FEM Design Verification Checklist for CSI.ETABS 2016 (Summary)

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

Abbreviations

ES = Every Story
BA = Analyze → Run Analysis
STAGE = Analyze → Run Analysis [Staged Building Analysis]
SAFE = FE Floor Analysis

MODEL = Model Explorer → Model → Model
TABLE = Model Explorer → Tables → Tables
DAS = Differential (Elastic, Creep, Shrinkage) Axial Shortening
OPTION = Model Explorer → Display → Model Windows → Options
DISPLAY = Model Explorer → Display → Model Windows → Display

Legend	☐
Pass	√
Fail	X
Not Applicable	NA

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

Checklist Inclusions and Exclusions

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

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

ITEM	CONTENT		√
1.0	**COMPANY STANDARD TEMPLATE CHECKS**		
1.1	**General**		
1.11	Company standard template used → MultiStorey-EQ ☐ MultiStorey-NoEQ ☐		☐
1.12	Date of release of company standard template.		☐
1.2	**Variations to Company Standard Template**		
1.21	OPTION → View by Colors of → Materials → check concrete grade for slab/beam/wall/column/foundation whilst ensuring OPTION → Frame/Shell Assignments → Material Overwrites are selected. MODEL → Properties → Frame Sections (of beams) → Property Modifiers → check (m11, m22, m33) 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 whilst ensuring OPTION → Frame Assignments → Property Modifiers are selected. MODEL → Properties → Slab Sections → Modifiers → check (m11, m22, m12) 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 whilst ensuring OPTION → Shell Assignments → Stiffness Modifiers are selected.		☐
1.22	Non-sway/sway column (note wall N/A).	Non-Sway/Sway	☐
1.23	Maximum beam/wall/column rebar diameter.		☐
1.24	Adoption of (unique) design links at beam supports.		☐
1.25	Beam section cuts (span only – once for every beam or once for every axis).		☐
1.26	Assign → Frame → End Length Offsets → assign Rigid-Zone Factor 1 (Maximum) or Rigid-Zone Factor 0 (None). Assign → Frame → End Length Offsets → assign Frame Self Weight Based on Clear Length or Frame Self Weight Based on Full Length.		☐
1.27	Compatibility torsion (m11=1.0) for transfer / edge beams for Class 1 PT or Class 2 PT. Compatibility torsion (m11=0.5) for transfer / edge beams for RC or Class 3 PT.		☐
1.28	Foundation load combinations G+Q load factor (1.00, 1.02, 1.05, 1.10).		☐
1.29	Etcetera.		☐
1.3	**Variations to Material Properties**		

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<table>
<tr><th>ITEM</th><th>CONTENT</th><th>√</th></tr>
<tr><td>1.31</td><td>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: -
<table>
<tr><th colspan="4">Capacity Design Concepts
(Optimum Location and Sequence of Attainment of Member Capacity)</th></tr>
<tr><th>Ductility Class</th><th>Element</th><th>BS EN1998-1 Clause</th><th>CSI.Etabs Representation</th></tr>
<tr><td rowspan="2">Ductility Class Medium (DCM) and Ductility Class High (DCH)</td><td>Primary Seismic Beam</td><td rowspan="2">cl.4.4.2.3
$\Sigma M_{Rc} \geq 1.3\Sigma M_{Rb}$</td><td>Maintain longitudinal bar strength grade at f_y</td></tr>
<tr><td>Primary Seismic Column</td><td>Reduce longitudinal bar strength grade to f_y / 1.3</td></tr>
</table>
</td><td>☐</td></tr>
<tr><td>1.32</td><td>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: -
<table>
<tr><th colspan="4">Capacity Design Concepts
(Favourable Mechanism of Deformation)</th></tr>
<tr><th>Ductility Class</th><th>Element</th><th>BS EN1998-1 Clause</th><th>CSI.Etabs Representation</th></tr>
<tr><td rowspan="2">Ductility Class Medium (DCM)</td><td>Primary Seismic Beam</td><td>cl.5.4.2.2 $\gamma_{Rd} = 1.0$</td><td rowspan="2">Reduce shear link strength grade to f_{yv} / 1.1</td></tr>
<tr><td>Primary Seismic Column</td><td>cl.5.4.2.3 $\gamma_{Rd} = 1.1$</td></tr>
<tr><td rowspan="2">Ductility Class High (DCH)</td><td>Primary Seismic Beam</td><td>cl.5.5.2.1 $\gamma_{Rd} = 1.2$</td><td rowspan="2">Reduce shear link strength grade to f_{yv} / 1.3</td></tr>
<tr><td>Primary Seismic Column</td><td>cl.5.5.2.2 $\gamma_{Rd} = 1.3$</td></tr>
</table>
</td><td>☐</td></tr>
<tr><td>**2.0**</td><td>**ARCHITECTURAL DESIGN INTENT CHECKS**</td><td></td></tr>
<tr><td>**2.1**</td><td>**General**</td><td></td></tr>
<tr><td>2.11</td><td>File → Import → .DXF/.DWG File of Architectural Plan → check consistency of wall/column positions (ES).</td><td>☐</td></tr>
<tr><td>2.12</td><td>File → Import → .DXF/.DWG File of Architectural Plan → check consistency of slab/beam drops (ES).</td><td>☐</td></tr>
<tr><td>2.13</td><td>File → Import → .DXF/.DWG File of Architectural Plan → check consistency of slab edges and openings (ES).</td><td>☐</td></tr>
<tr><td>2.14</td><td>MODEL → Structure Layout → Stories → Edit Stories → check storey labels, storey heights, h (m) including stump depth (h_{St01} > deepest beam to ensure correct wall/column base shears) and define base level as St00.</td><td>☐</td></tr>
<tr><td>2.15</td><td>MODEL → Structure Layout → Stories → Edit Stories → check total building elevation, H_T (m).</td><td>☐</td></tr>
<tr><td>**3.0**</td><td>**FRAMING AND LOADING CHECKS**</td><td></td></tr>
<tr><td>**3.1**</td><td>**Framing Intent**</td><td></td></tr>
<tr><td>3.11</td><td>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 → OPTION → {View by Colors of → Sections, Frame Assignments → Sections, Shell Assignments → 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 $M_{ULS}/bh^2 \approx 1N/mm^2 << 5N/mm^2$ and **SAFE 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 $V_{ULS}/bh \approx 3N/mm^2 << 5N/mm^2$ and ULS bending stress $M_{ULS}/bh^2 \approx 3N/mm^2 << 5N/mm^2$ and **SAFE 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 $A_{s,prov} \approx 3000 . M_{ULS} (kNm) / d (mm)$,

(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]** [#B1, #B2] 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],</td><td>☐</td></tr>
</table>

ITEM	CONTENT	√
	(iv) transfer beam sizes w.r.t. ULS shear stress **$V_{ULS}/bh \approx 3N/mm^2 << 5N/mm^2$** and ULS bending stress **$M_{ULS}/bh^2 \approx 3N/mm^2 << 5N/mm^2$**, ULS punching shear transfer column face stress **$V_{eff}/ud \approx 4N/mm^2 << 5N/mm^2$** (applicable when transfer beam width > column width), **deep beam design** #E1 and **STAGE 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** ≈ **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 face stress **$V_{eff}/ud \approx 4N/mm^2 << 5N/mm^2$**, ULS punching shear transfer column (or transfer column head where applicable) and transferred walls/columns first perimeter stress **V_{eff}/ud** @ 1.5d ≈ **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, **$A_C \approx F_{ULS}$ / [20@C35; 22@C40; 24@C45; 26@C50; 28@C55; 30@C60]** #B1, #B2 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 (non-sway/sway)** 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 (**$\delta_{total}/2 \leq H_{total}/500$** and **$\Delta\delta_{storey,I}/2 \leq h_{storey,I}/500$** with default stiffness parameters) and EQ #I (**$q.\delta_{total} \leq H_{total}/250$** and **$q.\Delta\delta_{storey,I} \leq h_{storey,I}/250$** (with fundamental period **$T_1/\sqrt{2}$**) with default stiffness parameters), (ES). **#A**: Note check wall/column for **Column Connectivity Length ≥ Storey Height**, correctness of **duplicate storeys** and perform **Check Model**. **#B1 [Textual]**: Note check TABLE → Design → Shear Wall Design → Shear Wall Pier Summary and TABLE → Model → Definitions → Pier/Spandrel Section Properties → Pier Section Properties for sectional area, A_C and BA/STAGE → TABLE → Design → Design Forces → Pier Design Forces for F_{ULS} to calculate ULS axial stress **F_{ULS}/A_C** (**BA / STAGE**) and check TABLE → Design → Shear Wall Design → Shear Wall Pier Summary for **% steel << 2%**(shear wall vertical steel % limit for avoidance of through-thickness links). **#B1 [Textual]**: Note check TABLE → Design → Concrete Design → Concrete Column Summary and TABLE → Model → Definitions → Frame Sections → Frame Sections for sectional area, A_C and BA/STAGE → TABLE → Design → Concrete Design → Concrete Column PMM Envelope for F_{ULS} to calculate ULS axial stress **F_{ULS}/A_C** (**BA / STAGE**) and check TABLE → Design → Concrete Design → Concrete Column PMM Envelope for **% steel << 5%**(column vertical steel % limit). **#B2 [Visual]**: Note check BA/STAGE → DISPLAY → Frame/Pier/Spandrel/Link Forces **(max) enveloping** ULS combinations axial load, F_{ULS} to calculate ULS axial stress **F_{ULS}/A_C** (**BA / STAGE**) manually and check Design → Shear Wall Design → Display Design Info → Design Output → Pier Reinforcing Ratio for **% steel << 2%**(shear wall vertical steel % limit for avoidance of through-thickness links). **#B2 [Visual]**: Note check BA/STAGE → DISPLAY → Frame/Pier/Spandrel/Link Forces **(max) enveloping** ULS combinations axial load, F_{ULS} to calculate ULS axial stress **F_{ULS}/A_C** (**BA / STAGE**) manually and check Design → Concrete Frame Design → Display Design Info → Design Output → Rebar Percentage for **% steel << 5%**(column vertical steel % limit). **#C**: Note check BA/STAGE → DISPLAY → Deformed Shape → Displacement UZ for **DAS** and BA/STAGE → DISPLAY → Deformed Shape → Displacement UX/UY and MODEL → Named Plots → Story Response Plots 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 BA → DISPLAY → Deformed Shape → Start Animation for **animated deflections** for spurious members and BA → DISPLAY → Frame/Pier/Spandrel/Link Forces → Axial Force **ensuring gradual wall/column axial load increment** and check BA/STAGE → TABLE → Analysis → Results → Frame Results → Column Forces, BA/STAGE → TABLE → Analysis → Results → Wall Results → Pier Forces and BA/STAGE → TABLE → Analysis → Results → Reactions → Base Reactions for **minimal discrepancy between BA and STAGE 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 BA/SAFE → DISPLAY → Deformed Shape → Displacement UZ !. 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.	

ITEM	CONTENT	√
	#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 $A_{s,prov} \approx 3800\ .\ M_{ULS}$ (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 $A_{s,prov} \approx 3800\ .\ M_{ULS}$ (kNm) / h (mm) and (c) transfer slab **longitudinal shear within web**. **#F1**: Note check BA/STAGE → DISPLAY → Frame/Pier/Spandrel/Link Forces → Moment 3-3 for **minimal discrepancy between BA and STAGE 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 BA/STAGE → DISPLAY → Shell Stresses/Forces → $\|M_{11}\|+\|M_{12}\|$ and $\|M_{22}\|+\|M_{12}\|$ for **minimal discrepancy between BA and STAGE 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 TABLE → Design → Shear Wall Design → Shear Wall Pier Summary and TABLE → Model → Definitions → Pier/Spandrel Section Properties → Pier Section Properties for sectional area, A_C and BA/STAGE → TABLE → Design → Design Forces → Pier Design Forces for V_{ULS} to calculate ULS shear stress $\boldsymbol{\tau = V_{ULS}/A_C \approx 3N/mm^2}$ (based on nominal link provision for vertical elements loaded to $40\%f_{cu}$ at ULS i.e. the capacity for a 0.4% steel reinforced vertical element) **<< $\boldsymbol{5N/mm^2}$** for all stability base shear resisting elements i.e. shear walls above transfer and shear walls below transfer. **#G**: Note check TABLE → Design → Concrete Design → Concrete Column Summary and TABLE → Model → Definitions → Frame Sections → Frame Sections for sectional area, A_C and BA/STAGE → TABLE → Design → Concrete Design → Concrete Column Shear Envelope for V_{ULS} to calculate ULS shear stress $\boldsymbol{\tau = V_{ULS}/A_C \approx 3N/mm^2}$ (based on nominal link provision for vertical elements loaded to $40\%f_{cu}$ at ULS i.e. the capacity for a 0.4% steel reinforced vertical element) **<< $\boldsymbol{5N/mm^2}$** for all stability base shear resisting elements i.e. mega columns below transfer. **#H**: Note ensure **no foundation uplift**. **#I**: Note check **on-plan torsional twist** due to NHF, wind and EQ loads.	
3.2	**Slab Loads**	
3.21	Assign → Shell Loads → Uniform → LL Pattern → add slab LL (ES). DISPLAY → Shell Load Assigns → LL Pattern → check slab LL (ES).	☐
3.22	Assign → Shell Loads → Uniform → SDL Pattern → add slab SDL (ES). DISPLAY → Shell Load Assigns → SDL Pattern → check slab SDL (ES).	☐
3.23	Assign → Frame Loads → Point → SDL/LL Pattern → add slab point loading on (null property) beam (ES). DISPLAY → Frame Load Assigns → SDL/LL Pattern → check slab point loading visually (ES). Assign → Frame Loads → Distributed → SDL/LL Pattern → add slab line loading on (null property) beam (ES). DISPLAY → Frame Load Assigns → SDL/LL Pattern → check slab line loading visually (ES). Assign → Shell Loads → Uniform → SDL/LL Pattern → add slab partial patch loading on (null property) slab (ES). DISPLAY → Shell Load Assigns → SDL/LL Pattern → check slab partial patch loading visually (ES).	☐
3.3	**Beam Loads**	
3.31	Assign → Frame Loads → Distributed → SDL Pattern → add beam internal cladding line load (ES). DISPLAY → Frame Load Assigns → SDL Pattern → check beam internal cladding line load visually (ES).	☐
3.32	Assign → Frame Loads → Distributed → SDL Pattern → add beam external cladding line load (ES). DISPLAY → Frame Load Assigns → SDL Pattern → check beam external cladding line load visually (ES).	☐
3.33	Assign → Frame Loads → Distributed → SDL/LL Pattern → add beam user defined line loads (ES). DISPLAY → Frame Load Assigns → SDL/LL Pattern → check beams with user defined line loads visually (ES).	☐
3.4	**Wall/Column Loads**	
3.41	Assign → Joint Loads → Force → SDL/LL Pattern → add wall/column user defined point loads (ES). DISPLAY → Joint Load Assigns → SDL/LL Pattern → check wall/column user defined point loads visually (ES).	☐
3.5	**Lateral Loads**	
3.51	Define → Load Patterns → add (automatic codified) NHF load patterns (ES). DISPLAY → Joint Load Assigns → Load Pattern NHF → check NHF loads (ES). Define → Load Patterns → add (manual user defined or automatic codified) wind load patterns (ES). DISPLAY → Joint Load Assigns → Load Pattern WL → check wind loads (ES).	☐
3.52	Define → Load Patterns → add (manual user defined or automatic codified) EQ load patterns (ES). DISPLAY → Joint Load Assigns → Load Pattern EQ → check EQ loads (ES).	☐

<table>
<tr><th>ITEM</th><th>CONTENT</th><th>√</th></tr>
<tr><td>3.6</td><td>Imposed Load Reduction</td><td></td></tr>
<tr><td>3.61</td><td>Design → Live Load Reduction Factors → check live load reduction factors.</td><td>☐</td></tr>
<tr><td>3.7</td><td>Load Combination Cases</td><td></td></tr>
<tr><td>3.71</td><td>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.</td><td>☐</td></tr>
<tr><td>3.72</td><td>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.
$1.0DL+1.0SDL+\boldsymbol{\psi_{2i}}LL+PT\pm1.0EQ_X$
$1.0DL+1.0SDL+\boldsymbol{\psi_{2i}}LL+PT\pm1.0EQ_Y$
$1.0DL+1.0SDL+\boldsymbol{\psi_{2i}}LL+PT\pm1.0EQ_X\pm0.3EQ_Y\pm0.3EQ_Z$
$1.0DL+1.0SDL+\boldsymbol{\psi_{2i}}LL+PT\pm0.3EQ_X\pm1.0EQ_Y\pm0.3EQ_Z$
$1.0DL+1.0SDL+\boldsymbol{\psi_{2i}}LL+PT\pm0.3EQ_X\pm0.3EQ_Y\pm1.0EQ_Z$</td><td>☐</td></tr>
<tr><td>4.0</td><td>BOUNDARY CONDITION CHECKS</td><td></td></tr>
<tr><td>4.1</td><td>Beam/Column Releases</td><td></td></tr>
<tr><td>4.11</td><td>OPTION → Frame Assignments → End Releases → check no end releases (ES).</td><td>☐</td></tr>
<tr><td>4.12</td><td>Check beams on corbels are defined with hinged ends (ES).</td><td>☐</td></tr>
<tr><td>4.13</td><td>Check stepped secondary beams across primary beams are defined with hinged ends for steps of a dimension greater than the width of the primary beam (ES).</td><td>☐</td></tr>
<tr><td>4.14</td><td>Check beams of depths significantly larger than the thickness of the supporting wall (orientated perpendicular to the longitudinal beam direction) e.g. basement retaining wall or lift core wall and beams of widths significantly larger than the thickness of the supporting wall (orientated parallel to the longitudinal beam direction) are defined with hinged ends with a nominal 50% of span steel defined at the hinged supports (ES).</td><td>☐</td></tr>
<tr><td>4.2</td><td>Wall/Column Clear Height</td><td></td></tr>
<tr><td>4.21</td><td>
<table>
<tr><th colspan="3">Wall/Column Clear Height Calculation</th></tr>
<tr><th>Item</th><th>Wall Clear Height</th><th>Column Clear Height</th></tr>
<tr><td>Beam Depths</td><td>Not Included</td><td>Not Included</td></tr>
<tr><td>Beam Drops or Elevation Vertical Offset</td><td>Included only if the corresponding vertical offset is explicitly modelled in the analytical frame model for the wall in the particular storey and the storey above.</td><td>Included only if the corresponding vertical offset is explicitly modelled in the analytical frame model for the column in the particular storey and the storey above.</td></tr>
<tr><td>Multiple Storey Wall/Column Spans</td><td>Not Included #A</td><td>Included only if the number of storeys that the column spans is specified in Unbraced Length Ratios #A</td></tr>
</table>
</td><td>☐</td></tr>
</table>

<table>
<tr><th>ITEM</th><th>CONTENT</th><th>√</th></tr>
<tr><td></td><td>
<table>
<tr><td></td><td>Alternatively, included only if the number of storeys that the wall spans is explicitly modelled in the analytical frame model, however with the disadvantage of loss of load within Story Forces in the particular storey only</td><td>Alternatively, included only if the number of storeys that the column spans is explicitly modelled in the analytical frame model, however with the disadvantage of loss of load within Story Forces in the particular storey only</td></tr>
</table>
#A: {**[Textual]**: TABLE → Design → Overwrites → Concrete Column Overwrites, **[Visual]**: Design → Concrete Frame Design → Display Design Info → Design Input → Unbraced Length L-Ratios} → check Unbraced Length Ratio = 1, 2, 3 etc., noting that **only columns (note walls N/A) that are strutted/tied in both directions may be considered Unbraced Length Ratio = 1 (ES)**. Struts/ties should be capable of resisting **2.5% of the design ultimate vertical load** that the column (note wall N/A) 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.
</td><td></td></tr>
<tr><td>4.22</td><td>
<table>
<tr><th colspan="3">Recognition of Unbraced Length Ratio ≥ 2 Wall/Column As Beam Supports for Beams Not on the Wall/Column Defined Storey</th></tr>
<tr><th>Item</th><th>BA</th><th>SAFE</th></tr>
<tr><td>**Wall**</td><td>N / A</td><td>N / A</td></tr>
<tr><td>**Column**</td><td>Recognized</td><td>Recognized</td></tr>
</table>
</td><td>☐</td></tr>
<tr><td>**4.3**</td><td>**Wall/Column Effective Length Factor**</td><td></td></tr>
<tr><td>4.31</td><td>
Design → Concrete Frame Design → Display Design Info → Design Input → Design Type → check **Braced (Non-Sway)** for columns (note walls N/A) 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 columns (note walls N/A) 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 columns (note walls N/A) in question)** magnitude of shear force **and** bending moment (**excluding** the bending moment back-calculated by multiplying the push-pull axial forces of the walls/columns at the frame extremity) based on the **Moment Ratio Check** ≤ 1/12th of the **total** magnitude of shear force **and** bending moment (**including** ditto) of the bracing elements resisting lateral movement of that storey (inferred from cl.6.2.5 ACI 318-14), **and**
(iv) that are within a **sway storey** (exhibiting $Q \leq 0.25$ or $\lambda \geq 4.0$) based on the **Sway Susceptibility Check** but with elastic second-order analysis / P-Δ analysis / lateral loads (wind, EQ) amplification with the amplified sway factor, $m = \lambda/(\lambda-1)$ performed (cl.6.2.6 and cl.R6.7.1.2 ACI 318-14), **or (albeit unconservatively)**
(v) that are within a **non-sway storey** (exhibiting $Q \leq 0.05$ or $\lambda \geq 20$) based on the **Sway Susceptibility Check** (based on cl.6.6.4.3(b) ACI 318-14).
Note that for **significant buildings**, a **first principle eigenvalue buckling analysis** (Define → Load Case → Load Case Type → Buckling) should be performed to confirm the **global building buckling** characteristics (requiring $\lambda \geq 4.0$ to cl.R6.2.6 ACI 318-14 and to verify the value for m in $m = \lambda/(\lambda-1)$) and **local mega column buckling** characteristics ((requiring $\lambda \geq 1$).
</td><td>☐</td></tr>
<tr><td>4.32</td><td>
Design → Concrete Frame Design → Display Design Info → Design Input → Design Type → check **Unbraced (Sway)** for columns (note walls N/A) 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 columns (note walls N/A) 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 columns (note walls N/A) 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 $\lambda < 20$) based on the **Sway Susceptibility Check** (based on cl.6.6.4.3(b) ACI 318-14).
Note that for **significant buildings**, a **first principle eigenvalue buckling analysis** (Define → Load Case → Load Case Type → Buckling) should be performed to confirm the **global building buckling** characteristics (requiring $\lambda \geq 4.0$ to cl.R6.2.6 ACI 318-14 and to verify the value for m in $m = \lambda/(\lambda-1)$) and **local mega column buckling** characteristics ((requiring $\lambda \geq 1$).
</td><td>☐</td></tr>
</table>

FEM Design Verification Checklist for CSI.ETABS 2016 (Summary)

ITEM	**CONTENT**	**√**
4.33	Design → Concrete Frame Design → Display Design Info → Design Input → Design Type → check **manual** Concrete Frame Design (Framing Type) Overwrites for columns (note walls N/A) in structures with **transferred** lateral stability (e.g. **braced (non-sway) shear wall** residential block on an **unbraced (sway) 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 (sway) 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 (non-sway)** (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	TABLE → Model → Assignments → Joint Assignments → Joint Assignments – Restraints → check user-defined supports (Define → Spring Properties → Point/Line/Area Springs → 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) explicitly modelled in the analytical frame model St01 wall/column base node definitions.	☐
4.43	Check **stepped** foundations levels relative to St0i where i≥1 explicitly modelled in the analytical frame model St0i+1 wall/column base node definitions (check user-defined supports) noting that user-defined support types are defined in Assign → Joint → Restraints.	☐
5.0	**MODELLING CHECKS**	
5.1	**General**	
5.11	Check all elements 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** (ES).	☐
5.13	Check 3D View with OPTION → Special Effects → {Object Shrink, Extrude Frame Objects, Extrude Shell Objects} for **accuracy of modelling** in particular: - • slab and beam drops and soffit continuity (ES). • consistency of inter-storey wall/column setting out (ES). • multi-storey (with the number of storeys > 1 that the wall/column spans explicitly modelled in the analytical frame model) wall/column element spans, noting that **only columns (note walls N/A) that are strutted/tied in both directions may be considered Unbraced Length Ratio = 1** (ES).	☐
5.14	Check validity of slab contributing 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 identified as such (ensuring the correct cantilever reinforcement detailing and the correct deflection assessment based on cantilever span / depth ratios) (ES).	☐
5.16	Check all duplicate storeys share the same storey height (**only beneath** for the BA/STAGE methods) with their parent storey to ensure that wall/column clear heights are accurately calculated. If Unbraced Length Ratio > 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 with their parent storey to ensure correct load take down.	☐
5.2	**Section and Material Properties**	
5.21	**% Reduction in Rigidity in BA** [#A]	☐

% Reduction in Rigidity in BA [#A]		
Action	**Slab/Beam**	**Wall/Column**
ULS DL, SDL, LL (V) [#B]	**Class 1 PT or Class 2 PT** 50%{EA} Uncracked, Creep 50%{EI} Uncracked, Creep 50%{GA_s} Uncracked, Creep	**Class 1 PT, Class 2 PT, RC or Class 3 PT** 50%{EA} Uncracked, Creep 50%{EI} Uncracked, Creep
ULS NHF (H) [#B]		
ULS Wind (H) [#B]		

FEM Design Verification Checklist for CSI.ETABS 2016 (Summary)

ITEM	CONTENT			√
	SLS DL, SDL, LL (V) [#C]	50%{GJ} Uncracked, Creep $k_E=1.0$, $k_I=1.0$, $k_J=1.0$, $k_A=1.0$ [2.0 x Default Parameters] **RC or Class 3 PT** 50%{EA} Uncracked, Creep 25%{EI} Cracked, Creep 50%{GA_s} Uncracked, Creep 25%{GJ} Cracked, Creep $k_E=1.0$, $k_I=0.5$, $k_J=0.5$, $k_A=1.0$ [Default Parameters]	50%{GA_s} Uncracked, Creep 50%{GJ} Uncracked, Creep $k_E=1.0$, $k_I=1.0$, $k_J=1.0$, $k_A=1.0$ [Default Parameters]	
	ULS EQ (H) [#B, #F]	**Class 1 PT or Class 2 PT** 50%{EA} Uncracked, Creep 50%{EI} Uncracked, Creep 50%{GA_s} Uncracked, Creep 50%{GJ} Uncracked, Creep $k_E=1.0$, $k_I=1.0$, $k_J=1.0$, $k_A=1.0$ [2.0 x Default Parameters] **RC or Class 3 PT** 50%{EA} Uncracked, Creep 25%{EI} Cracked, Creep 50%{GA_s} Uncracked, Creep 25%{GJ} Cracked, Creep $k_E=1.0$, $k_I=0.5$, $k_J=0.5$, $k_A=1.0$ [Default Parameters]	**Class 1 PT, Class 2 PT, RC or Class 3 PT** 50%{EA} Uncracked, Creep 25%{EI} Cracked, Creep 50%{GA_s} Uncracked, Creep 25%{GJ} Cracked, Creep $k_E=1.0$, $k_I=0.5$, $k_J=0.5$, $k_A=1.0$ [~0.5 x Default Parameters]	
	SLS NHF (H) [#C, #D] **SLS Wind (H) [#C, #D]** **SLS Vibration (H) [#C, #D]**	**Class 1 PT or Class 2 PT** 100%{EA} Uncracked, No Creep 100%{EI} Uncracked, No Creep 100%{GA_s} Uncracked, No Creep 100%{GJ} Uncracked, No Creep $k_E=2.0$, $k_I=1.0$, $k_J=1.0$, $k_A=1.0$ [4.0 x Default Parameters] **RC or Class 3 PT** 100%{EA} Uncracked, No Creep 50%{EI} Cracked, No Creep 100%{GA_s} Uncracked, No Creep 50%{GJ} Cracked, No Creep $k_E=2.0$, $k_I=0.5$, $k_J=0.5$, $k_A=1.0$ [2.0 x Default Parameters]	**Class 1 PT, Class 2 PT, RC or Class 3 PT** 100%{EA} Uncracked, No Creep 100%{EI} Uncracked, No Creep 100%{GA_s} Uncracked, No Creep 100%{GJ} Uncracked, No Creep $k_E=2.0$, $k_I=1.0$, $k_J=1.0$, $k_A=1.0$ [2.0 x Default Parameters]	
	SLS EQ (H) [#C, #D, #F]	**Class 1 PT or Class 2 PT** 100%{EA} Uncracked, No Creep 100%{EI} Uncracked, No Creep 100%{GA_s} Uncracked, No Creep 100%{GJ} Uncracked, No Creep $k_E=2.0$, $k_I=1.0$, $k_J=1.0$, $k_A=1.0$ [4.0 x Default Parameters] **RC or Class 3 PT** 100%{EA} Uncracked, No Creep 50%{EI} Cracked, No Creep 100%{GA_s} Uncracked, No Creep 50%{GJ} Cracked, No Creep $k_E=2.0$, $k_I=0.5$, $k_J=0.5$, $k_A=1.0$ [2.0 x Default Parameters]	**Class 1 PT, Class 2 PT, RC or Class 3 PT** 100%{EA} Uncracked, No Creep 50%{EI} Cracked, No Creep 100%{GA_s} Uncracked, No Creep 50%{GJ} Cracked, No Creep $k_E=2.0$, $k_I=0.5$, $k_J=0.5$, $k_A=1.0$ [~1.0 x Default Parameters]	
	ULS Sway Susceptibility (NHF) (H) [#E] **ULS Sway Susceptibility (Wind) (H) [#E]**	**Class 1 PT or Class 2 PT** 100%{EA} Uncracked, No Creep 70%{EI} Uncracked, No Creep 100%{GA_s} Uncracked, No Creep 70%{GJ} Uncracked, No Creep $k_E=2.0$, $k_I=0.7$, $k_J=0.7$, $k_A=1.0$ [~2.8 x Default Parameters] **RC or Class 3 PT** 100%{EA} Uncracked, No Creep 35%{EI} Cracked, No Creep 100%{GA_s} Uncracked, No Creep 35%{GJ} Cracked, No Creep	**Class 1 PT, Class 2 PT, RC or Class 3 PT** 100%{EA} Uncracked, No Creep 70%{EI} Uncracked, No Creep 100%{GA_s} Uncracked, No Creep 70%{GJ} Uncracked, No Creep $k_E=2.0$, $k_I=0.7$, $k_J=0.7$, $k_A=1.0$ [~1.4 x Default Parameters]	

<table>
<tr><th>ITEM</th><th>CONTENT</th><th>√</th></tr>
<tr><td></td><td>
<table>
<tr><td></td><td>$k_E=2.0$, $k_I=0.35$, $k_J=0.35$, $k_A=1.0$
[~1.4 x Default Parameters]</td><td></td></tr>
<tr><td rowspan="2">ULS Sway Susceptibility (EQ) (H) #E, #F</td><td>Class 1 PT or Class 2 PT
100%{EA} Uncracked, No Creep
70%{EI} Uncracked, No Creep
100%{GA_s} Uncracked, No Creep
70%{GJ} Uncracked, No Creep
$k_E=2.0$, $k_I=0.7$, $k_J=0.7$, $k_A=1.0$
[~2.8 x Default Parameters]</td><td rowspan="2">Class 1 PT, Class 2 PT, RC or Class 3 PT
100%{EA} Uncracked, No Creep
35%{EI} Cracked, No Creep
100%{GA_s} Uncracked, No Creep
35%{GJ} Cracked, No Creep
$k_E=2.0$, $k_I=0.35$, $k_J=0.35$, $k_A=1.0$
[~0.7 x Default Parameters]</td></tr>
<tr><td>RC or Class 3 PT
100%{EA} Uncracked, No Creep
35%{EI} Cracked, No Creep
100%{GA_s} Uncracked, No Creep
35%{GJ} Cracked, No Creep
$k_E=2.0$, $k_I=0.35$, $k_J=0.35$, $k_A=1.0$
[~1.4 x Default Parameters]</td></tr>
</table>
#A: These values of k_E, k_I, k_J and k_A within the table are formulated based on the premise that the elastic modulus, E value has been reduced to account for creep effects as the default. The reduction to the elastic modulus, E of 0.50 for typical office / residential buildings as stipulated by cl.14.5.2 of Report 110 Design of RC Flat Slabs to BS8100 (CIRIA) pp.34 is adopted.
#B: RC or Class 3 PT stiffness values for ULS design governed by 1.00Ig (wall, column) and 0.50Ig (slab) of TR.64 Guide to the Design and Construction of RC Flat Slabs (The Concrete Society) pp.31 and by cl.14.5.4 of Report 110 Design of RC Flat Slabs to BS8100 (CIRIA) pp.35 are adopted. The RC or Class 3 PT ratio of relative stiffness for ULS design between (wall, column) : (slab, beam) elements of 1.00 : 0.50 is also suggested by cl.6.6.3.1.1 ACI 318-14, i.e. in 0.70 : 0.35 although the stiffness reduction factor 0.70 is not adopted here as would have a somewhat negligible effect on the ULS effects. Creep on the other hand is included for ULS effects to cater for the additional effects generated by differential (elastic, creep, shrinkage) axial shortening of walls/columns.
#C: RC or Class 3 PT stiffness values for SLS design governed by 0.70Ig (wall, column), 0.35Ig (beam) and 1.00Ag (beam, wall, column) of cl.6.6.3.1.1 ACI 318-14 together with a 1.4 multiplier stipulated within cl.6.6.3.2.2 ACI 318-14 resulting in 1.00Ig (wall, column), 0.50Ig (beam) and 1.00Ag (beam, wall, column) are adopted. Similar RC or Class 3 PT stiffness values for SLS design of 1.00Ig (wall, column) and 0.50Ig (slab) are also suggested by TR.64 Guide to the Design and Construction of RC Flat Slabs (The Concrete Society) pp.31 and by cl.14.5.4 of Report 110 Design of RC Flat Slabs to BS8100 (CIRIA) pp.35.
#D: The elastic modulus, E value incorporating creep effects is still adopted for ULS NHF / ULS wind / ULS EQ as part of the ULS load combination cases involving vertical loads (even though wind / EQ are short-term phenomena), as the effect of which is deemed negligible as the ratio of stiffness between (wall, column) and (slab, beam) elements is similar to their ratio of stiffness without incorporating creep effects. On the other hand, for SLS NHF / SLS wind / SLS EQ / SLS vibration design, the elastic modulus, E without incorporating creep effects is employed.
#E: RC or Class 3 PT stiffness values for ULS design governed by 0.70Ig (wall, column), 0.35Ig (beam) and 1.00Ag (beam, wall, column) of cl.6.6.3.1.1 ACI 318-14 are adopted. Further, it is given in cl.R6.6.4.3 ACI 318-14 that if the lateral load deflections of the frame are calculated using service loads and the service load moments of inertia given in cl.6.6.3.2.2, it is permissible to calculate Q using 1.2 times the sum of the service gravity loads, the service load story shear, and 1.4 times the first order service load story deflections.
#F: Note that in certain circumstances, it may be deemed more appropriate to employ cracked 0.50Ig (wall, column) stiffness properties for ULS EQ or SLS EQ effects due to the large displacements involved as suggested by T.9.1 of the Manual for the Seismic Design of Steel and Concrete Buildings to EC8 (IStructE) pp.61.
</td><td></td></tr>
<tr><td>5.22</td><td>Check slab cover 25mm internal and 40mm external (e.g. ground, podium deck, swimming pool, water tank, roof) (ES).</td><td>☐</td></tr>
<tr><td>5.23</td><td>MODEL → Properties → Frame Sections (of beams) → Property Modifiers → check Torsional Constant (i.e. the torsional constant factor) = {0.01 Class 1 PT or Class 2 PT | 0.01 RC or Class 3 PT} for models without equilibrium torsional beams.</td><td>☐</td></tr>
<tr><td>5.24</td><td>MODEL → Properties → Frame Sections (of beams) → Property Modifiers → check Torsional Constant (i.e. the torsional constant factor) = {1.00 Class 1 PT or Class 2 PT | 0.50 RC or Class 3 PT} for models with equilibrium torsional beams (e.g. curved beams and straight beams that frame eccentrically to columns (especially heavily loaded beams in transfer floors)). Torsional stiffness may also be considered for: -
(i) heavily loaded straight transfer beams, and
(ii) straight edge beams in regular buildings
experiencing significant compatibility torsion.</td><td>☐</td></tr>
<tr><td>5.25</td><td>
<table>
<tr><th colspan="3">Equilibrium and Compatibility Torsion</th></tr>
<tr><th>Scenario</th><th>Equilibrium Torsion</th><th>Compatibility Torsion</th></tr>
<tr><td>Straight (Between Columns) Continuous Primary Beams</td><td>Not Generated</td><td>Generated</td></tr>
<tr><td>Facetted (Between Columns) Continuous Primary Beams</td><td>Generated</td><td>Generated</td></tr>
<tr><td>Curved (Between Columns) Continuous Primary Beams</td><td>Generated</td><td>Generated</td></tr>
</table>
</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: -</td><td>☐</td></tr>
</table>

ITEM | **CONTENT** | **√**

(a) as per cl.5.4.1.2.1 and cl.5.5.1.2.1,
primary seismic beam eccentricity, $e \leq$ column orthogonal dim, $b_c / 4$ (DCM, DCH)
primary seismic beam width, $b_w \leq \min\{$column orthogonal dim, $b_c +$ beam depth, h_w, $2b_c\}$ (DCM, DCH)
primary seismic beam width, $b_w \geq 200$mm (DCH)

(b) as per cl.5.4.1.2.2 and cl.5.5.1.2.2,
primary seismic column width, $h_c \geq$ (column clear height, $l_{cl} / 2) / 10$ (DCM, DCH)
primary seismic column width, $h_c \geq 250$mm (DCH)

5.27 For models with EQ loads stabilised by stability walls, as per the requirements of BS EN1998-1, the following geometrical constraints need to be achieved: - ☐

(a) as per cl.5.4.1.2.3 and cl.5.5.1.2.3,
ductile wall thickness, $b_{wo} \geq \max\{150$mm, 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)

5.3 Element Horizontal Framing

5.31 ☐

Requirement of Element to Frame Horizontally (Within the Same Storey) onto Element Insertion Point / Line (or Simply Within the Element Footprint on Plan)

Element	Slab	Beam	Wall	Column
Slab	N/A	Not Required [#A]	Not Required [#B]	Not Required [#C]
Beam	N/A	Required [#D]	Required [#E]	Required [#E]
Wall	N/A	N/A	Required [#F]	Required [#F]
Column	N/A	N/A	N/A	N/A

#A: Check slab footprint frame need only frame onto (**or through**) footprint of beam (ES).
#B: Check slab footprint frame need only frame onto (**or through**) footprint of wall (ES).
#C: Check slab footprint frame need only frame onto (**or through**) footprint of column (ES).
#D: Check secondary beam insertion lines frame onto primary beam insertion lines (ES).
#E: Check primary beam insertion lines frame onto wall/column insertion lines/points (ES).
#F: Check wall insertion lines frame onto wall/column insertion lines/points (ES).

Note that in all cases above, no element may frame through the other element (but instead only onto element insertion point/line or within the element footprint), unless specifically denoted otherwise.

5.32 ☐

Element	Method 1 (Insignificant Drops)	Method 2 (Significant Drops)
Slab	N/A	Defining **drops** by explicitly modelling them in the analytical frame model
Beam	N/A	Defining **drops / inclination** by explicitly modelling them in the analytical frame model
Wall	N/A	Defining **drops** by explicitly modelling them in the analytical frame model
Column	N/A	Defining **drops** by explicitly modelling them in the analytical frame model

5.4 Element Vertical Framing

5.41 ☐

Requirement of Element to Frame Vertically (Between Storeys) onto Element Insertion Point / Line (or Simply Within the Element Footprint on Plan)

Element	Slab	Beam	Wall	Column
Slab	N/A	N/A	N/A	N/A
Beam	N/A	N/A	N/A	N/A
Wall	Not Required [#A]	Required [#B2]	Required [#B1, #C]	Required [#B1]
Column	Not Required [#D]	Required [#E]	Required [#F]	Required [#F]

#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 frame onto insertion lines/points of wall/column (ES).

FEM Design Verification Checklist for CSI.ETABS 2016 (Summary)

<table>
<tr><th>ITEM</th><th>CONTENT</th><th>√</th></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 (Mid-Pier idealisation N/A) 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 (Mid-Pier idealisation N/A) is used.</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.</td><td>☐</td></tr>
<tr><td>5.45</td><td>
<table>
<tr><th colspan="5">Modelling of Transferred Walls</th></tr>
<tr><th>Transferred Wall</th><th>Transfer Wall/ Column #C</th><th>Rigid Zones</th><th>Overlap #A</th><th>Remark</th></tr>
<tr><td>Wall #B</td><td>Wall #B</td><td>None</td><td>No Overlap</td><td>• Correct flexible representation of transfer beam bending moment and shear force effects</td></tr>
<tr><td>Wall #B</td><td>Column</td><td>None</td><td>No Overlap</td><td>• Correct flexible representation of transfer beam bending moment and shear force effects</td></tr>
<tr><td>Wall #B</td><td>Wall #B</td><td>None #D</td><td>Full / Partial Overlap</td><td>• Correct flexible representation of transfer beam bending moment and shear force effects</td></tr>
<tr><td>Wall #B</td><td>Column</td><td>None</td><td>Full / Partial Overlap</td><td>• Correct flexible representation of transfer beam bending moment and shear force effects</td></tr>
<tr><td>Wall #B</td><td>Wall #B</td><td>Max</td><td>No Overlap</td><td>N/A</td></tr>
<tr><td>Wall #B</td><td>Column</td><td>Max</td><td>No Overlap</td><td>N/A</td></tr>
<tr><td>Wall #B</td><td>Wall #B</td><td>Max #D</td><td>Full / Partial Overlap</td><td>N/A</td></tr>
<tr><td>Wall #B</td><td>Column</td><td>Max</td><td>Full / Partial Overlap</td><td>N/A</td></tr>
</table>
#A: Overlap refers to overlap between transferred wall and transfer wall/column.
#B: Wall refer to FE Shell Model wall (Mid-Pier wall N/A). 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/columns does not 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 Rigid-Zones as None or Maximum in BA or SAFE. As an alternative to specifying Rigid-Zones as Maximum, specify walls instead of columns to effectively model columns with rigid beam arms.
</td><td>☐</td></tr>
<tr><td>5.5</td><td>Housekeeping</td><td></td></tr>
<tr><td>5.51</td><td>Edit → Auto Relabel All → re-label all slabs and beams independently between storeys.</td><td>☐</td></tr>
<tr><td>5.52</td><td>Edit → Auto Relabel All → re-label all walls and columns consistently between storeys.</td><td>☐</td></tr>
<tr><td>5.6</td><td>Model Integrity</td><td></td></tr>
<tr><td>5.61</td><td>Analyze → Check Model.</td><td>☐</td></tr>
<tr><td>5.62</td><td>Edit → Align Joints/Frames/Edges → Align Joints to Nearest Frame or Edge → OK.</td><td>☐</td></tr>
<tr><td>6.0</td><td>METHOD OF ANALYSIS CHECKS</td><td></td></tr>
<tr><td>6.1</td><td>Method of Slab Analysis and Design</td><td></td></tr>
<tr><td>6.11</td><td>
<table>
<tr><th rowspan="2">Method of Slab Analysis and Design</th><th>Method 1</th><th>Method 2</th></tr>
<tr><th>Conventional Codified BS8110 Coefficients Method</th><th>Full Finite Element Method Design Method</th></tr>
<tr><td>Slab Loads</td><td>N/A</td><td>Uniform, patch, line or point loads</td></tr>
<tr><td>Slab Openings</td><td>N/A</td><td>Supported</td></tr>
<tr><td>Irregular Floor Plates</td><td>N/A</td><td>Supported</td></tr>
<tr><td>Flat Slabs</td><td>N/A</td><td>Supported</td></tr>
</table>
</td><td>☐</td></tr>
<tr><td>6.2</td><td>Method of Application of Slab Loads onto Beams</td><td></td></tr>
</table>

FEM Design Verification Checklist for CSI.ETABS 2016 (Summary)

ITEM | **CONTENT** | **√**

6.21

Method of Load Application onto Beams	Method 1	Method 2
	Yield Line Method	Finite Element Method
Slab Loads	Uniform loads	N/A
Slab Openings	Not Supported	N/A
Irregular Floor Plates	Not Supported	N/A

☐

6.3 Method of Frame Analysis

6.31

Vertical Load Functional Framing and Lateral Load Stability Scheme	Method of Frame Analysis	
	Method 1	Method 2
	BA	STAGE
Beam-Column with Shear Wall	Supported	Supported
Beam-Column as Moment Frame	Supported	Supported
Flat Slab-Column with Shear Wall	Supported [#A]	Supported [#A]
Flat Slab-Column as Moment Frame	Supported [#B]	Supported [#B]

#A: Check flat slab / flat transfer slab analysis undertaken with Method 1 or Method 2 with lateral loads being resisted by shear walls.

#B: Check flat slab / flat transfer slab analysis undertaken with Method 1 or Method 2 with lateral loads being resisted by flat slab / flat transfer slab and columns moment frames.

☐

6.32

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	
1	BA	Supported #A, #B	Supported #A, #B	Supported #A, #B	Supported #C	Supported #D	Supported #D
2	STAGE	Supported #A, #B	Supported #A, #B	Supported #A, #B	Supported #C	Supported #D	Supported #D

#A: Check that the **envelope effects** of both Method 1 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 (more prominently than Method 2) 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. 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 (more importantly than Method 2) 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 **allows only limited** 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 **allows only limited** 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.

☐

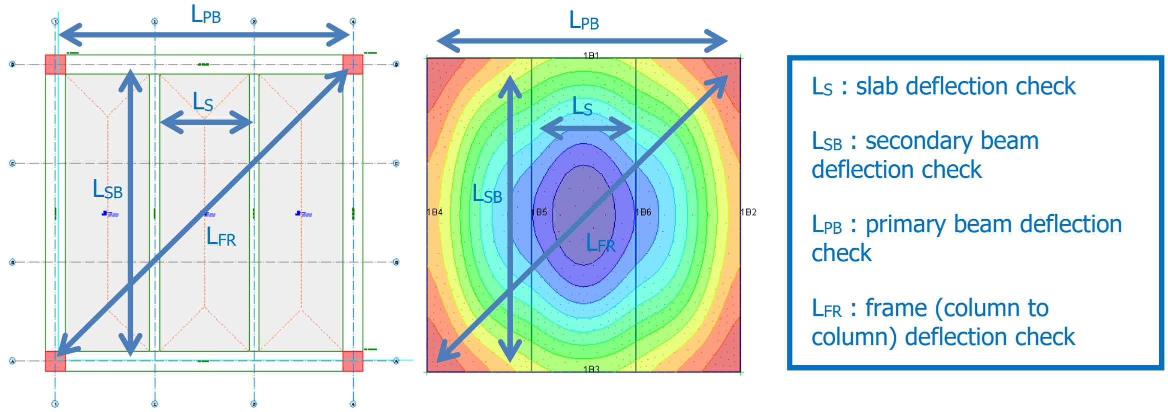
6.33

Item	Method of Frame Analysis	
	Method 1	Method 2
	BA	STAGE
Effect of Continuity on Beam Loading Tributary	Supported	Supported
Effect of Flat Slabing in Beam-Column Vertical Load Functional Framing	Supported	Supported
Pattern Loading	Supported	Supported
Effect of Slabs in Resisting Torsion of Beams	Supported	Supported

☐

FEM Design Verification Checklist for CSI.ETABS 2016 (Summary)

<table>
<tr><th>ITEM</th><th>CONTENT</th><th>√</th></tr>
<tr><td>7.0</td><td>SLAB ANALYSIS AND DESIGN CHECKS</td><td></td></tr>
<tr><td>7.1</td><td>General</td><td></td></tr>
<tr><td>7.11</td><td>In RC models, check sufficiency of rebar in orthogonal directions to fully mesh slab (ES).
In PT models, check sufficiency of tendons (and rebar) in orthogonal directions to fully mesh slab (ES).</td><td>☐</td></tr>
<tr><td>7.2</td><td>Conventional Codified BS8110 Coefficients Method</td><td></td></tr>
<tr><td>7.21</td><td>Manually check sufficiency of rebar based on conventional codified BS8110 coefficients method in RC models (ES).</td><td>☐</td></tr>
<tr><td>7.3</td><td>Full FE Method Design Method</td><td></td></tr>
<tr><td>7.31</td><td>MODEL → Properties → Frame Sections (of beams) → Property Modifiers → check (m11, m22, m33) 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 whilst ensuring OPTION → Frame Assignments → Property Modifiers are selected.
MODEL → Properties → Slab Sections → Modifiers → check (m11, m22, m12) 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 whilst ensuring OPTION → Shell Assignments → Stiffness Modifiers are selected.
SAFE → 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).</td><td>☐</td></tr>
<tr><td>7.32</td><td>
<table>
<tr><th colspan="3">Positive and Negative Moment Factors for SAFE Effects</th></tr>
<tr><th></th><th>Positive Moment Factor</th><th>Negative Moment Factor</th></tr>
<tr><td>(Less conservative) elasto-plastic slab design
(assuming conditions of cl.3.5.2.3 BS8110-1 satisfied)</td><td>1.2</td><td>0.8</td></tr>
<tr><td>(More conservative) elastic slab design
(assuming conditions of cl.3.5.2.3 BS8110-1 satisfied)</td><td>1.0</td><td>1.0</td></tr>
<tr><td>(More conservative) elastic slab design with equivalent pattern loading
(assuming conditions of cl.3.5.2.3 BS8110-1 not satisfied)</td><td>1.2</td><td>1.0</td></tr>
</table>
</td><td>☐</td></tr>
<tr><td>7.33</td><td>SAFE → check animated deflections for modelling accuracy (ES).</td><td>☐</td></tr>
<tr><td>7.34</td><td>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
SAFE → check |TLS|=|DL+PT| deflections ≤ {[span/500 to span/350].C_1, 20mm} (ES).
SAFE → check SLS=DL+SDL+LL+PT deflections ≤ [span/250].C_1 (ES).
SAFE → 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 total (elastic, creep, shrinkage) axial shortening of the one storey in question (ES).
SAFE → 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 total (elastic, creep, shrinkage) axial shortening of the one 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.


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)</td><td>☐</td></tr>
</table>

<table>
<tr><th>ITEM</th><th>CONTENT</th><th>√</th></tr>
<tr><td></td><td>(ES).</td><td></td></tr>
<tr><td>7.35</td><td>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
SAFE → 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
SAFE → 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 $A_{sv,req}/S$.
SAFE → check rebar (to resist ULS bending) required in X/Y directions (ES).

FE Analysis Method PT Analysis and Design
SAFE → check PT analysis and design in X/Y directions (ES)
→ check TLS/SLS bending effects $M_{TLS/SLS,E/E}+M_{TLS/SLS,E/L}$ are minimal.
→ check ULS bending effects $M_{ULS,E/E}+M_{ULS,S/E}$, note w.o./w. the differential (elastic, creep, shrinkage) axial shortening of adjacent supports.
Note by convention, +ve bending moment is sagging and –ve bending moment is hogging (<i>consistent</i> with SAFE).
→ 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 (<i>inconsistent</i> with SAFE).

PT Design Strip Design Sections FE Analysis Method Integration of Effects Analysis and PT Design Strip Design Sections Design
SAFE → 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 total (elastic, creep, shrinkage) axial shortening of the one 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 total (elastic, creep, shrinkage) axial shortening of the one 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</td><td>☐</td></tr>
</table>

ITEM	CONTENT	√

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.

→ check **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 **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 SAFE).

→ 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 **differential** (elastic, creep, shrinkage) axial shortening of **adjacent** supports.

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

→ 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 (*inconsistent* with SAFE).

→ 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** $A_{sv,req}/S$.

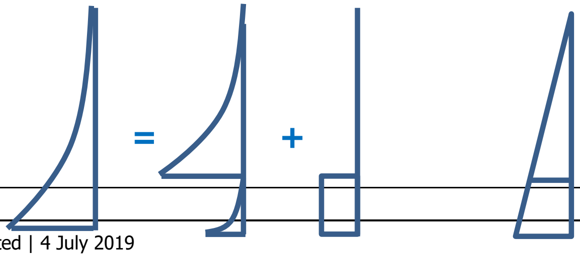
SAFE → check **rebar (to resist SLS tensile stress) required** in X/Y directions (ES).

RC or PT Method of Slab Detailing

RC or PT Method of Slab Detailing	
Method 1: Automatic Specification of Reinforcement Bars	**Automatic** specification of (**top** and **bottom**) reinforcement **bars** based on slab rebar settings with min steel bar size T10 (i.e. smallest available rebar diameter), bar spacing 100mm min to 250mm max and steel bar spacing step 25mm. Note in this method, only the 1/3rd span hogging regions will be automatically reinforced, manual addition required for top steel throughout.
Method 2: Semi-Automatic Specification of Reinforcement Mesh / Bars	**Automatic** specification of (**top**) reinforcement **mesh** / **bars** based on slab rebar settings with 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 SAFE rebar areas required {As(d)1, As(d)2} for slab panels (Method 3).
Method 3: Manual Specification of Reinforcement Mesh / Bars	**Manual** specification of (**top**) reinforcement **mesh** / **bars** based on SAFE 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 SAFE rebar areas required {As(d)1, As(d)2} for slab panels.

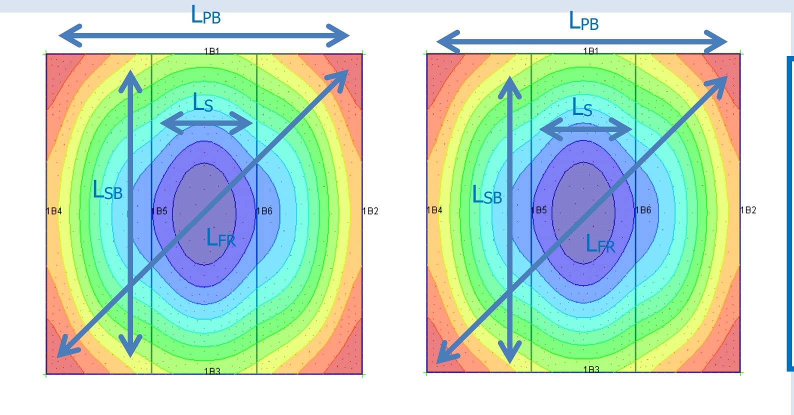
RC or PT Analysis and Design Summary Report

Check design strip design sections forces (ES).
Check design strip design sections rebar (ES).

ITEM	CONTENT	√
	Check design strip design sections moment capacities (ES). Check design strip design sections dimensions (ES). Check design strip design sections geometry (ES). Check tendon and rebar plans (ES).	
7.36	Manually check ULS shear stresses and shear design at beam/wall supports of heavily loaded slabs (ES).	☐
7.37	SAFE → check **ULS punching shear** at wall/column supports of flat slabs together with the associated **required shear links** $A_{sv,req}$ (ES).	☐
8.0	**BEAM AND WALL/COLUMN ANALYSIS AND DESIGN CHECKS**	
8.1	**Building Analysis Method**	
8.11	BA → DISPLAY → Deformed Shape → Start Animation → 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 by selecting BA → DISPLAY → Frame/Pier/Spandrel/Link Forces → Moment 3-3) (ES).	☐
8.12	BA → DISPLAY → Deformed Shape → check |TLS|=|DL+PT| deflections ≤ {[span/500 to span/350].C_1, 20mm} (ES). BA → DISPLAY → Deformed Shape → check SLS=DL+SDL+LL+PT deflections ≤ [span/250].C_1 (ES). BA → DISPLAY → Deformed Shape → check k_C.(DL+SDL)+LL+PT deflections ≤ {[span/500 to span/350].C_1, 20mm} (ES). BA → DISPLAY → Deformed Shape → check k_C.(DL+SDL)+LL+PT deflections at façade beams ≤ {[span/1000].C_1, 20mm} (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].	☐
8.13	BA → DISPLAY → Frame/Pier/Spandrel/Link Forces → check magnitude and shape of ULS effects (axial forces, shear forces, bending moments, torsional moments) (ES).	☐
8.14	BA → DISPLAY → Frame/Pier/Spandrel/Link Forces → perform the **Moment Ratio Check** to comprehend the building primary lateral stability elements by **both**: - (i) comparing the **relative magnitude** of the coupled shear wall / moment frame / outrigger frame / tube **(shear mode) equivalent global bending moment** (back-calculated by multiplying the push-pull axial forces of the walls/columns at the frame extremity with the frame extremity lever arm, noting that the effectiveness of the coupling beams / moment beams / outrigger beams / (framed) tube web spandrel beams in contributing to the base moment resisting lateral stability is measured from the existence of significant push-pull axial forces in the walls/columns at the frame extremity, from the existence of significant local zig-zag bending moments in the walls/columns (except outrigger columns and tube flange columns) or from the existence of significant zig-zag bending moments in the coupling beams / moment beams / outrigger beams / (framed) tube web spandrel beams themselves) **with** the magnitude of the shear wall **(bending mode) cumulative bending moment** (exhibited as cumulative bending moments in the shear walls or as push-pull axial forces within the flanges of flanged shear walls) from lateral loads only (noting that the summation of which shall match the **stability base moment**) (ES), **and** (ii) comparing the **relative magnitude** of the **summation** of the coupled shear wall / moment frame / outrigger frame (except outrigger columns) / (framed) tube (except tube flange columns) wall/column **(shear mode) shear forces** (which cause the local zig-zag bending moments in the walls/columns, noting that the effectiveness of the coupling beams / moment beams / outrigger beams / (framed) tube web spandrel beams in contributing to the base shear resisting lateral stability is measured from the existence of significant shear forces in the walls/columns (except outrigger columns and tube flange columns) or from the existence of significant shear forces in the coupling beams / moment beams / outrigger beams / (framed) tube web spandrel beams themselves) **with** the magnitude of the shear wall **(bending mode) cumulative shear force** from lateral loads only (noting that the summation of which shall match the **stability base shear**) (ES). Note that the effect to the **stability base moment** and **stability base shear** of a **transfer floor** (defined as a horizontal level at which the more extensive vertical elements on plan become discontinuous on elevation ensuing in less extensive vertical elements on plan) is **firstly**, the resolution of the stability base moment at the transfer level to **constant** push-pull axial forces in the walls/columns at the transfer frame extremity (somewhat akin to the effect of an outrigger) below the transfer level and **secondly**, the redistribution of stability base shear to different stability elements. 	☐

FEM Design Verification Checklist for CSI.ETABS 2016 (Summary)

ITEM	CONTENT	√
	Stability Base Moment (MNm) **Stability Base Shear (MN)**	
8.15	BA/STAGE → DISPLAY → Deformed Shape → and SAFE → 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 STAGE 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	**Staged Building Analysis Method**	
8.21	SAFE (STAGE) → check (uncracked) Stiffness Factors (i.e. EI) for (transfer) slab and (transfer) beam are (2/3rd).(1.00)≈0.66 for Class 1 PT or Class 2 PT, note the further 2/3rd 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). SAFE (STAGE) → check (cracked) Stiffness Factors (i.e. EI) for (transfer) slab and (transfer) beam are (2/3rd).(0.50)≈0.32 for RC or Class 3 PT, note the further 2/3rd 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** SAFE (STAGE) → check |TLS|=|DL+PT| **deflections** ≤ {[span/500 to span/350].C_1, 20mm}. SAFE (STAGE) → check SLS=DL+SDL+LL+PT **deflections** ≤ [span/250].C_1. SAFE (STAGE) → 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 **total** (elastic, creep, shrinkage) axial shortening of the **one** storey in question. SAFE (STAGE) → 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 **total** (elastic, creep, shrinkage) axial shortening of the **one** 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.	☐

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).	
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** SAFE (STAGE) → check RC **analysis and design** in X/Y directions → check **ULS bending** effects $M_{ULS,E/E}$, note w.o./w. the **differential** (elastic, creep, shrinkage) axial shortening of **adjacent** supports. → check **ULS shear** effects $V_{ULS,E/E}$, note w.o./w. the **differential** (elastic, creep, shrinkage) axial shortening of **adjacent** supports. **RC Design Strip Design Sections FE Analysis Method Integration of Effects Analysis and RC Design Strip Design Sections Design** SAFE (STAGE) → 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 **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** $A_{sv,req}/S$. SAFE (STAGE) → check **rebar (to resist ULS bending) required** in X/Y directions. **FE Analysis Method PT Analysis and Design** SAFE (STAGE) → check PT **analysis and design** in X/Y directions → check **TLS/SLS bending** effects $M_{TLS/SLS,E/E}+M_{TLS/SLS,E/L}$ are minimal. → check **ULS bending** effects $M_{ULS,E/E}+M_{ULS,S/E}$, note w.o./w. the **differential** (elastic, creep, shrinkage) axial shortening of **adjacent** supports. Note by convention, +ve bending moment is sagging and –ve bending moment is hogging (*consistent* with SAFE). → 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: $\vert\ -1.0 \le f'_t \le 0.50f_{ci}$ [CL1] $\vert\ -0.36\sqrt{f_{ci}} \le f'_t \le 0.50f_{ci}$ [CL2] $\vert\ -0.25f_{ci} \le f'_t \le 0.50f_{ci}$ [CL3] $\vert$ FS: $\vert\ -1.0 \le f'_t \le 0.24f_{ci}$ [CL1] $\vert\ -0.36\sqrt{f_{ci}} \le f'_t \le 0.24f_{ci}$ [CL2] $\vert\ -0.45\sqrt{f_{ci}} \le f'_t \le 0.24f_{ci}$ [CL3] $\vert$ → check **TLS bottom stress** $f'_{min,b} \le f'_b \le f'_{max,b}$ BM: $\vert\ -1.0 \le f'_b \le 0.50f_{ci}$ [CL1] $\vert\ -0.36\sqrt{f_{ci}} \le f'_b \le 0.50f_{ci}$ [CL2] $\vert\ -0.25f_{ci} \le f'_b \le 0.50f_{ci}$ [CL3] $\vert$ FS: $\vert\ -1.0 \le f'_b \le 0.33f_{ci}$ [CL1] $\vert\ -0.36\sqrt{f_{ci}} \le f'_b \le 0.33f_{ci}$ [CL2] $\vert\ -0.45\sqrt{f_{ci}} \le f'_b \le 0.33f_{ci}$ [CL3] $\vert$ → 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 -<.......> = 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 (*inconsistent* with SAFE). **PT Design Strip Design Sections FE Analysis Method Integration of Effects Analysis and PT Design Strip Design Sections Design** SAFE (STAGE) → 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 SAFE). → 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 SAFE). → 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 (*inconsistent* with SAFE). → 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. SAFE (STAGE) → check **rebar (to resist SLS tensile stress) required** in X/Y directions.	
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.	☐

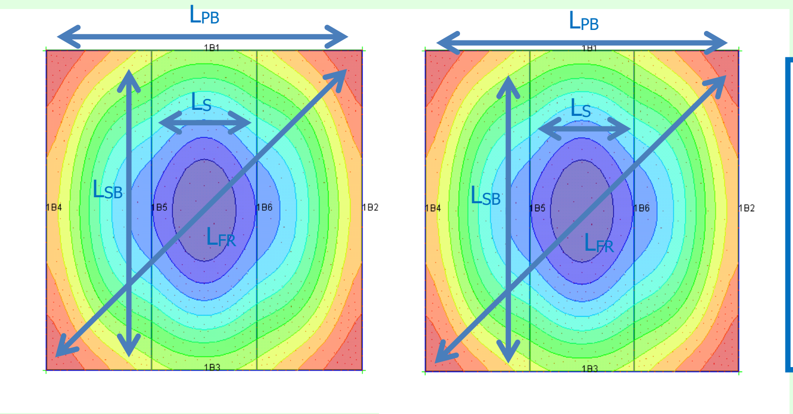
FEM Design Verification Checklist for CSI.ETABS 2016 (Summary)

ITEM	CONTENT	√
	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	SAFE (STAGE) → 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** BA → TABLE → Analysis → Story Forces → check consistency between the (non-cumulative) applied un-decomposed loads tables (TABLE → MODEL → Structure Data → Mass Summary → (G+Q) Mass Summary by Story) and the reactions presented in the (cumulative) Story Forces table. **Staged Building Analysis Method** STAGE → TABLE → Analysis → Story Forces → check consistency between the (non-cumulative) applied un-decomposed loads tables (TABLE → MODEL → Structure Data → Mass Summary → (G+Q) Mass Summary by Story) and the reactions presented in the (cumulative) Story Forces table.	☐
8.4	**Load Take Down**	
8.41	{BA/STAGE → TABLE → Analysis → Story Forces for SLS load, TABLE → MODEL → Structure Data → Material List → Material List by Story for floor areas} → 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 / STAGE**.	☐
8.42	BA/STAGE → DISPLAY → Frame/Pier/Spandrel/Link Forces → filtering out beams to only show walls/columns, check Axial Force 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**. BA/STAGE → DISPLAY → Frame/Pier/Spandrel/Link Forces → enable display of Axial Force, Moment and Shear for appropriate Loading Combinations **to visually display Bottom loading effects**, noting that directions 2-2 and 3-3 refer to the local axes (i.e. axis direction 2-2 and 3-3, respectively) → check Axial Force (ensuring no uplift) for all walls/columns and Axial Force (ensuring no uplift), Moment and Shear 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 / STAGE**.	☐
8.5	**Sway Susceptibility (NHF, Wind, EQ)**	
8.51	Check Sway Classification Report $Q \leq 0.05$ for $\lambda \geq 20$ for **BA / STAGE**, 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	MODEL → Named Plots → Story Response Plots → **optionally** check total building lateral deflections to **NHF**, $\delta_{total} \leq H_{total}/500$ and relative storey drift, $\Delta\delta_{storey,I} \leq h_{storey,I}/500$ (ES). NHF load combinations should be analysed with modified default stiffness parameters {Class 1 PT or Class 2 PT slab/beam: $k_E=2.0$, $k_I=1.0$, $k_J=1.0$; RC or Class 3 PT slab/beam: $k_E=2.0$, $k_I=0.5$, $k_J=0.5$; wall/column: $k_E=2.0$, $k_I=1.0$, $k_J=1.0$}, NHF load factors reset to 1.0, other lateral load combinations (wind, EQ) deleted and as a last resort adopting flanged beam sections in lieu of rectangular beam sections.	☐
8.62	BA → DISPLAY → Deformed Shape → **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.	☐

FEM Design Verification Checklist for CSI.ETABS 2016 (Summary)

ITEM	CONTENT	√
8.63	MODEL → Named Plots → Story Response Plots → check total building lateral deflections to **wind**, $\delta_{total} \le H_{total}/500$ and relative storey drift, $\Delta\delta_{storey,I} \le h_{storey,I}/500$ (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	BA → DISPLAY → Deformed Shape → 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	MODEL → Named Plots → Story Response Plots → check total building lateral deflections to **EQ**, $\nu.q.\delta_{total} \le H_{total}/250$ and relative storey drift, $\nu.q.\Delta\delta_{storey,I} \le h_{storey,I}/250$ (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	BA → DISPLAY → Deformed Shape → 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**	
8.71	TABLE → Design → Concrete Design → Concrete Beam Summary → check design status of RC beams (ES). Check design status of PT beam design strips design sections (ES).	☐
8.72	In RC models, Design → Concrete Frame Design → Start Design/Check for **BA / STAGE** (ES). In PT models, check beam design strip design sections tendons (and rebar) design for **BA / STAGE** (ES).	☐
8.73	In RC models, check **common beam details** in all duplicate storeys and between similar beams within the storey (ES). In PT models, check **common beam details** in all duplicate storeys and between similar beams within the storey (ES).	☐
8.74	In RC models, Design → Concrete Frame Design → Display Design Info → Design Output → Rebar Percentage → check % steel **<< 4%** and design shear stress ≈ **3N/mm²** (TABLE → Design → Concrete Design → Concrete Beam Summary and TABLE → Model → Definitions → Frame Sections → Frame Sections for sectional area, A_C and BA/STAGE → TABLE → Design → Design Forces → Beam Design Forces for V_{ULS} to calculate ULS shear stress **$\tau = V_{ULS}/A_C$) << 5N/mm²** for **BA / STAGE** (ES including duplicate storeys). In PT models, check design shear stress ≈ **3N/mm²** (TABLE → Design → Concrete Design → Concrete Beam Summary and TABLE → Model → Definitions → Frame Sections → Frame Sections for sectional area, A_C and BA/STAGE → TABLE → Design → Design Forces → Beam Design Forces for V_{ULS} to calculate ULS shear stress **$\tau = V_{ULS}/A_C$) << 5N/mm²** for **BA / STAGE** (ES including duplicate storeys).	☐
8.75	In RC models, check beam detailed design report for **BA / STAGE** (ES including duplicate storeys). In PT models, check beam detailed design report for **BA / STAGE** (ES including duplicate storeys).	☐
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 / STAGE**. 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 / STAGE** (ES).	☐
8.78	**Building RC and PT beam final comprehensive design check (ES)** #A	
8.781	BA → check design → % steel << 4% → τ ≈ 3 << 5N/mm² →	☐
8.782	STAGE → check design → % steel << 4% → τ ≈ 3 << 5N/mm² →	☐
	#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.	☐

ITEM	CONTENT					√
	(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 (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 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**					
8.81	TABLE → Design → Shear Wall Design → Shear Wall Pier Summary → check design status of walls (ES). TABLE → Design → Concrete Design → Concrete Column Summary → check design status of columns (ES).					☐
8.82	Design → Shear Wall Design → Start Design/Check for **both frame analysis methods** (ES). Note wall biaxial bending theory N/A. Design → Concrete Frame Design → Start Design/Check for **both frame analysis methods** and **both column design theories**, i.e. BA + cl.3.8.4.5 BS8110-1 theory, BA + biaxial bending theory, STAGE + cl.3.8.4.5 BS8110-1 theory and STAGE + biaxial bending theory (ES). Note that the cl.3.8.4.5 BS8110-1 theory is more conservative (less economic) compared to the biaxial bending theory.					☐
8.83	Check reinforcement only increases down the building and decreases up the building (in general).					☐
8.84	Check **common column details** between similar columns within the storey (ES).					☐
8.85	Design → Shear Wall Design → Display Design Info → Design Output → Pier Reinforcing Ratios → check % steel for walls (i.e. sections without through-thickness shear links) **<< 2%** and design shear stress ≈ **3N/mm²** (TABLE → Design → Shear Wall Design → Shear Wall Pier Summary and TABLE → Model → Definitions → Pier/Spandrel Section Properties → Pier Section Properties for sectional area, A_C and BA/STAGE → TABLE → Design → Design Forces → Pier Design Forces for V_{ULS} to calculate ULS shear stress **$\tau = V_{ULS}/A_C$**) **<< 5N/mm²** for **both frame analysis methods** (ES). Note wall biaxial bending theory N/A.					☐
8.86	TABLE → Design → Concrete Design → Concrete Column PMM Envelope → check % steel for columns (i.e. sections with through-thickness shear links) **<< 5%** and design shear stress ≈ **3N/mm²** (TABLE → Design → Concrete Design → Concrete Column Summary and TABLE → Model → Definitions → Frame Sections → Frame Sections for sectional area, A_C and BA/STAGE → TABLE → Design → Concrete Design → Concrete Column Shear Envelope for V_{ULS} to calculate ULS shear stress **$\tau = V_{ULS}/A_C$**) **<< 5N/mm²** for **both frame analysis methods** and **both column design theories**, i.e. BA + cl.3.8.4.5 BS8110-1 theory, BA + biaxial bending theory, STAGE + cl.3.8.4.5 BS8110-1 theory and STAGE + biaxial bending theory (ES).					☐
8.87	Check wall detailed design report → search for {< 15.0} for walls that are to be correctly defined as braced and {< 10.0} for walls that are to be correctly defined as unbraced (ES). Note wall biaxial bending theory N/A. Check column detailed design report → search for {< 15.0 or > 15.0} for columns that are to be correctly defined as braced and {< 10.0 or > 10.0} for 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] →	τ ≈ 3 << 5N/mm² →	☐
8.882	BA →	biaxial bending theory →	check design →	% steel << 2%/5% [#A] →	τ ≈ 3 << 5N/mm² →	☐
8.883	STAGE →	BS8110-1 theory →	check design →	% steel << 2%/5% [#A] →	τ ≈ 3 << 5N/mm² →	☐
8.884	STAGE →	biaxial bending theory →	check design →	% steel << 2%/5% [#A] →	τ ≈ 3 << 5N/mm² →	☐
	#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	Check Allowable Soil Stress Ultimate Strength Factor = (1.4DL+1.4SDL+1.6LL)/(DL+SDL+LL), 1.4 being conservative.					☐
9.2	**Pad Footing**					

ITEM	CONTENT	√
9.21	Check Footing Depth, Surcharge Height and Allowable Stress of Soil. Note perform load take down calculation for **BA / STAGE** for all load combinations.	☐
9.22	Perform a detailed design check of all pad footings for **BA / STAGE** for all load combinations.	☐
9.3	**Strip Footing**	
9.31	Check allowable stress of soil (kPa). Check coefficient of subgrade reaction (kN/m^3).	☐
9.32	Check range of Subgrade Coefficients, Footing Width and Footing Depth. Note perform load take down calculation for **BA / STAGE** for all load combinations.	☐
9.33	Perform a detailed design check of all strip footings for **BA / STAGE** for all load combinations.	☐
9.34	Check (strip footing) beam detailed design report for **BA / STAGE** for all load combinations.	☐
9.4	**Raft / Piled Raft Footing**	
9.41	Check allowable stress of soil (kPa). Check coefficient of subgrade reaction (kN/m^3). Check pile SWL and vertical Pile Spring Coefficient. Ensure no uniformly distributed SDL or LL on the raft / piled raft as this will not translate into bending or shear effects on the raft / piled raft, instead employ point loads with their spacing distributed to depict reality.	☐
9.42	Check raft / piled raft analysis by choosing *not to* Ignore Bearing Capacity of Soil. Note perform load take down calculation for **BA / STAGE** for all load combinations.	☐
9.43	Check raft / piled raft SLS rotations $\leq$ **1/250** to BS8110-2 cl.3.2.1.1 (note the Stiffness Factors (i.e. factor for bending rigidity EI) for (raft strip) beam and (raft) slab elements **should** be set to **(2/3rd).(0.50)≈0.32** (the further 2/3rd 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))). Note perform load take down calculation for **BA / STAGE** for all load combinations. Check raft / piled raft SLS tilt $\leq$ **1/400** (note that tilt is unaffected by E and I values but instead is dependent only on the loading magnitude and distribution and the soil stiffness). Note perform load take down calculation for **BA / STAGE** for all load combinations.  L_S : (raft) slab deflection check L_{SB} : secondary (raft strip) beam deflection check L_{PB} : primary (raft strip) beam deflection check L_{FR} : frame (column to column) deflection check Note if necessary, the simulation of the beneficial effect of additional reinforcement in controlling deflections can be made by factoring down the exhibited deflections by the ratio of the modified span / effective depth to the ratio of the basic span / effective depth (cantilever 7.0, simply supported 20.0, continuous 26.0).	☐
9.44	Check raft / piled raft $\|M_{11}\|+\|M_{12}\|$ and $\|M_{22}\|+\|M_{12}\|$ → manually check rebar areas required {As(d)1, As(d)2}, noting minimum steel. Note perform load take down calculation for **BA / STAGE** for all load combinations.	☐
9.45	Check raft / piled raft soil pressure. Note perform load take down calculation for **BA / STAGE** for all load combinations.	☐
9.46	Manually check raft ULS shear stresses and shear design at beam/wall framing. Note perform load take down calculation for **BA / STAGE** for all load combinations.	☐
9.47	Check raft ULS punching shear at wall/column framing. Note perform load take down calculation for **BA / STAGE** for all load combinations.	☐
9.48	Check (raft strip) beam detailed design report for **BA / STAGE** for all load combinations.	☐
9.49	Check factored pile forces (ensuring no tension due to uplift) against the factored pile capacity (especially for stability walls attracting significant moments obscuring the obvious adequacy of the pile group capacity). Note perform load take down calculation for **BA / STAGE** for all load combinations.	☐
9.5	**Pile Footing**	
9.51	Check pile SWL, Pile Size, vertical pile Spring Coefficient, Pile Cap Depth and Surcharge Height. Note perform load take down calculation for **BA / STAGE** for all load combinations.	☐
9.52	Perform a detailed design check of all pile footings for **BA / STAGE** for all load combinations.	☐

ITEM	CONTENT	√
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	Check estimate of the concrete volume (m^3). Check estimate of the formwork area (m^2). 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^{3}m^2) → 250-500. In RC or PT models, check formwork quantity to typical formwork rates (m^2/m^2) → 1.5-2.5. In RC models, check rebar quantity to typical rebar tonnages (kg/m^3) → one-way or two-way slabs 75-100, flat slabs 125-175, transfer slabs 150-350, beams 125-250, transfer beams 150-350, walls 100, columns 150-300, pile caps 150-200. In PT models, check tendon quantity to typical tendon tonnages (kg/m^3) → slabs 20-25, transfer slabs 20-25, beams 40-50. In PT models, check rebar quantity to typical rebar tonnages (kg/m^3) → slabs 20-35, transfer slabs 40-70, beams 40-70.	☐

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 {$-0.30f_c'$, ($-0.40f_c'^{2/3}$ to $-0.50f_c'^{2/3}$)-4N/mm^2/1.0%} as the code allows for an increase in the tensile stress limit from 1% of longitudinal steel (untensioned reinforcement) onwards (-4N/mm^2 for every 1% of longitudinal steel (untensioned reinforcement), increasing proportionally, up to the specified upper limit of $-0.30f_c'$).
#D3: Note flat slab option to T.4 TR.43-2 based on **full tributary width** design strip.

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

Appendix D: RC or PT Load Combination Cases

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

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

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

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

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

Load Combo	Description	Load Factor							
		PT	HYP	DL	SDL	LL	EQ$_X$	EQ$_Y$	EQ$_Z$
	Ultimate Limit State (ULS)								
EQ ULS01	1.0DL+1.0SDL+ψ_{2i}LL±1.0EQ$_X$+HYP 1.0DL+1.0SDL+ψ_{2i}LL±1.0EQ$_Y$+HYP	–	1.0	1.0	1.0	ψ_{2i}	±1.0	–	–
		–	1.0	1.0	1.0	ψ_{2i}	–	±1.0	–
EQ ULS02	1.0DL+1.0SDL+ψ_{2i}LL+HYP ±1.0EQ$_X$±0.3EQ$_Y$±0.3EQ$_Z$ 1.0DL+1.0SDL+ψ_{2i}LL+HYP ±0.3EQ$_X$±1.0EQ$_Y$±0.3EQ$_Z$ 1.0DL+1.0SDL+ψ_{2i}LL+HYP ±0.3EQ$_X$±0.3EQ$_Y$±1.0EQ$_Z$	–	1.0	1.0	1.0	ψ_{2i}	±1.0	±0.3	±0.3
		–	1.0	1.0	1.0	ψ_{2i}	±0.3	±1.0	±0.3
		–	1.0	1.0	1.0	ψ_{2i}	±0.3	±0.3	±1.0

	Serviceability Limit State (SLS)								
EQ SLS01	1.0DL+1.0SDL+ψ_{2i}LL±1.0EQ$_X$+PT [#A] 1.0DL+1.0SDL+ψ_{2i}LL±1.0EQ$_Y$+PT [#A]	1.0	–	1.0	1.0	ψ_{2i}	±1.0	–	–
		1.0	–	1.0	1.0	ψ_{2i}	–	±1.0	–
EQ SLS02	1.0DL+1.0SDL+ψ_{2i}LL+PT ±1.0EQ$_X$±0.3EQ$_Y$±0.3EQ$_Z$ [#A]	1.0	–	1.0	1.0	ψ_{2i}	±1.0	±0.3	±0.3
	1.0DL+1.0SDL+ψ_{2i}LL+PT ±0.3EQ$_X$±1.0EQ$_Y$±0.3EQ$_Z$ [#A]	1.0	–	1.0	1.0	ψ_{2i}	±0.3	±1.0	±0.3
	1.0DL+1.0SDL+ψ_{2i}LL+PT ±0.3EQ$_X$±0.3EQ$_Y$±1.0EQ$_Z$ [#A]	1.0	–	1.0	1.0	ψ_{2i}	±0.3	±0.3	±1.0

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

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

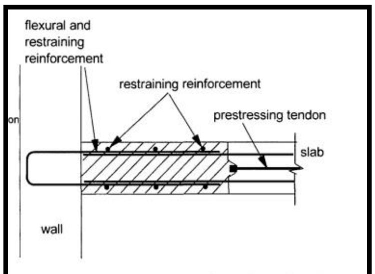
RC or PT Design Strip Design Sections Equivalent Frame Method Integration of Effects Analysis	RC or PT Design Strip Design Sections FE Analysis Method Integration of Effects Analysis
Does not consider the flat slab hogging moment stress concentrations, unconservatively	Does consider the flat slab hogging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

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

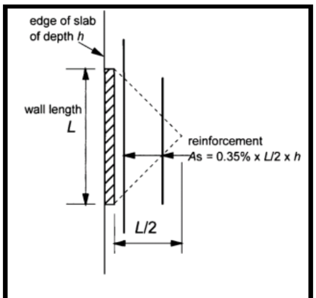
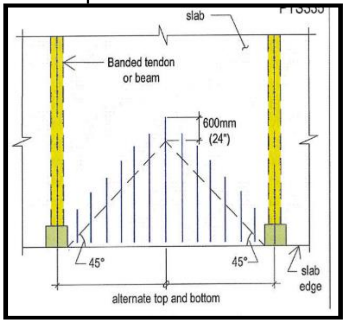


Figure 57: Distribution reinforcement close to restraining wall.

(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.)