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
BA = Building Analysis
STAGE = Building Analysis [Staged Building Analysis]
FEFA = FE Floor Analysis
MARD = Model and Analysis Results Display
APP = Analysis Post-Processing
DAS = Differential (Elastic, Creep, Shrinkage) Axial Shortening
VIM = Active Windows Settings → Visual Interrogation
CBAFE = Combination of Building Analysis and the FE Based Gravity Load Chase Down

Legend	☐
Pass	√
Fail	X
Not Applicable	NA

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 Excluded
- Hinged Beam Checks Excluded
- 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 Excluded
- Method of Slab Analysis, Beam Load Application and Frame Analysis Checks Excluded
- Redundant Slab, Beam and Wall / Column Analysis and Design Checks Excluded
- Rare Slab, Beam and Wall / Column Analysis and Design Checks Included
- Pad Footing Checks Excluded
- Strip Footing Checks Excluded
- Raft / Piled Raft Footing Checks Excluded
- 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 ☐ Housing-NoEQ ☐ MultiStorey-EQ ☐ MultiStorey-NoEQ ☐		☐
1.12	Date of release of company standard template.		☐
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_I 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_I=0.50, k_J=0.50	☐
1.22	Braced/unbraced wall/column.	Braced	☐
1.23	Maximum beam/wall/column rebar diameter.	T32/T32/T40	☐
1.24	Adoption of (unique) design links at beam supports.	Adopted	☐
1.25	Beam section cuts (span only – once for every beam or once for every axis).	Span, once every beam	☐
1.26	RigidZones Maximum or RigidZones None.	RigidZones None	☐
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	☐
1.28	Foundation load combinations G+Q load factor (1.00, 1.02, 1.05, 1.10).	1.00	☐
1.29	Etcetera.		☐
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)**		☐

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ITEM	CONTENT	√

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 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: - ☐

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 γ_{Rd} = 1.0	Reduce shear link strength grade to f_{yv} / 1.1
	Primary Seismic Column	cl.5.4.2.3 γ_{Rd} = 1.1	
Ductility Class High (DCH)	Primary Seismic Beam	cl.5.5.2.1 γ_{Rd} = 1.2	Reduce shear link strength grade to f_{yv} / 1.3
	Primary Seismic Column	cl.5.5.2.2 γ_{Rd} = 1.3	

ITEM	CONTENT	√
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 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: - ☐

(i) slab sizes w.r.t. span to depth ratios **(30 RC, 40 PT)**, ULS bending stress **$M_{ULS}/bh^2 \approx$ 1N/mm² << 5N/mm²**, ProtaStructure **analytical slab strips** and **FEFA deflections**, with **M_{ULS}** checked based on **1.4 x tributary width x (15.0-25.0kPa) x $L^2/12$**,

(ii) beam sizes w.r.t. span to depth ratios **(20 RC, 30 PT)**, ULS shear stress **$V_{ULS}/bh \approx$ 3N/mm² << 5N/mm²** and ULS bending stress **$M_{ULS}/bh^2 \approx$ 3N/mm² << 5N/mm²** and **FEFA deflections**, with **M_{ULS}** and **V_{ULS}** checked based on **1.4 x tributary width x (15.0-25.0kPa) x $L^2/12$** and **1.4 x tributary width x (15.0-25.0kPa) x L/2**, respectively with $A_{s,prov} \approx 3000 \cdot M_{ULS}$ (kNm) / d (mm),

(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],

(iv) transfer beam sizes w.r.t. ULS shear stress **$V_{ULS}/bh \approx$ 3N/mm² << 5N/mm²** and ULS bending stress **$M_{ULS}/bh^2 \approx$ 3N/mm² << 5N/mm²**, ULS punching shear transfer column face stress **$V_{eff}/ud \approx$ 4N/mm² << 5N/mm²** (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],

(v) transfer slab sizes w.r.t. ULS shear stress **V_{ULS}/bh** @ 1.0d ≈ **1.0N/mm² [RC]** to **1.5N/mm² [PT] << 5N/mm²** and ULS bending stress **$M_{ULS}/bh^2 \approx$ 1.5N/mm² [RC]** to **2.5N/mm² [PT] << 5N/mm²**, ULS punching shear transfer column (or transfer column head where applicable) and transferred walls/columns

ITEM	CONTENT	√
	face stress **V_{eff}/ud ≈ 4N/mm² << 5N/mm²**, ULS punching shear transfer column (or transfer column head where applicable) and transferred walls/columns first perimeter stress **V_{eff}/ud** @ 1.5d ≈ **0.6N/mm² [RC]** to **1.0N/mm² [PT]**, **deep beam design** #E2 and **CBAFE deflections**, with **M_{ULS} = F_{ULS}.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,	
	(vi) column #A sizes w.r.t. scheme design ratios (for 2.0% steel, **A_C ≈ 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,	
	(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 ≤ 0.05** and sway with **Q/1.4 ≤ 0.25** with default stiffness parameters; EQ: non-sway with **q.Q/0.7 ≤ 0.05** and sway with **q.Q/0.7 ≤ 0.25** with default stiffness parameters),	
	(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	
	(ix) lateral stability frame size and extent w.r.t. lateral deflections to NHF / wind #I (**δ_{total}/2 ≤ H_{total}/500** and **$\Delta\delta_{storey,I}$/2 ≤ $h_{storey,I}$/500** with default stiffness parameters) and EQ #I (**q.δ_{total} ≤ H_{total}/250** and **q.$\Delta\delta_{storey,I}$ ≤ $h_{storey,I}$/250** (with fundamental period **$T_1/\sqrt{2}$**) with default stiffness parameters), (ES).	
	#A: Note check wall/column for **Len≥1**, correctness of **duplicate storeys** and perform **Building Model Check**.	
	#B: Note check **Column Capacity Analyses Table** for ULS axial stress **F_{ULS}/A_C** (**BA / CBAFE**) and **% steel << 2%**(shear wall vertical steel % limit for avoidance of through-thickness links)**/5%**(column vertical steel % limit).	
	#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.	
	#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.	
	#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 ¼ of the required vertical steel) and transfer beam (acting as the tension element with the provision of rebar of $0.95f_y.A_{s,prov}$ to resist F_{ULS}/4 over the transfer beam depth of span/3), (b) transfer beam **deep beam design** with $A_{s,prov}$ ≈ 3800 . M_{ULS} (kNm) / h (mm), (c) transfer beam **longitudinal shear within web and between web and flanges** and (d) transfer beam **torsion design**.	
	#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 ¼ of the required vertical steel) and transfer slab (acting as the tension element with the provision of rebar of $0.95f_y.A_{s,prov}$ to resist F_{ULS}/4 over the transfer slab depth of span/3), (b) transfer slab **deep beam design** with $A_{s,prov}$ ≈ 3800 . M_{ULS} (kNm) / h (mm) and (c) transfer slab **longitudinal shear within web**.	
	#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.	
	#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.	
	#G: Note check **Column Capacity Analyses Table** for ULS shear stress **τ = V_{ULS}/A_C ≈ 3N/mm²** (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) **<< 5N/mm²** for all stability base shear resisting elements i.e. shear walls above transfer and shear walls / mega columns below transfer.	
	#H: Note ensure **no foundation uplift**.	
	#I: Note check **on-plan torsional twist** due to NHF, wind and EQ loads.	

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ITEM	CONTENT	√
3.2	**Slab Loads**	
3.21	VIM → Slab Live Loads → check slab LL (ES).	☐
3.22	VIM → Slab Additional Dead Loads → check slab SDL (ES).	☐
3.23	3D Visualisation → check slab point, line and partial patch loading visually (ES).	☐
3.3	**Beam Loads**	
3.31	VIM → Beam Wall Loads → check internal cladding load (ES).	☐
3.32	VIM → Beam Wall Loads → check external cladding load (ES).	☐
3.33	VIM → Beams with User Defined Loads → check beams with user defined loads (ES).	☐
3.4	**Wall/Column Loads**	
3.5	**Lateral Loads**	
3.51	Run → BA → Pre-Analysis Tab → Project Parameters and Loading Subsection → Storey Loads and Parameters → check wind loads (ES).	☐
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).	☐
3.6	**Imposed Load Reduction**	
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: - $1.0DL+1.0SDL+\psi_{2i}LL+HYP\pm1.0EQ_X\pm0.3EQ_Y\pm\mathbf{0.3}EQ_Z$ $1.0DL+1.0SDL+\psi_{2i}LL+HYP\pm0.3EQ_X\pm1.0EQ_Y\pm\mathbf{0.3}EQ_Z$ 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 $1.0DL+1.0SDL+\psi_{2i}LL+HYP\pm0.3EQ_X\pm0.3EQ_Y\pm\mathbf{1.0}EQ_Z$ 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: - $1.0DL+1.0SDL+\psi_{2i}LL+PT\pm1.0EQ_X\pm0.3EQ_Y\pm\mathbf{0.3}EQ_Z$ $1.0DL+1.0SDL+\psi_{2i}LL+PT\pm0.3EQ_X\pm1.0EQ_Y\pm\mathbf{0.3}EQ_Z$ 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 $1.0DL+1.0SDL+\psi_{2i}LL+PT\pm0.3EQ_X\pm0.3EQ_Y\pm\mathbf{1.0}EQ_Z$ 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.	☐
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. $1.0DL+1.0SDL+\boldsymbol{\psi_{2i}}LL+HYP\pm1.0EQ_X$ $1.0DL+1.0SDL+\boldsymbol{\psi_{2i}}LL+HYP\pm1.0EQ_Y$ $1.0DL+1.0SDL+\boldsymbol{\psi_{2i}}LL+HYP\pm1.0EQ_X\pm0.3EQ_Y\pm0.3EQ_Z$ $1.0DL+1.0SDL+\boldsymbol{\psi_{2i}}LL+HYP\pm0.3EQ_X\pm1.0EQ_Y\pm0.3EQ_Z$ $1.0DL+1.0SDL+\boldsymbol{\psi_{2i}}LL+HYP\pm0.3EQ_X\pm0.3EQ_Y\pm1.0EQ_Z$ 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. $1.0DL+1.0SDL+\boldsymbol{\psi_{2i}}LL+PT\pm1.0EQ_X$ $1.0DL+1.0SDL+\boldsymbol{\psi_{2i}}LL+PT\pm1.0EQ_Y$ $1.0DL+1.0SDL+\boldsymbol{\psi_{2i}}LL+PT\pm1.0EQ_X\pm0.3EQ_Y\pm0.3EQ_Z$ $1.0DL+1.0SDL+\boldsymbol{\psi_{2i}}LL+PT\pm0.3EQ_X\pm1.0EQ_Y\pm0.3EQ_Z$ $1.0DL+1.0SDL+\boldsymbol{\psi_{2i}}LL+PT\pm0.3EQ_X\pm0.3EQ_Y\pm1.0EQ_Z$	☐
4.0	**BOUNDARY CONDITION CHECKS**	
4.1	**Beam/Column Releases**	
4.11	Member → Member Tables → Beam/Column Table → check Hinge = None (ES).	☐
4.2	**Wall/Column Clear Height**	
4.21	(see table below)	☐

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

ITEM	CONTENT	√
	(continued table below)	

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

#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.

4.22 ☐

Item	**BA**	**FEFA**
Recognition of Len (Storey) ≥ 2 Wall/Column As Beam Supports for Beams Not on the Wall/Column Defined Storey		
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 Building → Parameters → Lateral Drift Tab → check **Braced** for walls/columns in a lateral stability system (ES): - ☐

- (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 ≤ 0.25 or λ ≥ 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 = λ/(λ–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 ≤ 0.05 or λ ≥ 20) based on the **Sway Susceptibility Check** (based on cl.6.6.4.3(b) ACI 318-14).

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 λ ≥ 4.0 to cl.R6.2.6 ACI 318-14 and to verify the value for m in m = λ/(λ–1)) and **local mega column buckling** characteristics ((requiring λ ≥ 1).

4.32 Building → Parameters → Lateral Drift Tab → check **Unbraced** for walls/columns in a lateral stability system (ES): - ☐

- (i) that exist in a **coupled shear wall (major plane only)** / **moment frame** / **outrigger frame (except outrigger columns)** / **(framed) tube web (major plane only)** lateral stability system (cl.3.8.1.5 BS8110-1), **or**
- (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**
- (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)**
- (iv) that are within a **sway storey** (exhibiting Q > 0.05 or λ < 20) based on the **Sway Susceptibility Check** (based on cl.6.6.4.3(b) ACI 318-14).

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

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ITEM	CONTENT	√
	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 $\lambda \geq 1$).	
4.33	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).	☐
4.4	**Wall/Column Base Support Conditions**	
4.41	Member → Member Tables → Wall/Column Table → Support Type → check User-Defined (Member → Support Type Definitions → introduce lateral and rotational flexibility): - **Pad, Strip, Raft, Piled Raft Foundations** - Introduce lateral flexibility in both directions in accordance with soil stiffness. - Introduce zero rotational flexibility in both planes. **Piled Foundations (with Dropped or Integrated Pile Caps)** - 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.	☐
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.	☐
4.43	Check **stepped** foundations levels relative to St0i where i≥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≥1 may be defined with Len (Storey) ≥ 2 and +ve del z (bot) upwards defined to extend beyond the storey height(s).	☐
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).	☐
5.12	Check that secondary beam spans **break** at primary beam crossings and that primary beam spans **break** at wall/column crossings (ES). 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). Check that beam insertion points do not project **through and beyond** the column insertion points (ES). 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).	☐
5.13	Check 3D Visualisation for **accuracy of modelling** in particular: - • 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 different stories (ES). • 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).	☐
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).	☐
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 *"automatically mark all cantilever beams"* should not be used with the existence of non-prismatic beams as they will be incorrectly marked as such (ES).	☐

<table>
<tr><th>ITEM</th><th>CONTENT</th><th>√</th></tr>
<tr><td>5.16</td><td>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.</td><td>☐</td></tr>
<tr><td>5.2</td><td>Section and Material Properties</td><td></td></tr>
<tr><td>5.22</td><td>Member → Member Tables → Slab Table → check cover 25mm internal and 40mm external (e.g. ground, podium deck, swimming pool, water tank, roof) (ES).</td><td>☐</td></tr>
<tr><td>5.26</td><td>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, $e \le$ column orthogonal dim, b_c / 4 (DCM, DCH)
primary seismic beam width, $b_w \le$ min {column orthogonal dim, b_c + beam depth, h_w, $2b_c$} (DCM, DCH)
primary seismic beam width, $b_w \ge$ 200mm (DCH)
(b) as per cl.5.4.1.2.2 and cl.5.5.1.2.2,
primary seismic column width, $h_c \ge$ (column clear height, l_{cl} / 2) / 10 (DCM, DCH)
primary seismic column width, $h_c \ge$ 250mm (DCH)</td><td>☐</td></tr>
<tr><td>5.27</td><td>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, $b_{wo} \ge$ 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)</td><td>☐</td></tr>
<tr><td>5.3</td><td>Element Horizontal Framing</td><td></td></tr>
<tr><td>5.4</td><td>Element Vertical Framing</td><td></td></tr>
<tr><td>5.41</td><td>
<table>
<tr><th colspan="5">Requirement of Element to Frame Vertically (Between Storeys)
onto Element Insertion Point / Line (or Simply Within the Element Footprint on Plan)</th></tr>
<tr><th>Element</th><th>Slab</th><th>Beam</th><th>Wall</th><th>Column</th></tr>
<tr><td>Slab</td><td>N/A</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td>Beam</td><td>N/A</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td>Wall</td><td>Not Required [#A]</td><td>Required [#B2]</td><td>Required [#B1, #C]</td><td>Required [#B1]</td></tr>
<tr><td>Column</td><td>Not Required [#D]</td><td>Required [#E]</td><td>Not Required [#F]</td><td>Not Required [#F]</td></tr>
</table>
#A: Check wall insertion lines need only frame onto footprint of transfer slab (ES).
#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 x clear span, ref. CIRIA Guide 2 and thickness of the transferred wall) for the transferred wall (ES).
#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).
#C: Check wall insertion lines frame onto wall insertion lines (ES).
#D: Check column insertion points need only frame onto footprint of transfer slab (ES).
#E: Check column insertion points frame onto transfer beam insertion lines (ES).
#F: Check column insertion points need only frame onto footprint of wall/column (ES).</td><td>☐</td></tr>
<tr><td>5.42</td><td>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.</td><td>☐</td></tr>
<tr><td>5.43</td><td>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.</td><td>☐</td></tr>
<tr><td>5.44</td><td>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.</td><td>☐</td></tr>
<tr><td>5.45</td><td>
<table>
<tr><th colspan="5">Modelling of Transferred Walls</th></tr>
<tr><th>Transfer</th><th>Transfer</th><th>Rigid</th><th>Overlap</th><th>Remark</th></tr>
</table></td><td>☐</td></tr>
</table>

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

ITEM	CONTENT	√

red Wall	Wall/ Column #C	Zones	#A	
Wall #B	Wall #B	None	No Overlap	• 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	• 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 Overlap	• Correct **rigid** representation of transfer beam bending moment and shear force effects • Incorrect RC rebar arrangement – manual elongation of rebar and link required (rebar linking across wall required)
Wall #B	Column	None	Full / Partial Overlap	• 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	• 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	• 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	• Incorrect representation of transfer beam bending moment and shear force effects
Wall #B	Column	Max	Full / Partial Overlap	• Incorrect representation of transfer beam bending moment and shear force effects

#A: Overlap refers to overlap between transferred wall and transfer wall/column.
#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.
#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).
#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 *Diagram Moments*. As an alternative to specifying RigidZones as Maximum, specify walls instead of columns to effectively model columns with rigid beam arms.

ITEM	CONTENT	√
5.5	**Housekeeping**	
5.51	Edit → Re-Label Members → re-label all slabs and beams independently between storeys.	☐
5.52	Edit → Re-Label Members → re-label all walls and columns consistently between storeys.	☐
5.6	**Model Integrity**	
5.61	Run → BA → Analysis Tab → Building Model Check Subsection → Building Model Check.	☐
5.62	Edit → Move Members to Axes → Start.	☐
6.0	**METHOD OF ANALYSIS CHECKS**	
6.1	**Method of Slab Analysis and Design**	
6.2	**Method of Application of Slab Loads onto Beams**	
6.3	**Method of Frame Analysis**	
6.32	(see table below)	☐

Method of Frame Analysis	Transferred Beam/Slab on Transferred Wall/Column on Transfer Beam/Slab					
	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	

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

ITEM	CONTENT	√

1	**BA**	Supported #A, #B	Supported (Meshed Slabs) #A, #B	Supported (Meshed Slabs) #A, #B	Supported #C	Supported (Meshed Slabs) #D	Supported (Meshed Slabs) #D
2	**CBAFE**	Not Supported #A	Not Supported	Not Supported	Supported #C	Supported #D	Supported #D

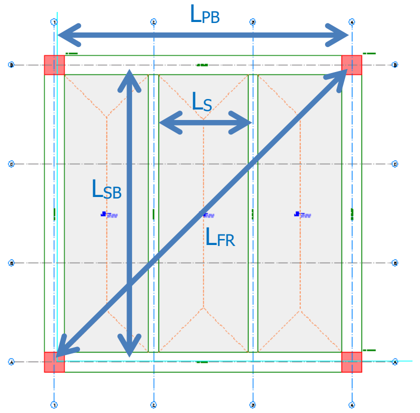
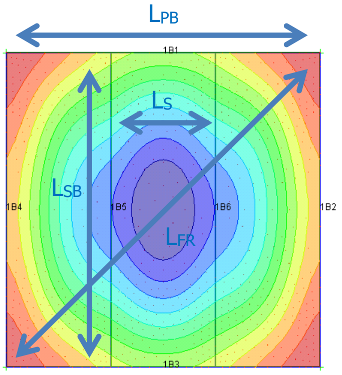
#A: Check that the **envelope effects** of both Method 1 (meshed slabs) and Method 2 are used in the design of transferred beams, transferred slabs in vicinity, transferred slabs and transferred walls/columns, noting that Method 1 (meshed slabs) supports the effects of **differential support settlement** 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.

7.0	**SLAB ANALYSIS AND DESIGN CHECKS**	
7.1	**General**	
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).	☐
7.2	**Conventional Codified BS8110 Coefficients Method**	
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).	☐
7.32	(see table below)	☐

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).	☐
7.34	**PT Tendon Modelling** Check tendons based on prestress force and eccentricity required for load balancing and prestress force for average precompression (ES). **RC or PT Deflection Checks** Run → FEFA → APP → check |TLS|=|DL+PT| **deflections** ≤ {[span/500 to span/350].C_1, 20mm} (ES). Run → FEFA → APP → check SLS=DL+SDL+LL+PT **deflections** ≤ [span/250].C_1 (ES). Run → FEFA → APP → check k_C.(DL+SDL)+LL+$k_{C,PT}$.PT **deflections** ≤ {[span/500 to span/350].C_1, 20mm}, note the creep term also includes the **<u>total</u>** (elastic, creep, shrinkage) axial shortening of the **<u>one</u>** storey in question (ES). Run → FEFA → APP → check k_C.(DL+SDL)+LL+$k_{C,PT}$.PT **deflections** at façade beams ≤ {[span/1000].C_1, 20mm}, note the creep term also includes the **<u>total</u>** (elastic, creep, shrinkage) axial shortening of the **<u>one</u>** storey in question (ES). Note C_1 = {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 (1-0.5/K_{LT}.K_{ST}).(1-0.4)=0.2625.	☐

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

ITEM	CONTENT	√
	  L_S : slab deflection check L_{SB} : secondary beam deflection check L_{PB} : primary beam deflection check L_{FR} : frame (column to column) deflection check 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).	
7.35	**PT Tendon Modelling** Check tendons based on prestress force and eccentricity required for load balancing and prestress force for average precompression (ES). **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). **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. **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 x tributary width x (15.0-25.0kPa) x $L^2/12$, 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 x tributary width x (15.0-25.0kPa) x 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). **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 (*consistent* 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** $f'_{min,t} \le f'_t \le f'_{max,t}$ BM:| $-1.0 \le f'_t \le 0.50f_{ci}$ [CL1] | $-0.36\sqrt{f_{ci}} \le f'_t \le 0.50f_{ci}$ [CL2] | $-0.25f_{ci} \le f'_t \le 0.50f_{ci}$ [CL3] | FS:| $-1.0 \le f'_t \le 0.24f_{ci}$ [CL1] | $-0.36\sqrt{f_{ci}} \le f'_t \le 0.24f_{ci}$ [CL2] | $-0.45\sqrt{f_{ci}} \le f'_t \le 0.24f_{ci}$ [CL3] | → check **TLS bottom stress** $f'_{min,b} \le f'_b \le f'_{max,b}$ BM:| $-1.0 \le f'_b \le 0.50f_{ci}$ [CL1] | $-0.36\sqrt{f_{ci}} \le f'_b \le 0.50f_{ci}$ [CL2] | $-0.25f_{ci} \le f'_b \le 0.50f_{ci}$ [CL3] | FS:| $-1.0 \le f'_b \le 0.33f_{ci}$ [CL1] | $-0.36\sqrt{f_{ci}} \le f'_b \le 0.33f_{ci}$ [CL2] | $-0.45\sqrt{f_{ci}} \le f'_b \le 0.33f_{ci}$ [CL3] | → check **SLS top stress** $f_{min,t} \le f_t \le f_{max,t}$	☐

ITEM	CONTENT	√

BM:| $-0.0 \le f_t \le 0.33f_{cu}$ [CL1] | $-0.36\sqrt{f_{cu}} \le f_t \le 0.33f_{cu}$ [CL2] | $-<.......> \le f_t \le 0.33f_{cu}$ [CL3] |
FS:| $-0.0 \le f_t \le 0.33f_{cu}$ [CL1] | $-0.36\sqrt{f_{cu}} \le f_t \le 0.33f_{cu}$ [CL2] | $-0.45\sqrt{f_{cu}} \le f_t \le 0.33f_{cu}$ [CL3] |
Note $-<.......> = \text{MAX}\{-0.25f_{cu}, (0.7\text{-}1.1).(-0.58\sqrt{f_{cu}}\text{ to }-0.82\sqrt{f_{cu}})\text{-}4N/mm^2/1.0\%\}$.

→ check **SLS bottom stress** $f_{min,b} \le f_b \le f_{max,b}$
BM:| $-0.0 \le f_b \le 0.40f_{cu}$ [CL1] | $-0.36\sqrt{f_{cu}} \le f_b \le 0.40f_{cu}$ [CL2] | $-<.......> \le f_b \le 0.40f_{cu}$ [CL3] |
FS:| $-0.0 \le f_b \le 0.24f_{cu}$ [CL1] | $-0.36\sqrt{f_{cu}} \le f_b \le 0.24f_{cu}$ [CL2] | $-0.45\sqrt{f_{cu}} \le f_b \le 0.24f_{cu}$ [CL3] |
Note $-<.......> = \text{MAX}\{-0.25f_{cu}, (0.7\text{-}1.1).(-0.58\sqrt{f_{cu}}\text{ to }-0.82\sqrt{f_{cu}})\text{-}4N/mm^2/1.0\%\}$.

Note by convention, +ve stress is compressive and –ve stress is tensile (*consistent* with ProtaStructure).

PT Design Strip Design Sections FE Analysis Method Integration of Effects Analysis and PT Design Strip Design Sections Design

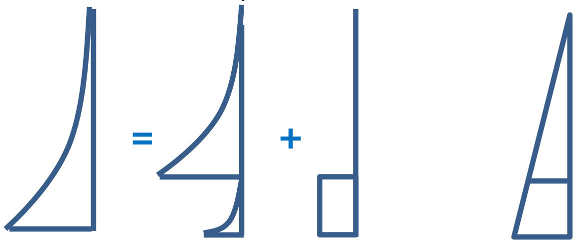
Run → FEFA → APP → check design strip design sections **PT analysis and design** in X/Y directions (ES)
→ check |TLS|=|DL+PT| **deflections** ≤ {[span/500 to span/350].C_1, 20mm}.
→ check SLS=DL+SDL+LL+PT **deflections** ≤ [span/250].C_1.
→ check k_C.(DL+SDL)+LL+$k_{C,PT}$.PT **deflections** ≤ {[span/500 to span/350].C_1, 20mm}, note the creep term also includes the **<u>total</u>** (elastic, creep, shrinkage) axial shortening of the **<u>one</u>** storey in question.
→ check k_C.(DL+SDL)+LL+$k_{C,PT}$.PT **deflections** at façade beams ≤ {[span/1000].C_1, 20mm}, note the creep term also includes the **<u>total</u>** (elastic, creep, shrinkage) axial shortening of the **<u>one</u>** storey in question.
Note C_1 = {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 $(1\text{-}0.5/K_{LT}.K_{ST}).(1\text{-}0.4)=0.2625$.
→ check percentage of **DL+SDL load balancing** is approximately 70-100%.
→ check **TLS/SLS bending** effects $M_{TLS/SLS,E/E}+M_{TLS/SLS,E/L}$ are minimal.
→ check **ULS bending** effects $M_{ULS,E/E}+M_{ULS,S/E}$ based on 1.4 x tributary width x (15.0-25.0kPa) x $L^2/12$ and hyperstatic effects, note w.o./w. the **<u>differential</u>** (elastic, creep, shrinkage) axial shortening of **<u>adjacent</u>** supports.
Note by convention, +ve bending moment is sagging and –ve bending moment is hogging (*consistent* with ProtaStructure).
→ check **TLS/SLS shear** effects $V_{TLS/SLS,E/E}+V_{TLS/SLS,E/L}$ are minimal.
→ 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 **<u>differential</u>** (elastic, creep, shrinkage) axial shortening of **<u>adjacent</u>** supports.
Note an arbitrary sign convention adopted for shear force (*consistent* with ProtaStructure).
→ check **TLS/SLS average precompression** 0.7-2.5N/mm^2 for slab and 2.5-4.5N/mm^2 for beam.
→ check **TLS top stress** $f'_{min,t} \le f'_t \le f'_{max,t}$
BM:| $-1.0 \le f'_t \le 0.50f_{ci}$ [CL1] | $-0.36\sqrt{f_{ci}} \le f'_t \le 0.50f_{ci}$ [CL2] | $-0.25f_{ci} \le f'_t \le 0.50f_{ci}$ [CL3] |
FS:| $-1.0 \le f'_t \le 0.24f_{ci}$ [CL1] | $-0.36\sqrt{f_{ci}} \le f'_t \le 0.24f_{ci}$ [CL2] | $-0.45\sqrt{f_{ci}} \le f'_t \le 0.24f_{ci}$ [CL3] |
→ check **TLS bottom stress** $f'_{min,b} \le f'_b \le f'_{max,b}$
BM:| $-1.0 \le f'_b \le 0.50f_{ci}$ [CL1] | $-0.36\sqrt{f_{ci}} \le f'_b \le 0.50f_{ci}$ [CL2] | $-0.25f_{ci} \le f'_b \le 0.50f_{ci}$ [CL3] |
FS:| $-1.0 \le f'_b \le 0.33f_{ci}$ [CL1] | $-0.36\sqrt{f_{ci}} \le f'_b \le 0.33f_{ci}$ [CL2] | $-0.45\sqrt{f_{ci}} \le f'_b \le 0.33f_{ci}$ [CL3] |
→ check **SLS top stress** $f_{min,t} \le f_t \le f_{max,t}$
BM:| $-0.0 \le f_t \le 0.33f_{cu}$ [CL1] | $-0.36\sqrt{f_{cu}} \le f_t \le 0.33f_{cu}$ [CL2] | $-<.......> \le f_t \le 0.33f_{cu}$ [CL3] |
FS:| $-0.0 \le f_t \le 0.33f_{cu}$ [CL1] | $-0.36\sqrt{f_{cu}} \le f_t \le 0.33f_{cu}$ [CL2] | $-0.45\sqrt{f_{cu}} \le f_t \le 0.33f_{cu}$ [CL3] |
Note $-<.......> = \text{MAX}\{-0.25f_{cu}, (0.7\text{-}1.1).(-0.58\sqrt{f_{cu}}\text{ to }-0.82\sqrt{f_{cu}})\text{-}4N/mm^2/1.0\%\}$.
→ check **SLS bottom stress** $f_{min,b} \le f_b \le f_{max,b}$
BM:| $-0.0 \le f_b \le 0.40f_{cu}$ [CL1] | $-0.36\sqrt{f_{cu}} \le f_b \le 0.40f_{cu}$ [CL2] | $-<.......> \le f_b \le 0.40f_{cu}$ [CL3] |
FS:| $-0.0 \le f_b \le 0.24f_{cu}$ [CL1] | $-0.36\sqrt{f_{cu}} \le f_b \le 0.24f_{cu}$ [CL2] | $-0.45\sqrt{f_{cu}} \le f_b \le 0.24f_{cu}$ [CL3] |
Note $-<.......> = \text{MAX}\{-0.25f_{cu}, (0.7\text{-}1.1).(-0.58\sqrt{f_{cu}}\text{ to }-0.82\sqrt{f_{cu}})\text{-}4N/mm^2/1.0\%\}$.
Note by convention, +ve stress is compressive and –ve stress is tensile (*consistent* with ProtaStructure).
→ check **rebar areas (to resist SLS tensile stress) required** {As(d)1, As(d)2}, noting minimum steel.
→ check **ULS moment capacity**, M_u is greater than ULS bending effects $M_{ULS,E/E}+M_{ULS,S/E}$.
→ 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** $A_{sv,req}/S$.
Run → Slab Analysis and Design → check **sufficiency of rebar (to resist SLS tensile stress)** at all FE slab strips (ES).

RC or PT Method of Slab Detailing

RC or PT Method of Slab Detailing	
Method 1: Automatic	**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.

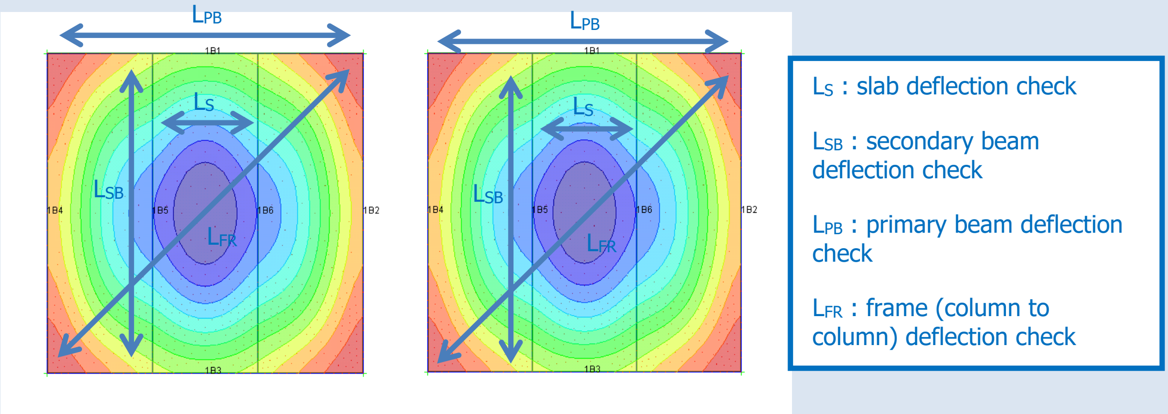
<table>
<tr><th>ITEM</th><th>CONTENT</th><th>√</th></tr>
<tr><td></td><td>
<table>
<tr><td>Specification of Reinforcement Bars #A</td><td>smallest available rebar diameter), Bar Spacing 100mm Min to 250mm Max and Steel Bar Spacing Step 25mm. Note in this method, only the 1/3rd span hogging regions will be automatically reinforced, manual addition required for top steel throughout.</td></tr>
<tr><td>Method 2:
Semi-Automatic Specification of Reinforcement Mesh / Bars #A</td><td>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 {As(d)1, As(d)2} for slab panels (Method 3).</td></tr>
<tr><td>Method 3:
Manual Specification of Reinforcement Mesh / Bars #B</td><td>Manual specification of (top) reinforcement mesh / bars based on FEFA rebar areas required {As(d)1, As(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 {As(d)1, As(d)2} for slab panels.</td></tr>
</table>
#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.

RC or PT Analysis and Design Summary Report
Check design strip design sections forces (ES).
Check design strip design sections rebar (ES).
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).
</td><td></td></tr>
<tr><td>7.36</td><td>Manually check ULS shear stresses and shear design at beam/wall supports of heavily loaded slabs (ES).</td><td>☐</td></tr>
<tr><td>7.37</td><td>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).</td><td>☐</td></tr>
<tr><td>8.0</td><td>BEAM AND WALL/COLUMN ANALYSIS AND DESIGN CHECKS</td><td></td></tr>
<tr><td>8.1</td><td>Building Analysis Method</td><td></td></tr>
<tr><td>8.11</td><td>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).</td><td>☐</td></tr>
<tr><td>8.13</td><td>Run → BA → Post Analysis → MARD → check magnitude and shape of ULS effects (axial forces, shear forces, bending moments, torsional moments) (ES).</td><td>☐</td></tr>
<tr><td>8.14</td><td>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</td><td>☐</td></tr>
</table>

ITEM	CONTENT	√
	akin to the effect of an outrigger) below the transfer level and **secondly**, the redistribution of stability base shear to different stability elements.  **Stability Base Moment (MNm)** **Stability Base Shear (MN)**	
8.15	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 ≤ 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 ≤ 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).	☐
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).	☐
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).	☐
8.18	Manually check ULS shear stresses and shear design at transferred walls on transfer beams.	☐
8.19	Manually check ULS punching shear at transferred walls/columns on transfer beams.	☐
8.2	**Combination of Building Analysis and the FE Based Gravity Load Chase Down Method**	
8.21	Run → FEFA (CBAFE) → check (uncracked) Stiffness Factors (i.e. EI) for (transfer) slab and (transfer) beam are $(2/3^{rd}).(1.00)\approx0.66$ for Class 1 PT or Class 2 PT, note 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). Run → FEFA (CBAFE) → check (cracked) Stiffness Factors (i.e. EI) for (transfer) slab and (transfer) beam are $(2/3^{rd}).(0.50)\approx0.32$ for RC or Class 3 PT, note 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).	☐
8.22	**PT Tendon Modelling** Check tendons based on prestress force and eccentricity required for load balancing and prestress force for average precompression. **RC or PT Deflection Checks** Run → FEFA (CBAFE) → APP → check |TLS|=|DL+PT| **deflections** ≤ {[span/500 to span/350].C_1, 20mm}. Run → FEFA (CBAFE) → APP → check SLS=DL+SDL+LL+PT **deflections** ≤ [span/250].C_1. Run → FEFA (CBAFE) → APP → check k_C.(DL+SDL)+LL+$k_{C,PT}$.PT **deflections** ≤ {[span/500 to span/350].C_1, 20mm}, note the creep term also includes the **<u>total</u>** (elastic, creep, shrinkage) axial shortening of the **<u>one</u>** storey in question. Run → FEFA (CBAFE) → APP → check k_C.(DL+SDL)+LL+$k_{C,PT}$.PT **deflections** at façade beams ≤ {[span/1000].C_1, 20mm}, note the creep term also includes the **<u>total</u>** (elastic, creep, shrinkage) axial shortening	☐

ITEM	CONTENT	√

of the **<u>one</u>** storey in question.
Note deflections above refer to deflections of all transfer slabs and slabs in the vicinity of transfer beams.
Note C_1 = {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 (1-0.32).(1-0.4)DL+1.0SDL=k_C.(DL+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=[0.4DL+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.



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).

8.23 ☐

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.

PT Tendon Modelling
Check tendons based on prestress force and eccentricity required for load balancing and prestress force for average precompression.

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).

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 **<u>differential</u>** (elastic, creep, shrinkage) axial shortening of **<u>adjacent</u>** supports.
→ check **ULS shear** effects $V_{ULS,E/E}$, note w.o./w. the **<u>differential</u>** (elastic, creep, shrinkage) axial shortening of **<u>adjacent</u>** supports.

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 x tributary width x (15.0-25.0kPa) x L^2/12, note w.o./w. the **<u>differential</u>** (elastic, creep, shrinkage) axial shortening of **<u>adjacent</u>** supports.
→ check **ULS shear** effects $V_{ULS,E/E}$ based on 1.4 x tributary width x (15.0-25.0kPa) x L/2, note w.o./w. the **<u>differential</u>** (elastic, creep, shrinkage) axial shortening of **<u>adjacent</u>** 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 → FEFA (CBAFE) → Run → Slab Analysis and Design → check **sufficiency of rebar (to resist ULS bending)** at all FE slab strips.

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 **<u>differential</u>** (elastic, creep, shrinkage) axial shortening of **<u>adjacent</u>** supports.
Note by convention, +ve bending moment is sagging and –ve bending moment is hogging (*consistent* with

ITEM	CONTENT	√

ProtaStructure).

→ check **TLS/SLS average precompression** 0.7-2.5N/mm^2 for slab and 2.5-4.5N/mm^2 for beam.

→ check **TLS top stress** $f'_{min,t} \le f'_t \le f'_{max,t}$

BM:| $-1.0 \le f'_t \le 0.50f_{ci}$ [CL1] | $-0.36\sqrt{f_{ci}} \le f'_t \le 0.50f_{ci}$ [CL2] | $-0.25f_{ci} \le f'_t \le 0.50f_{ci}$ [CL3] |

FS:| $-1.0 \le f'_t \le 0.24f_{ci}$ [CL1] | $-0.36\sqrt{f_{ci}} \le f'_t \le 0.24f_{ci}$ [CL2] | $-0.45\sqrt{f_{ci}} \le f'_t \le 0.24f_{ci}$ [CL3] |

→ check **TLS bottom stress** $f'_{min,b} \le f'_b \le f'_{max,b}$

BM:| $-1.0 \le f'_b \le 0.50f_{ci}$ [CL1] | $-0.36\sqrt{f_{ci}} \le f'_b \le 0.50f_{ci}$ [CL2] | $-0.25f_{ci} \le f'_b \le 0.50f_{ci}$ [CL3] |

FS:| $-1.0 \le f'_b \le 0.33f_{ci}$ [CL1] | $-0.36\sqrt{f_{ci}} \le f'_b \le 0.33f_{ci}$ [CL2] | $-0.45\sqrt{f_{ci}} \le f'_b \le 0.33f_{ci}$ [CL3] |

→ check **SLS top stress** $f_{min,t} \le f_t \le f_{max,t}$

BM:| $-0.0 \le f_t \le 0.33f_{cu}$ [CL1] | $-0.36\sqrt{f_{cu}} \le f_t \le 0.33f_{cu}$ [CL2] | -<.......> $\le f_t \le 0.33f_{cu}$ [CL3] |

FS:| $-0.0 \le f_t \le 0.33f_{cu}$ [CL1] | $-0.36\sqrt{f_{cu}} \le f_t \le 0.33f_{cu}$ [CL2] | $-0.45\sqrt{f_{cu}} \le f_t \le 0.33f_{cu}$ [CL3] |

Note -<.......> = MAX {$-0.25f_{cu}$, (0.7-1.1).($-0.58\sqrt{f_{cu}}$ to $-0.82\sqrt{f_{cu}}$)-4N/mm^2/1.0%}.

→ check **SLS bottom stress** $f_{min,b} \le f_b \le f_{max,b}$

BM:| $-0.0 \le f_b \le 0.40f_{cu}$ [CL1] | $-0.36\sqrt{f_{cu}} \le f_b \le 0.40f_{cu}$ [CL2] | -<.......> $\le f_b \le 0.40f_{cu}$ [CL3] |

FS:| $-0.0 \le f_b \le 0.24f_{cu}$ [CL1] | $-0.36\sqrt{f_{cu}} \le f_b \le 0.24f_{cu}$ [CL2] | $-0.45\sqrt{f_{cu}} \le f_b \le 0.24f_{cu}$ [CL3] |

Note -<.......> = MAX {$-0.25f_{cu}$, (0.7-1.1).($-0.58\sqrt{f_{cu}}$ to $-0.82\sqrt{f_{cu}}$)-4N/mm^2/1.0%}.

Note by convention, +ve stress is compressive and –ve stress is tensile (*consistent* with ProtaStructure).

PT Design Strip Design Sections FE Analysis Method Integration of Effects Analysis and PT Design Strip Design Sections Design

Run → FEFA (CBAFE) → APP → check design strip design sections PT **analysis and design** in X/Y directions

→ check |TLS|=|DL+PT| **deflections** ≤ {[span/500 to span/350].C_1, 20mm}.

→ check SLS=DL+SDL+LL+PT **deflections** ≤ [span/250].C_1.

→ check k_C.(DL+SDL)+LL+$k_{C,PT}$.PT **deflections** ≤ {[span/500 to span/350].C_1, 20mm}, note the creep term also includes the **<u>total</u>** (elastic, creep, shrinkage) axial shortening of the **<u>one</u>** storey in question.

→ check k_C.(DL+SDL)+LL+$k_{C,PT}$.PT **deflections** at façade beams ≤ {[span/1000].C_1, 20mm}, note the creep term also includes the **<u>total</u>** (elastic, creep, shrinkage) axial shortening of the **<u>one</u>** storey in question.

Note C_1 = {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.

→ check percentage of **DL+SDL load balancing** is approximately 70-100%.

→ check **TLS/SLS bending** effects $M_{TLS/SLS,E/E}$+$M_{TLS/SLS,E/L}$ are minimal.

→ check **ULS bending** effects $M_{ULS,E/E}$+$M_{ULS,S/E}$ based on 1.4 x tributary width x (15.0-25.0kPa) x L^2/12 and hyperstatic effects, note w.o./w. the **<u>differential</u>** (elastic, creep, shrinkage) axial shortening of **<u>adjacent</u>** supports.

Note by convention, +ve bending moment is sagging and –ve bending moment is hogging (*consistent* with ProtaStructure).

→ check **TLS/SLS shear** effects $V_{TLS/SLS,E/E}$+$V_{TLS/SLS,E/L}$ are minimal.

→ 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 **<u>differential</u>** (elastic, creep, shrinkage) axial shortening of **<u>adjacent</u>** supports.

Note an arbitrary sign convention adopted for shear force (*consistent* with ProtaStructure).

→ check **TLS/SLS average precompression** 0.7-2.5N/mm^2 for slab and 2.5-4.5N/mm^2 for beam.

→ check **TLS top stress** $f'_{min,t} \le f'_t \le f'_{max,t}$

BM:| $-1.0 \le f'_t \le 0.50f_{ci}$ [CL1] | $-0.36\sqrt{f_{ci}} \le f'_t \le 0.50f_{ci}$ [CL2] | $-0.25f_{ci} \le f'_t \le 0.50f_{ci}$ [CL3] |

FS:| $-1.0 \le f'_t \le 0.24f_{ci}$ [CL1] | $-0.36\sqrt{f_{ci}} \le f'_t \le 0.24f_{ci}$ [CL2] | $-0.45\sqrt{f_{ci}} \le f'_t \le 0.24f_{ci}$ [CL3] |

→ check **TLS bottom stress** $f'_{min,b} \le f'_b \le f'_{max,b}$

BM:| $-1.0 \le f'_b \le 0.50f_{ci}$ [CL1] | $-0.36\sqrt{f_{ci}} \le f'_b \le 0.50f_{ci}$ [CL2] | $-0.25f_{ci} \le f'_b \le 0.50f_{ci}$ [CL3] |

FS:| $-1.0 \le f'_b \le 0.33f_{ci}$ [CL1] | $-0.36\sqrt{f_{ci}} \le f'_b \le 0.33f_{ci}$ [CL2] | $-0.45\sqrt{f_{ci}} \le f'_b \le 0.33f_{ci}$ [CL3] |

→ check **SLS top stress** $f_{min,t} \le f_t \le f_{max,t}$

BM:| $-0.0 \le f_t \le 0.33f_{cu}$ [CL1] | $-0.36\sqrt{f_{cu}} \le f_t \le 0.33f_{cu}$ [CL2] | -<.......> $\le f_t \le 0.33f_{cu}$ [CL3] |

FS:| $-0.0 \le f_t \le 0.33f_{cu}$ [CL1] | $-0.36\sqrt{f_{cu}} \le f_t \le 0.33f_{cu}$ [CL2] | $-0.45\sqrt{f_{cu}} \le f_t \le 0.33f_{cu}$ [CL3] |

Note -<.......> = MAX {$-0.25f_{cu}$, (0.7-1.1).($-0.58\sqrt{f_{cu}}$ to $-0.82\sqrt{f_{cu}}$)-4N/mm^2/1.0%}.

→ check **SLS bottom stress** $f_{min,b} \le f_b \le f_{max,b}$

BM:| $-0.0 \le f_b \le 0.40f_{cu}$ [CL1] | $-0.36\sqrt{f_{cu}} \le f_b \le 0.40f_{cu}$ [CL2] | -<.......> $\le f_b \le 0.40f_{cu}$ [CL3] |

FS:| $-0.0 \le f_b \le 0.24f_{cu}$ [CL1] | $-0.36\sqrt{f_{cu}} \le f_b \le 0.24f_{cu}$ [CL2] | $-0.45\sqrt{f_{cu}} \le f_b \le 0.24f_{cu}$ [CL3] |

Note -<.......> = MAX {$-0.25f_{cu}$, (0.7-1.1).($-0.58\sqrt{f_{cu}}$ to $-0.82\sqrt{f_{cu}}$)-4N/mm^2/1.0%}.

Note by convention, +ve stress is compressive and –ve stress is tensile (*consistent* with ProtaStructure).

→ check **rebar areas (to resist SLS tensile stress) required** {As(d)1, As(d)2}, noting minimum steel.

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

ITEM	CONTENT	√
	→ check **ULS moment capacity**, M_u is greater than ULS bending effects $M_{ULS,E/E}+M_{ULS,S/E}$. → 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** $A_{sv,req}/S$. Run → FEFA (CBAFE) → Run → Slab Analysis and Design → check **sufficiency of rebar (to resist SLS tensile stress)** at all FE slab strips.	
8.24	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. **RC or PT Analysis and Design Summary Report** 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.	☐
8.25	Manually check ULS shear stresses and shear design at beam/wall supports of transfer slabs.	☐
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** $A_{sv,req}$.	☐
8.27	Manually check ULS shear stresses and shear design at transferred walls on transfer slabs.	☐
8.28	Manually check ULS punching shear at transferred walls/columns on transfer slabs.	☐
8.3	**FE Model Ill-Conditioning**	
8.31	**Building Analysis Method** Run → BA → Analysis Tab → Axial Load Comparison Report → check consistency between the applied un-decomposed slab loads (Table 1), applied decomposed slab loads (Table 2) and the reactions presented in the column / wall axial loads (Table 3). **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 un-decomposed slab loads (Table 1) and the reactions presented in the FE analysis column / wall axial loads (Table 4).	☐
8.4	**Load Take Down**	
8.41	Run → BA → Analysis Tab → Axial Load Comparison Report → check SLS load ≈ 15.0-25.0kPa for typical concrete and 10.0kPa for typical steel residential and commercial buildings (ES). Note check load take down calculation for **BA / CBAFE**.	☐
8.42	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**. 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**.	☐
8.5	**Sway Susceptibility (NHF, Wind, EQ)**	
8.51	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). • 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.	☐
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	☐

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ITEM	CONTENT	√
	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.	
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 ≤ 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 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.	☐
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 ≤ 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.	☐
8.65	Run → BA → Reports Tab → Storey Displacements Report → check total building lateral deflections to **EQ**, $\nu.q.\delta_{total} \leq H_{total}/250$ and relative storey drift, $\nu.q.\Delta\delta_{storey,I} \leq h_{storey,I}/250$ (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.	☐
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 ≤ 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.	☐
8.7	**Beam Design**	
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).	☐
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).	☐
8.78	**Building RC and PT beam final comprehensive design check (ES)** #A	
8.781	BA → | check design → | % steel << 4% → | $\tau \approx 3 << 5N/mm^2$ →	☐
8.782	CBAFE → | check design → | % steel << 4% → | $\tau \approx 3 << 5N/mm^2$ →	☐
	#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 {beam depth / 4; 24 x link diameter; 225mm; 8 x longitudinal bar diameter} and cl.5.5.3.1.3 BS	☐

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ITEM	CONTENT	√
	EN1998-1 (DCH) which states s = min {beam depth / 4; 24 x link diameter; 175mm; 6 x longitudinal bar diameter} (ES).	
8.8	**Wall/Column Design**	
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).	☐
8.88	**Building wall/column final comprehensive design check (ES)** [#B, #C]	
8.881	BA → BS8110-1 theory → check design → % steel << 2%/5% [#A] → $\tau \approx 3 << 5N/mm^2$ →	☐
8.882	BA → biaxial bending theory → check design → % steel << 2%/5% [#A] → $\tau \approx 3 << 5N/mm^2$ →	☐
8.883	CBAFE → BS8110-1 theory → check design → % steel << 2%/5% [#A] → $\tau \approx 3 << 5N/mm^2$ →	☐
8.884	CBAFE → biaxial bending theory → check design → % steel << 2%/5% [#A] → $\tau \approx 3 << 5N/mm^2$ →	☐
	#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 {(minimum column dimension excluding cover and half link diameter) / 2; 175mm; 8 x longitudinal bar diameter} and cl.5.5.3.2.2 BS EN1998-1 (DCH) which states s = min {(minimum column dimension excluding cover and half link diameter) / 3; 125mm; 6 x longitudinal bar diameter} (ES).	☐
9.0	**FOUNDATION CHECKS**	
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.	☐
9.2	**Pad Footing**	
9.3	**Strip Footing**	
9.4	**Raft / Piled Raft Footing**	
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.	☐
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.	☐
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.	☐
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).	☐
10.12	In RC or PT models, check concrete quantity to typical concrete equivalent floor thicknesses ($m^3/10^3m^2$) → 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.	☐

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Appendix A: PT Permissible Stress

Permissible Stress [N/mm²] [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} [#A1] 0.24 f_{ci} [#A2]	0.50 f_{ci} [#A1] 0.33 f_{ci} [#A2]	0.50 f_{ci} [#A1] 0.24 f_{ci} [#A2]	0.50 f_{ci} [#A1] 0.33 f_{ci} [#A2]	0.50 f_{ci} [#A1] 0.24 f_{ci} [#A2]	0.50 f_{ci} [#A1] 0.33 f_{ci} [#A2]
TLS tensile $f'_{min,t/b}$	-1.0 [#B]	-1.0 [#B]	-0.36 $\sqrt{f_{ci}}$ [#B]	-0.36 $\sqrt{f_{ci}}$ [#B]	-0.25 f_{ci} [#B1] -0.45 $\sqrt{f_{ci}}$ [#B2]	-0.25 f_{ci} [#B1] -0.45 $\sqrt{f_{ci}}$ [#B2]
SLS comp $f_{max,t/b}$	0.33 f_{cu} [#C1] 0.33 f_{cu} [#C2]	0.40 f_{cu} [#C1] 0.24 f_{cu} [#C2]	0.33 f_{cu} [#C1] 0.33 f_{cu} [#C2]	0.40 f_{cu} [#C1] 0.24 f_{cu} [#C2]	0.33 f_{cu} [#C1] 0.33 f_{cu} [#C2]	0.40 f_{cu} [#C1] 0.24 f_{cu} [#C2]
SLS tensile $f_{min,t/b}$	-0.0 [#D]	-0.0 [#D]	-0.36 $\sqrt{f_{cu}}$ [#D]	-0.36 $\sqrt{f_{cu}}$ [#D]	-<.......> [#D1] -0.45 $\sqrt{f_{cu}}$ [#D2]	-<.......> [#D1] -0.45 $\sqrt{f_{cu}}$ [#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 -<.......> = MAX {-0.25f_{cu}, (0.7-1.1).(-0.58$\sqrt{f_{cu}}$ to -0.82$\sqrt{f_{cu}}$)-4N/mm²/1.0%} as the code allows for an increase in the tensile stress limit from 1% of longitudinal steel (untensioned reinforcement) onwards (-4N/mm² 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}' [#A]	0.60 f_{ci}' [#A]	0.60 f_{ci}' [#A]	0.60 f_{ci}' [#A]	0.60 f_{ci}' [#A]	0.60 f_{ci}' [#A]
TLS tensile $f'_{min,t/b}$	-0.25 $\sqrt{f_{ci}'}$ [#B]	-0.25 $\sqrt{f_{ci}'}$ [#B]	-0.25 $\sqrt{f_{ci}'}$ [#B]	-0.25 $\sqrt{f_{ci}'}$ [#B]	-0.30 f_{ci}' [#B1] -0.50 $\sqrt{f_{ci}'}$ [#B2]	-0.30 f_{ci}' [#B1] -0.50 $\sqrt{f_{ci}'}$ [#B2]

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 $f_{min,t/b}$	$-0.62 \sqrt{f_c'}$ #D1 $-0.50 \sqrt{f_c'}$ #D2	$-0.62 \sqrt{f_c'}$ #D1 $-0.50 \sqrt{f_c'}$ #D2	$-1.00 \sqrt{f_c'}$ #D1 $-0.50 \sqrt{f_c'}$ #D2	$-1.00 \sqrt{f_c'}$ #D1 $-0.50 \sqrt{f_c'}$ #D2	$-0.30 f_c'$ #D1 $-0.50 \sqrt{f_c'}$ #D2	$-0.30 f_c'$ #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/mm²] [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	$-0.30 f_{ci}'$ #B1 $-0.60 \sqrt{f_{ci}'}$ #B2	$-0.30 f_{ci}'$ #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	$-0.30 f_c'$ #D1 $-0.60 \sqrt{f_c'}$ #D2	$-0.30 f_c'$ #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/mm²] [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 $f'_{max,t/b}$	$0.50 f_{ci}'$ #A1 $0.30 f_{ci}'$ #A2	$0.50 f_{ci}'$ #A1 $0.40 f_{ci}'$ #A2	$0.50 f_{ci}'$ #A1 $0.30 f_{ci}'$ #A2	$0.50 f_{ci}'$ #A1 $0.40 f_{ci}'$ #A2	$0.50 f_{ci}'$ #A1 $0.30 f_{ci}'$ #A2	$0.50 f_{ci}'$ #A1 $0.40 f_{ci}'$ #A2
TLS tensile $f'_{min,t/b}$	$-0.21 f_{ci}'^{2/3}$ #B1 $-0.09 f_{ci}'^{2/3}$ #B2	$-0.21 f_{ci}'^{2/3}$ #B1 $-0.09 f_{ci}'^{2/3}$ #B2	$-0.21 f_{ci}'^{2/3}$ #B1 $-0.09 f_{ci}'^{2/3}$ #B2	$-0.21 f_{ci}'^{2/3}$ #B1 $-0.09 f_{ci}'^{2/3}$ #B2	$-0.30 f_{ci}'$ #B1 $-0.27 f_{ci}'^{2/3}$ #B2	$-0.30 f_{ci}'$ #B1 $-0.27 f_{ci}'^{2/3}$ #B2
SLS comp $f_{max,t/b}$	$0.60 f_c'$ #C1 $0.40 f_c'$ #C2	$0.60 f_c'$ #C1 $0.30 f_c'$ #C2	$0.60 f_c'$ #C1 $0.40 f_c'$ #C2	$0.60 f_c'$ #C1 $0.30 f_c'$ #C2	$0.60 f_c'$ #C1 $0.40 f_c'$ #C2	$0.60 f_c'$ #C1 $0.30 f_c'$ #C2
SLS tensile $f_{min,t/b}$	$-0.21 f_c'^{2/3}$ #D1 $-0.09 f_c'^{2/3}$ #D3	$-0.21 f_c'^{2/3}$ #D1 $-0.09 f_c'^{2/3}$ #D3	$-0.21 f_c'^{2/3}$ #D1 $-0.09 f_c'^{2/3}$ #D3	$-0.21 f_c'^{2/3}$ #D1 $-0.09 f_c'^{2/3}$ #D3	-<.......> #D2 $-0.27 f_c'^{2/3}$ #D3	-<.......> #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 -<.......> = MAX {$-0.30 f_c'$, ($-0.40 f_c'^{2/3}$ to $-0.50 f_c'^{2/3}$)-4N/mm²/1.0%} as the code allows for an increase in the tensile stress limit from 1% of longitudinal steel (untensioned reinforcement) onwards (-4N/mm² for every 1% of longitudinal steel (untensioned reinforcement), increasing proportionally, up to the specified upper limit of $-0.30 f_c'$).
#D3: Note flat slab option to T.4 TR.43-2 based on **full tributary width** design strip.

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 ϕ_s = 12.7mm Strand	12.70	98.71	186.0	1860	183.7
[ASTM A416] Grade 270 ϕ_s = 15.24mm Strand	15.24	140.00	186.0	1860	260.7
[BS5896] 7-Wire Super ϕ_s = 12.9mm Strand	12.90	100.00	195.0	1860	186.0
[BS5896] 7-Wire Super ϕ_s = 15.7mm 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

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Appendix D: RC or PT Load Combination Cases

Load Case	Load Case Symbol Description
DL	Dead load (self-weight of the structure) case
DL+SDL	Dead load (self-weight of the structure) and superimposed dead load case
LL	Live load case
WL	Wind load
NHL | EHF	Notional horizontal load | Equivalent horizontal force
PT	Equivalent (primary and secondary) load case (prestressing) after long-term losses
PT$_i$	Equivalent (primary and secondary) load case (prestressing) after short-term losses
HYP	Hyperstatic (secondary) load case (prestressing)
EQ	Earthquake load
ψ_{2i}	Combination coefficient for variable action *i*
q	Behaviour factor

	Description	Load Factor [BS8110]								
	Ultimate Limit State (ULS)	**PT**	**HYP**	**DL**	**SDL**	**LL**	**WL$_X$**	**WL$_Y$**	**NHL$_X$**	**NHL$_Y$**
ULS 1	1.4DL+1.4SDL+1.6LL+HYP [#A, #B]	–	1.0	1.4	1.4	1.6	–	–	–	–
ULS 2A	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
ULS 2B	1.0DL+1.0SDL±1.0NHL+HYP [#A]	–	1.0	1.0	1.0	–	–	–	±1.0	–
		–	1.0	1.0	1.0	–	–	–	–	±1.0
ULS 2C	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
ULS 3A	1.4DL+1.4SDL±1.4WL+HYP [#A]	–	1.0	1.4	1.4	–	±1.4	–	–	–
		–	1.0	1.4	1.4	–	–	±1.4	–	–
ULS 3B	1.0DL+1.0SDL±1.4WL+HYP [#A]	–	1.0	1.0	1.0	–	±1.4	–	–	–
		–	1.0	1.0	1.0	–	–	±1.4	–	–
ULS 3C	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)	**PT**	**HYP**	**DL**	**SDL**	**LL**	**WL$_X$**	**WL$_Y$**	**NHL$_X$**	**NHL$_Y$**
TLS 1	1.0DL+1.15PT$_i$ [#D]	1.15	–	1.0	–	–	–	–	–	–
	Serviceability Limit State (SLS) Long-Term Total Effects	**PT**	**HYP**	**DL**	**SDL**	**LL**	**WL$_X$**	**WL$_Y$**	**NHL$_X$**	**NHL$_Y$**
SLS 1A	1.0DL+1.0SDL+1.0LL+PT [#A, #E]	1.0	–	1.0	1.0	1.0	–	–	–	–
SLS 2	1.0DL+1.0SDL+1.0LL±0.8NHL+PT [#A, #G]	1.0	–	1.0	1.0	1.0	–	–	±0.8	–
		1.0	–	1.0	1.0	1.0	–	–	–	±0.8
SLS 3	1.0DL+1.0SDL+1.0LL±0.8WL+PT [#A, #G]	1.0	–	1.0	1.0	1.0	±0.8	–	–	–
		1.0	–	1.0	1.0	1.0	–	±0.8	–	–
	Serviceability Limit State (SLS) Long-Term Incremental Effects	**PT**	**HYP**	**DL**	**SDL**	**LL**	**WL$_X$**	**WL$_Y$**	**NHL$_X$**	**NHL$_Y$**
SLS 1B	0.67k_{cp}.DL+1.0SDL+1.0LL+0.67k_{cp}.PT [#F]	0.67 k_{cp}	–	0.67 k_{cp}	1.0	1.0	–	–	–	–

#A For 3D building finite element models, the load combinations inherently include the effects of **differential** (elastic, creep, shrinkage to cl.3.1.4 EC2) axial shortening based on a 10-day per floor **staged construction analysis** of the corresponding load combination case. For 2D floor plate models on the other hand, these load combinations shall be appended with a 30-year **differential** (elastic, creep, shrinkage to cl.3.1.4

EC2) axial shortening 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 on a 3D model. Note that in the 2D model, although initial section property modifier for inertia I is 1.00, i.e. uncracked, an **explicit cracked deflection analysis** is undertaken to establish regions which are cracked and those which are uncracked. In the 3D model, the load combination case shall employ **cracked** element properties as defined (for applicable elements).

#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] ≤ 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.

#E Note **long-term** modulus of elasticity, $E_{c,long\text{-}term} = E_{c,short\text{-}term} / (1+\phi=2.0)$ for slabs and beams. Note that in the 2D model, although initial section property modifier for inertia I is 1.00, i.e. uncracked, an **explicit cracked deflection analysis** is undertaken to establish regions which are cracked and those which are uncracked.

#F Note equivalent $\phi = 2.0$ creep load combination factor [1-(1/(1+2.0))] = 0.67 on FE models employing **long-term** modulus of elasticity, $E_{c,long\text{-}term} = E_{c,short\text{-}term} / (1+\phi=2.0)$ for slabs and beams. Note additional k_{cp} factor of (1-0.4) for the remaining 60% component of DL creep deflection after 1 month (cl.7.3 BS8110-2). Note that in the 2D model, although initial section property modifier for inertia I is 1.00, i.e. uncracked, an **explicit cracked deflection analysis** is undertaken to establish regions which are cracked and those which are uncracked.

#G Note that back-analyzed load factor 1/1.25=0.80 [to cl.2.3.2.4.3 BS8004 which allows a 25% pile overstress in wind load combinations] are added to these SLS load combination cases, conservatively only onto the NHL and WL load cases.

	Description	Load Factor [EN1990]								
	Ultimate Limit State (ULS)	**PT**	**HYP**	**DL**	**SDL**	**LL**	**WL_X**	**WL_Y**	**EHF_X**	**EHF_Y**
ULS 1	1.35DL+1.35SDL+1.5LL+HYP #A, #B	–	1.0	1.35	1.35	1.5	–	–	–	–
ULS 2A	1.35DL+1.35SDL±1.0EHF+HYP #A	–	1.0	1.35	1.35	–	–	–	±1.0	–
		–	1.0	1.35	1.35	–	–	–	–	±1.0
ULS 2B	1.0DL+1.0SDL±1.0EHF+HYP #A	–	1.0	1.0	1.0	–	–	–	±1.0	–
		–	1.0	1.0	1.0	–	–	–	–	±1.0
ULS 2C	1.35DL+1.35SDL+1.5LL ±1.0EHF+HYP #A	–	1.0	1.35	1.35	1.5	–	–	±1.0	–
		–	1.0	1.35	1.35	1.5	–	–	–	±1.0
ULS 3A	1.35DL+1.35SDL±1.5WL ±1.0EHF+HYP #A	–	1.0	1.35	1.35	–	±1.5	–	±1.0	–
		–	1.0	1.35	1.35	–	–	±1.5	–	±1.0
ULS 3B	1.0DL+1.0SDL±1.5WL ±1.0EHF+HYP #A	–	1.0	1.0	1.0	–	±1.5	–	±1.0	–
		–	1.0	1.0	1.0	–	–	±1.5	–	±1.0
ULS 3C1	1.35DL+1.35SDL+1.5LL±0.5(1.5WL) ±1.0EHF+HYP #A	–	1.0	1.35	1.35	1.5	±0.75	–	±1.0	–
		–	1.0	1.35	1.35	1.5	–	±0.75	–	±1.0
ULS 3C2	1.35DL+1.35SDL+0.7(1.5LL)±1.5WL ±1.0EHF+HYP #A	–	1.0	1.35	1.35	1.05	±1.5	–	±1.0	–
		–	1.0	1.35	1.35	1.05	–	±1.5	–	±1.0
	Transfer Limit State (TLS)	**PT**	**HYP**	**DL**	**SDL**	**LL**	**WL_X**	**WL_Y**	**EHF_X**	**EHF_Y**
TLS 1	1.0DL+1.15PT_i #D	1.15	–	1.0	–	–	–	–	–	–
	Serviceability Limit State (SLS) Long-Term Total Effects	**PT**	**HYP**	**DL**	**SDL**	**LL**	**WL_X**	**WL_Y**	**EHF_X**	**EHF_Y**
SLS 1A	1.0DL+1.0SDL+1.3LL+PT #A, #E	1.0	–	1.0	1.0	1.3	–	–	–	–
SLS 2	1.0DL+1.0SDL+1.3LL±1.0EHF+PT #A	1.0	–	1.0	1.0	1.3	–	–	±1.0	–
		1.0	–	1.0	1.0	1.3	–	–	–	±1.0
SLS 3C1	1.0DL+1.0SDL+1.3LL±0.5(1.3WL) +PT #A	1.0	–	1.0	1.0	1.3	±0.65	–	–	–
		1.0	–	1.0	1.0	1.3	–	±0.65	–	–
SLS 3C2	1.0DL+1.0SDL+0.7(1.3LL)±1.3WL +PT #A	1.0	–	1.0	1.0	0.9	±1.3	–	–	–
		1.0	–	1.0	1.0	0.9	–	±1.3	–	–
	Serviceability Limit State (SLS) Long-Term Incremental Effects	**PT**	**HYP**	**DL**	**SDL**	**LL**	**WL_X**	**WL_Y**	**EHF_X**	**EHF_Y**
SLS 1B	0.67k_{cp}.DL+1.0SDL+1.3LL+0.67k_{cp}.PT #F	0.67 k_{cp}	–	0.67 k_{cp}	1.0	1.3	–	–	–	–

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#A For 3D building finite element models, the load combinations inherently include the effects of **differential** (elastic, creep, shrinkage to cl.3.1.4 EC2) axial shortening based on a 10-day per floor **staged construction analysis** of the corresponding load combination case. For 2D floor plate models on the other hand, these load combinations shall be appended with a 30-year **differential** (elastic, creep, shrinkage to cl.3.1.4 EC2) axial shortening based on a 10-day per floor **staged construction analysis** of the load combination case 1.35DL+1.35SDL or 1.0DL+1.0SDL as appropriate on a 3D model. Note that in the 2D model, although initial section property modifier for inertia I is 1.00, i.e. uncracked, an **explicit cracked deflection analysis** is undertaken to establish regions which are cracked and those which are uncracked. In the 3D model, the load combination case shall employ **cracked** element properties as defined (for applicable elements).
#B Note that it is ensured that the construction load combination is less onerous than ULS 01.
#C Not used.
#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.
#E Note **long-term** modulus of elasticity, $E_{c,long\text{-}term} = E_{c,short\text{-}term} / (1+\phi=2.0)$ for slabs and beams. Note that in the 2D model, although initial section property modifier for inertia I is 1.00, i.e. uncracked, an **explicit cracked deflection analysis** is undertaken to establish regions which are cracked and those which are uncracked.
#F Note equivalent ϕ = 2.0 creep load combination factor [1-(1/(1+2.0))] = 0.67 on FE models employing **long-term** modulus of elasticity, $E_{c,long\text{-}term} = E_{c,short\text{-}term} / (1+\phi=2.0)$ for slabs and beams. Note additional k_{cp} factor of (1-0.4) for the remaining 60% component of DL creep deflection after 1 month (cl.7.3 BS8110-2). Note that in the 2D model, although initial section property modifier for inertia I is 1.00, i.e. uncracked, an **explicit cracked deflection analysis** is undertaken to establish regions which are cracked and those which are uncracked.

	Load Combination	Load Factor [EN1990 | EN1998-1]							
	Ultimate Limit State (ULS)	**PT**	**HYP**	**DL**	**SDL**	**LL**	**EQ_X**	**EQ_Y**	**EQ_Z**
EQ-ULS 1	1.0DL+1.0SDL+ψ_{2i}LL±1.0EQ_X+HYP #A	–	1.0	1.0	1.0	ψ_{2i}	±1.0 #B5	–	–
	1.0DL+1.0SDL+ψ_{2i}LL±1.0EQ_Y+HYP #A	–	1.0	1.0	1.0	ψ_{2i}	–	±1.0 #B5	–
EQ-ULS 2	1.0DL+1.0SDL+ψ_{2i}LL+HYP ±1.0EQ_X±0.3EQ_Y±0.3EQ_Z #A	–	1.0	1.0	1.0	ψ_{2i}	±1.0 #B5	±0.3 #B5	±0.3 #B2, #B5
	1.0DL+1.0SDL+ψ_{2i}LL+HYP ±0.3EQ_X±1.0EQ_Y±0.3EQ_Z #A	–	1.0	1.0	1.0	ψ_{2i}	±0.3 #B5	±1.0 #B5	±0.3 #B2, #B5
	1.0DL+1.0SDL+ψ_{2i}LL+HYP ±0.3EQ_X±0.3EQ_Y±1.0EQ_Z #A	–	1.0	1.0	1.0	ψ_{2i}	±0.3 #B5	±0.3 #B5	±1.0 #B2, #B5
	Serviceability Limit State (SLS)	**PT**	**HYP**	**DL**	**SDL**	**LL**	**EQ_X**	**EQ_Y**	**EQ_Z**
EQ-SLS 1	1.0DL+1.0SDL+ψ_{2i}LL ±0.65EQ_X+PT #A, #B1, #C	1.0	–	1.0	1.0	ψ_{2i}	±0.65 #B3, #B4	–	–
	1.0DL+1.0SDL+ψ_{2i}LL ±0.65EQ_Y+PT #A, #B1, #C	1.0	–	1.0	1.0	ψ_{2i}	–	±0.65 #B3, #B4	–
EQ-SLS 2	1.0DL+1.0SDL+ψ_{2i}LL+PT ±0.65EQ_X±0.2EQ_Y±0.2EQ_Z #A, #B1, #C	1.0	–	1.0	1.0	ψ_{2i}	±0.65 #B3, #B4	±0.2 #B3, #B4	±0.2 #B2
	1.0DL+1.0SDL+ψ_{2i}LL+PT ±0.2EQ_X±0.65EQ_Y±0.2EQ_Z #A, #B1, #C	1.0	–	1.0	1.0	ψ_{2i}	±0.2 #B3, #B4	±0.65 #B3, #B4	±0.2 #B2
	1.0DL+1.0SDL+ψ_{2i}LL+PT ±0.2EQ_X±0.2EQ_Y±0.65EQ_Z #A, #B1, #C	1.0	–	1.0	1.0	ψ_{2i}	±0.2 #B3, #B4	±0.2 #B3, #B4	±0.65 #B2

#A For 3D building finite element models, the load combinations inherently include the effects of **differential** (elastic, creep, shrinkage to cl.3.1.4 EC2) 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 to cl.3.1.4 EC2) axial shortening based on a 10-day per floor **staged construction analysis** of the load combination case 1.0DL+1.0SDL on a 3D model. Note that in the 2D model, although initial section property modifier for inertia I is 1.00, i.e. uncracked, an **explicit cracked deflection analysis** is undertaken to establish regions which are cracked and those which are uncracked. In the 3D model, the load combination case shall employ **cracked** element properties as defined (for applicable elements).
#B1 Note that the **lateral** and **vertical** EQ loads in the EQ SLS combination cases here are based on the **inelastic** design EQ loads and are **not** enhanced by the adopted behaviour factor, q as per cl.4.3.4 EN1998-1 as these EQ SLS combinations are required for PT SLS design.
#B2 Note that the **vertical** EQ loads may be **neglected** if they are less than 0.25g to cl.4.3.3.5.2 EN1998-1.
#B3 Note that the evaluation of **EQ foundation loads** should be based on the amplified (by the over-strength, γ_{Rd} and multiplicative, Ω factors) **lateral** (only) earthquake loads to cl.4.4.2.6 EN1998-1.
#B4 Note that the evaluation of **EQ deflections** should be based on amplified (by the factor q) deflection values to cl.4.3.4(1) EN1998-1.
#B5 Note that all moment frames that resist earthquake forces are designed to **capacity design principles** which require firstly, 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 (cl.4.4.2.3 EN1998-1), and secondly, 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 (cl.5.4.2.2, cl.5.4.2.3, cl.5.5.2.1 and cl.5.5.2.2 EN1998-1).
#C Note that although there are no EQ-SLS checks within the code, back-analyzed load factors DA1-C1/DA1-C2: MIN{1.2/2.0=0.60 driven, 1.2/1.85=0.65 bored} are added to these EQ-SLS load combination cases, conservatively only onto the EQ load cases.

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	Description	Load Factor [ASCE7]								
	Ultimate Limit State (ULS)	**PT**	**HYP**	**DL**	**SDL**	**LL**	**WL$_X$**	**WL$_Y$**	**NHL$_X$**	**NHL$_Y$**
ULS 1A	1.4DL+1.4SDL+HYP [#A, #B]	–	1.0	1.4	1.4	–	–	–	–	–
ULS 1B	1.2DL+1.2SDL+1.6LL+HYP [#A, #B]	–	1.0	1.2	1.2	1.6	–	–	–	–
ULS 2A	1.2DL+1.2SDL±1.0NHL+HYP [#A]	–	1.0	1.2	1.2	–	–	–	±1.0	–
		–	1.0	1.2	1.2	–	–	–	–	±1.0
ULS 2B	0.9DL+0.9SDL±1.0NHL+HYP [#A]	–	1.0	0.9	0.9	–	–	–	±1.0	–
		–	1.0	0.9	0.9	–	–	–	–	±1.0
ULS 2C	1.2DL+1.2SDL+1.0LL±1.0NHL+HYP [#A]	–	1.0	1.2	1.2	1.0	–	–	±1.0	–
		–	1.0	1.2	1.2	1.0	–	–	–	±1.0
ULS 3A	1.2DL+1.2SDL±1.0WL+HYP [#A]	–	1.0	1.2	1.2	–	±1.0	–	–	–
		–	1.0	1.2	1.2	–	–	±1.0	–	–
ULS 3B	0.9DL+0.9SDL±1.0WL+HYP [#A]	–	1.0	0.9	0.9	–	±1.0	–	–	–
		–	1.0	0.9	0.9	–	–	±1.0	–	–
ULS 3C	1.2DL+1.2SDL+1.0LL±1.0WL+HYP [#A]	–	1.0	1.2	1.2	1.0	±1.0	–	–	–
		–	1.0	1.2	1.2	1.0	–	±1.0	–	–
	Transfer Limit State (TLS)	**PT**	**HYP**	**DL**	**SDL**	**LL**	**WL$_X$**	**WL$_Y$**	**NHL$_X$**	**NHL$_Y$**
TLS 1	1.0DL+1.15PT$_i$ [#D]	1.15	–	1.0	–	–	–	–	–	–
	Serviceability Limit State (SLS) Long-Term Total Effects	**PT**	**HYP**	**DL**	**SDL**	**LL**	**WL$_X$**	**WL$_Y$**	**NHL$_X$**	**NHL$_Y$**
SLS 1A	1.0DL+1.0SDL+1.0LL+PT [#A, #E]	1.0	–	1.0	1.0	1.0	–	–	–	–
SLS 2	1.0DL+1.0SDL+0.75LL±0.53NHL+PT [#A]	1.0	–	1.0	1.0	0.75	–	–	±0.53	–
		1.0	–	1.0	1.0	0.75	–	–	–	±0.53
SLS 3	1.0DL+1.0SDL+0.75LL±0.45WL+PT [#A]	1.0	–	1.0	1.0	0.75	±0.45	–	–	–
		1.0	–	1.0	1.0	0.75	–	±0.45	–	–
	Serviceability Limit State (SLS) Long-Term Incremental Effects	**PT**	**HYP**	**DL**	**SDL**	**LL**	**WL$_X$**	**WL$_Y$**	**NHL$_X$**	**NHL$_Y$**
SLS 1B	0.67k_{cp}.DL+1.0SDL+1.0LL+0.67k_{cp}.PT [#F]	0.67 k_{cp}	–	0.67 k_{cp}	1.0	1.0	–	–	–	–

#A For 3D building finite element models, the load combinations inherently include the effects of **differential** (elastic, creep, shrinkage to cl.3.1.4 EC2) axial shortening based on a 10-day per floor **staged construction analysis** of the corresponding load combination case. For 2D floor plate models on the other hand, these load combinations shall be appended with a 30-year **differential** (elastic, creep, shrinkage to cl.3.1.4 EC2) axial shortening based on a 10-day per floor **staged construction analysis** of the load combination case 1.4DL+1.4SDL, 1.2DL+1.2SDL or 0.9DL+0.9SDL as appropriate on a 3D model. Note that in the 2D model, although initial section property modifier for inertia I is 1.00, i.e. uncracked, an **explicit cracked deflection analysis** is undertaken to establish regions which are cracked and those which are uncracked. In the 3D model, the load combination case shall employ **cracked** element properties as defined (for applicable elements).
#B Note that it is ensured that the construction load combination is less onerous than ULS 01.
#C Not used.
#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.
#E Note **long-term** modulus of elasticity, $E_{c,long-term} = E_{c,short-term} / (1+\phi=2.0)$ for slabs and beams. Note that in the 2D model, although initial section property modifier for inertia I is 1.00, i.e. uncracked, an **explicit cracked deflection analysis** is undertaken to establish regions which are cracked and those which are uncracked.
#F Note equivalent ϕ = 2.0 creep load combination factor [1-(1/(1+2.0))] = 0.67 on FE models employing **long-term** modulus of elasticity, $E_{c,long-term} = E_{c,short-term} / (1+\phi=2.0)$ for slabs and beams. Note additional k_{cp} factor of (1-0.4) for the remaining 60% component of DL creep deflection after 1 month (cl.7.3 BS8110-2). Note that in the 2D model, although initial section property modifier for inertia I is 1.00, i.e. uncracked, an **explicit cracked deflection analysis** is undertaken to establish regions which are cracked and those which are uncracked.

	Description	Load Factor [ASCE7]

FEM Design Verification Checklist for ProtaStructure 2019 (Summary)

	Ultimate Limit State (ULS)	PT	HYP	DL	SDL	LL	EQ$_X$	EQ$_Y$	EQ$_Z$
EQ-ULS 1	1.2DL+1.2SDL+1.0LL±1.0EQ$_X$+HYP [#A] 1.2DL+1.2SDL+1.0LL±1.0EQ$_Y$+HYP [#A]	–	1.0	1.2	1.2	1.0	±1.0 #B5, #B6	–	–
		–	1.0	1.2	1.2	1.0	–	±1.0 #B5, #B6	–
EQ-ULS 2A	1.2DL+1.2SDL+1.0LL+HYP ±1.0EQ$_X$±0.3EQ$_Y$+0.3EQ$_Z$ [#A] 1.2DL+1.2SDL+1.0LL+HYP ±0.3EQ$_X$±1.0EQ$_Y$+0.3EQ$_Z$ [#A] 1.2DL+1.2SDL+1.0LL+HYP ±0.3EQ$_X$±0.3EQ$_Y$+1.0EQ$_Z$ [#A]	–	1.0	1.2	1.2	1.0	±1.0 #B5, #B6	±0.3 #B5, #B6	+0.3 #B2, #B5, #B6
		–	1.0	1.2	1.2	1.0	±0.3 #B5, #B6	±1.0 #B5, #B6	+0.3 #B2, #B5, #B6
		–	1.0	1.2	1.2	1.0	±0.3 #B5, #B6	±0.3 #B5, #B6	+1.0 #B2, #B5, #B6
EQ-ULS 2B	0.9DL+0.9SDL+HYP ±1.0EQ$_X$±0.3EQ$_Y$–0.3EQ$_Z$ [#A] 0.9DL+0.9SDL+HYP ±0.3EQ$_X$±1.0EQ$_Y$–0.3EQ$_Z$ [#A] 0.9DL+0.9SDL+HYP ±0.3EQ$_X$±0.3EQ$_Y$–1.0EQ$_Z$ [#A]	–	1.0	0.9	0.9	–	±1.0 #B5, #B6	±0.3 #B5, #B6	–0.3 #B2, #B5, #B6
		–	1.0	0.9	0.9	–	±0.3 #B5, #B6	±1.0 #B5, #B6	–0.3 #B2, #B5, #B6
		–	1.0	0.9	0.9	–	±0.3 #B5, #B6	±0.3 #B5, #B6	–1.0 #B2, #B5, #B6
	Serviceability Limit State (SLS)	**PT**	**HYP**	**DL**	**SDL**	**LL**	**EQ$_X$**	**EQ$_Y$**	**EQ$_Z$**
EQ-SLS 1	1.0DL+1.0SDL+0.75LL±0.7EQ$_X$+PT [#A, #B1] 1.0DL+1.0SDL+0.75LL±0.7EQ$_Y$+PT [#A, #B1]	1.0	–	1.0	1.0	0.75	±0.7 #B3, #B4	–	–
		1.0	–	1.0	1.0	0.75	–	±0.7 #B3, #B4	–
EQ-SLS 2A	1.0DL+1.0SDL+0.75LL+PT ±0.7EQ$_X$±0.2EQ$_Y$+0.2EQ$_Z$ [#A, #B1] 1.0DL+1.0SDL+0.75LL+PT ±0.2EQ$_X$±0.7EQ$_Y$+0.2EQ$_Z$ [#A, #B1] 1.0DL+1.0SDL+0.75LL+PT ±0.2EQ$_X$±0.2EQ$_Y$+0.7EQ$_Z$ [#A, #B1]	1.0	–	1.0	1.0	0.75	±0.7 #B3, #B4	±0.2 #B3, #B4	+0.2 #B2
		1.0	–	1.0	1.0	0.75	±0.2 #B3, #B4	±0.7 #B3, #B4	+0.2 #B2
		1.0	–	1.0	1.0	0.75	±0.2 #B3, #B4	±0.2 #B3, #B4	+0.7 #B2
EQ-SLS 2B	0.6DL+0.6SDL+PT ±0.7EQ$_X$±0.2EQ$_Y$–0.2EQ$_Z$ [#A, #B1] 0.6DL+0.6SDL+PT ±0.2EQ$_X$±0.7EQ$_Y$–0.2EQ$_Z$ [#A, #B1] 0.6DL+0.6SDL+PT ±0.2EQ$_X$±0.2EQ$_Y$–0.7EQ$_Z$ [#A, #B1]	1.0	–	0.6	0.6	–	±0.7 #B3, #B4	±0.2 #B3, #B4	–0.2 #B2
		1.0	–	0.6	0.6	–	±0.2 #B3, #B4	±0.7 #B3, #B4	–0.2 #B2
		1.0	–	0.6	0.6	–	±0.2 #B3, #B4	±0.2 #B3, #B4	–0.7 #B2

#A For 3D building finite element models, the load combinations inherently include the effects of **differential** (elastic, creep, shrinkage to cl.3.1.4 EC2) 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 to cl.3.1.4 EC2) axial shortening based on a 10-day per floor **staged construction analysis** of the load combination case 1.0DL+1.0SDL on a 3D model. Note that in the 2D model, although initial section property modifier for inertia I is 1.00, i.e. uncracked, an **explicit cracked deflection analysis** is undertaken to establish regions which are cracked and those which are uncracked. In the 3D model, the load combination case shall employ **cracked** element properties as defined (for applicable elements).
#B1 Note that the **lateral** and **vertical** EQ loads in the EQ SLS combination cases here are based on the **inelastic** design EQ loads and **not** enhanced by the adopted response modification factor, R as per T.12.2-1 ASCE7 as these EQ SLS combinations are required for PT SLS design.
#B2 Note that the **vertical** EQ loads may **not** be neglected in any circumstances in ASCE7.
#B3 Note that the evaluation of **EQ foundation loads** should be based on the amplified (by the over-strength factor Ω_0) **lateral** (only) earthquake loads to cl.12.4.3.1 ASCE7.
#B4 Note that the evaluation of **EQ deflections** should be based on amplified (by the factor C_d as per T.12.2-1 ASCE7) deflection values.
#B5 Note that all moment frames and shear walls that resist earthquake forces are designed to **capacity design principles**, which require firstly, 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 / wall** plastic moment capacity. Secondly, **beam shears** shall be designed to 2.0E to

cl.18.4.2.3(b) ACI318, **column shears** shall be designed to Ω_0E to cl.18.4.3.1(b) ACI318 and **wall shears** shall be designed to Ω_0E to cl.18.10.8.1(a) ACI318.

#B6 Deformation compatibility of structural components **not** included in the seismic force-resisting system (and thus **not** subject to the capacity design principles) shall be ensured by designing them to be adequate for the gravity load effects and the seismic forces resulting from the displacement caused by the design storey drift (amplified by the factor C_d as per T.12.2-1 ASCE7) as per cl.12.12.5 ASCE7.

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

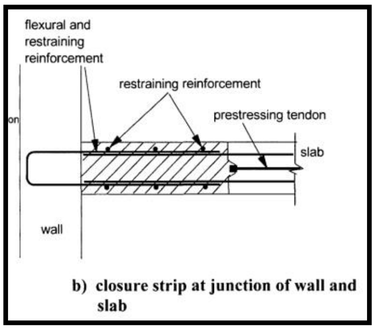
RC or PT Design Strip Design Sections Equivalent Frame Method Integration of Effects Analysis	RC or PT Design Strip Design Sections FE Analysis Method Integration of Effects Analysis
Does not consider the flat slab hogging moment stress concentrations, unconservatively	Does consider the flat slab hogging 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

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



b) closure strip at junction of wall and slab

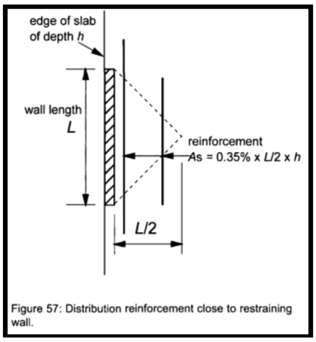
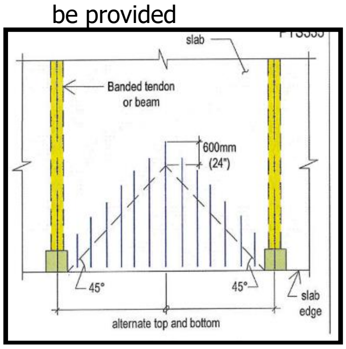


Figure 57: Distribution reinforcement close to restraining wall.

(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 MAX(l_a,$0.7l_a$+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]

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}

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. $1.0S+1.0S_{\text{UPPER STOREYS OF STG(i=1)}}+1.15PT$
- 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, etc.)