# 4. DESIGN MODELS

## 4.1 General

The design models used in the strength and deflection design methods and their limits of application are briefly explained in this section. The limits of application arise mainly from the parameter ranges covered in experimental and theoretical studies undertaken to verify the models. This may explain somewhat arbitrary nature of some of the limits of application. Nevertheless, the limits encompass a range sufficiently wide for most practical applications. These limits are described in detail in Section 6.

## 4.2 Strength Design Model

### *Strength Design Criterion*

The strength design criterion for a web penetration in a bare steel or composite simply-supported beam is represented as the following cubic moment-shear interaction equation,

$$\left|\frac{M^*}{\phi\overline{M}_b}\right|^3 + \left(\frac{V^*}{\phi\overline{V}_u}\right)^3 \leq 1.0 \qquad (4.1)$$

where, $M^*$ and $V^*$ are the design bending moment and shear force, respectively, at the mid-length of the penetration; $\phi\overline{M}_b$ is the design moment capacity of the beam cross-section at *HME* of the penetration; and $\phi\overline{V}_u$ is the design shear capacity for the segment of beam over the length of the penetration.

A value of 0.9 has been chosen for the capacity factor, $\phi$, in Eq. 4.1 based on the findings of a reliability analysis on the experimental results [11]. This value is the same as that used for bending and shear strength, in AS 4100 for bare steel beams and in AS 2327.1 for composite beams.

The curve described by Eq. 4.1 is shown graphically in Fig. 4.1, and the design combinations of $\left(M^*, V^*\right)$ falling within the shaded area represent satisfactory designs which satisfy the criterion.

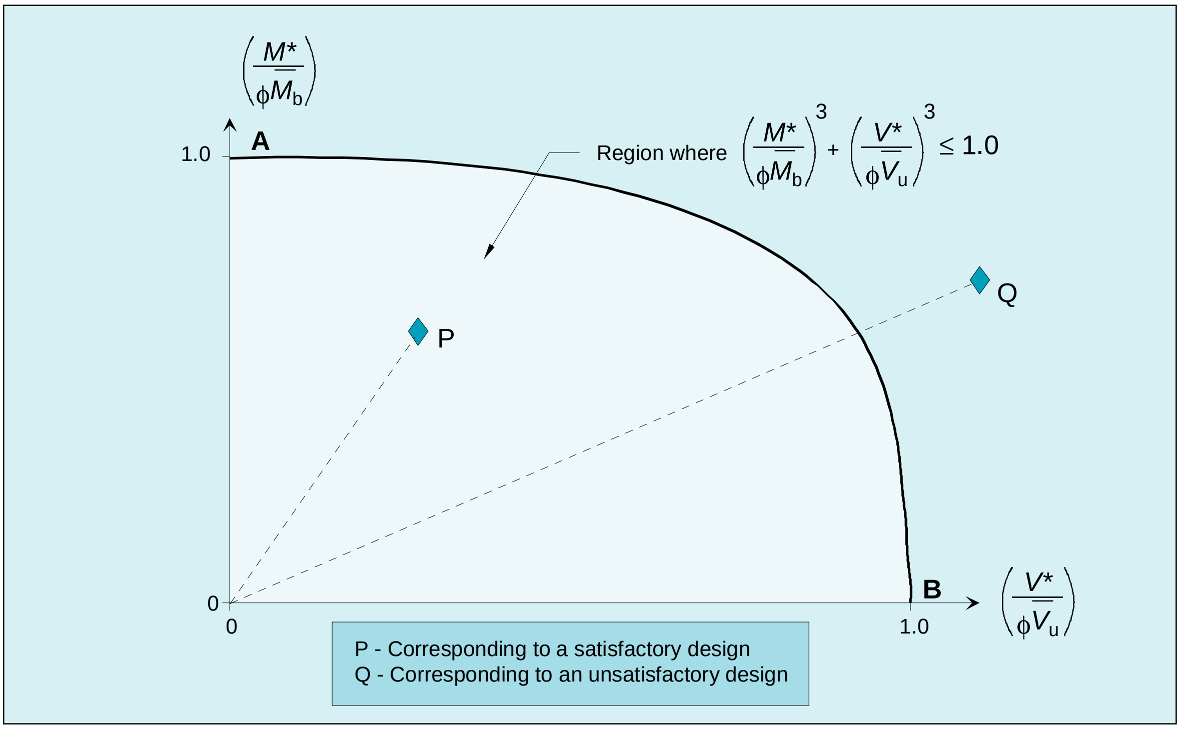


**Figure 4.1 Moment-Shear Interaction Model**

When the design bending moment, $M^*$, and design shear force, $V^*$, at the mid-length of the penetration have been calculated, the next step of the strength design calculation is to determine the values of $\phi\overline{M}_b$ and $\phi\overline{V}_u$ at the penetration.

### *Design Moment Capacity*

The design moment capacity, $\phi\overline{M}_b$, at a penetration is calculated at the *HME* in accordance with AS 2327.1 using rectangular stress block theory. In this calculation, the shear force at the cross-section is assumed to be zero. The degree of shear connection, $\overline{\beta}$, at the cross-section is calculated using Clause 6.6 of AS 2327.1 and accounting for the reduced steel section due to the penetration.

### *Design Shear Capacity*

The design shear capacity, $\phi\overline{V}_u$, at a web penetration is calculated as the sum of the contributions from the top and bottom steel webs and the concrete flange. In this calculation, the effect of overall bending at the cross-section is ignored, while the flexural stresses in the top and bottom T-sections caused by Vierendeel action due to shear are determined.

The following assumptions are made in the calculation:

(a) the net axial force in the top and bottom T-sections is zero;

(b) a simplified version of the von Mises yield criterion is used to account for the interaction between shear and bending stresses;

(c) the plastic neutral axes of the top and bottom T-sections due to Vierendeel action lie in their respective steel flanges; and

(d) a width of $3D_c$ of the concrete flange contributes to the shear capacity of the top T-section, if the shear capacity of the steel web of the top T-section is fully utilised.

These assumptions greatly simplify the design model while not significantly affecting the accuracy of the calculation.

### *Limits of Applicability of the Strength Design Model*

The strength design model is primarily formulated for rectangular web penetrations in a simply-supported bare steel or composite beam. Circular web penetrations are designed by converting the circular penetration into an equivalent rectangular penetration. Web penetration size, shape and location limits are given in Section 6.2.

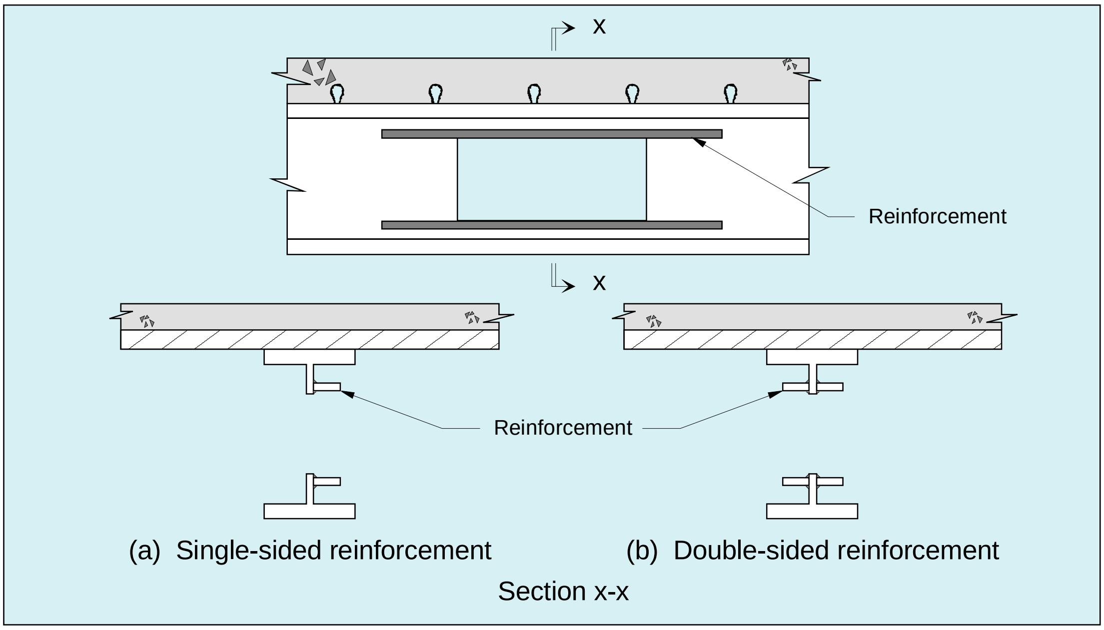


**Figure 4.2 Web Penetration Reinforcement Arrangements**

Web penetrations may be either unreinforced or reinforced, and possibly eccentric to the centroid of the steel beam section. It is assumed that any web penetration reinforcement is continuously welded as close as practicable to the top and bottom horizontal edges of the penetration. In addition, the reinforcement shall be rectangular in cross-section and shall not exceed the dimensions specified in Section 6.7. Acceptable reinforcement arrangements are shown in Fig. 4.2 for a rectangular penetration.

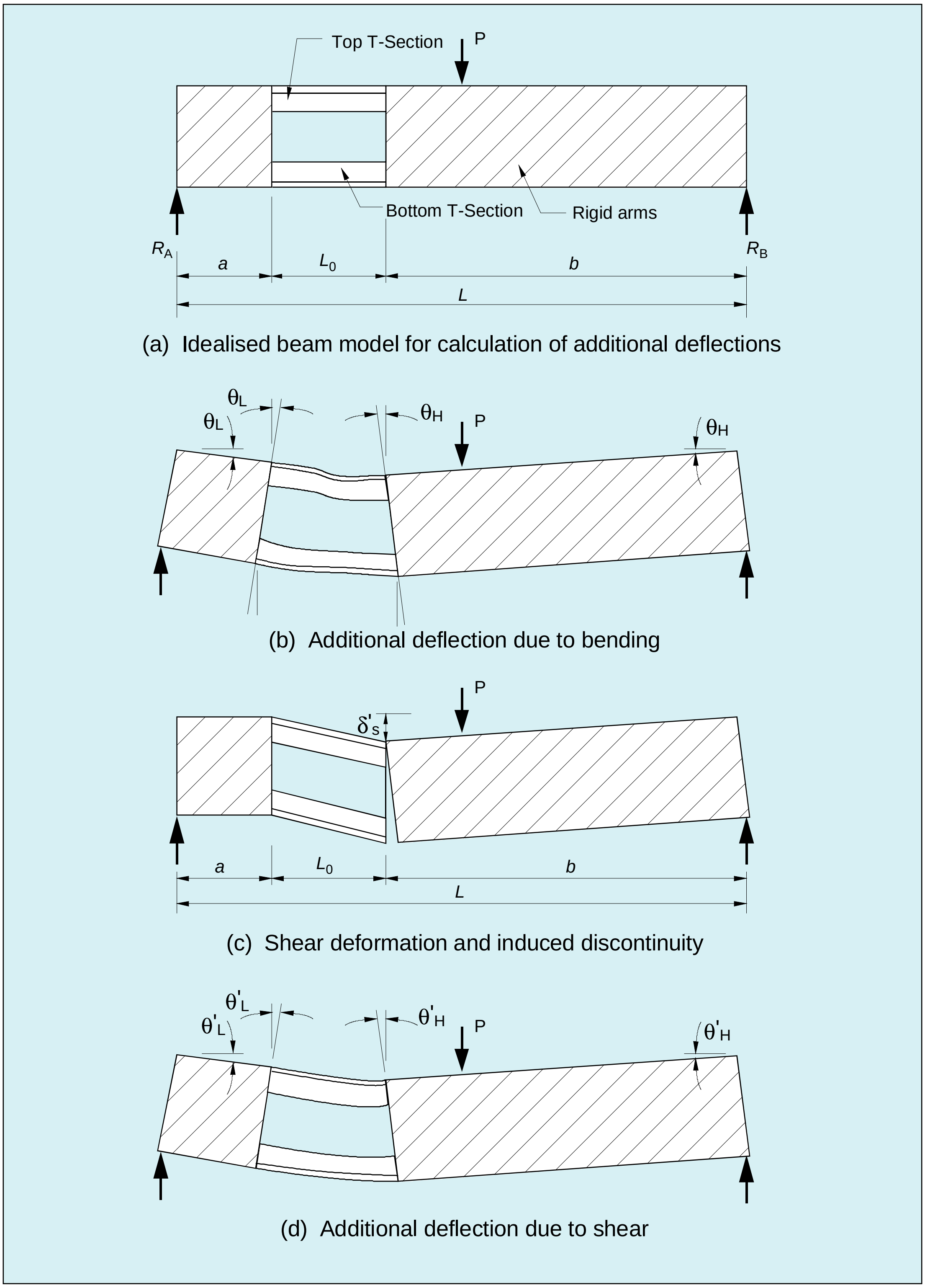


**Figure 4.3 Deflections of the Beam**

The steel section shall be compact or non-compact in accordance with the requirements of AS 2327.1. Slenderness limitations have been imposed in the region of the web penetration to avoid buckling of the webs of the T-sections and overall buckling of the top T-section in compression. These limitations are given in Section 6.6. As the resistance of bare steel and composite beams to lateral and flexural-torsional buckling may be lowered with the introduction of a web penetration, the effect of reduced lateral and flexural-torsional buckling loads also needs to be considered in design.

The strength design method is not applicable to beams subjected to significant load fluctuations, which may lead to fatigue.

## 4.3 Deflection Design Model

### *Deflection Component Without a Web Penetration*

The deflection of the beam without a penetration is determined by the simplified method specified in Appendix B of AS 2327.1. This method is based on elastic bending theory, and uses the effective second moments of area of the beam, which accounts for partial shear connection.

### *Additional Deflection Components due to Web Penetration*

The additional deflection components due to bending and shear deformations at the web penetration are determined using a model where only the top and bottom T-sections at the penetration are assumed to undergo deformation. The remaining parts of the beam on both sides of the penetration are assumed to be rigid (see Fig. 4.3(c)). These rigid arms, which are connected to each end of the penetration, rotate in order to maintain compatibility with the local deformations at the penetration, as shown in Fig. 4.3.

# Design of Simply-Supported Composite Beams with Large Web Penetrations

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# Foreword

OneSteel is a leading manufacturer of steel long products in Australia after its spin-off from BHP Pty Ltd on the 1st November 2000. It manufactures a wide range of steel products, including structural, rail, rod, bar, wire, pipe and tube products and markets welded beams.

OneSteel is committed to providing to design engineers, technical information and design tools to assist with the use, design and specification of its products. This design booklet “Design of Simply-Supported Beams with Large Web Penetrations” was the third design booklet of the Composite Structures Design Manual, which is now being completed and maintained by OneSteel.

The initial development work required to produce the design booklets was carried out at BHP Melbourne Research Laboratories before its closure in May 1998. OneSteel Market Mills is funding the University of Western Sydney’s Centre for Construction Technology and Research in continuing the research and development work to publish this and future booklets.

**The Composite Structures Design Manual refers specifically to the range of long products that are manufactured by OneSteel and plate products that continue to be manufactured by BHP. It is strongly recommended that OneSteel sections and reinforcement and BHP plate products are specified for construction when any of the design models in the design booklets are used, as the models and design formulae including product tolerances, mechanical properties and chemical composition have been validated by detailed structural testing using only OneSteel and BHP products.**

**To ensure that the Designer’s intent is met, it is recommended that a note to this effect be included in the design documentation.**

# Contents

# Preface

*This design booklet forms part of a suite of booklets covering the design of simply-supported and continuous composite beams, composite slabs, composite columns, steel and composite connections and related topics. The booklets are part of the OneSteel Market Mills' Composite Structures Design Manual which has been produced to foster composite steel-frame building construction in Australia to ensure cost-competitive building solutions for specifiers, builders and developers.*

The additional design information necessary to allow large web penetrations to be incorporated into simply-supported bare steel and composite beams is presented in this booklet. Design issues with respect to strength and deflection control are addressed. The non-composite bare steel state arises during construction prior to the concrete hardening.

Large rectangular and circular penetrations are often made in the steel web of composite beams for the passage of horizontal building services. This allows the plenum height to be reduced when using economical, standard UB and WB steel sections. However, large penetrations weaken a composite beam locally and reduce its overall flexural stiffness, and therefore their effect must be considered in design.

Neither the Steel Structures Standard AS 4100 nor the Composite Beam Standard AS 2327.1 contains design provisions for large web penetrations. The rules provided in the booklet for designing bare steel beams with large penetrations are compatible with AS 4100. For the composite state, the rules are compatible with AS 2327.1, and have been proposed as an acceptable method of design to be referred to in Amendment No. 1 of this Standard expected to be published this year.

Information is also given to assist design engineers to understand the engineering principles on which the design methods are based. This includes:

(a) explanatory information on important concepts and models;

(b) the limits of application of the methods; and

(c) worked examples.

Design capacity tables are given in Appendix C to simplify the strength design process. The information provided can be used to design for either the bare steel or composite states. The tables cover a range of situations involving 300PLUS® UB and WB steel sections supporting a composite slab and incorporating large web penetrations. A spreadsheet program named WEBPEN™ is available to assist with the strength design calculations.

Although these design aids are intended to make the design process more efficient, it is essential that the user obtain a clear understanding of the basis of the design rules and the design approach by working through this document and the relevant parts of associated design Standards such as AS 4100 and AS 2327.1.