STRUCTURAL FIREMAN PROFESSIONAL SERIES

# STRUCTURAL ENGINEERING FUNDAMENTALS & HKIE MCQ MASTERY

FOR GRADUATE ENGINEERS

AND HKIE STRUCTURAL EXAMINATION CANDIDATES

## VOLUME 1

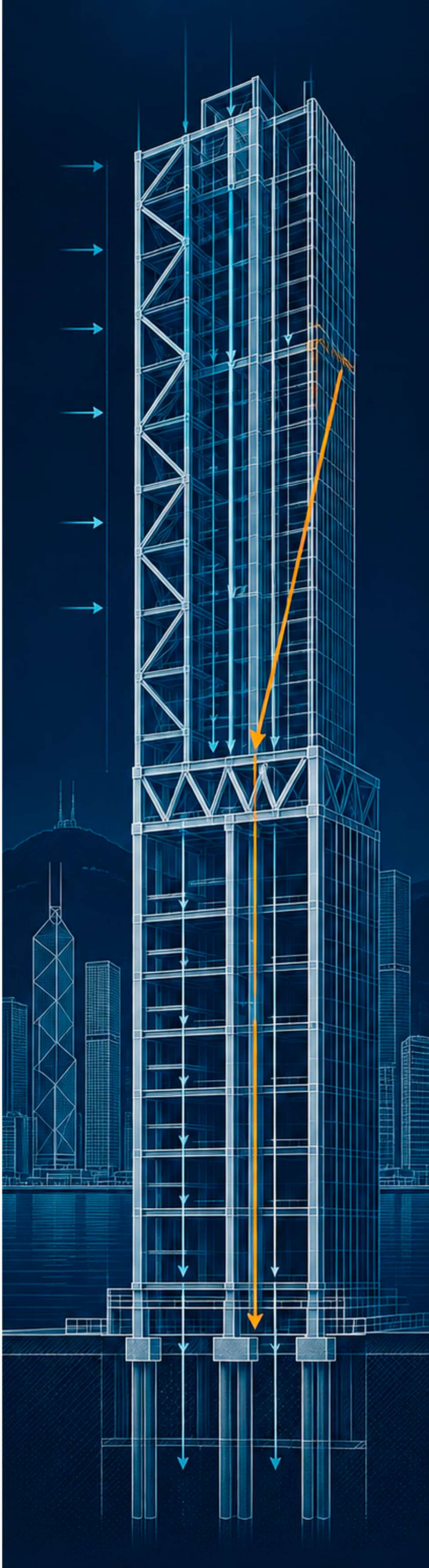
### STRUCTURAL BEHAVIOUR AND ENGINEERING JUDGEMENT

CONCEPTS • LOAD PATHS • STABILITY

FAILURE MODES • PRACTICAL JUDGEMENT

**BY STRUCTURAL FIREMAN**

INDEPENDENT EXAM PREPARATION GUIDE



# Inside This Sample

Four short selections show how the book connects structural behaviour with engineering judgement. Printed page numbers refer to the full volume.



The complete volume also includes chapter reviews, mock papers and appendices.

# Introduction

HKIE Structural Examination 的筆試分為兩節：Section 1 為一小時的 Multiple Choice Questions，Section 2 為 Design Questions。考生須分別通過兩節，才算通過筆試。本書集中處理 Section 1，其考核範圍包括 Structural Engineering Concept、Construction Skills、Building Control、Contract and Construction Management，以及經濟、健康、安全和法定規定等課題。HKIE 列出的是主要範疇，並沒有逐項列明所有可能出現的知識點；考生需要在掌握基本概念之餘，懂得自行查閱相關的 Code、PNAP 及法例。

這些課題看似分散，實際上都與結構工程師的日常判斷有關。設計時要理解 load path，以及 support 和 member 的實際行為；施工時要考慮 temporary condition、construction sequence 和現場條件；處理圖則、法定要求或合約事項時，則要分清各方的責任及決策依據。Section 1 的題目通常篇幅不長，但一個被忽略的條件，已足以改變答案。

Section 1 容許使用參考書、筆記及指定電子設備，但 open-book 考試並不代表考生有時間從頭翻閱每份文件。本書也不可能涵蓋所有 Code 細節；例如 reinforcement lap length 或 structural glass design，考生須知道應查閱哪份文件，並理解找到的條文在甚麼條件下適用。準備考試時，宜預先整理可搜尋的 Codes of Practice、PNAP 及相關法例，核對文件版本，建立清楚的檔名和索引，並練習以關鍵字找出所需資料。考試當日可使用甚麼設備及資料，仍須以當屆 HKIE 指引為準；不要預設試場提供網絡連線。

本書分為兩冊。Volume 1 集中討論 structural behaviour 和 engineering judgement；Volume 2 涵蓋 construction、building control、site practice 及 professional practice。各章的 MCQ 不應只用來記住答案字母。讀者更應留意答案成立所依賴的條件，並思考其他選項為何不成立。當 load、support 或結構系統改變，即使題目表面相似，所需的判斷也可能不同。

Volume 1 由 supports、equilibrium 和 load path 入手，逐步討論 truss behaviour、shear force、bending moment、deflected shape 及 frame behaviour。其後各章涵蓋 actions and load combinations、reinforced concrete、steel and composite structures、ground and foundations，以及 robustness、dynamics、wind 和 fire。這些課題並非各自獨立：同一個設計決定，可能同時影響 load path、member forces、deflection 和整體穩定性。本冊最後以 hand calculations、FEA 判讀及 mock examination，讓讀者練習把不同概念結合起來。

答題時，宜先看清楚結構系統、support condition、load 和題目採用的假設，再判斷應使用哪項原則或簡單計算。不要一見數值便急於代入公式，也不要只因某個選項的數字看似合理便選擇它。各 section 內的 Example MCQ 適合即學即答；每章末的 Chapter Review MCQ 則適合在完成該章後集中作答，練習在有限時間內辨認關鍵條件，作出有根據的 engineering judgement。

# Table of Contents

## 2.7 Load Transfer at Discontinuities

### 2.7.1 Meaning of a Discontinuity

Discontinuity 是 geometry、support、stiffness 或 member arrangement 出現明顯改變的位置。它不一定代表 structure 有缺陷，但原本直接的 force flow 可能需要轉向、集中或重新分配。

香港 building 常見例子包括上蓋 column grid 與 podium grid 不一致、core wall 在某層收窄、slab 有 large opening，以及 beam depth 突然改變。做題時，先在這些位置停下來，抽出局部 free body，再追查 force 如何跨過 interface。若一條 upper column 在某層終止，該 column 的 axial force 不會因為圖則上沒有下一段 column 而消失。它必須由 transfer member 承接，再傳到其他 supports。

### 2.7.2 Geometrical Discontinuities and Disturbed Regions

在集中 load、support reaction、opening corner 及 section 突變附近，stress distribution 可以與一般 slender beam region 不同。不能把「plane sections remain plane」及簡單 linear strain distribution 無條件套用到整個 local region。

對 RC members，可用 strut-and-tie concept 理解某些 disturbed regions：compression struts 把 force 傳往 supports；tension ties 令 system 維持 equilibrium；nodes 是 forces 交匯的位置。這裏先掌握力學概念，不展開完整 strut-and-tie design。一個畫得出來的 truss 形狀，仍須對應實際可提供的 concrete compression paths、reinforcement 及 anchorage。不能將 tension tie 畫在沒有 reinforcement continuity 的位置。

### 2.7.3 Additional Moment from Eccentricity

若一個 force 的 line of action 相對於參考位置偏移 e，其等效作用包含同一個 force 及 moment：

$$M = Pe$$

但這個 moment 屬於 bending 還是 torsion，要看 force、offset 及 member longitudinal axis 的相對方向。

例如 vertical load 相對於 beam longitudinal axis 有橫向偏移，便可能對 beam 產生 torsion。若 load 只是在 beam length 方向改變施加位置，則通常首先改變 support reactions 及 bending distribution，不能一律稱為 torsion。

### 2.7.4 Force flow around openings

一塊 diaphragm 若在主要 force flow 途中開洞，forces 需要經 opening 兩旁的剩餘 slab 及相關 members 繞過。Opening 附近可能出現較集中的 shear、chord force 及 collector force。判斷 opening 影響時，要看位置及 load path。兩個 area 相同的 openings，若一個靠近重要 collector，另一個遠離主要 force transfer region，影響未必相同。面積比例不能取代 force path 檢查。

### 2.7.5 Interface and Connection Continuity

在 construction joint、precast connection、steel splice 或不同 materials 交界，應逐項檢查需要傳遞的 axial force、shear 及 moment。例如 bearing detail 可以傳 compression，但未必能傳 tension；ideal pin 可傳相應 forces，但不提供 moment restraint；movement joint 若刻意容許某方向 relative movement，便不能同時無條件假設該方向有完整 force continuity。閱讀 detail 時，應問「這個 interface 能夠傳甚麼」，而不是只問「兩個 members 是否接觸」。

***Worked Example 2.7 Eccentric vertical force***

一個 vertical force P = 400 kN，與指定 support reference line 相距 0.25 m。將 force 移到該 reference line 作等效 free body：

$$\text{Eccentricity Moment} = 400 \times 0.25 = 100 \text{ kNm}$$

Equilibrium system 包括 400 kN vertical force 及 100 kNm moment，不能只保留其中一項。這個計算未決定 moment 由哪個 member 分擔；仍須查看 connections 及整體 stiffness。

***Example MCQ 2.7***

**A vertical force of 400 kN has a line of action at a horizontal distance of 0.25 m from a reference point. Which equivalent force system at that point preserves the external force and moment?**

A. A vertical force of 100 kN only.
B. A moment of 100 kNm only.
C. A vertical force of 400 kN with no moment.
D. A vertical force of 400 kN and a moment of 100 kNm in the appropriate sense.
E. A vertical force of 1,600 kN and a moment of 100 kNm.

**Answer: D**

Explanation: Moving a force to a different point requires the original force plus the moment of that force about the new point. Here, M = Pe = 100 kNm. A force alone or a couple alone is not equivalent to the original loading.

## 2.8 Transfer Beams, Transfer Plates and Transfer Structures

### 2.8.1 Role of a Transfer Structure

Transfer structure 把上方 members 的 loads，轉移到位置或 arrangement 不同的下方 supports。香港常見的情況是住宅上蓋採用較密的 column 或 wall layout，而 podium、商場或 car park 需要較大的 clear space。

Transfer level 並不是 load path 的終點。完整路徑應追查至 lower columns 或 walls，再到 foundation 及 ground。

選擇 transfer system 時，要同時考慮 force level、span、available depth、deflection、construction sequence 及 foundation reactions。Member 有足夠 flexural strength 只是其中一項要求。

### 2.8.2 Transfer beam

Transfer beam 可承接一條或多條 upper columns，以及適用的 wall 或 floor loads。Upper column reaction 在 beam model 中通常表現為 concentrated load，而非一般 uniform floor load。

其 behaviour 視乎 geometry 及 support conditions，可以接近 slender beam，也可以有明顯 deep-beam action。不能因為名稱有「transfer」，便斷定所有 transfer beams 都必須用同一種 analysis model。

常見需要檢查的項目包括 flexure、shear、local bearing、anchorage、torsion，以及 short-term 和 long-term deflection。集中 load 附近的 local force transfer 亦不能只靠整條 beam 的 maximum moment 判斷。

### 2.8.3 Transfer plate

Transfer plate 或 transfer slab 透過 plate action，把 upper columns 或 walls 的 loads 分配至 lower supports。由於 upper 及 lower support grids 可能不同，load distribution 往往是 two-dimensional，不能任意切成互不相連的 beam strips。

除了 global bending 及 shear，亦須留意 upper loaded areas、lower supporting columns 附近的 local effects，以及適用的 punching shear mechanisms。厚度較大不代表可略過 local checks。

FEA 內的 sharp point load 或 ideal point support 可能產生高度集中的 results。Interpretation 需要對照 actual loaded area、support dimensions、mesh behaviour 及適用 design method；不能直接把單一 peak colour 當作完整 engineering conclusion。

### 2.8.4 Transfer Trusses and Other Arrangements

Transfer truss 可透過 chords 及 web members 的 axial action，把 upper loads 傳到較遠的 supports。理想 pin-jointed model 通常假設 loads 施加在 nodes；若 load 落在 node 之間，相關 chord 可能另有 bending。

Transfer frame 則可能依靠 beam-column joint moment transfer。若把關鍵 joints 全部 release 成 pins，便可能失去原先假定的 transfer mechanism。

| System | 主要分析概念 | 需要特別留意 |
|---|---|---|
| Transfer beam | Beam action 或適用的 deep-beam action | Concentrated load、shear、deflection、local regions |
| Transfer plate | Two-dimensional plate action | Support layout、punching、local force transfer |
| Transfer truss | 以 axial action 為主 | Node loading、member stability、connections |
| Transfer frame | Frame action | Joint stiffness、bending 及 stability |

### 2.8.5 Deflection and Superstructure Interaction

Transfer member deflect 時，所支承的 upper column bases 亦會移動。這些 movements 可影響上方 continuous beams、slabs 及 walls 的 force distribution。

因此，「transfer member 的 deflection 符合某個單一 ratio」未必已經說明所有上蓋 elements 都可接受。要知道 deflection 發生在哪個施工階段，以及相連 members 當時是否已存在並發展 stiffness。

對 RC transfer structures，cracking、creep 及 shrinkage 可以影響 effective stiffness 及 long-term behaviour。本章集中概念；任何數值 limit 及 Code 要求應在採用相應 source 後另行核實。

### 2.8.6 Propping and Construction Sequence

若 transfer level 在 propped condition 下澆築，上方 loads 可能暫時透過 props 傳往下層。拆除 props 後，load 才按當時的 stiffness 及 sequence 重新分配。

檢查時要向下追查 prop reactions 由哪些 floors 及 foundations 承受。不能只確認 transfer slab 本身的 strength，而忽略下方樓層的 construction-stage loading。

相關實務延伸閱讀可參考 IStructE 的 transfer slabs 專題資料；本節的例題採用明確的簡化 support conditions，不把實際 transfer system 預設為 simply supported。

### *Worked Example 2.8 Off-centre column on a transfer beam*

一條 simply supported transfer beam AB 長 10 m。Upper column 向下傳 600 kN，load 位於 A 右方 4 m。忽略 beam self-weight 及其他 loads，A 和 B 不下沉。

Taking moments about A：

$R_B \times 10 = 600 \times 4$

$R_B = 240$ kN　　$R_A = 600 - 240 = 360$ kN

Maximum sagging moment 在 point load 位置：

$M_{max} = 360 \times 4 = 1{,}440$ kNm

Load 兩旁的 shear 由+360 kN 跳至−240 kN；在這個例子，shear 沒有一段等於零，maximum moment 仍出現在 point load 處。這亦提醒我們：「maximum moment 在 zero shear」需按 continuous region 或 shear sign change 正確理解。

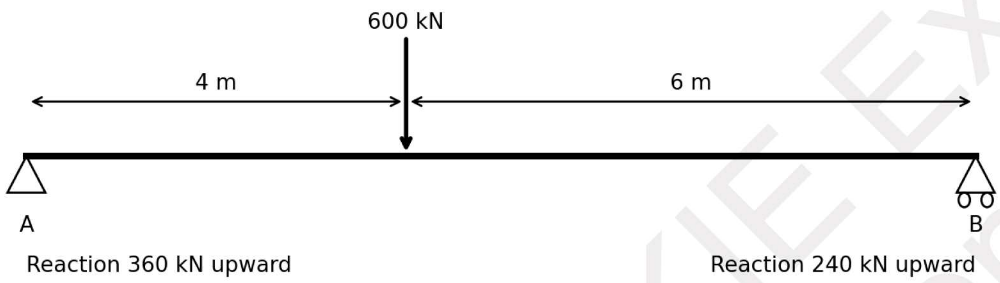



Figure 2.1 Transfer beam free body

### *Example MCQ 2.8*

**A simply supported transfer beam AB is 10 m long. A column applies a vertical load of 600 kN at a point 4 m from A. Ignoring all other loads, what are the reactions at A and B respectively?**

A. 360 kN and 240 kN.
B. 300 kN and 300 kN.
C. 240 kN and 360 kN.
D. 600 kN and 0 kN.
E. 0 kN and 600 kN.

**Answer: A**

Explanation: Moment equilibrium about A gives $R_B = 600 \times 4/10 = 240$ kN. Vertical equilibrium gives $R_A = 360$ kN. The load is closer to A, so A carries the larger reaction in this simply supported model.

## 4.13 Maximum Moment and Zero Shear

### 4.13.1 Understand What Maximum Means First

Maximum sagging moment 是最大 positive M；maximum hogging magnitude 是最負 M 的 absolute value；maximum absolute moment 則比較全段所有 |M|。單寫 maximum moment 有時會含糊，解題時應先看題目是否指定 sign 或 magnitude。

例如 cantilever 的 M 由 fixed end 的 −56 kNm 增加至 free end 的零，algebraic maximum M 是零，但 maximum absolute moment 是 56 kNm，位置在 fixed end。

### 4.13.2 A Smooth Stationary Point Is Only a Candidate

在可微分的 interior region，$dM/dx = V$，所以 $V = 0$ 是 stationary moment condition。下一步要看 V 在該處左右的 sign：positive 至 negative 對應 local maximum；negative 至 positive 對應 local minimum。

$V = 0$ 不保證 extremum。例如 local coordinate ξ 以 metres 表示，$V = 3\xi^2$ kN、$M = \xi^3$ kNm。在 $\xi = 0$，$V = 0$，但 V 兩側均為 positive，M 持續增加，沒有 local maximum 或 minimum。此數學例子對應 $w = -6\xi$ kN/m 的 signed distributed load，並非 full-span downward UDL。

### 4.13.3 Do Not Omit Jump Positions and Boundaries

有 point force 的位置，V 可以直接由 positive jump 至 negative，使 M 在該處出現 cusp maximum。此時不能要求左右 shear 都等於零。

遇到 applied couple，M 的左右 limiting values 都要列入比較。Fixed ends、free ends、beam ends 及其他 relevant boundaries 也要檢查。求 global maximum |M|，只解 smooth regions 的 $V = 0$ 會漏掉不少答案。

### 4.13.4 Zero-shear Interval and Plateau

若某一整段 $V = 0$，且其中沒有 applied couples，則 M 在該段為 constant。這可以是非零 pure-bending region；最大 moment 也可能由整段共同達到，不一定只有一個 location。

例如 simply supported beam 承受兩個對稱 point loads，兩個 loads 之間沒有 distributed load，在適當 reactions 下該區 $V = 0$、M 為 constant。不要為了找「唯一答案位置」而把 plateau 強行標成 midspan point。

*Example MCQ 4.13A*

**A beam has candidate moments of 0, +18, −30 and +12 kNm at all relevant boundaries, stationary points and discontinuities. What is the maximum absolute bending moment?**
A. +18 kNm.
B. −30 kNm as a magnitude.
C. 12 kNm.
D. 60 kNm.
E. 30 kNm, occurring where the signed moment is −30 kNm.

**Answer: E**
Explanation: Compare the absolute values 0, 18, 30 and 12. The governing magnitude is 30 kNm. A magnitude is nonnegative, while the associated signed moment identifies hogging.

*Example MCQ 4.13B*

**In a smooth beam region, $V = 3\xi^2$ kN and $M = \xi^3$ kNm, where ξ is a local coordinate in metres. What occurs at $\xi = 0$?**
A. M has zero slope but no local maximum or minimum.
B. M has a local maximum because $V = 0$.
C. M has a local minimum because $V = 0$.
D. M has a jump.
E. An internal hinge must be present.

**Answer: A**
Explanation: V is positive on both sides of $\xi = 0$, so M increases through the point. A zero first derivative alone does not establish an extremum; the surrounding behaviour must also be checked.

## 4.14 SFD and BMD Shape Recognition

### 4.14.1 Identify Segment by Segment, Not by Guessing the Whole Diagram

先找 point actions、support reactions 及 distributed-load boundaries，把 beam 分段。每個 open interval 再用 slope relationship 判斷 diagram shape。Whole beam 的 BMD 可以同時含 straight lines、parabolic curves 及 jumps，不需要只有一個「圖形名稱」。

| Loading in an open interval | SFD | BMD |
|---|---|---|
| w = 0 | Horizontal | Straight, or horizontal if V = 0 |
| Nonzero constant w | Straight with nonzero slope | Quadratic |
| Linearly varying w with nonzero gradient | Quadratic | Cubic |

Polynomial degree 只描述該區段的 analytical form，不決定 diagram 在 zero line 上方或下方。Integration constants 由整體 equilibrium 及 boundary conditions 決定。

### 4.14.2 Signature of a Point Action

Downward point force 令 SFD downward jump，而 BMD 保持 continuous 但 slope 改變；pure couple 令 BMD jump，而 SFD 不因該 couple 本身 jump。若同一位置同時有 point force 及 couple，兩個 diagrams 可以同時 jump。

Finite UDL intensity 的開始或終止只改變 SFD slope，不會造成 finite shear jump。Support reaction 是 force，所以其 SFD signature 與其他 concentrated force 相同；只看 jump 本身，不能判定它一定是 support。

***Worked Example 4.14 Reading a patch load***

考慮 8 m simply supported beam，只在 x = 2 至 6 m 承受 10 kN/m downward UDL。兩端 reactions 各為 20 kN。與 4.4 的 numerical example 相同，這裡集中讀 diagram shapes。

$0 < x < 2$：沒有 distributed load，$V = +20$ kN，BMD straight 且增加。

$2 < x < 6$：$V = 20 - 10(x - 2)$，SFD linear decreasing；BMD quadratic，於 x = 4 m 達到 +60 kNm。

$6 < x < 8$：$V = -20$ kN，BMD straight 且減少至零。

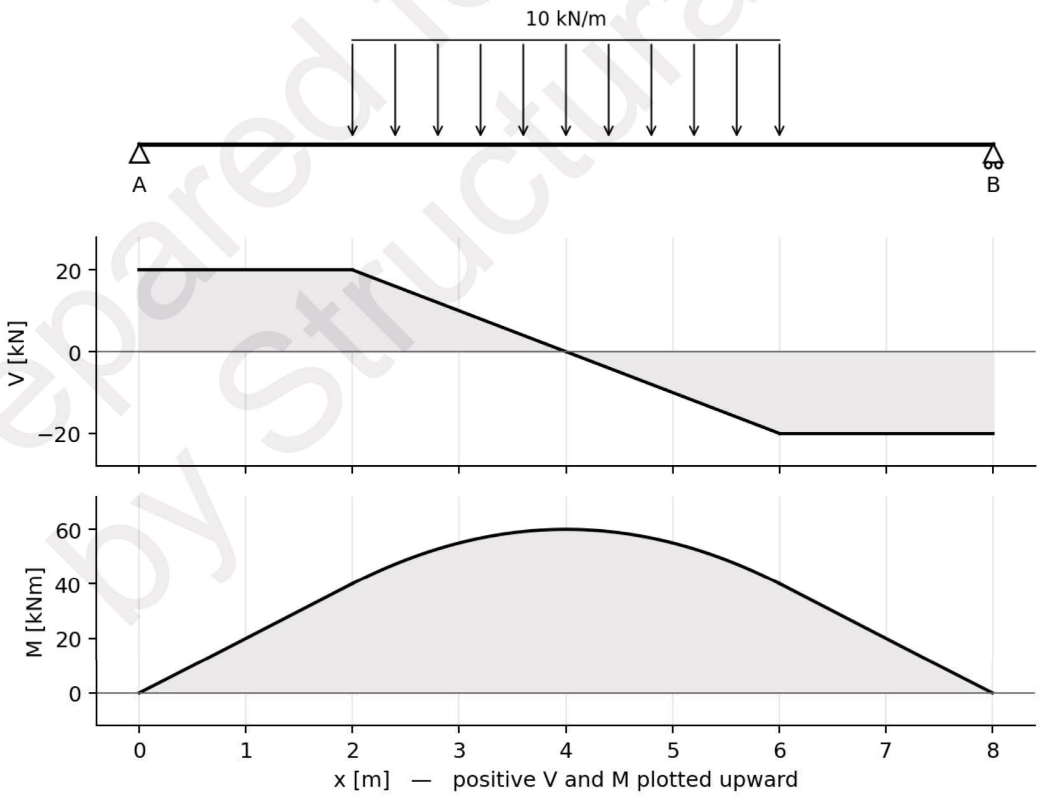



*Figure 4.12 Patch UDL and continuous diagram transitions*

x = 2 及 x = 6 m 沒有 point force 或 couple，所以 V、M 及 BMD slope 均 continuous。SFD 在這些位置有 corner；BMD 則是 tangent 連續的 straight-to-parabolic transition，不是 sharp kink。

### 4.14.3 Cross-checking the Three Diagrams

第一個檢查是 units：load intensity 的 area 得到 force；SFD 的 area 得到 moment。第二個是 direction：downward w 對應 SFD 向右下降；positive V 對應 M 向右增加。第三個是 endpoints 及 jumps 是否與 support / load model 相符。

例如一段沒有 distributed load，但 SFD 斜着下降，便與 $dV/dx = -w$ 不符。又如沒有 applied couple，BMD 卻突然跳開，便需要重新檢查 model 或圖形。

BMD 的 polynomial shape 並不能直接指出 support type。相同的局部 straight segment 可以出現在 simply supported、cantilever 或 continuous beam；必須配合 boundary conditions 及完整 loading。

*Example MCQ 4.14A*

**A nonzero UDL stops at x = a. No point force or concentrated couple acts there. Which description is correct?**
A. Both V and M jump.
B. V jumps but M remains continuous.
C. V and M remain continuous; the SFD slope changes, while the BMD slope remains continuous.
D. M jumps while V remains continuous.
E. Both V and M must become zero at x = a.

**Answer: C**
Explanation: A finite change in w changes dV/dx, not V itself. With no force jump, V is continuous; therefore dM/dx is also continuous. A finite load-intensity transition does not create a moment jump.

*Example MCQ 4.14B*

**In a smooth open interval, the SFD is a non-horizontal straight line. Which loading and BMD combination is consistent with the beam relationships?**
A. Zero distributed load and a linear BMD.
B. A nonzero constant distributed load and a quadratic BMD.
C. A point load at every section and a constant BMD.
D. A nonzero linearly varying distributed load and a linear BMD.
E. A pure concentrated couple and a cubic BMD throughout the interval.

**Answer: B**
Explanation: A constant nonzero slope of V gives a constant nonzero $w = -dV/dx$. Integrating the linear shear gives a quadratic moment function in that interval.

## 7.8 Punching Shear

### 7.8.1 Two-way Shear Transfer near Concentrated Supports

Flat slab 把 distributed floor loads 傳到 column 時，column 附近的 slab 必須把 load 集中傳入較小的支承面積。Punching shear 可沿 column 周圍形成傾斜破壞面，其機制與沿一條 beam section 檢查 one-way shear 不同。Flexural reinforcement 有足夠 moment resistance，不會自動保證 slab–column connection 能傳遞全部 reaction。

對指定 control perimeter，先畫出內部區域 free body。若 column reaction 向上而該區域的 floor load 向下，crossing perimeter 的 net vertical shear 為兩者之差。Reaction 與扣除的 load 必須來自同一 load case 及同一 factor basis；不可把全部 tributary floor load 再扣一次，亦不可用沒有定義的 perimeter 套入公式。

### 7.8.2 Average Stress Is Not the Maximum Stress Everywhere

在題目指定的均勻分布模型內，可用 v = V/(ud)計算平均 shear stress，u 為有效 perimeter、d 為 effective depth。若存在 unbalanced moment、edge 或 corner column、鄰近 opening，perimeter 及 stress distribution 均可能改變。Punching design 的相關規定見；本節不自行指定通用 perimeter offset。

增加 slab depth、採 drop panel 或 column head、配置適當 anchored punching reinforcement，可能改善抗力，但各自仍需檢查完整 load path 及適用限制。不能假定只在 column 旁加 top flexural bars 便能解決所有 punching 問題。

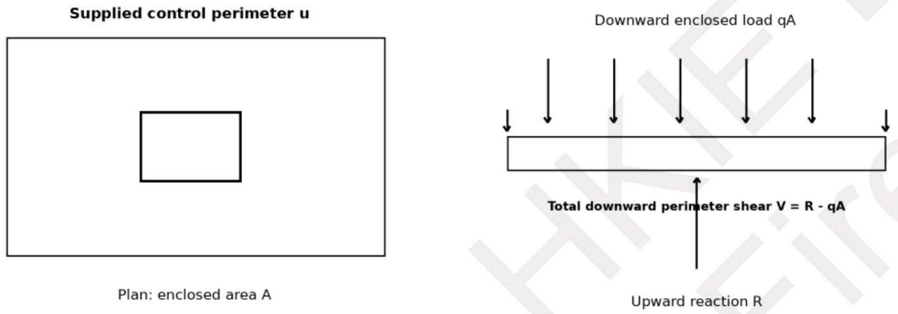



*Figure 7.8  Free body inside a supplied control perimeter. Net shear equals the upward reaction minus the downward load enclosed by that perimeter.*

***Worked Example 7.8***

An interior slab–column connection has an upward design reaction of 900 kN. The specified square control perimeter has u = 8.0 m and encloses 4.0 m² carrying a downward design load of 15 kN/m². Take d = 200 mm. Assume concentric transfer and a uniform shear-stress model. Find the net shear and average stress at this supplied perimeter.

$$V = 900 - 15 \times 4.0 = 840\ \text{kN}$$

$$v = \frac{V}{ud} = \frac{840000}{8000 \times 200} = 0.525\ \text{N/mm}^2$$

The result is a demand, not a resistance check. No punching capacity has been supplied. A design with moment transfer or openings would require the applicable non-uniform stress and effective-perimeter rules.

**Exam Trap**

V/(ud)中的 V 不是必然等於 column reaction；先看 perimeter 內還有哪些 loads。Average stress 也不能在有 moment transfer 時直接當成 maximum stress。

***Example MCQ 7.8***

**A flat slab passes its flexural resistance checks. An opening is then proposed close to an interior column. Which is the best next action?**

A. Accept it because flexural resistance proves punching safety.
B. Increase the column reaction by the opening area alone.
C. Ignore it if no longitudinal bar is cut.
D. Reassess punching transfer, the effective perimeter and local detailing.
E. Treat the column as a free edge without examining the geometry.

**Answer: D**

Explanation: An opening can interrupt the load-transfer region and alter the effective perimeter and local stress distribution. Its actual location and size must be considered; flexural resistance alone does not resolve these effects.

## 7.9 Bond, Anchorage and Development Length

### 7.9.1 Bar Force Must Transfer into Concrete along Its Length

Bond 把 bar force 的變化傳入 surrounding concrete。對 straight circular bar 的簡化均勻 bond model，傳力面積是 bar circumference 乘 embedded length，而不是 bar cross-sectional area。所需 length 取決於要 develop 的 force；在相同 steel stress 及 bond stress 下，bar diameter 越大，所需 anchorage length 越長。

實際 bond 並非沿 length 均勻分布。Rib bearing 可引起周圍 concrete 的 splitting；cover、bar spacing、transverse reinforcement、casting conditions 及 concrete strength 均影響表現。不能只延長一根處於不適當 confinement 中的 bar，便宣稱所有 anchorage 問題已解決。

### 7.9.2 Anchorage and Development Are Force-transfer Issues

Development length 描述建立指定 bar force 所需的傳力長度；anchorage 可涉及 straight embedment、bend、hook 或其他經設計的 mechanism。Hook 不是任意位置皆可使用的免費 capacity，也不代表 compression anchorage 可完全照搬 tension detail。相關 code 規定見。

在 ideal section analysis 中假設 steel 達到某一 stress，前提是 detail 能把該 force 傳遞出去。若 bond splitting 或 pull-out 先發生，單憑 As 及 fy 計算的 flexural resistance 便未必能發揮。

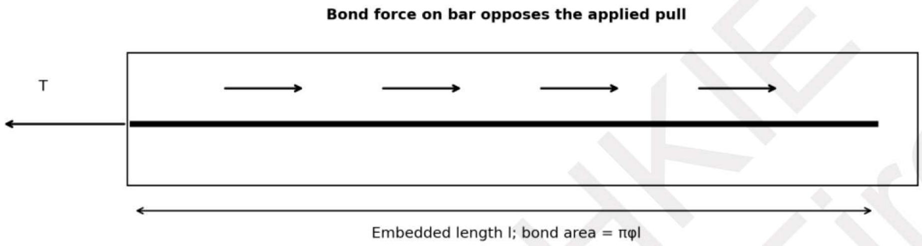



*Figure 7.9 In a uniform-bond idealisation, the embedded bar transfers its end force through its circumference over length l. This is an equilibrium model, not a universal detailing rule.*

#### *Worked Example 7.9*

A straight 20 mm diameter bar must develop a tensile stress of 400 N/mm². Use an assumed uniform transferable bond stress of 2.0 N/mm² over the full circumference. Ignore end bearing and all code detailing factors for this equilibrium exercise. Find the required embedded length.

$$T = \frac{\pi \times 20^2}{4} \times 400 = 125664\ \mathrm{N}$$

$$T = \tau\pi\varphi l$$

$$l = \frac{\varphi\sigma_s}{4\tau} = \frac{20 \times 400}{4 \times 2.0} = 1000\ \mathrm{mm}$$

The assumed model requires 1,000 mm. This is not an approved code anchorage length: cover, confinement, bond conditions, minimum lengths and other applicable detailing requirements remain to be checked.

**Exam Trap**

Bond area 為 πφl，steel area 為 πφ²/4。把兩者混淆會得到錯誤 units 或 bar-size trend。Development length 也不是固定的「所有情況一律若干個 diameters」。

#### *Example MCQ 7.9*

**In the uniform-bond model l = φσ/(4τ), both steel stress and bond stress remain unchanged. What happens when bar diameter increases from 16 mm to 24 mm?**

A. Required length becomes two-thirds of its original value.
B. Required length is unchanged.
C. Required length increases by a factor of 1.5.
D. Required length increases by a factor of 2.25.
E. Required length becomes zero if the bar is ribbed.

**Answer: C**

Explanation: Length is proportional to diameter under the stated assumptions. The ratio is 24/16 = 1.5, because bar force scales with diameter squared while bond force per unit length scales with diameter.

## 7.10 Lap Location and Reinforcement Curtailment

### 7.10.1 A Lap Is Not Two Bars Welded Directly Together

一般 non-welded lap splice 靠第一根 bar 與 concrete 的 bond，再由 concrete 把 force 傳到第二根 bar。Lap region 需要足夠 length、spacing 及 confinement；把兩根 bars 在圖上重疊，並不等於 force 已直接跨過接駁點。大量 bars 在同一 section lapped 亦會增加局部傳力需求及 congestion。

選 lap location 應檢查各 load cases 的 force envelope、moment reversal、ductility 需求及施工可行性。某個 gravity load case 的低 moment 位置，在 wind、pattern loading 或另一 construction stage 可能不是低 demand 位置。Staggering 可以分散 splice demand，但不會免除 lap length 及 transverse detailing checks。

### 7.10.2 Theoretical Redundancy Does Not Permit Immediate Curtailment

Curtailment 先看 required reinforcement envelope，再考慮 force development、shear-related tension 及 code 要求的 extension。Bar 的 force 不會在 theoretical cut-off point 突然無條件變成零；也不能因為某個 section moment 等於零，就假定該處所有 bars 都可停止。

實務須保留所需 continuity、minimum reinforcement 及 support anchorage，並檢查 construction-stage load path。以下例題把額外 extension 直接給定，只示範如何區分 theoretical point 與 physical bar end，不推導 code curtailment rule。

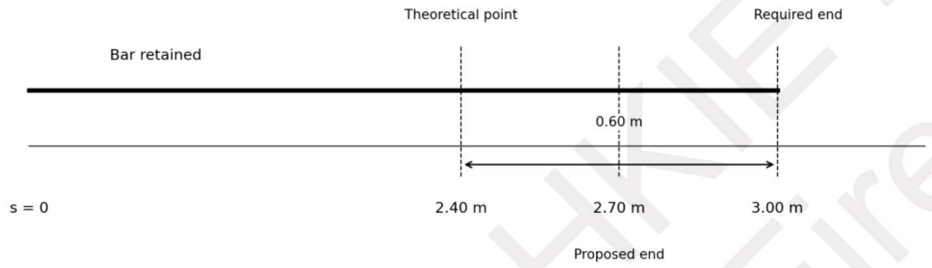



*Figure 7.10 A supplied theoretical cut-off point and the physical bar end are different locations. The shown extension is an explicit example input, not a general code value.*

***Worked Example 7.10***

Along a beam, coordinate s is measured from the left support. A supplied reinforcement-demand envelope permits a particular bar to become unnecessary beyond s = 2.40 m towards the right. The detailing requirement supplied for this example is an additional 0.60 m extension in that direction. A proposed bar end is at s = 2.70 m. Find the earliest permitted end under this supplied rule and the shortfall.

$$s_{end} = 2.40 + 0.60 = 3.00\ \mathrm{m}$$

$$\Delta l = 3.00 - 2.70 = 0.30\ \mathrm{m}$$

The proposed end is 300 mm short of the stated requirement. This exercise does not establish that the supplied 0.60 m satisfies an actual project code check; it only applies the explicitly given rule.

**Exam Trap**

Zero moment、bar force 已充分 developed 及可 cut off，是三個不同判斷。Lap location 亦不能只憑「遠離 support」或「放在 midspan」作通用答案。

***Example MCQ 7.10***

**Which statement best describes a conventional non-welded tension lap splice?**

A. The two bars transfer all force directly through end-to-end steel bearing.
B. Force passes through bond into the surrounding concrete and then into the overlapping bar.
C. Any visible overlap is sufficient, irrespective of length.
D. Staggering eliminates the need for confinement checks.
E. The splice can always be placed at the maximum tensile-force section without further assessment.

**Answer: B**

Explanation: A lap is a bond-mediated transfer region. Its length, spacing, confinement, stress level and location matter; overlap alone does not demonstrate adequate force transfer.

## 11.7 Load Input and Combination Errors

Load input 檢查應由單一 basic load case 開始，包括 units、direction、global/local axes、loaded area 及 self-weight setting。Area load 轉成 line load 時要核對 tributary width；surface normal load 與 global vertical load 對斜面可以不同。不得只看總數而忽略 location 及 eccentricity。

Self-weight 可能由 software 自動生成，再被手動重複加入。Combination 亦可能把同一 action 重複 factor，或把不同物理情況誤當成同時作用。Pattern loading、wind direction 及有利/不利 action 須按指定 design basis 處理，不能只計一個全滿載 case。

Linear superposition 只在相應 linear model 及固定 stiffness、boundary conditions 下成立。Tension-only、contact、plasticity 或 large-displacement response 可能使「先各自分析再相加」與 combined-load analysis 不同。

### *Worked Example 11.7*

A beam receives an area imposed load of 5 kN/m² over a tributary width of 3 m. Its permanent line load is 10 kN/m, including self-weight. For this example only, the supplied combination is 1.2G + 1.5Q. Find the combined line load.

$$Q = 5 \times 3 = 15\,kN/m$$

$$w = 1.2 \times 10 + 1.5 \times 15 = 34.5\,kN/m$$

Do not add self-weight again: it is already included in G. The supplied factors are example data, not a universal code combination.

**Exam Trap：load case 名稱正確不代表 input 正確；先看 units、direction 及 total applied load，再看 combination 結果。**

### *Example MCQ 11.7A*

**An area load of 4 kN/m² acts over a tributary width of 2.5 m. What equivalent uniformly distributed line load acts on the supporting beam?**

A. 10 kN/m
B. 1.6 kN/m
C. 6.5 kN/m
D. 10 kN/m²
E. 0.625 kN/m

**Answer: A**
Explanation: The line load is area load multiplied by tributary width: 4 × 2.5 = 10 kN/m.

### *Example MCQ 11.7B*

**A permanent load case includes automatic self-weight. The engineer also applies the same member self-weight manually in that case. What is the direct input error?**

A. Self-weight has been omitted
B. The member stiffness has been halved
C. The supports have been released
D. The imposed load has been reversed
E. Self-weight has been counted twice

**Answer: E**
Explanation: Both the automatic and manual entries represent the same physical action, so the case contains duplicate self-weight.

## 11.8 Reading FEA Output

閱讀 output 應由 deformed shape 開始，再看 reactions、member forces 及 local stresses。先核對 load case 或 combination、units、axes、sign convention 及 scale factor。放大 deformation 圖用來辨認 behaviour，並不是實際 movement 的直接尺寸圖。

Beam actions、shell resultants 及 solid stresses 是不同 quantities。Shell bending moment 常以 moment per unit width 表示，例如 kN m/m，不能直接當成整條 beam 的 kN m。Top/bottom stress 及 local axis 方向亦須核對 software 定義，尤其相鄰 elements 的 normals 不一致時。

Envelope 的各個 maximum 未必來自同一 load case。需要同時作用的 N、M 及 V 時，應提取同一 combination 的 coincident values；把每個 independent maximum 拼在一起，通常不能代表一個實際 equilibrium state。

*Worked Example 11.8*

A shell result reports a uniform bending moment resultant of 25 kN m/m across a 2 m wide strip. Find the integrated bending moment across that strip. Assume the reported component is the one acting about the required strip axis.

$$M = 25 \times 2 = 50\,kN\,m$$

The multiplication is valid because the resultant is uniform across the stated width. For a varying distribution, integrate the correct component across the section rather than multiplying the peak by an arbitrary width.

**Exam Trap：maximum N、maximum M 及 maximum V 可能並不同時出現；envelope 不能自動當成單一 load case。**

*Example MCQ 11.8A*

**A uniform shell moment resultant is 18 kN m/m across a 3 m strip. What is the integrated moment across that width?**
A. 6 kN m
B. 18 kN m
C. 54 kN m
D. 162 kN m
E. 54 kN/m

**Answer: C**
Explanation: A moment per unit width must be integrated across width. For a uniform value, the result is 18 × 3 = 54 kN m.

*Example MCQ 11.8B*

**Why should coincident axial force and bending moment be extracted from a specified combination when checking combined action?**
A. Every envelope maximum always occurs simultaneously
B. The separate envelope maxima may come from different combinations
C. Bending moments have no units in an envelope
D. Axial force must be zero whenever moment is maximum
E. Combination identification is irrelevant to equilibrium

**Answer: B**
Explanation: Independent extrema may occur under different loading states. Coincident values preserve the actions associated with the selected combination.

## 11.9 Detecting Unrealistic Results

不合理結果的常見徵兆包括：本應連接的位置出現 relative separation、restrained DOF 有非預期 movement、對稱 model 在對稱 load 下出現無依據的不對稱 response、reaction 不足以平衡荷載，或 deflection 量級偏離簡單估計。先確認 plot 設定，再逐層檢查 input 及 model。

Duplicate nodes、未 merge 的 mesh、錯誤 release、rigid link、section orientation 及 units 都可能造成問題。極小 stiffness 或極大 stiffness 亦可能令數值系統 ill-conditioned。Solver 完成並不等於 model 正確；warning 與 non-convergence 須有解釋，不能以漂亮 contour 取代。

對 linear static case，先比較完整 load 及 reaction vectors，並以一致 origin 核對 moment equilibrium。若檢查的是部分 structure，cut-section forces 及 boundary actions 也必須計入。局部不平衡可由漏取 actions 造成，不能立即判定 software 出錯。

### *Worked Example 11.9*

A complete linear static model has 1,000 kN downward applied load. The reported upward support reactions total 760 kN. No other vertical boundary action exists. Find the force imbalance as a percentage of applied load.

$$Imbalance = 1000 - 760 = 240\,kN$$

$$Ratio = \frac{240}{1000} \times 100 = 24\,percent$$

This is a substantial unexplained imbalance for the stated complete model. Check that the same case, all supports and all applied loads have been selected before accepting any design output.

**Exam Trap：調細 deformation scale 只改變圖像，不會修正 displacement；「analysis completed」亦不是 engineering acceptance。**

### *Example MCQ 11.9A*

**A beam model appears disconnected at a location intended to be continuous. Which input should be checked first?**
A. The magnitude of the applied load alone
B. The specified material yield strength alone
C. The partial factors used in the design check alone
D. Node connectivity and unintended releases at that location
E. The member self-weight density alone

**Answer: D**
Explanation: A discontinuity in the intended load path is directly associated with connectivity or releases. Changing load magnitude, strength or density alone does not restore a missing mechanical connection.

### *Example MCQ 11.9B*

**A complete static model has 500 kN downward load and 450 kN upward reactions, with no other vertical boundary action. What is the imbalance relative to applied load?**
A. 10 percent
B. 5 percent
C. 50 percent
D. 90 percent
E. 111.1 percent

**Answer: A**
Explanation: The missing balance is 50 kN. Relative to 500 kN applied load, this is 50/500 × 100 = 10 percent.