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SECTION 12 DESIGN OF NON-FLEXURAL MEMBERS, END ZONES AND BEARING SURFACES

SECTION 12 DESIGN OF NON-FLEXURAL MEMBERS, END ZONES AND BEARING SURFACES
plus
SECTION 7 STRUT AND TIE MODELLING

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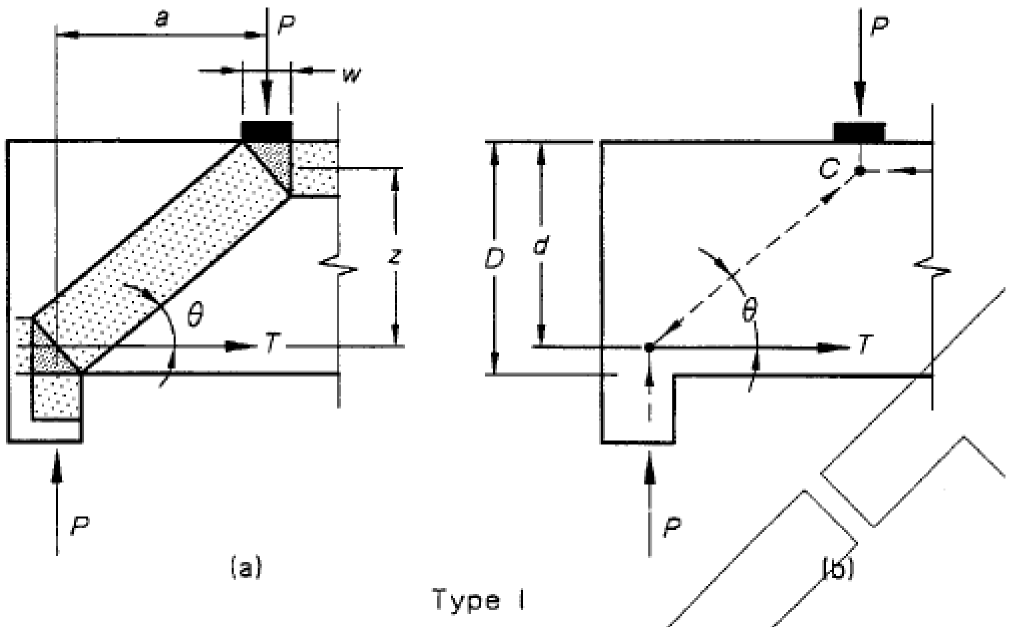

FIGURE 12.2 a) STRUT AND TIE MODELS, AND b) SIMPLIFIED DESIGN MODELS

Proposed Revisions to AS3600, Concrete Structures

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Western Australia Division

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20 June 2006

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(b) *Type II* The shear is taken to the supports by a combination of primary (major) and secondary (minor) struts. Hanger reinforcement is required to return the vertical components of forces developed in the secondary struts to the top of the member.

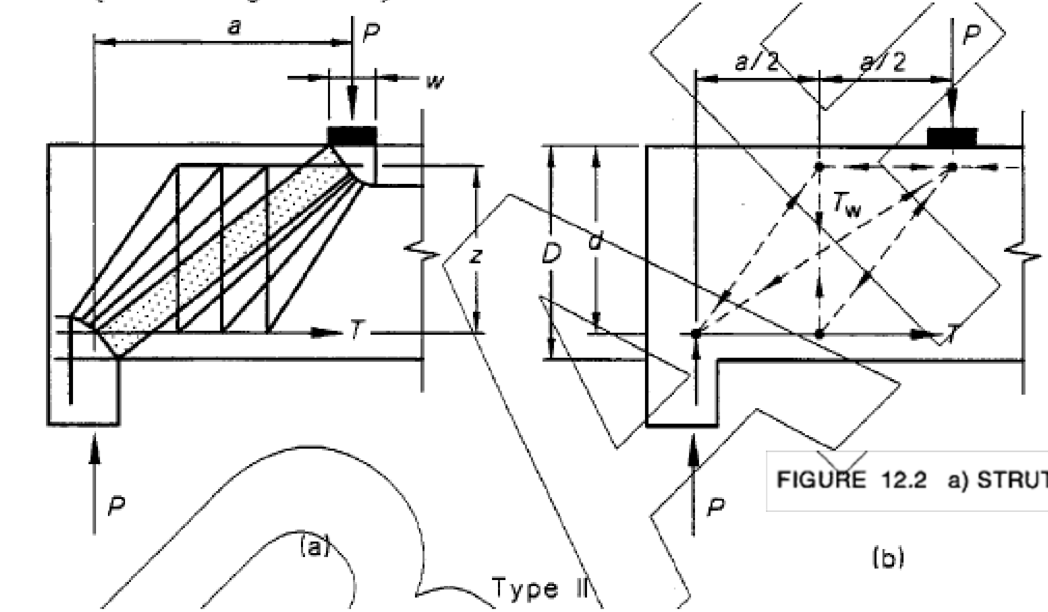

FIGURE 12.2 a) STRUT AND TIE MODELS, AND b) SIMPLIFIED DESIGN MODELS

For the Type II model the ~~ratio~~proportion of shear forces carried by the secondary struts shall be within the limits $0 \leq T_w \leq F$, where T_w is the vertical component of the force carried by the secondary struts and F is the total vertical component of the external load carried through the shear span.

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(c) *Type III* The shear is carried to the supports via a series of minor struts with hanger reinforcement used to return the vertical components of the strut forces to the top of the member.

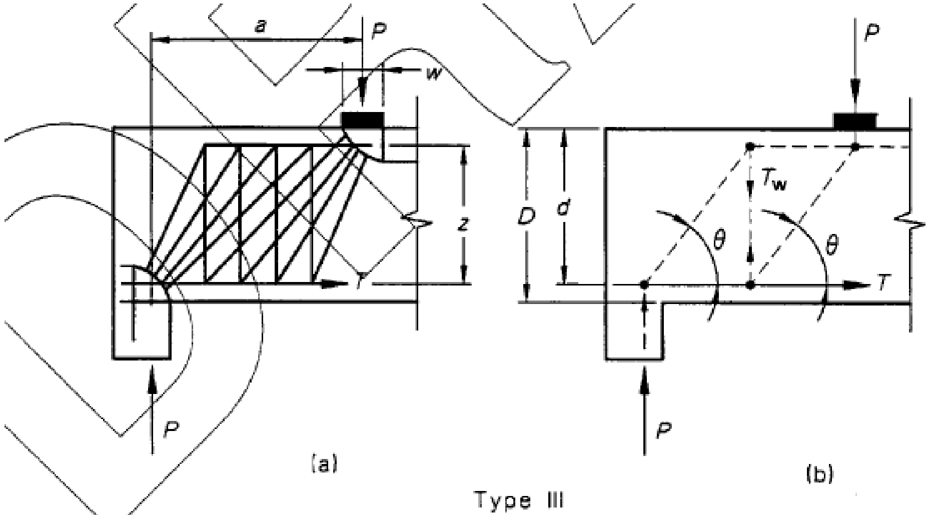

FIGURE 12.2 a) STRUT AND TIE MODELS, AND b) SIMPLIFIED DESIGN MODELS

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SECTION 7 STRUT-AND-TIE MODELLING

7.1 GENERAL

It shall be permissible to use strut-and-tie models to represent the conditions at overload and at failure in non-flexural members and in non-flexural regions of members, as a basis both for strength design and for evaluating strength.

A strut-and-tie model shall consist of compression elements (struts) and tension elements (ties) that are connected together at nodes to form a load-resisting structural system.

Strut-and-tie models shall satisfy the following requirements:

(a) Loads shall be applied at nodes, and the struts and ties shall only be subjected only to axial force.

(b) The model shall provide load paths to carry the loads and other actions to the supports or into adjacent regions.

(c) The model shall be in equilibrium with the applied loads and the reactions.

(d) In determining the geometry of the model, the dimensions of the struts, ties, and nodal zones shall be taken into account.

(e) Ties shall be permitted to cross struts.

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(f) Struts shall cross or intersect only at nodes.

(g) For reinforced concrete members at a node point, the angle between the axes of any strut and any tie shall not be less than 30°.

(h) For prestressed concrete members at a node point, the angle between the axes of any strut and any tie with a tendon acting as the reinforcement shall not be less than 20°.

7.2 CONCRETE STRUTS

7.2.1 Types of struts

Struts shall be of prismatic, fan or bottle shape, depending on the geometry of the compression field, as shown in Figure 7.1. Prismatic struts shall be used only where the compressive stress field cannot diverge.

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7.2.2 Strut efficiency factor

For prismatic struts, the strut efficiency factor (β_s) that is used to determine the design strength, shall be taken as 1.0.

For fan and bottle-shaped compression fields that are unconfined, the strut efficiency factor shall be taken as:

$$\beta_s = \frac{1}{1.0 + 0.66\cot^2\theta} \text{ within the limits } 0.3 \le \beta_s \le 1.0 .$$

The angle θ is measured between the axis of the strut and the axis of a tie passing through a common node (see Figure 7.2). Where more than one tie passes through a node, or where the angle θ is different for nodes at each end of a strut, the smallest value of θ shall be used in determining β_s.

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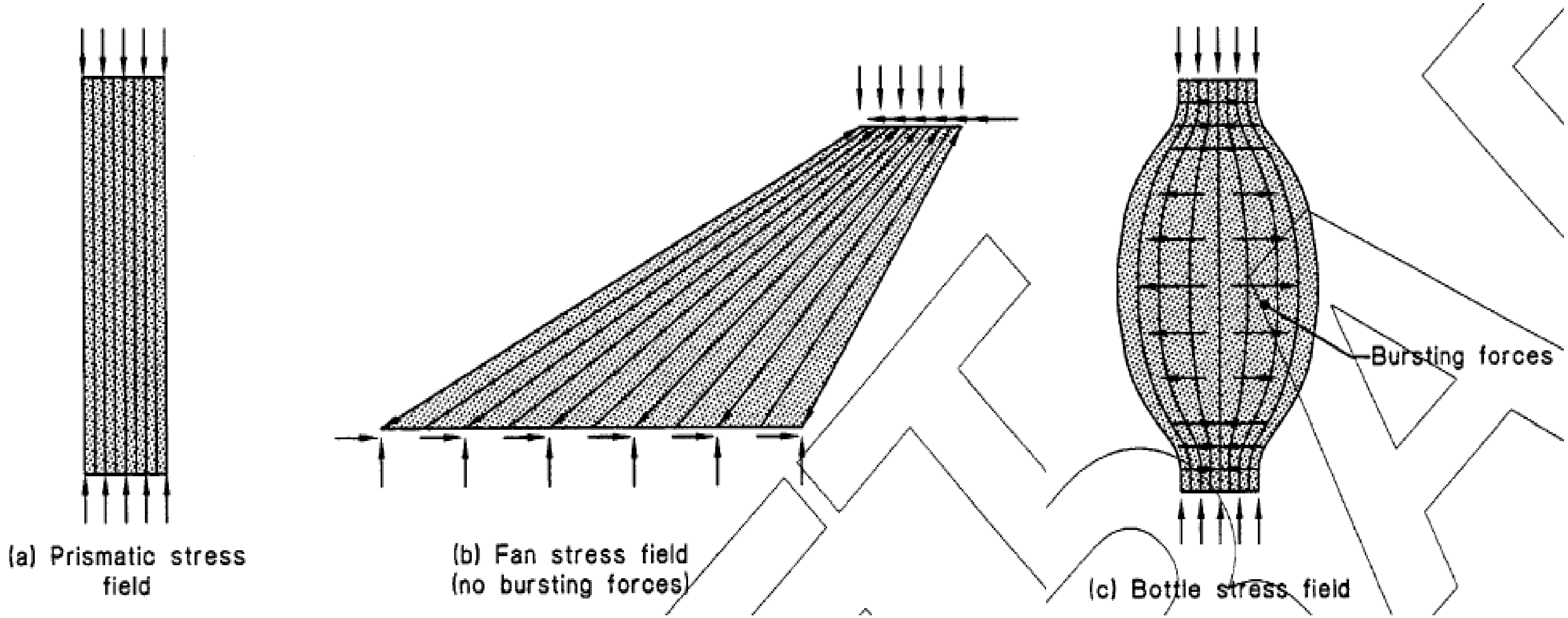

FIGURE 7.1 TYPES OF STRUTS

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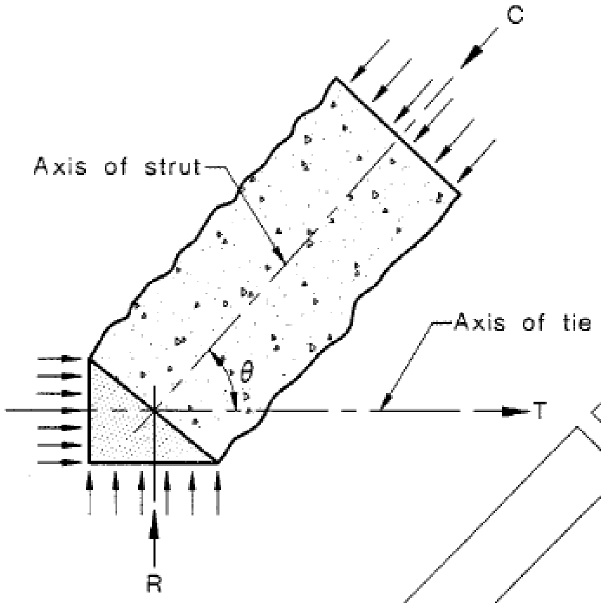

FIGURE 7.2 DEFINITION OF θ

7.2.3 Design strength of struts

The design strength of a concrete strut shall be taken as $\phi\beta_s 0.9f'_c A_c$ where—

A_c = the smallest cross-sectional area of the concrete strut at any point along its length and measured normal to the line of action of the strut.

β_s = an efficiency factor given in Clause 7.2.2.

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The value of the strength reduction factor (ϕ) shall be obtained from Table 2.2.4.

Compressive reinforcement may be used to increase the strength of a strut. Compression reinforcement shall be placed parallel to the axis of the strut, located within the strut and enclosed in ties or spirals satisfying Clause 10.7. The compressive reinforcement shall be properly anchored. The strength of a longitudinally reinforced strut may be calculated as for a prismatic, pin-ended short column, of similar geometry.

7.2.4 Bursting reinforcement in bottle-shaped struts

In the design of bottle-shaped struts, where the bursting force T_b is greater than $0.5T_{b.cr}$, transverse reinforcement shall be provided to carry bursting forces.

Bursting forces (T_b) shall be taken as the greater of the following:

(a) that calculated such that the bursting strength of the strut after cracking is not less than that before cracking. The bursting tension across the strut at cracking may be taken as

$$T_{b.cr} = 0.7 b l_b f'_{ct}$$

where b = thickness of member

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(b) that calculated using an equilibrium model, consistent with the bottle shape as shown in Figure 7.3. To ensure adequate crack control, splitting forces shall be assessed at both service and ultimate limit states. The divergence angle (α) for the bottle strut shall be assessed for each situation but shall not be less than—

(i) tan α = 1/2........for serviceability; and

(ii) tan α = 1/5........for strength.

Bursting reinforcement shall be evenly distributed throughout the bursting zone l_b (Figure 7.3), where—

$$l_b = \sqrt{z^2 + a^2} - d_c$$

and a and z are the shear span and the projection of the inclined compressive strut normal to the shear span, respectively (see Figure 7.3).

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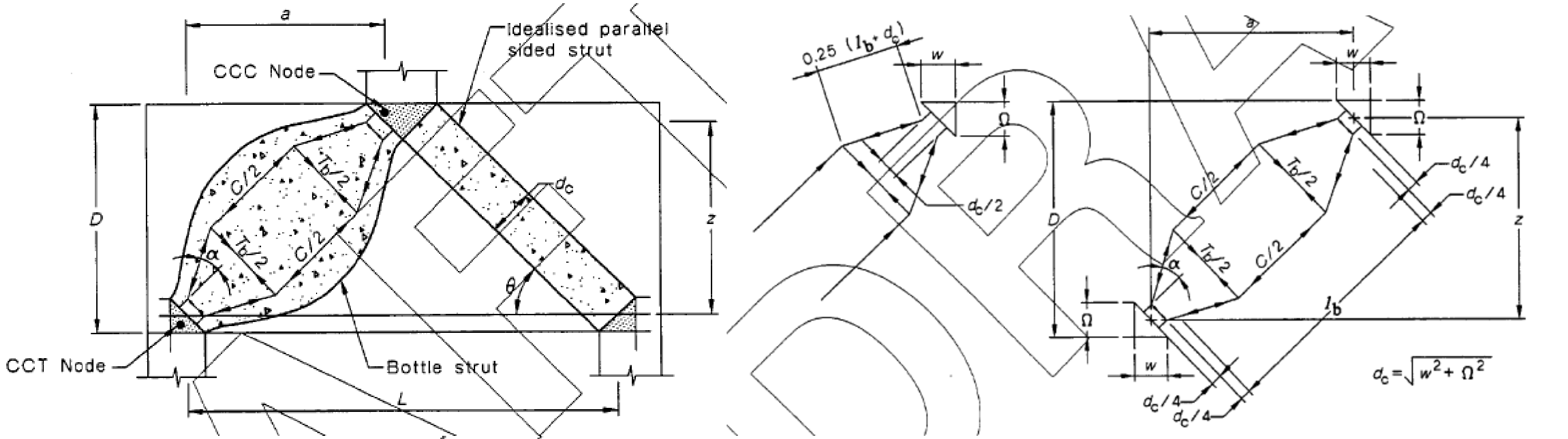

FIGURE 7.3 BURSTING FORCES IN BOTTLE-SHAPED STRUTS

The bursting reinforcement shall be uniformly distributed through the bursting zone l_b and be placed in either: two orthogonal directions at angles γ_1 and γ_2 to the axis of the strut, or in one direction at an angle γ to the axis of the strut. If the reinforcement is in only one direction, γ shall not be less than 40 degrees.

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To provide adequate strength, the quantity of reinforcement shall be such that—

$$\phi \Sigma A_{si} f_{sy} \sin \gamma_i \geq T_b^*$$

To provide adequate crack control, the quantity of reinforcement shall be such that—

$$\Sigma A_{si} f_{si} \sin \gamma_i \geq T_{b.s}^*$$

In the above expressions A_{si} is the area of reinforcement in directions 1 and 2 crossing a strut at an angle γ_i to the axis of the strut (see Figure 7.4) and f_{si} is the serviceability limit stress in the reinforcement as specified in Clause 12.7; T^*_b and $T^*_{b.s}$ are bursting forces calculated using the design load for strength and serviceability, respectively.

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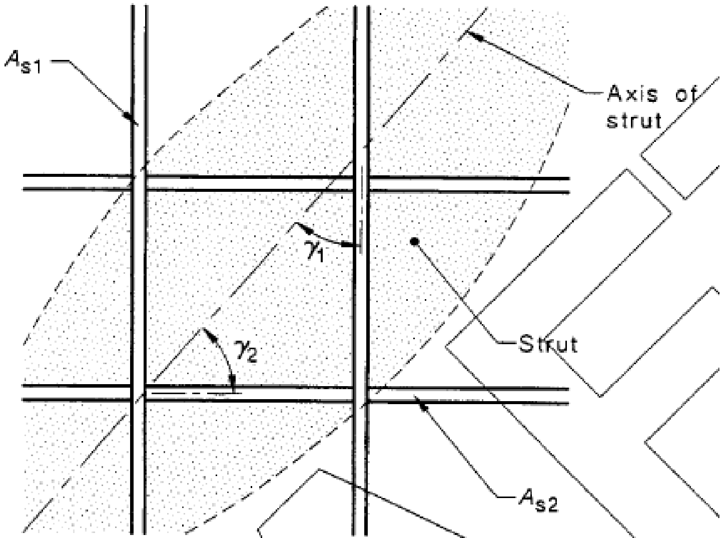

FIGURE 7.4 BURSTING REINFORCEMENT

7.3 TIES

7.3.1 Arrangement of ties

Ties shall consist of reinforcing steel and/or prestressing tendons. The reinforcement and or tendons shall be evenly distributed across the nodal regions at each end of the tie, and arranged such that the resultant tensile force coincides with the axis of the tie in the strut-and-tie model.

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7.3.2 Design strength of ties

The design strength of a tie shall be taken as $\phi\,[A_{st}f_{sy} + A_p(\sigma_{p.ef} + \Delta\sigma_p)]$ where $(\sigma_{p.ef} + \Delta\sigma_p)$ shall not exceed f_{py}. The value of ϕ shall be obtained from Table 2.2.4.

7.3.3 Anchorage of ties

To provide adequate anchorage at each end of the tie, the reinforcement or tendon shall be extended beyond the node to achieve the design strength of the tie at the node and anchored in accordance with Clause 13.1.

Anchorage of reinforcement beyond the node may also be achieved either by a welded or mechanical anchorage or by forming a loop located entirely outside of the node in a vertical, horizontal or inclined plane.

7.4 NODES

7.4.1 Types of nodes

Three types of node are distinguished by the arrangement of the entering struts and ties, and the confinement thus provided, as follows—

(a) CCC – there are only struts entering the node;

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(b) CCT—here are two or more struts and a single tension tie entering the node;

(c) CTT—here are two or more tension ties entering the node.

7.4.2 Design strength of nodes

Where confinement is not provided to the nodal region, the design strength of the node shall be such that the principal compressive stress on any nodal face, determined from the normal and shear stresses on that face, is not greater than $\phi\beta_n 0.9f'_c$ where—

(i) For CCC nodes $\beta_n = 1.0$

(ii) For CCT nodes $\beta_n = 0.8$

(iii) For CTT nodes $\beta_n = 0.6$

The value of the strength reduction factor ϕ shall be taken from Table 2.2.4.

Where confinement is provided to the nodal region, the design strength of the node may be determined by tests or calculation, considering the confinement, but shall not exceed a value corresponding to a maximum compressive principal stress on any face of $\phi\, 1.8\, f'_c$.

7.5 ANALYSIS OF STRUT-AND-TIE MODELS

In the analysis of a strut-and-tie model to determine the internal forces in the struts and ties, the requirements of Clause 6.1.1 shall be satisfied, and Clauses 6.1.2 and 6.8.2 shall be complied with.

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7.6 DESIGN BASED ON STRUT-AND-TIE MODELLING

7.6.1 Design for strength

When strut-and-tie modelling is used for strength design, the requirements of Clause 2.2.4 shall be satisfied.

7.6.2 Serviceability checks

When design for strength is based on strut-and-tie modelling, separate checks shall be undertaken to ensure that the design requirements for serviceability are satisfied.

12.7 CRACK CONTROL

The requirements of crack control may be deemed to be satisfied if the stress in the reinforcement is not greater than the following:

(a) Where a minor degree of control over cracking is required .... 250 MPa.

(b) Where a moderate degree of control over cracking is required .... 200 MPa.

(c) Where a strong degree of control over cracking is required .... 150 MPa.

NOTE: For prestressed concrete the change in stress in the tendons after the point of decompression shall not exceed the limits given by (a), (b) or (c), as appropriate.

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SECTION 13 STRESS DEVELOPMENT AND SPLICING OF REINFORCEMENT AND TENDONS

SECTION 13 STRESS DEVELOPMENT AND SPLICING OF REINFORCEMENT AND TENDONS

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13.1.2.4 *Development length of a bar with a standard hook*

Where a bar ends in a standard hook complying with Clause 13.1.2.5, the tensile development length of that end of the bar, measured from the outside of the hook, shall be taken as $0.5L_{sy.t}$ or $0.5L_{st}$ as applicable.

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13.1.2.4 *Development length of a bar with a standard hook*

Where a plain bar ends in a standard hook complying with Clause 13.1.2.5, the tensile development length of that end of the bar, measured from the outside of the hook, shall be taken as $0.5L_{sy.t}$ or $0.5L_{st}$ as applicable.

Where a ribbed bar ends in a standard hook complying with Clause 13.1.2.5, the tensile development length of that end of the bar, measured from the outside of the hook, shall be taken as $0.2L_{sy.t}$ or $0.2L_{st}$ as applicable.

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13.3.2 Development length of pretensioned tendons

In the absence of substantiated test data, the development length (L_p) of pretensioned tendons for gradual release shall be taken as the transmission length given in Table 13.3.2, as appropriate to type of tendon and the strength of the concrete at transfer (f_{cp}).

Where strand or wire is untensioned, the development length shall be taken as not less than 1.5 times the value given in Table 13.3.2, as appropriate.

It shall be assumed that no change in the position of the inner end of the transmission length occurs with time but that a completely unstressed zone of length $0.1L_p$ develops at the end of the tendon.

Draft AS3600

13.3.2.2 *Development length of pretensioned strand*

In absence of test data the bonded length to develop the stress in seven wire pretensioned strand at ultimate strength shall be taken as not less than—

$$L_p = 0.145(\sigma_{pu} - 0.67\sigma_{p.ef})d_b \geq 60d_b$$

Where $\sigma_{p.ef}$ is the effective stress in the tendon after allowing for all losses. Both σ_{pu} and $\sigma_{p.ef}$ are in MPa and the expression in parenthesis is used without units.

Draft AS3600

Embedment less than the development length shall be permitted at a section of a member provided the design stress in the strand at that section does not exceed the values obtained from the ~~tri~~bi-linear relationship defined by this Clause and Clause 13.3.2.1.

The development length of de-bonded strand shall be taken to be $2L_p$ where the design includes tension in accordance with Clauses 8.6.2 and 9.4.2 in the development length.

13.3.2.3 *Development length of pretensioned wire*

Pretensioned indented and ~~crimped~~ wire tendons shall be bonded beyond the critical section for a length sufficient to develop the design stress in the wire but not less than 2.25 times the value for the transmission length in Table 13.3.2 as appropriate.

13.3.2.4 *Development length of untensioned strand or wire*

Where strand or wire is untensioned, the development length shall be taken as not less than 2.5 times the value of the appropriate transmission length of a stressed tendon given in Table 13.3.2 for a tendon stressed to the tensile strength, f_p, in Table 6.3.1.

Current AS3600 → Draft AS3600

Current AS3600		Draft AS3600	
SECTION 14	JOINTS, EMBEDDED ITEMS, FIXINGS AND CONNECTIONS	SECTION 14	JOINTS, EMBEDDED ITEMS, FIXINGS AND CONNECTIONS
SECTION 15	PLAIN CONCRETE MEMBERS	SECTION 15	PLAIN CONCRETE PEDESTALS AND FOOTINGS
SECTION 16	CONCRETE PAVEMENTS, FLOORS AND RESIDENTIAL FOOTINGS	SECTION 16	SLAB ON GROUND FLOORS AND PAVEMENTS
SECTION 17	LIQUID RETAINING STRUCTURES	~~SECTION 17~~	~~LIQUID RETAINING STRUCTURES~~
SECTION 18	MARINE STRUCTURES	~~SECTION 18~~	~~MARINE STRUCTURES~~
SECTION 19	MATERIAL AND CONSTRUCTION REQUIREMENTS	SECTION 17	MATERIAL AND CONSTRUCTION REQUIREMENTS

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ALL THE SECTIONS LISTED ABOVE which have been retained are essentially similar and will produce similar design outcomes. However Draft AS3600 is substantially reworded in number of instances.

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APPENDICES

A ADDITIONAL REQUIREMENTS FOR STRUCTURES SUBJECT TO EARTHQUAKE LOADS

APPENDICES

A REQUIREMENTS FOR STRUCTURES SUBJECT TO EARTHQUAKE ACTIONS

Current AS3600

EARTHQUAKE REQUIREMENTS essentially unchanged as a design outcome although Draft AS3600 is substantially reworded. The level of requirement is related to Table of Structural Ductility Factors shown below.

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TABLE A4

STRUCTURAL DUCTILITY FACTOR, μ, AND STRUCTURAL PERFORMANCE FACTOR, S_p

Structural system description	μ	S_p	S_p/μ	μ/S_p
Special moment-resisting frames (fully ductile) *	4	0.67	0.17	6
Ductile coupled walls (fully ductile)*	4	0.67	0.17	6
Ductile partially coupled walls *	4	0.67	0.17	6
Intermediate moment-resisting frames (moderately ductile) designed in accordance with this Standard and Paragraph A5 of this Appendix	3	0.67	0.22	4.5
Combined systems of intermediate moment-resisting frames and ductile shear-walls designed in accordance with this Standard and Paragraphs A5 and A6 of this Appendix	3	0.67	0.22	4.5
Ordinary moment-resisting frames designed in accordance with the main body of this Standard	2	0.77	0.38	2.6
Limited ductile shear-walls designed in accordance with the main body of this Standard	2	0.77	0.38	2.6
Ordinary moment resisting frames in combination with limited ductile shear-walls designed in accordance with the main body of this Standard	2	0.77	0.38	2.6
Other concrete structures not listed above	1.5	0.77	0.5	2

Current AS3600 → Draft AS3600

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<tr><td>C</td><td>REFERENCED DOCUMENTS</td><td>C</td><td>NORMATIVE REFERENCES</td></tr>
<tr><td></td><td></td><td>plus</td><td></td></tr>
<tr><td></td><td></td><td>D</td><td>BIBLIOGRAPHY</td></tr>
</table>

Current AS3600

OTHER APPENDICES essentially unchanged but Draft AS3600 splits the REFERENCES into NORMATIVE and BIBLIOGRAPHY.

Draft AS3600

The use of a NORMATIVE set of References elevates the whole of that Reference to an intergral part of the Standard, where previously it may have been referred to only in particular instances within the Standard, or perhaps not at all other than in the References. Note for example that the Building Code of Australia is now a NORMATIVE referred document in Draft AS3600.

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Review of the Proposed Revisions to AS3600, Concrete Structures

Talk presented by Joe Wyche, Director, Wyche Consulting

Institution of Engineers Australia, Perth WA

20 June 2006

THANK YOU FOR ATTENDING