 \sqrt{f_{cu}} \text{ #D2}$

#A1: Note beam, one-way slab or two-way slab option to cl.4.3.5.1 BS8110.

#A2: Note flat slab option to T.2 TR.43 and cl.6.10.2 TR.43.

#B: Note beam, one-way slab, two-way slab or flat slab option to cl.4.3.5.2 BS8110.

#B1: Note beam, one-way slab or two-way slab option to cl.4.3.5.2 BS8110.

#B2: Note flat slab option to T.2 TR.43 and cl.6.10.2 TR.43 based on **full tributary width** design strip.

#C1: Note beam, one-way slab or two-way slab option to cl.4.3.4.2 BS8110.

#C2: Note flat slab option to T.2 TR.43.

#D: Note beam, one-way slab, two-way slab or flat slab option to cl.4.3.4.3 BS8110.

#D1: Note beam, one-way slab or two-way slab option to cl.4.3.4.3 BS8110. Note $-\langle \dots \rangle = \text{MAX} \{-0.25f_{cu}, (0.7-1.1) \cdot (-0.58\sqrt{f_{cu}} \text{ to } -0.82\sqrt{f_{cu}}) - 4\text{N/mm}^2/1.0\%$ as the code allows for an increase in the tensile stress limit from 1% of longitudinal steel (untensioned reinforcement) onwards (-4N/mm^2 for every 1% of longitudinal steel (untensioned reinforcement), increasing proportionally, up to the specified upper limit of $-0.25f_{cu}$).

#D2: Note flat slab option to T.2 TR.43 based on **full tributary width** design strip.

Table 4.2 – Design Hypothetical Flexural Tensile Stresses for Class 3 Members [N/mm²]

Group	Limiting Crack Width [mm]	Design Stress for Concrete Grade		
		30	40	50
Grouted Post-Tensioned Tendons	0.1	3.2	4.1	4.8
	0.2	3.8	5.0	5.8

Table 4.3 – Depth Factors for Design Tensile Stresses for Class 3 Members

Depth of Member [mm]	Factor
≤ 200	1.1
400	1.0
600	0.9
800	0.8
≥ 1000	0.7

Permissible Stress [N/mm²] [ACI318]

	Serviceability Class U Uncracked		Serviceability Class T Transition		Serviceability Class C Cracked	
	Top	Bottom	Top	Bottom	Top	Bottom
TLS comp $f'_{max,t/b}$	$0.60 f_{ci}' \text{ #A}$	$0.60 f_{ci}' \text{ #A}$	$0.60 f_{ci}' \text{ #A}$	$0.60 f_{ci}' \text{ #A}$	$0.60 f_{ci}' \text{ #A}$	$0.60 f_{ci}' \text{ #A}$
TLS tensile $f'_{min,t/b}$	$-0.25 \sqrt{f_{ci}'} \text{ #B}$	$-0.25 \sqrt{f_{ci}'} \text{ #B}$	$-0.25 \sqrt{f_{ci}'} \text{ #B}$	$-0.25 \sqrt{f_{ci}'} \text{ #B}$	$-0.30 f_{ci}' \text{ #B1}$ $-0.50 \sqrt{f_{ci}'} \text{ #B2}$	$-0.30 f_{ci}' \text{ #B1}$ $-0.50 \sqrt{f_{ci}'} \text{ #B2}$

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

SLS comp $f_{max,t/b}$	$0.60 f_c' \#C$	$0.60 f_c' \#C$	$0.60 f_c' \#C$	$0.60 f_c' \#C$	$0.60 f_c' \#C$	$0.60 f_c' \#C$
SLS tensile $f_{min,t/b}$	$\frac{-0.62 \sqrt{f_c' \#D1}}{-0.50 \sqrt{f_c' \#D2}}$	$\frac{-0.62 \sqrt{f_c' \#D1}}{-0.50 \sqrt{f_c' \#D2}}$	$\frac{-1.00 \sqrt{f_c' \#D1}}{-0.50 \sqrt{f_c' \#D2}}$	$\frac{-1.00 \sqrt{f_c' \#D1}}{-0.50 \sqrt{f_c' \#D2}}$	$\frac{-0.30 f_c' \#D1}{-0.50 \sqrt{f_c' \#D2}}$	$\frac{-0.30 f_c' \#D1}{-0.50 \sqrt{f_c' \#D2}}$

- #A: Note beam, one-way slab, two-way slab or flat slab option to cl.24.5.3.1 ACI318.
 #B: Note beam, one-way slab, two-way slab or flat slab option to cl.24.5.3.2 ACI318.
 #B1: Note beam, one-way slab or two-way slab option analogous to cl.4.3.5.2 BS8110.
 #B2: Note flat slab option to cl.24.5.3.2.1 ACI318 based on **full tributary width** design strip.
 #C: Note beam, one-way slab, two-way slab or flat slab option to cl.24.5.4.1 ACI318.
 #D1: Note beam, one-way slab or two-way slab option to cl.24.5.2.1 ACI318 and analogous to cl.4.3.4.3 BS8110.
 #D2: Note flat slab option to cl.24.5.2.1 ACI318 based on **full tributary width** design strip.

Permissible Stress [N/mm ²] [AS3600]						
	Serviceability Class U Uncracked		Serviceability Class T Transition		Serviceability Class C Cracked	
	Top	Bottom	Top	Bottom	Top	Bottom
TLS comp $f'_{max,t/b}$	$0.50 f_{ci}' \#A$	$0.50 f_{ci}' \#A$	$0.50 f_{ci}' \#A$	$0.50 f_{ci}' \#A$	$0.50 f_{ci}' \#A$	$0.50 f_{ci}' \#A$
TLS tensile $f'_{min,t/b}$	$-0.25 \sqrt{f_{ci}' \#B}$	$-0.25 \sqrt{f_{ci}' \#B}$	$-0.60 \sqrt{f_{ci}' \#B}$	$-0.60 \sqrt{f_{ci}' \#B}$	$\frac{-0.30 f_{ci}' \#B1}{-0.60 \sqrt{f_{ci}' \#B2}}$	$\frac{-0.30 f_{ci}' \#B1}{-0.60 \sqrt{f_{ci}' \#B2}}$
SLS comp $f_{max,t/b}$	$0.50 f_c' \#C$	$0.50 f_c' \#C$	$0.50 f_c' \#C$	$0.50 f_c' \#C$	$0.50 f_c' \#C$	$0.50 f_c' \#C$
SLS tensile $f_{min,t/b}$	$-0.25 \sqrt{f_c' \#D}$	$-0.25 \sqrt{f_c' \#D}$	$-0.60 \sqrt{f_c' \#D}$	$-0.60 \sqrt{f_c' \#D}$	$\frac{-0.30 f_c' \#D1}{-0.60 \sqrt{f_c' \#D2}}$	$\frac{-0.30 f_c' \#D1}{-0.60 \sqrt{f_c' \#D2}}$

- #A: Note beam, one-way slab, two-way slab or flat slab option to cl.8.1.6.2 AS3600.
 #B: Note beam, one-way slab, two-way slab or flat slab option to cl.8.6.2 and cl.9.4.2 AS3600.
 #B1: Note beam, one-way slab or two-way slab option analogous to cl.4.3.5.2 BS8110.
 #B2: Note flat slab option to cl.9.4.2 AS3600 based on **column strip tributary width** design strip.
 #C: Note beam, one-way slab, two-way slab or flat slab option to cl.8.1.6.2 AS3600.
 #D: Note beam, one-way slab, two-way slab or flat slab option to cl.8.6.2 and cl.9.4.2 AS3600.
 #D1: Note beam, one-way slab or two-way slab option analogous to cl.4.3.4.3 BS8110.
 #D2: Note flat slab option to cl.9.4.2 AS3600 as an alternative to cl.6.9.5.3 AS3600 based on **column strip tributary width** design strip.

Permissible Stress [N/mm ²] [EC2 and TR.43-2]						
	Serviceability Class U Uncracked		Serviceability Class T Transition		Serviceability Class C Cracked	
	Top	Bottom	Top	Bottom	Top	Bottom
TLS comp $f'_{max,t/b}$	$\frac{0.50 f_{ci}' \#A1}{0.30 f_{ci}' \#A2}$	$\frac{0.50 f_{ci}' \#A1}{0.40 f_{ci}' \#A2}$	$\frac{0.50 f_{ci}' \#A1}{0.30 f_{ci}' \#A2}$	$\frac{0.50 f_{ci}' \#A1}{0.40 f_{ci}' \#A2}$	$\frac{0.50 f_{ci}' \#A1}{0.30 f_{ci}' \#A2}$	$\frac{0.50 f_{ci}' \#A1}{0.40 f_{ci}' \#A2}$
TLS tensile $f'_{min,t/b}$	$\frac{-0.21 f_{ci}'^{2/3} \#B1}{-0.09 f_{ci}'^{2/3} \#B2}$	$\frac{-0.21 f_{ci}'^{2/3} \#B1}{-0.09 f_{ci}'^{2/3} \#B2}$	$\frac{-0.21 f_{ci}'^{2/3} \#B1}{-0.09 f_{ci}'^{2/3} \#B2}$	$\frac{-0.21 f_{ci}'^{2/3} \#B1}{-0.09 f_{ci}'^{2/3} \#B2}$	$\frac{-0.30 f_{ci}' \#B1}{-0.27 f_{ci}'^{2/3} \#B2}$	$\frac{-0.30 f_{ci}' \#B1}{-0.27 f_{ci}'^{2/3} \#B2}$
SLS comp $f_{max,t/b}$	$\frac{0.60 f_c' \#C1}{0.40 f_c' \#C2}$	$\frac{0.60 f_c' \#C1}{0.30 f_c' \#C2}$	$\frac{0.60 f_c' \#C1}{0.40 f_c' \#C2}$	$\frac{0.60 f_c' \#C1}{0.30 f_c' \#C2}$	$\frac{0.60 f_c' \#C1}{0.40 f_c' \#C2}$	$\frac{0.60 f_c' \#C1}{0.30 f_c' \#C2}$
SLS tensile $f_{min,t/b}$	$\frac{-0.21 f_c'^{2/3} \#D1}{-0.09 f_c'^{2/3} \#D3}$	$\frac{-0.21 f_c'^{2/3} \#D1}{-0.09 f_c'^{2/3} \#D3}$	$\frac{-0.21 f_c'^{2/3} \#D1}{-0.09 f_c'^{2/3} \#D3}$	$\frac{-0.21 f_c'^{2/3} \#D1}{-0.09 f_c'^{2/3} \#D3}$	$\frac{<.....> \#D2}{-0.27 f_c'^{2/3} \#D3}$	$\frac{<.....> \#D2}{-0.27 f_c'^{2/3} \#D3}$

- #A1: Note beam, one-way slab or two-way slab option to cl.5.8.2 TR.43-2.
 #A2: Note flat slab option to T.4 TR.43-2 and cl.5.8.2 TR.43-2.
 #B1: Note beam, one-way slab or two-way slab option to cl.5.8.2 TR.43-2 and analogous to cl.4.3.5.2 BS8110.
 #B2: Note flat slab option to T.4 TR.43-2 and cl.5.8.2 TR.43-2 based on **full tributary width** design strip.
 #C1: Note beam, one-way slab or two-way slab option to cl.5.10.2.2 EC2.
 #C2: Note flat slab option to T.4 TR.43-2.
 #D1: Note beam, one-way slab or two-way slab option analogous to cl.5.8.2 TR.43-2.
 #D2: Note beam, one-way slab or two-way slab option to cl.5.8.1 TR.43-2. Note $<.....> = \text{MAX} \{-0.30f_c', (-0.40f_c'^{2/3} \text{ to } -0.50f_c'^{2/3}) - 4N/mm^2/1.0\%$ as the code allows for an increase in the tensile stress limit from 1% of longitudinal steel (untensioned reinforcement) onwards ($-4N/mm^2$ for every 1% of longitudinal steel (untensioned reinforcement), increasing proportionally, up to the specified upper limit of $-0.30f_c'$).
 #D3: Note flat slab option to T.4 TR.43-2 based on **full tributary width** design strip.

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

Appendix B: **PT** Prestress Strand Types

PT Prestress Strand Types	ϕ_s [mm]	A_s [mm ²]	E_p [GPa]	f_{pk} [N/mm ²]	F_{pk} [kN]
[ASTM A416] Grade 270 $\phi_s = 12.7$ mm Strand	12.70	98.71	186.0	1860	183.7
[ASTM A416] Grade 270 $\phi_s = 15.24$ mm Strand	15.24	140.00	186.0	1860	260.7
[BS5896] 7-Wire Super $\phi_s = 12.9$ mm Strand	12.90	100.00	195.0	1860	186.0
[BS5896] 7-Wire Super $\phi_s = 15.7$ mm Strand	15.70	150.00	195.0	1860	279.0

Appendix C: **PT** Tendon Duct Dimensions

PT Tendon Ducts Horizontal $D_{T,H}$ and Vertical $D_{T,V}$ External Dimensions					
Maximum Number of Prestress Strands in Each Tendon, N_s	Default for 0.5" Strands		Default for 0.6" Strands		Remark
	$D_{T,H}$ (mm)	$D_{T,V}$ (mm)	$D_{T,H}$ (mm)	$D_{T,V}$ (mm)	
3	55	23	55	23	Default refers to flat ducts
5	75	23	90	23	Default refers to flat ducts
7	55	55	70	70	Default refers to round ducts
12	80	80	85	85	Default refers to round ducts
19	95	95	100	100	Default refers to round ducts
27	100	100	115	115	Default refers to round ducts
37	115	115	135	135	Default refers to round ducts
42	125	125	145	145	Default refers to round ducts

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

Appendix D: RC or PT Load Combination Cases

Load Combo	Description	Load Factor								
		PT	HYP	DL	SDL	LL	WL _x	WL _y	NHL _x	NHL _y
Ultimate Limit State (ULS)										
ULS01	1.4DL+1.4SDL+1.6LL+HYP #A, #B	-	1.0	1.4	1.4	1.6	-	-	-	-
ULS02	1.4DL+1.4SDL±1.0NHL+HYP #A, #C	-	1.0	1.4	1.4	-	-	-	±1.0	-
		-	1.0	1.4	1.4	-	-	-	-	±1.0
ULS03	1.0DL+1.0SDL±1.0NHL+HYP #A	-	1.0	1.0	1.0	-	-	-	±1.0	-
		-	1.0	1.0	1.0	-	-	-	-	±1.0
ULS04	1.2DL+1.2SDL+1.2LL±1.0NHL+HYP #A, #C	-	1.0	1.2	1.2	1.2	-	-	±1.0	-
		-	1.0	1.2	1.2	1.2	-	-	-	±1.0
ULS05	1.4DL+1.4SDL±1.4WL+HYP #A	-	1.0	1.4	1.4	-	±1.4	-	-	-
		-	1.0	1.4	1.4	-	-	±1.4	-	-
ULS06	1.0DL+1.0SDL±1.4WL+HYP #A	-	1.0	1.0	1.0	-	±1.4	-	-	-
		-	1.0	1.0	1.0	-	-	±1.4	-	-
ULS07	1.2DL+1.2SDL+1.2LL±1.2WL+HYP #A	-	1.0	1.2	1.2	1.2	±1.2	-	-	-
		-	1.0	1.2	1.2	1.2	-	±1.2	-	-
Transfer Limit State (TLS)										
TLS01	1.0DL+1.15PT #D	1.15	-	1.0	-	-	-	-	-	-
Serviceability Limit State (SLS)										
SLS01	1.0DL+1.0SDL+1.0LL+PT #A	1.0	-	1.0	1.0	1.0	-	-	-	-
SLS02	1.0DL+1.0SDL+1.0LL±1.0NHL+PT #A	1.0	-	1.0	1.0	1.0	-	-	±1.0	-
		1.0	-	1.0	1.0	1.0	-	-	-	±1.0
SLS03	1.0DL+1.0SDL+1.0LL±1.0WL+PT #A	1.0	-	1.0	1.0	1.0	±1.0	-	-	-
		1.0	-	1.0	1.0	1.0	-	±1.0	-	-

#A For 3D building finite element models, the load combinations inherently include the effects of differential (elastic, creep, shrinkage) axial shortening. For 2D floor plate models on the other hand, these load combinations shall be appended with a 30-year differential (elastic, creep, shrinkage) axial shortening load case based on a 10-day per floor staged construction analysis of the load combination case 1.4DL+1.4SDL, 1.2DL+1.2SDL or 1.0DL+1.0SDL as appropriate. Calculation of the elastic, creep and shrinkage components of the axial shortening shall be based on cl.3.1.4 EC2.

#B Note that it is ensured that the construction load combination is less onerous than ULS 01.

#C Note that the load combination case 1.4DL+1.4SDL±1.0NHL+HYP need not be applied if it is deemed to be always less onerous than 1.2DL+1.2SDL+1.2LL±1.0NHL+HYP. This will be the case always as long as $[DL+SDL]/[DL+SDL+LL] \leq 0.85$.

#D Note that for transfer storeys, the TLS load combination case only considers the self-weight of the particular storey (and not the self-weight from any upper storey) in its dead load case, DL.

Load Combo	Description	Load Factor							
		PT	HYP	DL	SDL	LL	EQ _x	EQ _y	EQ _z
Ultimate Limit State (ULS)									
EQ ULS01	1.0DL+1.0SDL+ $\psi/2$ LL±1.0EQ _x +HYP 1.0DL+1.0SDL+ $\psi/2$ LL±1.0EQ _y +HYP	-	1.0	1.0	1.0	$\psi/2$	±1.0	-	-
		-	1.0	1.0	1.0	$\psi/2$	-	±1.0	-
EQ ULS02	1.0DL+1.0SDL+ $\psi/2$ LL+HYP ±1.0EQ _x ±0.3EQ _y ±0.3EQ _z 1.0DL+1.0SDL+ $\psi/2$ LL+HYP ±0.3EQ _x ±1.0EQ _y ±0.3EQ _z 1.0DL+1.0SDL+ $\psi/2$ LL+HYP ±0.3EQ _x ±0.3EQ _y ±1.0EQ _z	-	1.0	1.0	1.0	$\psi/2$	±1.0	±0.3	±0.3
		-	1.0	1.0	1.0	$\psi/2$	±0.3	±1.0	±0.3
		-	1.0	1.0	1.0	$\psi/2$	±0.3	±0.3	±1.0

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

Serviceability Limit State (SLS)									
EQ SLS01	1.0DL+1.0SDL+ $\psi/2$ LL+1.0EQ _x +PT ^{#A}	1.0	-	1.0	1.0	$\psi/2i$	±1.0	-	-
	1.0DL+1.0SDL+ $\psi/2$ LL±1.0EQ _y +PT ^{#A}	1.0	-	1.0	1.0	$\psi/2i$	-	±1.0	-
EQ SLS02	1.0DL+1.0SDL+ $\psi/2$ LL+PT ^{#A} ±1.0EQ _x ±0.3EQ _y ±0.3EQ _z	1.0	-	1.0	1.0	$\psi/2i$	±1.0	±0.3	±0.3
	1.0DL+1.0SDL+ $\psi/2$ LL+PT ^{#A} ±0.3EQ _x ±1.0EQ _y ±0.3EQ _z	1.0	-	1.0	1.0	$\psi/2i$	±0.3	±1.0	±0.3
	1.0DL+1.0SDL+ $\psi/2$ LL+PT ^{#A} ±0.3EQ _x ±0.3EQ _y ±1.0EQ _z	1.0	-	1.0	1.0	$\psi/2i$	±0.3	±0.3	±1.0

^{#A} Note that the lateral EQ loads in the EQ SLS combination cases here are **not** enhanced by the adopted behaviour factor, q as per cl.4.3.4 BS EN1998-1 as these EQ SLS combinations are required for PT SLS design and also represent the foundation load combination cases. The evaluation of EQ deflections should be based on an amplified (by the factor q) deflection value instead.

Appendix E: RC or PT Design Strip Design Sections Equivalent Frame Method Integration of Effects Analysis vs FE Analysis Method Integration of Effects Analysis

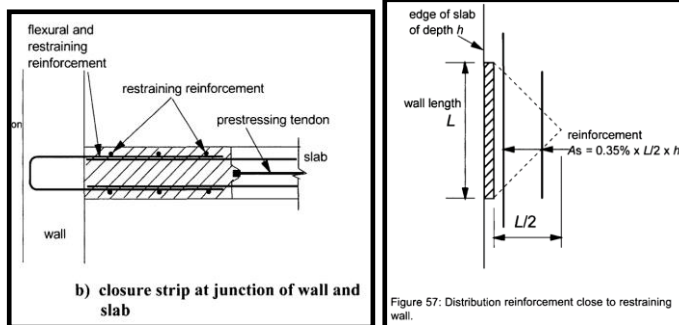
RC or PT Design Strip Design Sections Equivalent Frame Method Integration of Effects Analysis	RC or PT Design Strip Design Sections FE Analysis Method Integration of Effects Analysis
Does not consider the flat slab hogging moment stress concentrations, unconservatively	Does consider the flat slab hogging moment stress concentrations, conservatively
Does not inherently consider external loads and tendons outside of the design strip (but still offers an effect), unconservatively	Does inherently consider external loads and tendons outside of the design strip (but still offers an effect), conservatively

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

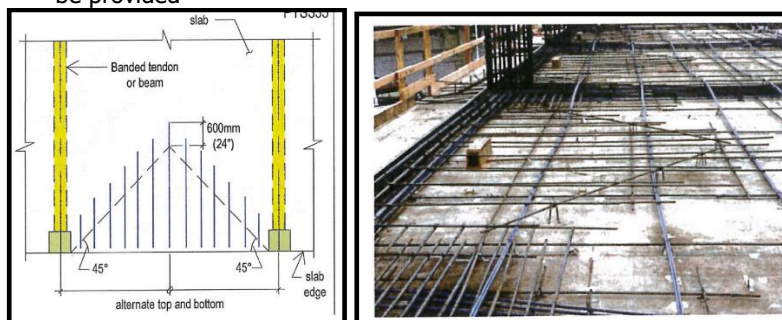
Appendix F: PT Additional Detailing Requirements

The following additional detailing requirements are required: -

- (i) the provision of minimum longitudinal steel (untensioned reinforcement) for unbonded tendon construction [cl.6.10.6 TR.43]
- (ii) the provision of flexural and restraining longitudinal and transverse steel (untensioned reinforcement) near restraining walls



- (iii) the provision of longitudinal and transverse steel (untensioned reinforcement) between tendon anchorages at flat slab edges [cl.6.13 TR.43]
 - parallel to the edge, untensioned and/or tensioned reinforcement to resist the ULS bending moment for a continuous slab spanning l_a , which is the centre to centre distance between (groups of) anchorages, evenly distributed across a width of $0.7l_a$ should be provided, and
 - perpendicular to the edge, untensioned reinforcement greater than $0.13\%bh$ and $1/4$ x parallel reinforcement, evenly distributed between the anchorages and extending $\text{MAX}(l_a, 0.7l_a + \text{anchorage})$ should be provided



- (iv) the provision of minimum longitudinal steel (untensioned reinforcement) at column positions for all flat slabs of at least 0.075% of the gross concrete cross-sectional area, concentrated between lines that are 1.5 times the slab depth either side of the width of the column and extending $0.2L$ into the span, L [cl.6.10.6 TR.43]

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

Appendix G: PT Dual-Cast Construction

Dual-cast construction may be simplistically simulated by: -

- (i) first, performing the first-cast PT structural analysis after
 - modelling the structure corresponding to the first-cast (e.g. a transfer storey structure with a reduced initial thickness without any upper storey superstructure walls that may provide a stiffening effect)
 - modelling the PT tendons corresponding to the first-cast only whilst **excluding** that of the second-cast (e.g. a transfer storey structure with PT tendons within the first-cast initial thickness only)
 - applying external superimposed dead and live loads corresponding to the first-cast (e.g. a transfer storey structure with external self-weight of the additional second cast included as superimposed dead load and construction live load)
 - defining a **standard** TLS load combination case, e.g. 1.0S+1.15PT
 - defining standard SLS/ULS load combination cases with PT load combination cases
- (ii) second, performing the first-cast PT design TLS/SLS/ULS checks whilst
 - recording the **representative** SLS stress at bottom face which should be positive (i.e. compressive) for the dual-cast construction method to be effective, however negative (i.e. tensile) stresses should be considered and recorded if indeed that is the case (noting that by convention, positive stress is compressive and negative stress is tensile)
- (iii) third, performing the second-cast PT structural analysis after
 - modelling the structure corresponding to the second-cast (e.g. a transfer storey structure with an increased final thickness and upper storey superstructure walls potentially providing a stiffening effect)
 - modelling the PT tendons corresponding to the second-cast only whilst **excluding** that of the first-cast (e.g. a transfer storey structure with PT tendons within the second-cast final thickness only)
 - modelling the additional first-cast PT tendon area as equivalent [factored by f_{pk}/f_y] bottom longitudinal steel (untensioned reinforcement) area for the PT design ULS bending and shear checks, although for any quantity take-off purposes, the second-cast bottom longitudinal steel (untensioned reinforcement) quantity should then be factored down and for completion, the second-cast PT tendon quantity factored up to include the first-cast PT tendon quantity
 - applying external dead, superimposed dead and live loads corresponding to the second-cast (e.g. a transfer storey structure with external dead, superimposed dead and live loads from the particular storey and all upper storeys)
 - defining a **non-standard** TLS load combination case to exclude the beneficial effect (of counteracting the prestressing equivalent load) of the self-weight of the second-cast structure section which can no longer be considered as it has already been considered in the bending of the first-cast structure section, e.g. 0.0S+1.15PT, noting that all **transfer storeys** should thus be designated as such so that the dead load (self-weight of the structure) case, S within the TLS load combination case (thus defined when the type of load combination case is designated by the user as **initial**) will refer to the self-weight of only the particular storey (and not the self-weight from any upper storey)
 - defining standard SLS/ULS load combination cases with PT load combination cases, noting that the effect of the self-weight of the second-cast structure section can conservatively be double-counted, the effect being marginal in practice as it would be resisted by the full second-cast structure section elastic section modulus $Z_{t/b}$ and would form only a fraction of the full SLS load combination cases whilst ensuring that the correct external load effects are maintained for presentation purposes and other PT design SLS/ULS checks
- (iv) fourth, performing the second-cast PT design TLS/SLS/ULS checks whilst
 - subtracting the recorded first-cast **representative** SLS stress at bottom face from the criteria f_{min}'/f_{min} and f_{max}'/f_{max}

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

Appendix H: **PT** Multi-Stage Stressing

Multi-stage stressing may be simplistically simulated by: -

- (i) first,
 - modelling the structure corresponding to the first stressing stage, $STG(i=1)$ (e.g. a transfer storey structure with a reduced total number of upper storeys above the transfer storey)
 - modelling the PT tendons corresponding to the first stressing stage, $STG(i=1)$ (e.g. a transfer storey structure with a reduced total number of PT tendons)
 - applying external superimposed dead and live loads corresponding to the first stressing stage, $STG(i=1)$ (e.g. a transfer storey structure with external loads consistent with the reduced total number of upper storeys above the transfer storey)
 - defining a **standard** TLS load combination case, e.g. $1.0S+1.15PT$, noting that all **transfer storeys** should thus be designated as such so that the dead load (self-weight of the structure) case, S within the TLS load combination case (thus defined when the type of load combination case is designated by the user as **initial**) will refer to the self-weight of only the particular storey (and not the self-weight from any upper storey)
 - defining standard SLS/ULS load combination cases with PT load combination cases
 - performing the PT structural analysis
 - performing the PT design TLS/SLS/ULS checks corresponding to the first stressing stage, $STG(i=1)$
- (ii) second,
 - modelling the structure corresponding to the second stressing stage, $STG(i=2)$ (e.g. a transfer storey structure with an increased total number of upper storeys above the transfer storey)
 - modelling the PT tendons corresponding to the second stressing stage, $STG(i=2)$ (e.g. a transfer storey structure with an increased total number of PT tendons)
 - applying external superimposed dead and live loads corresponding to the second stressing stage, $STG(i=2)$ (e.g. a transfer storey structure with external loads consistent with the increased total number of upper storeys above the transfer storey)
 - defining a **non-standard** TLS load combination case to include the effects of the self-weight from the upper storeys corresponding to the preceding stressing stage (pre-calculated and applied as superimposed dead load), e.g. $1.0S+1.0S_{UPPER\ STOREYS\ OF\ STG(i=1)}+1.15PT$
 - defining standard SLS/ULS load combination cases with PT load combination cases
 - performing the PT structural analysis
 - performing the PT design TLS/SLS/ULS checks corresponding to the second stressing stage, $STG(i=2)$
- (iii) third and thereafter, repeating the second step corresponding to the third and thereafter stressing stages, $STG(i=3, 4, 5, \text{etc.})$