

SCI PUBLICATION 102

CONNECTIONS BETWEEN STEEL AND OTHER MATERIALS

INTERFACES

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Published by:

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Publication Number: SCI-P-102

ISBN 1 85942 004 4

British Library Cataloguing-in-Publication Data.
A catalogue record for this book is available from the British Library.

FOREWORD

This publication, together with previous titles in the series, result from research into interface problems in modern commercial buildings, initiated by the Steel Construction Review. The publication presents an overview of methods of making structural connections between steelwork and concrete or masonry structures. The work was prepared by Richard Henley of Ove Arup & Partners, and Dr Raymond Ogden, The Steel Construction Institute Reader in Architecture at Oxford Brookes University.

Other publications in this series are *Curtain Wall Connections to Steel Frames* (Ogden, R. G; 1992) and *Electric Lift Installations in Steel Frame Buildings* (Ogden, R. G; 1994) both published by The Steel Construction Institute. A relevant companion publication, *Brick Cladding to Steel Framed Buildings*, published jointly by British Steel and the Brick Development Association in 1980, addresses the attachment of new masonry cladding to steel frames.

The group responsible for the production of this publication was as follows:

| | |
|---------------------------|---|
| Mr R Gordon (Chairman) | MACE Limited (formerly Bovis Construction Ltd) |
| Mr B Boys | British Steel plc |
| Mr P Craddock | Ove Arup & Partners |
| Mr R Naman | Jenkins & Potter Consulting Engineers |
| Dr G Owens | The Steel Construction Institute |

Mr M Salmon (Fixing Consultant), prepared an earlier SCI report on connections between steel and other materials that provided important source material for this study.

The contribution of Mr G Weston of Ove Arup and Partners is gratefully acknowledged.

The work leading to this publication was funded by the Ove Arup Partnership, British Steel (Sections, Plates and Commercial Steels), the Department of the Environment, and the following industrial and professional sponsors:

Booth Industries Plc
McCalls Special Products Limited
Gifford & Partners
John Grant & Associates
William Hare Limited
Hilti (Great Britain) Limited
Jenkins & Potter Consulting Engineers
J N Rowen Limited
Taylor Woodrow Construction Limited
Robert Watson & Company Limited
Graham Wood Structural Limited
Octavius Atkinson & Sons Limited

The Steel Construction Institute would like to thank the following organisations, who either assisted in the preparation of the working details in Section 2 of this publication, or who commented on the draft details.

Ove Arup Partnership
Alan Baxter Associates
Bovis Construction Limited
British Constructional Steelwork Association Limited
Clarke Nicholls & Marcel
Oscar Faber
Gifford & Partners
John Grant & Associates
Jenkins & Potter
Knapp Hicks & Partners
J N Rowen Limited
Whitby & Bird

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SUMMARY

Many building and refurbishment projects require structural connections between steelwork and other materials, such as concrete or masonry. This publication examines the design and construction issues implicit in these connections, and presents a range of details. Each detail is appraised in terms of its structural performance and construction qualities, and an indication is given of where the detail may appropriately be used.

There are many factors that influence the form of connection details, and these vary considerably from project to project. Details are therefore presented as schematic arrangements that may be adapted to suit the requirements of individual projects.

Interfaces: Liaisons entre l'acier et d'autres matériaux

Résumé

Dans beaucoup d'immeubles nouveaux ou lors de projets de réhabilitation, des liaisons entre la structure métallique et d'autres matériaux, comme le béton et la maçonnerie, sont nécessaires. Cette publication analyse les problèmes que posent ces liaisons et présente une série de liaisons types pouvant convenir tant pour des immeubles nouveaux que lors de transformations. Chaque détail de construction est analysé en termes de performance structurale et de facilité de réalisation. Des indications sont données quant aux domaines d'application des différents types de liaisons.

Vu le très grand nombre de variables rencontrés, les types de liaisons sont présentés de manière schématique afin de pouvoir s'adapter à chaque circonstance particulière.

Verbindungen zwischen Stahl und anderen Materialien

Zusammenfassung

Bei vielen neuen Gebäuden und Sanierungen sind Verbindungen zwischen Stahl und anderen Materialien, wie z.B. Beton oder Mauerwerk, nötig. Diese Veröffentlichung untersucht die Berechnungs- und Konstruktionsproblematik an diesen

Grenzflächen und stellt eine Reihe geeigneter Verbindungen für Neubau und Renovierungen vor. Jedes Detail wird hinsichtlich statischem Tragverhalten und Konstruktion beurteilt und es werden Hinweise auf geeignete Anwendungen gegeben.

Als Konsequenz der Fülle von Berechnungs- und Konstruktionsparameter auf die man trifft, werden Details in schematischer Form vorgestellt, mit der Absicht, daß diese an die Erfordernisse individueller Projekte angepaßt werden.

Interfacce: collegamenti tra acciaio e altri materiali

Sommario

Molti nuovi edifici o progetti di ristrutturazione prevedono collegamenti strutturali tra elementi in acciaio ed altri materiali come calcestruzzo o muratura. Questa pubblicazione esamina la progettazione ed i conseguenti problemi costruttivi relativi a queste interfacce; viene presentata in dettaglio una varietà di soluzioni adatte per applicazioni in nuovi edifici e nel campo della ristrutturazione. Ognuna di queste è valutata tanto considerando il comportamento strutturale e i dettagli costruttivi che fornendo indicazioni relative al campo preferenziale di applicabilità.

Dato il vasto campo di variabili progettuali e costruttive che si incontrano comunemente, le soluzioni sono presentate in forma sintetica in modo che siano applicabili in relazione agli specifici requisiti del progetto

Interfases: Unión del Acero con Otros Materiales

Resumen

Tanto en edificios nuevos como en proyectos de rehabilitación se requiere a menudo la unión del acero a otros materiales como hormigón o mampostería. En esta publicación se analizan los temas de proyecto y construcción que surgen en estas interfases y se presenta un conjunto de detalles apto tanto para construcciones nuevas como en rehabilitación.

Cada detalle se contempla en función de sus propiedades constructivas y estructurales y se indica

en qué tipo de aplicaciones puede ser apropiado.

A causa del gran número de variables que se encuentran habitualmente en proyecto y construcción, los detalles se presentan esquemáticamente con idea que puedan ser adaptados a las condiciones de cada proyecto específico.

Anslutningar: Förband mellan stål och andra material

Sammanfattning

Många nya byggnader och renoveringsprojekt fordrar konstruktionsförband mellan stålbärverk och andra material, såsom betong och murverk. Denna publikation tar upp olika aspekter rörande utformning och utförande av sådana anslutningar, och redovisar ett flertal detaljlösningar som är lämpliga både vid nybyggnation och renovering. Varje detalj bedöms med avseende på konstruktivt verkningssätt och utförande, och lämpliga användningsområden för detaljerna ges.

Efterom det normalt är ett stort antal faktorer som måste beaktas vid projektering och byggande, presenteras de olika detaljerna i ett schema, med avsikten att lämpliga detaljer kan väljas och anpassas till de krav som ställs för det enskilda projektet.

INTRODUCTION

Where structural steelwork is used in conjunction with other structural materials, various connection details may be required. These include:

- steel column connections to foundations and floor slabs
- steel beam connections to concrete core walls
- steel beam connections to concrete columns, and beams
- steel beam connections to masonry walls.

Connection details should recognise the physical characteristics of both steelwork and the material to which the steelwork is connected. Details should generally seek to optimise structural requirements, buildability and cost. Where architectural or other criteria demand unique or specialised details beyond the scope of this publication, similar design principles will apply. However, there will usually be an additional aesthetic requirement.

Section 1 of this publication sets out performance requirements for connection between steel and other materials. Section 2 presents a range of schematic details.

1 DESIGN CONSIDERATIONS

1.1 Introduction

Considerations that influence the design of connections between steel and other materials include:

- buildability and safety
- construction tolerances and dimensional variations
- deflections and long term movements
- load transfer between components
- variability in materials
- durability and maintenance

- fire protection
- cost (both of the connection and of installation)
- design responsibilities and design programming.

Each of these areas is discussed in detail in the following sections.

The details that are presented in this publication illustrate the general principles of connecting steel members to concrete and masonry, but are not the only details that can be used. The publication is intended not to be comprehensive in the range of materials and applications that it includes, but rather is intended to provide useful precedents and to establish design principles.

1.2 Installation Operations

There are normally several distinct operations involved in achieving a structural connection. These may include:

1. Construction or erection of *supporting* elements, and installation of any connection brackets.
2. Pre-alignment of brackets and seatings.
3. Construction or erection of *supported* elements.
4. In-situ adjustment of brackets or seatings.
5. Temporary attachment of the *supported* and *supporting* elements prior to a permanent connection being made.
6. Permanent connection of the structural elements.

Not all of these operations are required for every connection detail. The shims used to level beams carried on padstones may for instance be installed in advance of the beam being placed (stage 2), thus avoiding any need for further vertical adjustment (stage 4). Similarly, there are many types of detail where no temporary attachment is necessary (stage 5), since permanent attachment can be made immediately (stage 6).

1.3 Assembly and Erection Operations

Care should be taken to ensure that erection operations can be carried out reliably, on programme, and in an economic way. Careful planning is necessary especially where several trades are required to complete a connection. Early consultation between designers and contractors is advisable.

Connections that have to be made quickly should generally be 'steel-to-steel'. Connections between structural steelwork and other structural building elements are often therefore based upon steel connection brackets. These brackets are installed in advance of erection operations.

Generally, new buildings allow designers freedom to organise structural systems in ways that are practical to construct and that avoid awkward or unnecessarily complicated details. Existing buildings, however, tend to be restrictive and can compromise the design of new structural elements. It is usual to ascertain the form and condition of existing structures, through general surveys, supplemented by local detailed surveys carried out whilst construction proceeds. Readers are referred to *Appraisal of Existing Structures* (Happold, E; The Institution of Structural Engineers, 1980) and *Appraisal of Iron and Steel Structures* (Bussell, M; to be published by The Steel Construction Institute, 1996).

Connections to existing reinforced concrete structures can present particular difficulties. Where there is a possibility of fixing positions clashing with reinforcement, reinforcing bars should be located using a covermeter and confirmed by pilot drilling or chasing the surface of the concrete. Fixings for connection brackets may then be located to avoid the reinforcement (slotted holes or alternative fixing positions may be provided for this purpose). Alternatively, special brackets may be designed with predetermined fixing positions that reliably avoid the reinforcement.

1.4 Speed of Construction

One of the benefits of steel frames is their speed of construction. In order to optimise this speed it is important to use appropriate connections, that

minimise erection time, whilst maintaining good safety standards. For this reason, connection brackets that can be pre-aligned are often specified. Fast erection procedures shorten the building programme and tend to reduce overall costs.

1.5 Safety

Where possible, heavy components should be supported on positive seatings (ledge brackets etc.), both to improve safety during construction and to reduce crane hook time. Connections should be designed so that simple bolting can provide safe initial connection. In many instances, further bolts are introduced after the crane hook is released to complete connections.

1.6 Construction Tolerances

The levels of accuracy associated with construction materials differ considerably. Dimensional variations associated with in-situ concrete elements, for instance, are normally significantly greater than those associated with steel construction. The expected dimensional variations should be reflected in the amount of adjustment that is provided at the connection detail.

Construction tolerances are permitted variations from nominal dimensions. They are normally expressed as $+X$, $-Y$, where X and Y are the acceptable margins of deviation in particular directions. The amount of adjustment that should be provided by a connection detail to accommodate building tolerance, depends to a large extent upon the materials that are to be connected. Materials prone to large dimensional variations require connections that have greater potential for adjustment than other materials may require.

The adjustment provided at connections should also reflect the tendency for tolerances to compound over a structure. If a series of beams, for instance, in a frame, are each longer than the nominal length, the overall size of a structure may increase unacceptably. This can be avoided completely by provision of sufficient adjustment at the connections. Alternatively, it may be reasonable to accept some

compounding of building tolerances, but limit this by allowing a particular level of adjustment at the connections. The amount of adjustment actually provided should reflect the design requirements of individual structures. *BS 6954: 1988 Tolerances for Building* provides a theoretical basis for calculating tolerances.

Tolerances may be taken up by slotted holes, shims or other devices. Brackets designed to accommodate particularly large tolerances can be problematic, in that they sometimes result in high levels of eccentricity at the point of load transfer from one element to another. The benefit of allowing high levels of adjustment to accommodate the maximum dimensional variation must therefore be balanced against possible increases in the size, cost and complexity of brackets, arising from increased eccentricities. Detailed surveys can often allow tolerances to be reduced, and can therefore simplify design.

BS 5606: 1990 Guide to Accuracy in Building suggests tolerances for building elements constructed using various materials. Some of these are based on the results of surveys carried out on completed buildings. If designers do not specify building tolerances, then it is likely that contractors will follow those cited in this Standard.

The National Structural Steelwork Specification for Building Construction (NSSS) published by The British Constructional Steelwork Association Limited (BCSA) and The Steel Construction Institute, provides widely accepted guidance on steelwork tolerances. Examples of permitted deviations for multi-storey steel frames taken from the NSSS (3rd Edition, 1994) are as follows:

Steelwork

| | |
|--|----------|
| Alignment of adjacent perimeter columns (on plan) | +/-10 mm |
| Alignment of adjacent beams (elevation) | +/- 5 mm |
| Level of beams | +/-10 mm |
| Difference in level between each end of a beam | +/- 5 mm |

There are no current nationally accepted specifications with the same standing as the NSSS for concrete and masonry structures. The following values, taken from building specifications, are however considered representative:

Concrete

| | |
|---|----------|
| General permitted deviation of concrete surfaces | +/-15 mm |
| Cross section of columns, walls, up to 1m | +/- 5 mm |
| Level of beams | +/-15 mm |
| Permitted deviation of element centroid in each storey height | +/-10 mm |
| Level at any point on a surface (not foundations) | +/-10 mm |
| Level at any two points 6 m apart (not foundations) | +/- 5 mm |

Masonry

| | Length of wall: | | |
|------------------|-----------------|-----------|------------|
| | 300 mm - 2 m | 2 m - 5 m | 5 m - 10 m |
| Position on plan | +/- 5 mm | +/- 10 mm | +/- 15 mm |
| Cross section | +/- 5 mm | +/- 10 mm | +/- 15 mm |
| Level | +/- 5 mm | +/- 10 mm | +/- 15 mm |

1.7 Movement

Structural movements have a variety of causes, including changes in loading, environmental effects (such as thermal expansion/contraction), and changes in the dimensions of materials over time (such as permanent expansion of masonry). The magnitude and direction of movements must be determined, and suitable adjustment provided in connection details. *Design for Movement in Buildings* (Alexander, S. J. and Lawson, R. M; CIRIA Technical Note 107, 1981) offers concise advice on this subject.

When designing new steel structures in existing buildings, it is important to have an understanding of the way in which the structure copes with

movement. Movement joints should be maintained unless a large-scale replacement of the structure, incorporating alternative provision for building movements, is proposed.

1.8 Load Transfer

Aspects of load transfer that may need to be considered include:

- The effects of concentrated load on supporting elements.
- The effects of eccentricities on the supported and the supporting elements.
- The ability of reinforcement in concrete structures to provide adequate tying action (for robustness requirements).
- The ability of the connection to accommodate building movements and tolerances.

Structural steel member spacings and connection details are often determined by the local capacity of the supporting structure. Weak structures may be encountered in refurbishment work where building elements may not have been designed with significant redundant structural capacity, or may have deteriorated over time.

Connection details sometimes have to be 'locked' so that they can transfer loads parallel to the direction of any sliding adjustment that may have been provided to accommodate building tolerances. Connections may be locked by a variety of means, including welding or clamping, or brackets with serrated faces.

Dimensional variations may affect the end bearing of steel sections on their supports, or the alignment of bolts and sockets. It is therefore important to ensure that load transfer is satisfactory in all circumstances within the extremes of tolerance, and that proper assembly can be achieved.

1.9 Variability in Materials

Masonry

It is important to establish whether masonry (particularly stone) is solid, an outside leaf (possibly retaining rubble infill) or used simply as a facing material. Where masonry is solid, or has sufficient thickness to be loadbearing, it is important to assess the structural properties of the material. This may involve testing. The structural properties of masonry can limit the total load that can be imposed on a building element, and the way in which these loads can be distributed.

Concrete

The surface of reinforced concrete elements can deteriorate due either to carbonation or corrosion of embedded reinforcement. It is therefore important that connections are made into the body of elements, to a depth where the concrete has appropriate strength and long-term integrity.

1.10 Durability and Maintenance

Whilst there is established guidance on the durability of concrete and steel structural elements, there is considerably less guidance relating to the durability of connections between these materials. The following issues should however be addressed:

- Connections should be designed with regard to the service and environmental conditions in which they are expected to perform. Where connections are subject to moisture they should be particularly resistant to corrosion (including the effects of bimetallic action).
- Connections should be able to resist all erection and service loads without deforming excessively, or being damaged, and without detriment to any corrosion protection systems.
- Connections should be able to accommodate all predictable building movements (both dynamic and static).
- Connections should be designed to have life expectancies at least commensurate with the design life of the building in which they are used.

1.11 Fire Protection

Connections between structural steelwork and other materials must generally be fire-resistant for a period at least equivalent to that of the least fire resistance of the elements that they connect. Resin anchors (see Appendix A) tend to soften or lose strength prematurely when exposed to fire, and must often be fire-protected.

Where connections have to be inspected or maintained, fire protection should be of a type that can be easily removed and replaced (i.e. board-based systems rather than sprayed or blanket types).

Where sliding fixings are used, the protection detail should not restrict movement or be damaged when movement occurs.

1.12 Cost

High quality connection details that embody the principles set out in the preceding Sections may sometimes be more expensive to fabricate than basic connection details. High quality connections that provide a good level of adjustment and facilitate safe, rapid and reliable construction can however provide significant cost savings during construction, and avoid costly delays that would be caused by bad fit or other assembly problems.

Generally, connection design should seek to minimise total construction costs rather than simply minimise fabrication costs.

1.13 Design Programming

Many connection details require components to be built into concrete or masonry structures as they are constructed. These connections must be fully resolved early in the construction programme.

Certain types of connection can however be detailed relatively late in the design programme, often after construction has begun. For instance, drilled-in connections permit the exact number and location of fixings to be determined after concrete elements are constructed. These connections can be particularly useful on projects where the main contractor,

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sub-contractors or the suppliers of structural components, have not been selected at the time that the initial structural design takes place. Late resolution of connection details does however present certain risks. Cost variations or programme delays may be incurred if designs cannot be developed in the ways originally envisaged, or if details cannot be readily resolved.

2 CONNECTIONS

2.1 Introduction to the Connection Details

This Section presents schematic designs for a range of connections between structural steelwork, and new or existing concrete or masonry.

Each connection is reviewed under the following headings: Applications, Construction, Adjustments, Load Paths, and Critical Appraisal.

A design checklist based upon the general headings: Buildability, Adjustment and Load Paths is also included for quick reference. An additional heading 'Fire Protection' appears in the design check list where particular fire protection measures may be required at the connection detail.

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The following notations have been used in the design checklist to describe general load transfer capacities:

- L - Light duty, for working loads of up to 20 kN.
- M - Medium duty, for working loads of up to 150 kN.
- H - Heavy duty, for working loads above 150 kN.

2.2 Steel Column to Existing Concrete Foundation

Applications

- Connection of new steel columns to existing concrete pads, strips or pile caps.
- Connection of new steel columns to existing concrete beams.

Construction

The detail shows grouted threaded rods used to bolt the column baseplate to the foundation (Figure 1). Alternative methods of connection include expanding anchors and expanding sockets. Columns are set to line and level using steel shims, and afterwards the space between the base plate and concrete is filled with non-shrinking grout or drypack. Threaded rods are normally grouted in place before the steelwork is erected.

Where foundations are constructed from mass concrete, bolt holes in column baseplates should be sized as follows:

bolt diameter + 4 mm for holes up to 16 mm

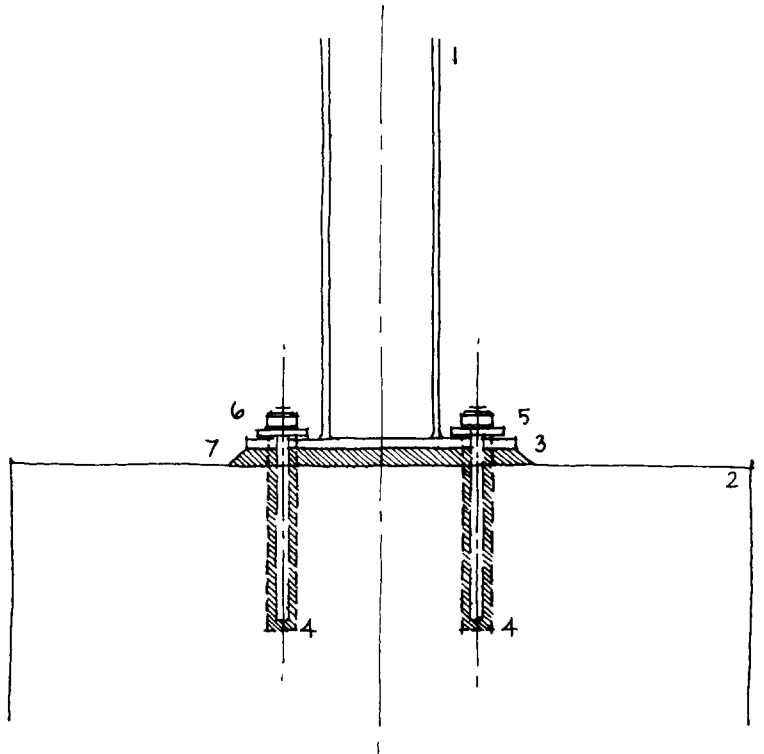
bolt diameter + 6 mm for holes over 16 mm

Where foundations are constructed from reinforced concrete and the location of the reinforcement is not certain, bolt holes in column baseplates should be larger than the sizes given above. Larger holes will normally require plate washers, which may need to be site-welded to the base plate if the connection is to transmit large shear forces.

It is acceptable to form bolt holes in concrete foundations using diamond core techniques. If pull out capacity is needed, the sides of the core hole should be roughened.

Additional 50 mm holes may be required for large base plates (exceeding approximately 0.5 m² in area). These holes permit air to escape and provide visible confirmation that grout is present beneath the base plate.

INTERFACES



1. Steel column
2. Concrete base
(e.g. pad, strip, pile cap or raft)
3. Base plate
4. Threaded rod, grouted in drilled holes
5. Oversized holes in base plate
6. Plate washer
7. Grout or dry pack

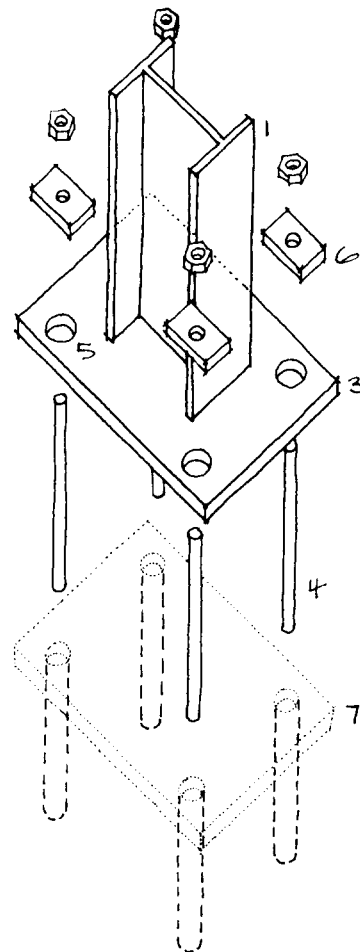


Figure 1
Schematic arrangement

Adjustments

- Horizontal adjustment in the two orthogonal plan directions is by oversized holes.
- Vertical adjustment (prior to grouting) is by steel shims between the base plate and the concrete foundation.

Load paths

Compression transfer is through the grout beneath the base plate (Figure 2). Tension is transferred by the threaded rods. Shear may be transferred by the threaded rods, by friction between the baseplate grout and foundations or by alternative means. Bending moments are resisted by the rods and the base plate, which should be sized accordingly (refer to *Joints in Steel Construction: Moment Connections*, SCI and BCSA, 1995).

1. Compression in column
2. Bearing
3. Lateral restraint (frictional resistance and possible shear of bolts)
4. Bending moment
4. Pull out (if required)

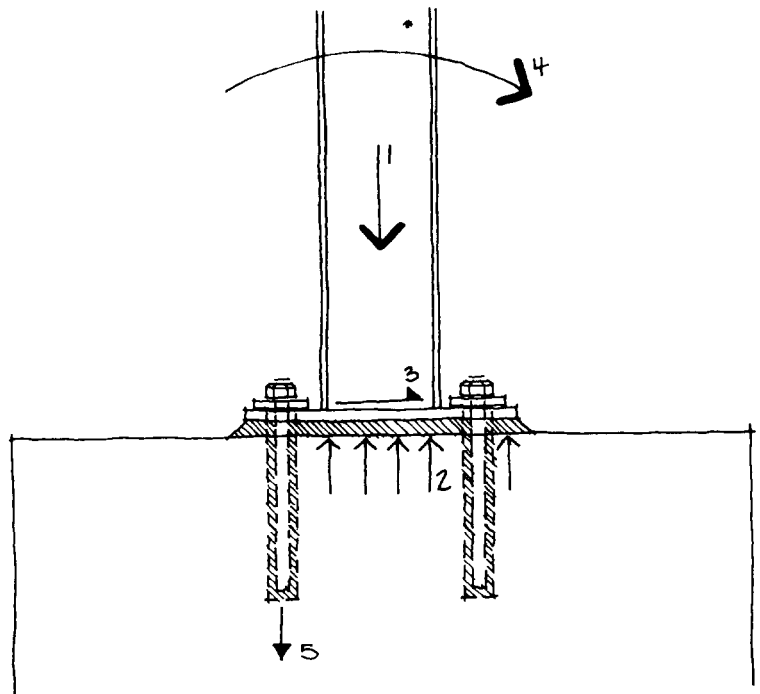


Figure 2 Load path diagram

Critical appraisal

This detail is relatively simple to fabricate and construct. It relies upon the principal forces being transferred by direct bearing.

Oversized holes in base plates can allow the threaded rods to be located to avoid reinforcement in foundations. However, the plate washer should be big enough to cover these over sized holes, with adequate bearing on either side.

Two bolt connections are sometimes used with small base plates. Where this is done, special consideration must be given to stability of the steel column during construction. Temporary propping may be required.

Expansion anchors may be used to connect balustrades or similar light duty vertical elements to existing concrete beams. Sufficient tolerances must be allowed to avoid clashes between fixings and reinforcement. Edge distances should be sufficient to prevent bursting of the concrete.

Design checklist

Buildability

| | |
|-----------------|--|
| Site Operations | <ol style="list-style-type: none"> 1. Holes are drilled in concrete foundation. 2. Threaded rods are grouted in place 3. Shims are installed to the correct level. 3. Steel column is located. 4. Base plate is bolted down. 5. Base plate is grouted. |
| Setting Out | A template should be used to set out bolt holes in foundations |
| Skill Level | Normal |
| Handling | Temporary support will usually be needed during erection |
| Safety | Particular care necessary where two bolt base plates are used, to ensure adequate propping during construction |

In-situ Adjustment

| | |
|------------|-------------------------------|
| Horizontal | Oversized holes in base plate |
| Vertical | Shims beneath baseplate |

Load Transfer

| | |
|-------------------------------|---|
| Compression | M - H through the grout |
| Tension | L. Usually there is only a nominal requirement |
| Shear | If required (usually in M - H range) plate washers may be site welded |
| Moment | L. Nominal moment transfer |
| Connection stiffness/strength | A robust connection |

2.3 Steel Column to New Concrete Foundation

Applications

- Connection of new steel columns to new concrete pads, strips or pile caps.
- Connection of new steel columns to new concrete beams.

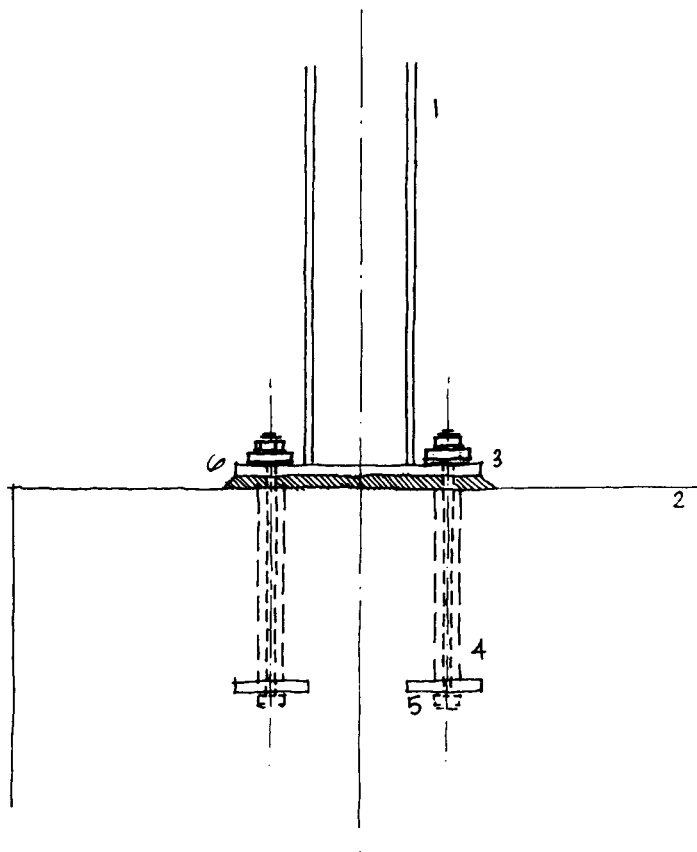
Construction

Cast-in bolt groups are used to connect the column baseplate to the concrete foundation. Columns are set to level using steel shims. The bolt pockets and the space between the base plate and the foundation, are filled with non-shrinking grout or drypack (Figure 3). Cementitious grout is placed by enclosing the area to be filled beneath the base plate and pouring grout into the enclosed area. Care must be taken to ensure that the bolt pockets are properly filled.

Bolts are held captive on a pair of steel plates embedded into the concrete. The plates not only tie the bolt group into the concrete, but also ensure that the bolts are positioned accurately. Lugs or small angles may be welded to the underside of the plate to stop bolt heads rotating during installation. The pair of steel plates are sometimes replaced by a single plate, to improve accuracy, however care should be taken to ensure that a void is not allowed to form beneath the plate when concrete is poured.

Bolt pockets may be straight-sided or tapered and should be sized such that the lower plate is embedded sufficiently to resist any uplift.

The bolt pocket diameter should allow for the bolt to be inclined to the vertical at a maximum of 1 in 20 in order to provide adequate horizontal adjustment of the base plate. Steeper inclinations may cause the bolt to be bent or may prevent nuts being tightened effectively.



1. Steel column
2. Concrete base
(e.g. pad, strip, pile cap or raft)
3. Thick base plate
4. Bolts set in pockets
5. Normally two plates or angles
6. Grout

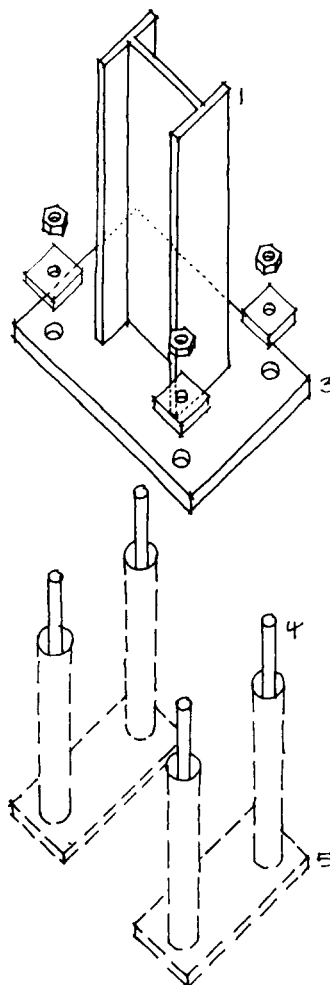


Figure 3
Schematic arrangement

Additional 50 mm diameter grout holes in the column base plate may be required if the base plate area exceeds 0.5 m².

Adjustments

- Horizontal adjustment in the two orthogonal plan directions is by movement of the bolts in the bolt pockets. Within 24 hours of the concrete operation, prior to erection of the column, the bolts should be checked for freedom of movement.
- Vertical adjustment is by steel shims between the base plate and the concrete.
- It is recommended that the permitted deviation of the top surface of the foundation should be specified within the range +0 to -30 mm from the levels shown on the drawings.

Load paths

Compression transfer is through the grout beneath the base plate. Tension is transferred by the holding down bolts and the embedded plates. Shear may be transferred by the holding down bolts, by friction between the base plate grout and foundations or by alternative means. Bending moments are resisted by the bolts and base plate (Figure 4).

1. Compression of column
2. Bearing
3. Lateral restraint (frictional resistance and possible shear of bolts)
4. Bending moment
4. Pull-out concrete reaction against plate

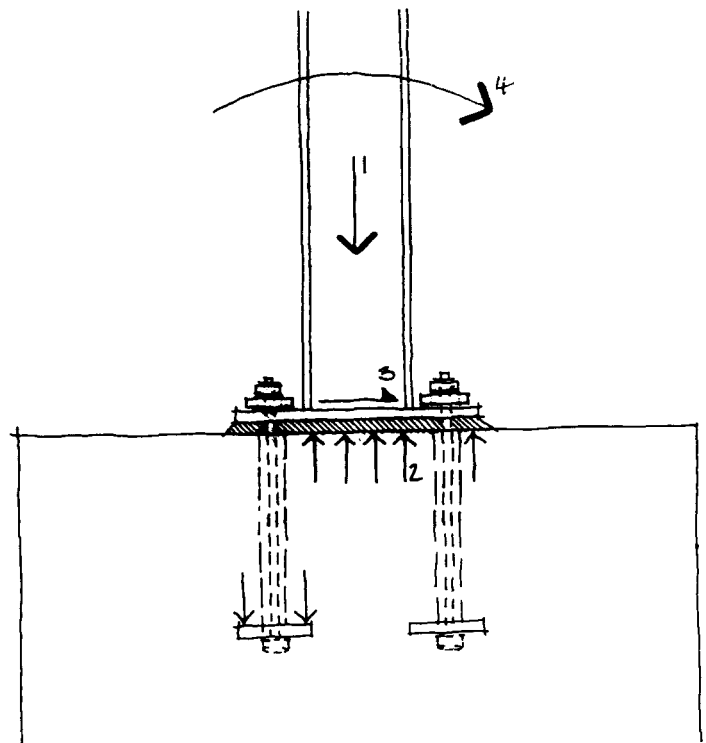


Figure 4 Load path diagram

Critical appraisal

This is a relatively simple connection detail, in which the principal forces are transferred by direct bearing. Any pull-out requirement should be designed to be transferred to the adjacent concrete via the bolt group and plates.

Where tolerance problems are envisaged, a single embedded plate should be used. For larger columns, two smaller plates or angles may be more economic. Problems are frequently experienced on site due to incorrect setting out. Initial setting out must therefore be accurate and the freedom of bolts within bolt pockets should be checked during the curing period of the concrete.

Two bolt connections are sometimes used with small base plates. Where this is done special consideration must be given to the stability and safety of the steel column during construction. Temporary propping may be required.

Particular care should be taken where connections require significant moment transfer. The thickness of the base plate and the diameter of the holding down bolts should be designed in accordance with *Joints in Steel Construction: Moment Connections* (SCI and BCSA, 1995) to ensure adequate moment capacity.

Design Checklist

Buildability

| | |
|-----------------|--|
| Site Operations | <ol style="list-style-type: none"> 1. Bolt groups are located and foundation is poured. 2. Shims are installed to the correct level. 3. Steel column is located. 4. Base plate is bolted down. 5. Bolt pockets and baseplate are grouted. |
| Setting Out | A template may be used to set out bolt group in formwork. |
| Skill Level | Normal |
| Handling | Temporary support may be needed during erection. |
| Safety | Particular care necessary when 2 bolt base plates are used to ensure adequate propping during construction. |

In-situ Adjustment

| | |
|------------|-----------------------------------|
| Horizontal | Movement of bolts in bolt pockets |
| Vertical | Shims |

Load Transfer

| | |
|-------------------------------|--|
| Compression | M - H through the grout. |
| Tension | L - Usually there is only a nominal requirement. |
| Shear | If required (usually in M -H range). |
| Moment | M - H when required |
| Connection stiffener/strength | A robust connection. |

2.4 Steel Beam to Existing Concrete Beam 1

Applications

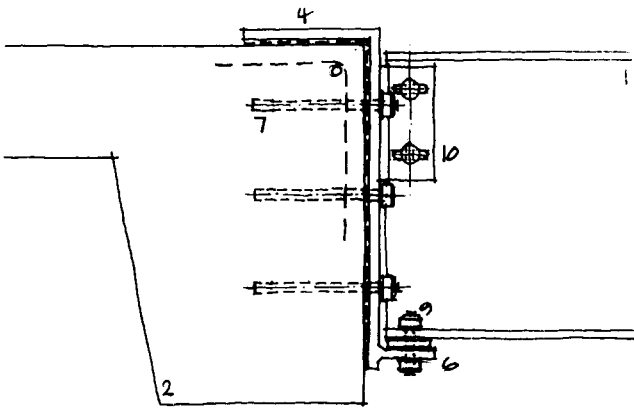
- Connections between simply supported steel beams and existing concrete beams or downstands.

Construction

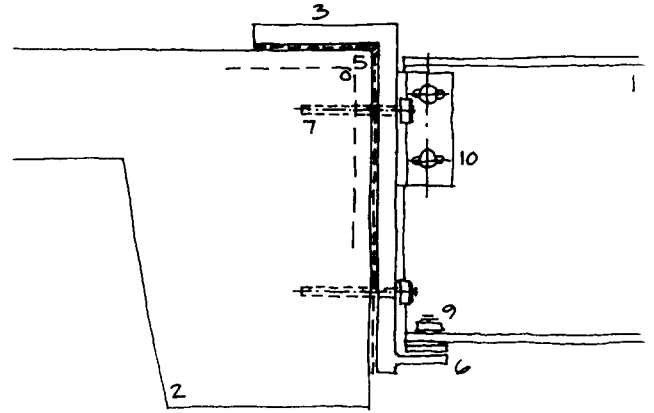
A steel connection plate is bolted to the side of the concrete beam using expanding anchors, and is set to line and level on an epoxy bed (Figure 5). Alternatively, epoxy grout may be injected after the plate is in position.

The steel beam is located on the seating bracket and is bolted down and connected to a web cleat. If the steel beam is required to transmit axial load (because no alternative load path exists), high strength friction grip (HSFG) bolts should be used.

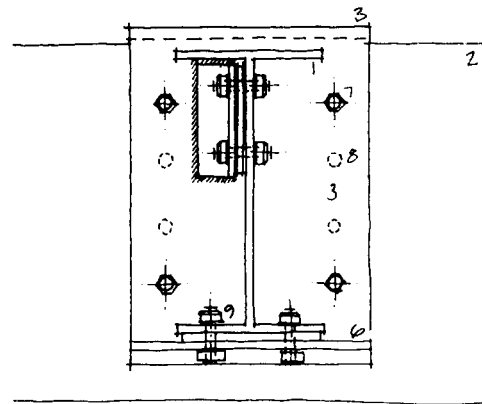
The connection plate may be bent from plate, welded from separate plates or cut out from a rolled section if this reduces fabrication costs. Alternatively, in lightly loaded applications, a single T section may be attached to the side of the beam by expansion anchors.



Light plate option

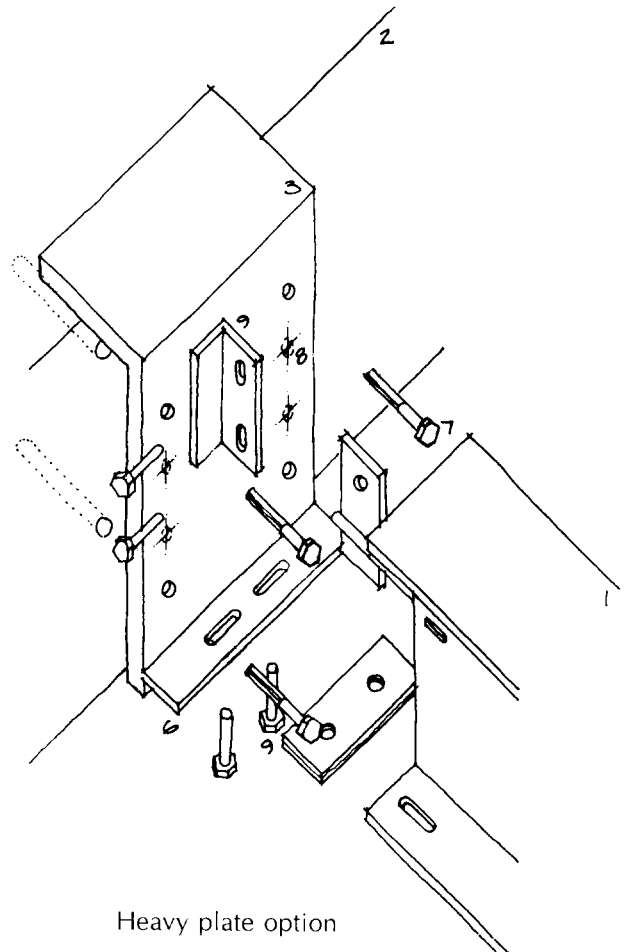


Heavy plate option



1. Steel beam
2. Concrete beam
3. Heavy connection plate on epoxy bed
4. Light connection plate on epoxy bed
5. Soft pack on edge of slab
6. Seating
7. Expanding anchor
8. Spare holes
9. Bolts and Shims
10. Cleat

Figure 5
Schematic arrangement



Heavy plate option

Adjustments

- Vertical adjustment is by shims between the steel beam and the seating, together with slotted holes in the cleat.
- Horizontal adjustment is by slotted holes in the seating and shims between the web and cleat.
- Adjustment along the main member is by slotted holes in the beam flange and web.

Load paths

The connection may be designed to transfer load in two ways:

A heavy bracket may transfer vertical load to the top of the concrete beam (Figure 6) by direct bearing of the top plate. This requires that the bracket is sufficiently rigid to resist deflection and spread the load over a reasonable area. A soft pack should be included to protect the edge of the concrete beam from concentrated loads that may cause spalling.

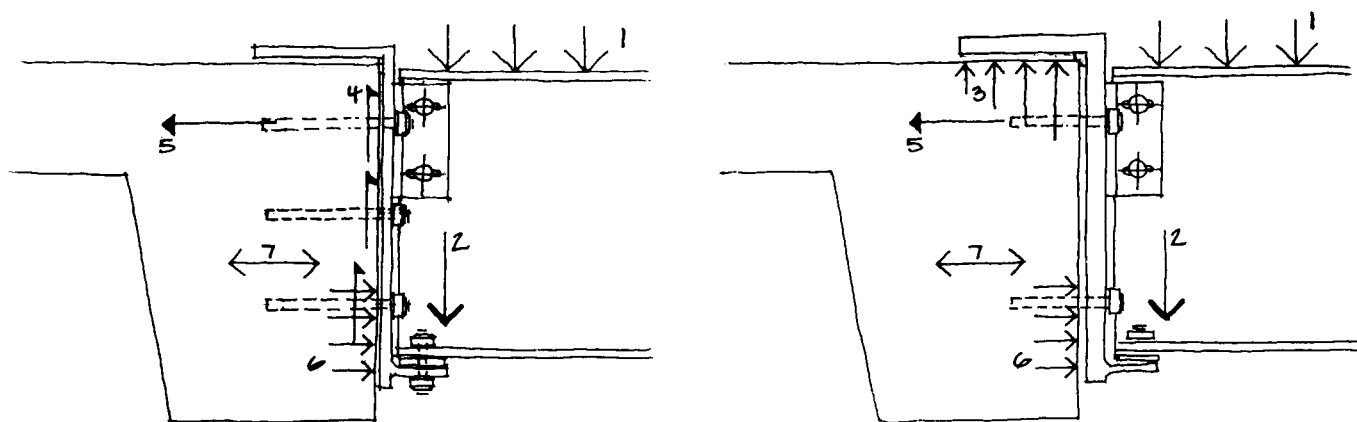


Figure 6
Load path diagram

1. Load on beam
2. Load on connection
3. Vertical reaction
4. Shear on bolt
5. Pull out due to eccentricity
6. Compression due to eccentricity
7. Tie forces (if required) by anchor pull out or concrete bearing.

Alternatively, a lighter plate may be bolted to the side of the concrete beam and the vertical load transferred through the bolts which must resist the shear force. In this case, the top plate is only for location purposes.

Critical appraisal

Adjustment is easily achieved in three directions. The connection can accept large dimensional variations in the concrete, but this may mean that eccentricity becomes a dominant design criterion for the plate.

The thickness of the plates requires particular consideration when vertical loads are transferred by direct bearing of the top plate on the concrete beam. Stiffeners may be required where there are high vertical loads. The size and consequent weight of the plate affects handling.

The position of reinforcement in the concrete should be determined before the connection plate is detailed. Where accurate surveys are not possible, additional holes may be provided in the bracket (instead of slotted holes) to allow some adjustment in the position of the fixings.

Design Checklist

Buildability

| | |
|-----------------|--|
| Site Operations | <ol style="list-style-type: none"> 1. Connection plate is located. 2. Holes are drilled and anchors are installed. 3. Beam is positioned on shims. 4. Bolts are installed. |
| Setting Out | Connection plate may be used as template. Seating may be pre-shimmed. |
| Skill Level | Normal |
| Handling | Consider weight of connection plate. Seating minimises crane hook time. |
| Safety | Provides positive seating during erection. |

In-situ Adjustment

| | |
|-------------------|-----------------|
| Horizontal | Slots and shims |
| Vertical | Slots and shims |
| Along Main Member | Slots in beam |

Load Transfer

| | |
|-------------------------------|---|
| Compression | L - M depending on existing construction |
| Tension | Nominal |
| Shear | M - H limited by bearing capacity of top plate on top of concrete beam, or capacity of anchors connecting bracket to vertical face of concrete beam, depending on design. |
| Moment | L. Not normally required |
| Connection stiffness/strength | Nominal rotational stiffness. |

2.5 Steel Beam to Existing Concrete Beam 2

Applications

- Connections between steel beams transferring moments to concrete beams.

Construction

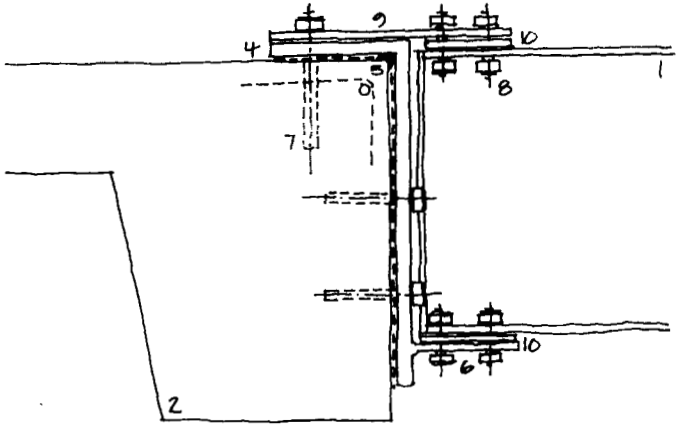
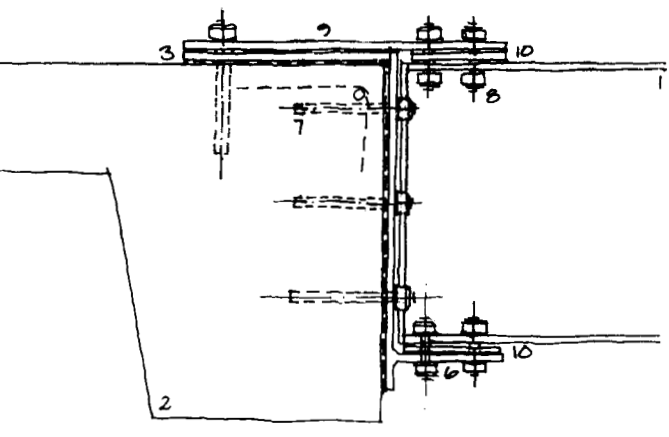
A steel connection plate is fixed to the side of the concrete beam using expanding or chemical anchors and is set to line and level on an epoxy bed. The top plate is fixed using similar expansion anchors (Figure 7).

Levelling shims are set on the seating cleat and the steel beam is set in place and located using HSFG bolts. The top plate is fixed to the beam also using HSFG bolts.

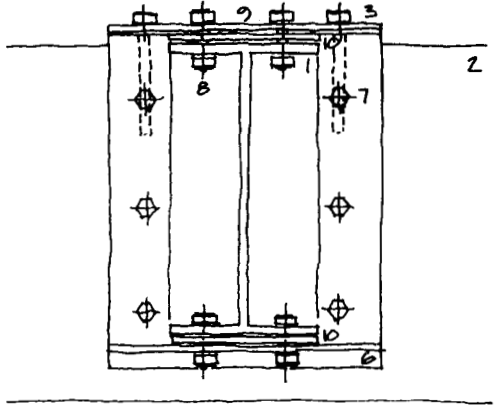
Alternatively, the top plate may be site welded to the connection plate providing that it is arranged to avoid the heads of the expanding anchors.

Adjustments

- Vertical adjustment is by shims between the flanges of the steel beam and the connection plates.
- Horizontal adjustment is by slotted holes in the connection plate.
- Adjustment along the main member is by slotted holes in the beam flanges.

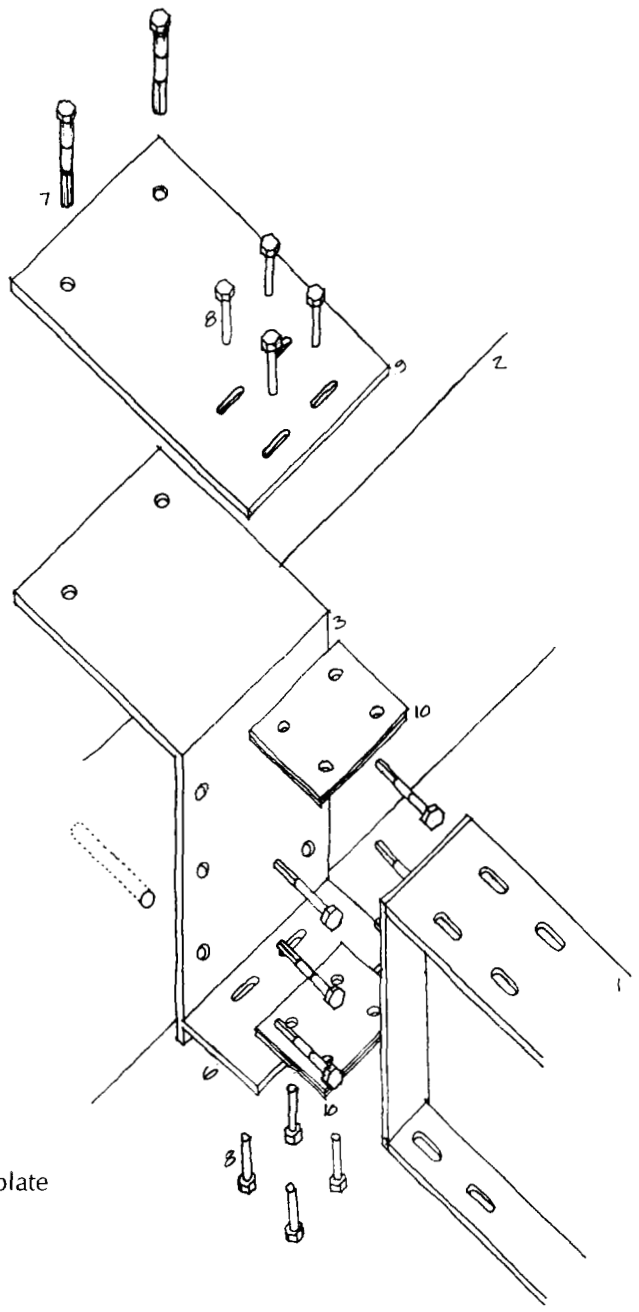


Heavy plate



Light plate

1. Steel beam
2. Concrete beam
3. Light connection plate on epoxy bed
4. Heavy connection on epoxy bed
5. Soft pack on edge of slab
6. Seating
7. Expanding anchor
8. HSFG
9. Bolted plate
10. Shims



Light plate

Figure 7
Schematic arrangement

Load paths

The upper plate transfers bending moment in the form of horizontal shear to the top of the concrete beam. The ability of the connection to transfer moments depends upon the concrete, and the shear capacity of the anchor bolts. Otherwise, the moment transfer is generally limited by the shear capacity of the bolts connecting into the beam. (Figure 8).

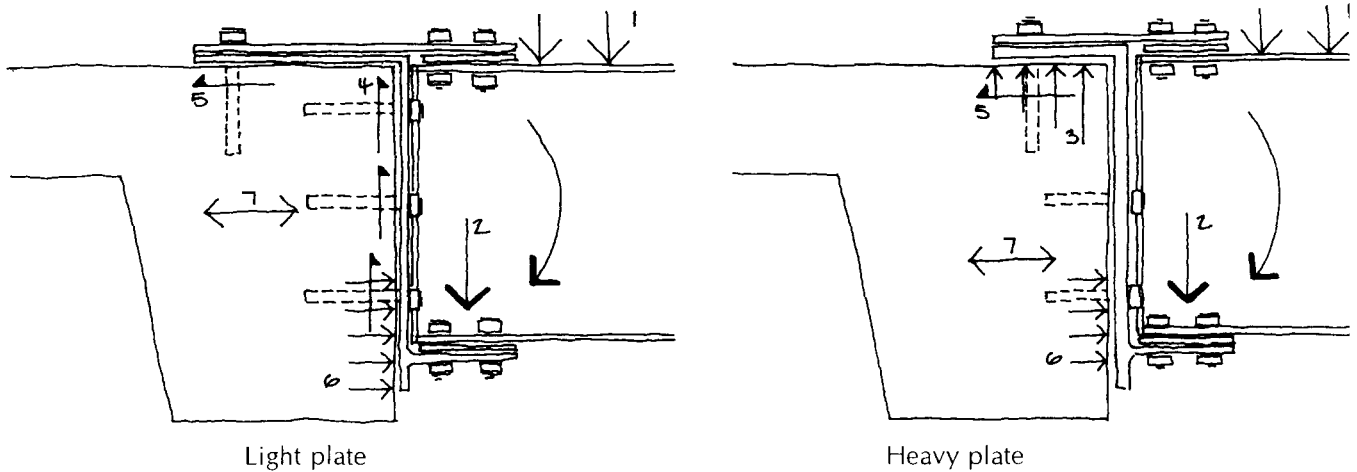


Figure 8
Load path diagram

1. Load on beam
2. Load on connection
3. Vertical reaction
4. Shear on bolts
5. Anchor shear due to moment and eccentricity
6. Compression due to moment and eccentricity
7. Tie forces (if required) by anchor shear or concrete bearing

Vertical load may be transferred by either bending and tension in the connection bracket, or by shear in the anchor bolts connecting the bracket to the vertical face of the concrete. If the first method is adopted, the bracket will need to be relatively thick to ensure that the load is properly distributed into the top surface of the concrete. A soft pack should be included to protect the edge of the concrete from concentrated load that may cause spalling. If the second method is adopted, additional anchors may be required to connect the bracket to the vertical face of the concrete. The principles behind the alternative approaches, and the effect that these may have on the design of the connection bracket, are described in relation to the previous detail, 2.4.

Critical appraisal

This detail permits a degree of structural continuity between the steel beam and the concrete structure. Moments are resisted by anchors acting in shear, and bearing of the plate on the side of the concrete beam.

Adjustment is possible in three directions, and the connection can accommodate large dimensional variations in the concrete. A site welded flange plate is likely to give a more compact connection than the bolted option.

Heavily reinforced concrete beams may restrict the location of the anchors. This may be overcome using oversized connection plates with redundant anchor holes, or horizontal slots.

Where large brackets or connection plates are required, special consideration should be given to handling.

The lower seating plate should be able to resist any temporary loading that may occur during construction, prior to the upper bolted connections being made.

Moments are later transferred by push-pull effects which cause shear in the various bolt groups. The moment transfer is often limited by the moment or torsional capacity of the concrete structure, which should be checked.

Care should be taken if end plates are welded to the beam (as shown) and the connection is used externally, to ensure that the gap between the end plate and the connection plate can be maintained and will not cause water entrapment.

Design Checklist

Buildability

| | |
|-----------------|---|
| Site Operations | <ol style="list-style-type: none"> 1. Plate is located on an epoxy bed. 2. Holes are drilled and anchors are installed. 3. Beam is positioned on shims. 4. Bolts are installed. |
| Setting Out | Connection plate may be used as template. Seating may be pre-levelled using shims. |
| Skill Level | Special skills needed for site weld option. |
| Handling | Consider weight of connection plate. Seating minimises crane hook time. |
| Safety | Provides positive seating during erection. |

In-situ Adjustment

| | |
|-------------------|-----------------------|
| Horizontal | Slots or site welding |
| Vertical | Shims |
| Along Main Member | Slots in beam |

Load Transfer

| | |
|-------------------------------|--|
| Compression | L - M |
| Tension | Nominal |
| Shear | M - H limited by capacity of anchors connecting bracket to vertical face of concrete beam. |
| Moment | M - H moment limited by anchor shear and adjacent concrete |
| Connection stiffness/strength | Limits beam rotation |

Special Notes: Connection plate may need stiffeners

2.6 Steel Beam to Concrete Wall

Applications

- Connection of steel beams to new concrete walls.
- Connection of steel beams to deep downstand concrete beams.
- Connection of steel beams to existing walls.

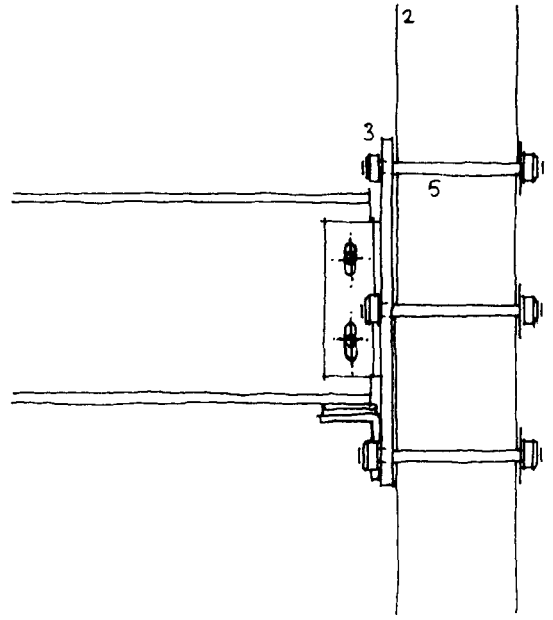
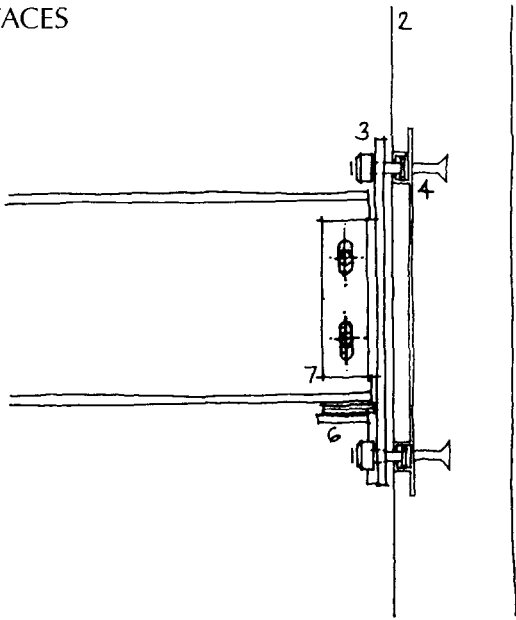
Construction

A pre-fabricated connection plate is bolted to the wall. Bolts may connect to cast-in channels or sockets, or through bolts may be used (particularly in relation to existing structures). In very light duty applications, expanding or chemical anchors may be used (Figure 9).

Where cast-in channels are used, these are fixed to the wall shuttering prior to the concrete being cast, and are normally strapped together to improve accuracy. Where through bolts are used, the connection plate can act as a drilling template.

The seating bracket is levelled using shims. The steel beam is then located and bolted to the web cleat. Horizontal shims may be installed, as required.

INTERFACES



1. Steel beam
2. Concrete wall
3. Connection plate on epoxy bed
4. Strapped together fixing channels
5. Through bolts in drilled holes
6. Seating bracket with optional stiffening fins
7. Shims for vertical adjustment
8. Shims for horizontal adjustment

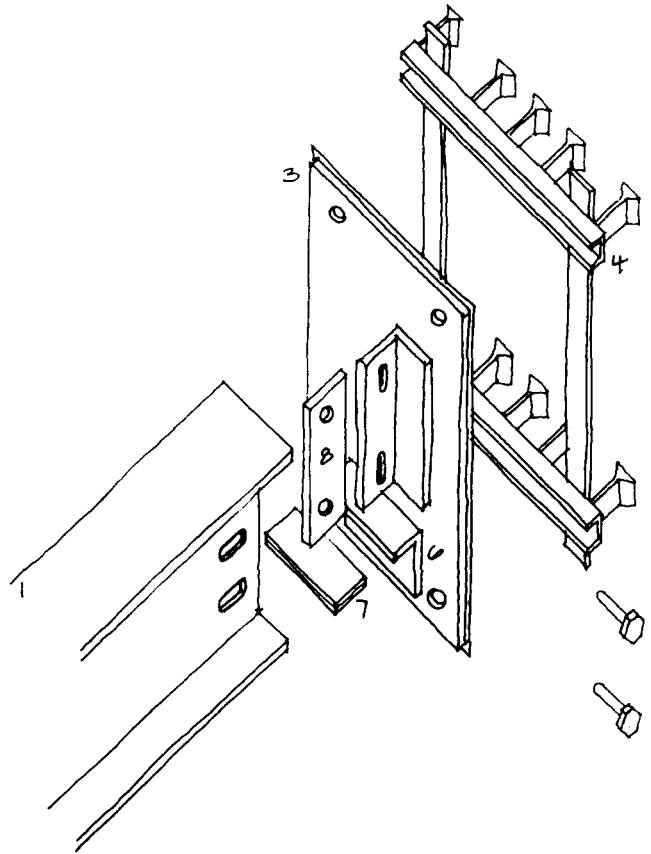


Figure 9
Schematic arrangement

Adjustments

- Vertical adjustment is by shims between the beam flange and the seating bracket, and slots in the fixing cleat.
- Fine horizontal adjustment is by shims between the beam web and the fixing cleat. Where cast in channels are used, coarse adjustments may be made at the connection.
- Adjustment along the main member is by slots in the beam web.

Load paths

The seating angle transfers vertical force during construction. If friction bolts are used through the slotted holes, the subsequent vertical force is transferred by the side angle cleat (Figure 10). If not, the seating angle should be assumed to resist all the load.

If friction bolts are used, consideration needs to be given to the additional forces arising from the connection rigidity.

1. Load on beam
2. Load on connection
3. Shear of anchors
4. Pull out due to eccentricity
5. Compression due to eccentricity
6. Tie forces (if required) by anchor tension or concrete bearing

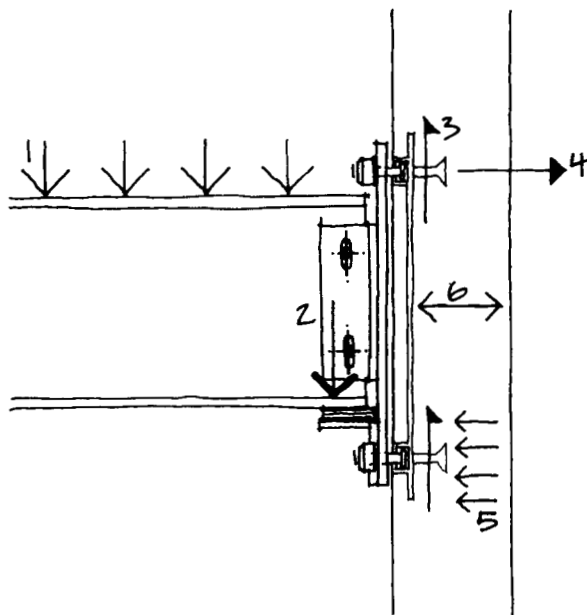


Figure 10
Load path diagram

Critical appraisal

Cast-in channels are easily installed during construction of new concrete elements. However, care should be taken to ensure accurate setting out, especially in the direction transverse to the axis of the channels.

Seating brackets permit safe temporary support of the steel beam, and are the means of load transfer prior to the beam being connected to the angle cleat.

Care must be taken to avoid excessive eccentricities as resistance is limited by the pull out capacity of cast-in channels. Where connections have to carry heavy loads or resist large eccentricities, through bolt options may prove most cost effective.

Design checklist

Buildability

| | |
|-----------------|--|
| Site Operations | <ol style="list-style-type: none"> 1. Channels are located and concrete is poured, or holes are drilled for through bolts depending upon detail. 2. Connection bracket is attached. 3. Beam is positioned on shim. 4. Bolts are installed. |
| Setting Out | Care required in locating cast-in channels in formwork |
| Skill Level | Normal |
| Handling | Consider the weight of the fixing plate. Seating minimises crane hook time. |
| Safety | Provides positive seating during erection. |

In-situ Adjustment

| | |
|-------------------|----------------------------|
| Horizontal | Cast in channels and shims |
| Vertical | Shims and slots |
| Along Main Member | Slots in beam |

Load Transfer

| | |
|-------------------------------|---|
| Compression | Nominal |
| Tension | Limited by cast-in channels |
| Shear | M - for cast-in channels M - H for through bolts |
| Moment | Not recommended |
| Connection stiffness/strength | Heavy loads and large eccentricities require particular consideration |

2.7 Steel Beam to Concrete Wall with Pockets

Applications

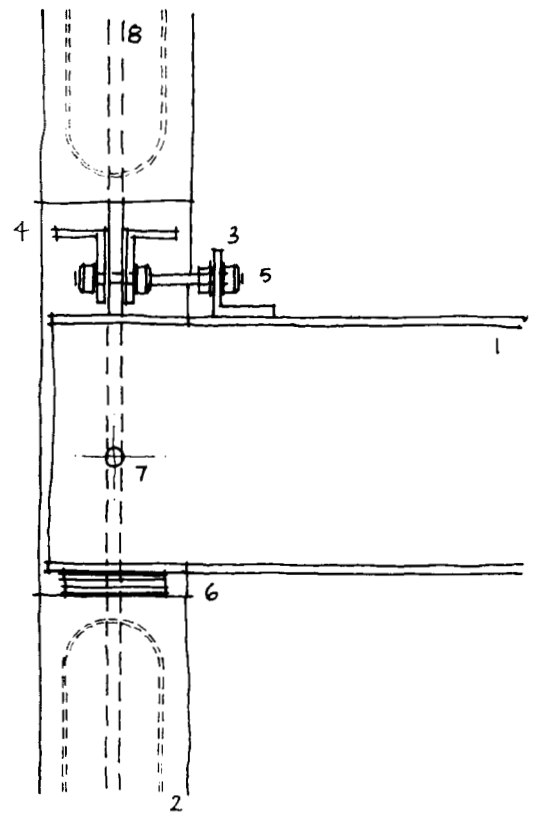
- Connection of steel beams to concrete core walls.
- Connection of steel beam to walls with preformed pockets.

Construction

An opening is cast in a concrete wall using specially designed box-outs in the formwork. A steel beam is introduced into the opening and is located using shims bedded on epoxy or grout. The beam is attached to the reinforcement in the wall to form a temporary connection, and the opening is infilled with well compacted concrete (Figure 11).

Shear studs or drag cleats may be welded to the steel beam during fabrication to enhance the anchorage into the concrete.

The reinforcement clamp detail may not be required if the beam is adequately restrained against longitudinal movement at its other end. When the clamp is omitted, consideration should be given to the effect that movement of the restrained end of the beam may have at the connection to the wall.



- 1. Steel beam
- 2. Concrete wall
- 3*. Bracket welded to beam
- 4*. Reinforcement bracket/clamp
- 5*. Connecting rod
- 6. Shims on grout bed
- 7*. Shear connector
- 8. Local additional reinforcement
- * Optional, do not omit both 4 & 7

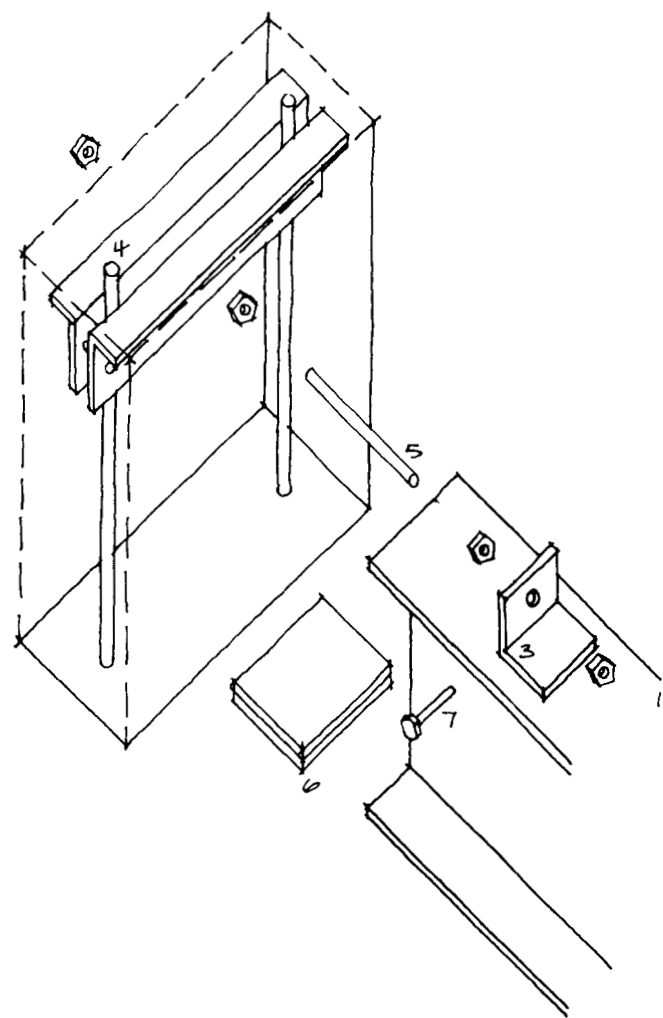


Figure 11
Schematic arrangement

Adjustments

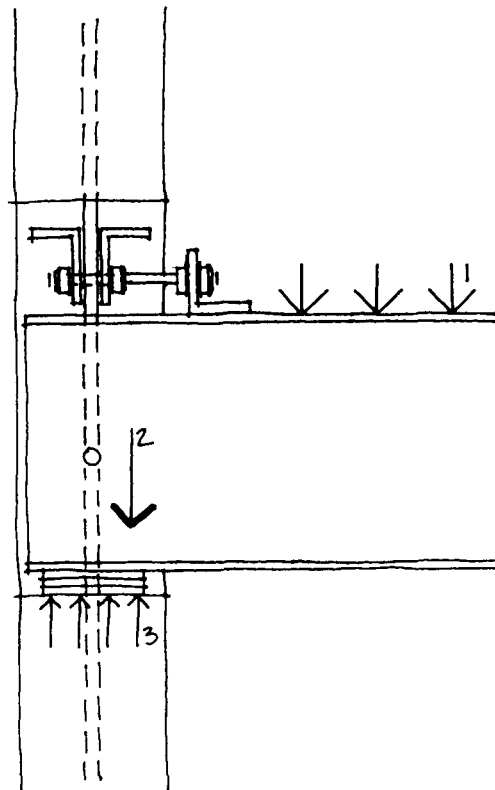
- Vertical adjustment is by shims between the concrete and the beam flange.
- Horizontal adjustment is by the fixing position of the reinforcement clamp. It is limited by the width of the opening in the wall.
- Adjustment along the main member is limited by the wall thickness, minimum bearing and the maximum permissible protrusion of the steel beam on the rear face of the wall.

Load paths

Vertical load transfer is by direct bearing of the beam on the wall beneath. Moment transfer is nominal (Figure 12).

1. Load on beam
2. Load on connection
3. Vertical action in bearing.

Figure 12
Load path diagram



Critical appraisal

This detail provides a simple connection that permits high levels of adjustment. Care is needed during construction if the stability of the beam relies on the concrete infill as this is installed after the beam has been positioned.

Where large axial forces must be transferred to the core by the beams, additional shear connectors may be required.

Design checklist

Buildability

| | |
|-----------------|---|
| Site Operations | <ol style="list-style-type: none"> 1. A pocket is formed in wall. 2. Beam is located on shim. 3. Beam is clamped to reinforcement. 4. Pocket is filled. |
| Setting Out | "Coarse" setting out of box-out in wall |
| Skill Level | Normal |
| Handling | Beam may be positioned quickly thus minimising crane hook time |
| Safety | Provides positive seating during erection. |

In-situ Adjustment

| | |
|-------------------|--|
| Horizontal | Large range possible |
| Vertical | Shims |
| Along Main Member | Limited by wall thickness and other factors (refer text) |

Load Transfer

| | |
|-------------------------------|-----------------------|
| Compression | L - M limited by wall |
| Tension | L - M limited by wall |
| Shear | L - M limited by wall |
| Moment | Nominal |
| Connection stiffness/strength | Monolithic joint |

Special Note: Consider beam stability before final concrete infill is completed.

2.8 Steel Beam to Concrete Wall without Pockets

Applications

- Connection of steel beams to slip formed concrete core walls.
- Connection of steel beams to concrete walls.
- Connection between steel beams and deep downstand concrete beams.
- Connection of steel beams to concrete columns.

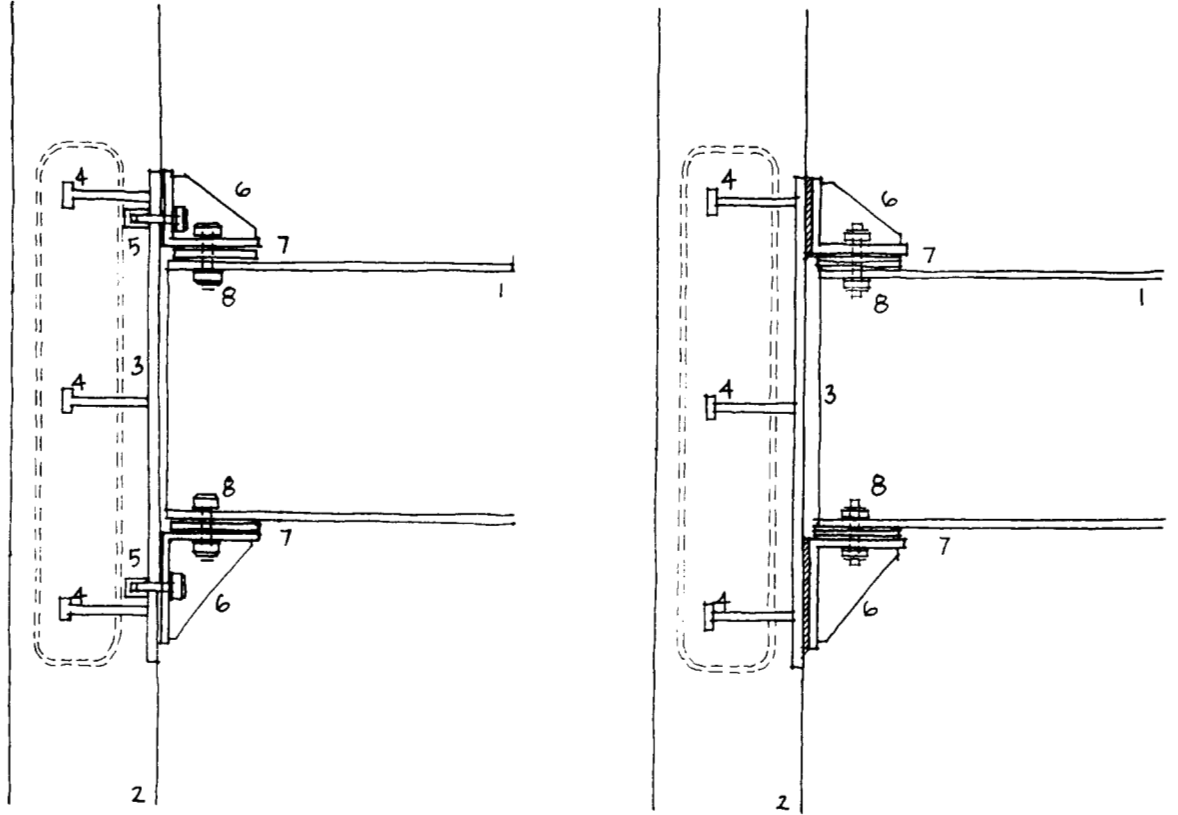
Construction

A steel connection plate is cast into a concrete wall, so that its surface is flush with the face of the concrete. The plate is pre-fabricated to include welded shear connectors and blind bolt fixings (Figure 13). Stiffened cleats are bolted to the connection plate (the lower cleat being intended to provide the main beam support, and the upper cleat being intended to restrain the top flange).

Blind bolt fixing caps may be fabricated from circular steel tubes, or an internally threaded socket may be welded to the back of the connection plate. Both arrangements must be suitably sealed to prevent any ingress of concrete. Captive nuts may be used to fix the plate to the formwork.

Where necessary, supplementary reinforcement may be required in the zone of the shear connectors.

INTERFACES



- 1. Steel beam
- 2. Concrete wall
- 3. Steel plate
- 4. Shear connectors
- 5. Blind bolt fixing
- 6. Stiffened cleat bolted to steel plate
- 6a. Stiffened cleat site welded to steel plate
- 7. Shims
- 8. HSFG
- 9. Supplementary reinforcement

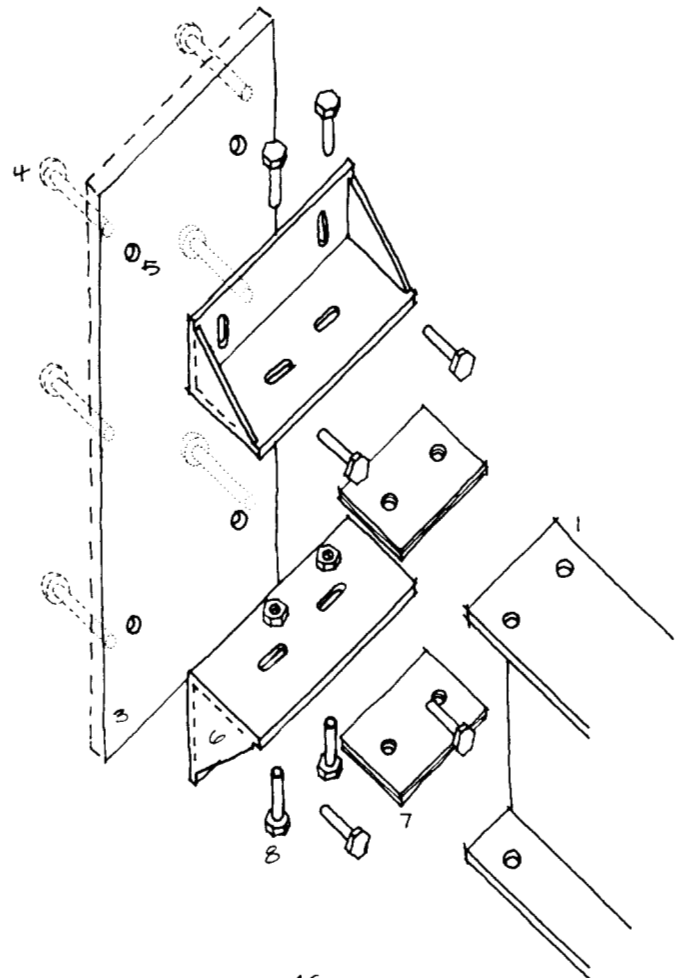


Figure 13
Schematic arrangement

Adjustments

- Vertical adjustment is achieved using shims between the beam and the cleats.
- Horizontal adjustment is by slotted holes in the cleats at the fixing to the beam.
- Adjustment along the main member is by slotted holes in the cleat at the fixing to the beam or by slotted holes in the beam flanges.

Load paths

Tension forces are limited by the shear resistance of the top and bottom bolts (Figure 14).

1. Load on beam
2. Load on connection
3. Shear at anchors
4. Pull-out due to eccentricity
5. Compression due to eccentricity
6. Tie forces (if required) by anchor tension or concrete bearing.

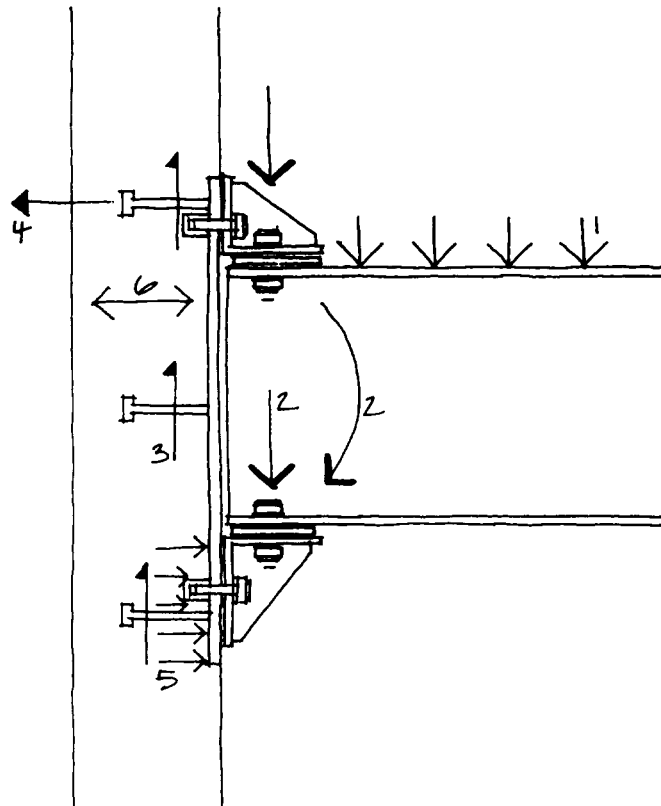


Figure 14
Load path diagram

Critical appraisal

This detail provides a reasonable degree of adjustment and safe temporary location of the steel beam.

The design and detail of the blind bolt fixing must ensure adequate run out of the bolt.

The connection plate is relatively heavy. It must be located accurately in the formwork and prevented from moving under the pressure of the wet concrete.

This detail can be easier to construct than alternative details based upon openings in the wall, as it does not require subsequent infilling.

A variation of this connection is to weld fixing cleats, or fixing and support cleats, to the embedded plate as opposed to using bolted details. In this case, it may be necessary to consider the heat sink effect of the concrete.

Design checklist

Buildability

| | |
|-----------------|--|
| Site Operations | <ol style="list-style-type: none"> 1. Plate is located in formwork and concrete is poured. 2. Cleats are installed. 3. Beam is positioned on shim. 4. Bolts are installed. |
| Setting Out | Care is needed to position the steel plate accurately in the wall formwork |
| Skill Level | Normal |
| Handling | Consider the weight of the steel plate. The lower cleat provides an immediate seating for the beam thus reducing crane hook time |
| Safety | Provides positive seating during erection |

In-situ Adjustment

| | |
|-------------------|-------------------------|
| Horizontal | Slots in cleats |
| Vertical | Shims |
| Along Main Member | Slots in cleats or beam |

Load Transfer

| | |
|-------------------------------|--|
| Compression | M |
| Tension | M |
| Shear | M |
| Moment | Must resist moments caused by eccentricities |
| Connection stiffness/strength | Beam rotation limited if HSFG bolts are used |

2.9 Steel Beam to Masonry Wall 1

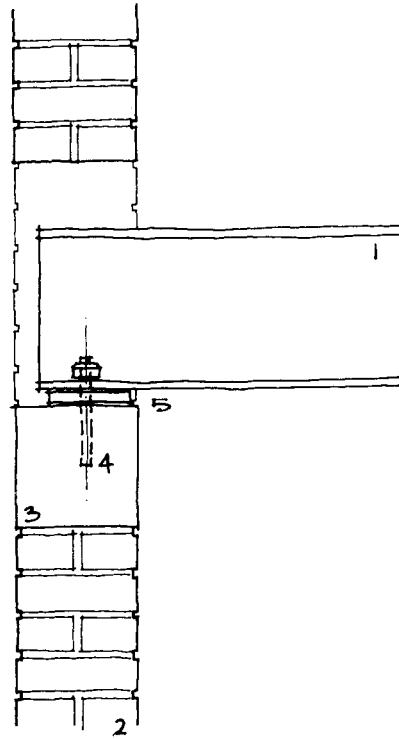
Applications

- Connection of simply supported steel beams to load-bearing masonry walls.

Construction

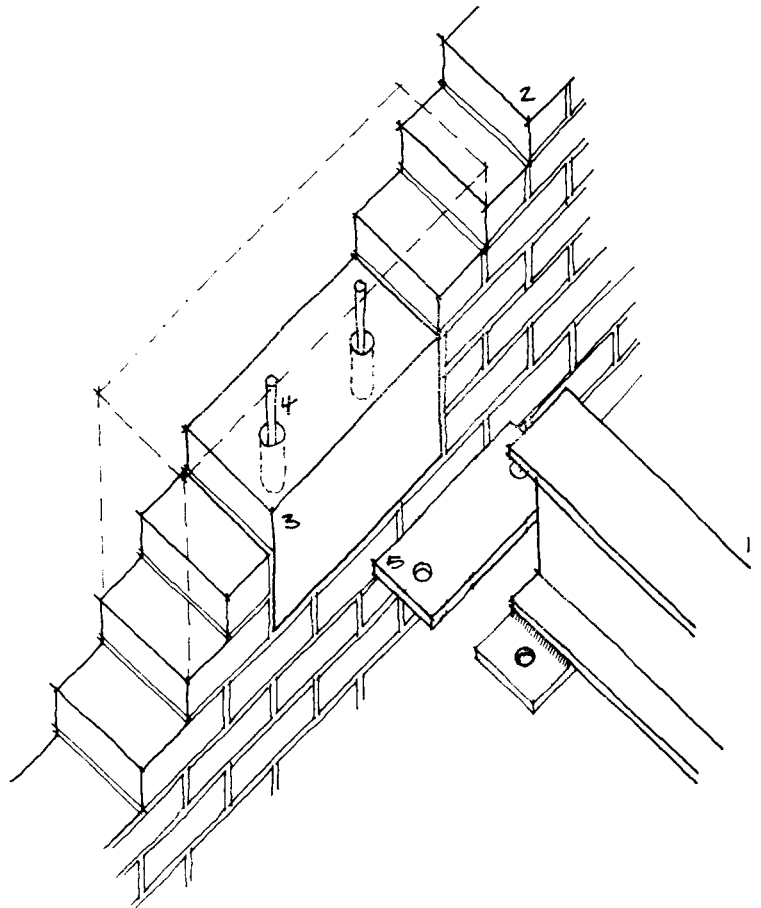
An opening is formed in the brickwork wall to accommodate a suitable padstone and allow for installation of the steel beam (Figure 15).

The padstone may be pre-cast or cast in-situ, and is designed to incorporate either cast-in bolts or bolt pockets. Oversized holes and plate washers may be used to provide adjustment where cast-in bolts are used, or additional adjustment where bolt pockets are used. The steel beam is lifted into place, set to line and level using shims, and bolted to the padstone. Bolt pockets are then grouted. The detail is completed by infilling the remaining part of the opening with masonry. If lateral restraint of the beam flange is required, it is important to ensure that masonry is packed tight around the beam.



- 1. Steel beam
- 2. Masonry wall
- 3. Padstone
- 4. Cast-in bolt or pocket
- 5. Shims

Figure 15
Schematic arrangement



Adjustments

- Vertical adjustment is by steel shims between the padstone and beam flange.
- Horizontal adjustment is by oversized holes in the beam flange or oversized bolt pockets.
- Adjustment along the main member is by slotted holes in the bearing plate or over-sized bolt pockets.

Load paths

1. Load on beam
2. Load on connection
3. Vertical reaction
4. Nominal tie force capacity

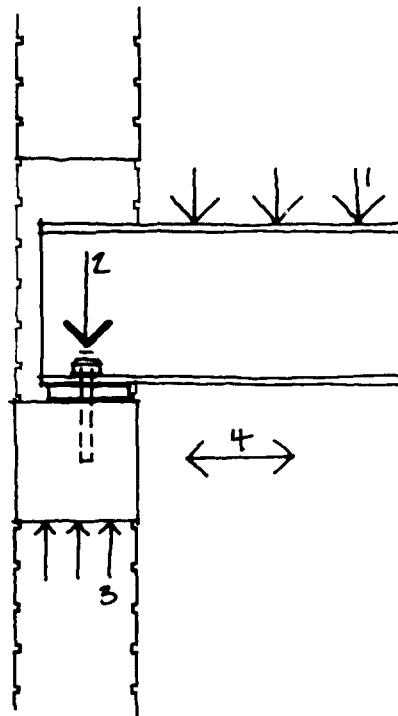


Figure 16
Load path diagram

Critical Appraisal

This is a simple traditional detail that permits a reasonable range of adjustment. The padstone should be sized to achieve proper dispersion of the beam reaction into the masonry wall. Where possible, however, the weight of the padstone should be light enough to allow safe installation by two operatives. Cast in-situ and recently pre-cast padstones must be allowed to cure to an appropriate strength before loading.

In party walls, the depth of the opening and of the padstone should be limited to half the wall thickness and any local eccentricities should be considered.

If the concrete is visible externally, care should be taken to achieve a suitable finish on the exposed surface.

Design checklist

Buildability

| | |
|-----------------|--|
| Site Operations | <ol style="list-style-type: none"> 1. Concrete padstone is cast in-situ or precast padstone is installed. 2. Beam is positioned on shims. 3. Beam is bolted in position. 4. Infill masonry is constructed. |
| Setting Out | Generally not critical. Care required at party walls. |
| Skill Level | Normal |
| Handling | Opening in wall should be large enough to manoeuvre beam into place. Consideration should be given to the weight of the padstone. |
| Safety | Padstone provides positive seating |

In-situ Adjustment

| | |
|-------------------|----------------------------|
| Horizontal | Oversized holes or pockets |
| Vertical | Shims |
| Along Main Member | Slotted holes or pockets |

Load Transfer

| | |
|-------------------------------|--------------------------------|
| Compression | Nominal |
| Tension | Nominal |
| Shear | L - M limited by wall capacity |
| Moment | Not recommended |
| Connection stiffness/strength | Nominal |

Special Notes: Consider wall stability and local strength of party walls. Plate washers required if oversized holes are used. Small local shims may be used in conjunction with grout, to replace full sized shims illustrated.

2.10 Steel Beam to Masonry Wall 2

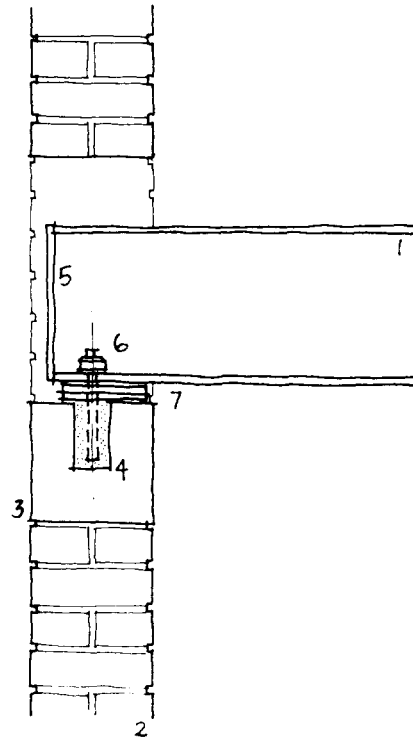
Applications

- Connection of simply supported steel beams to load-bearing masonry walls.

Construction

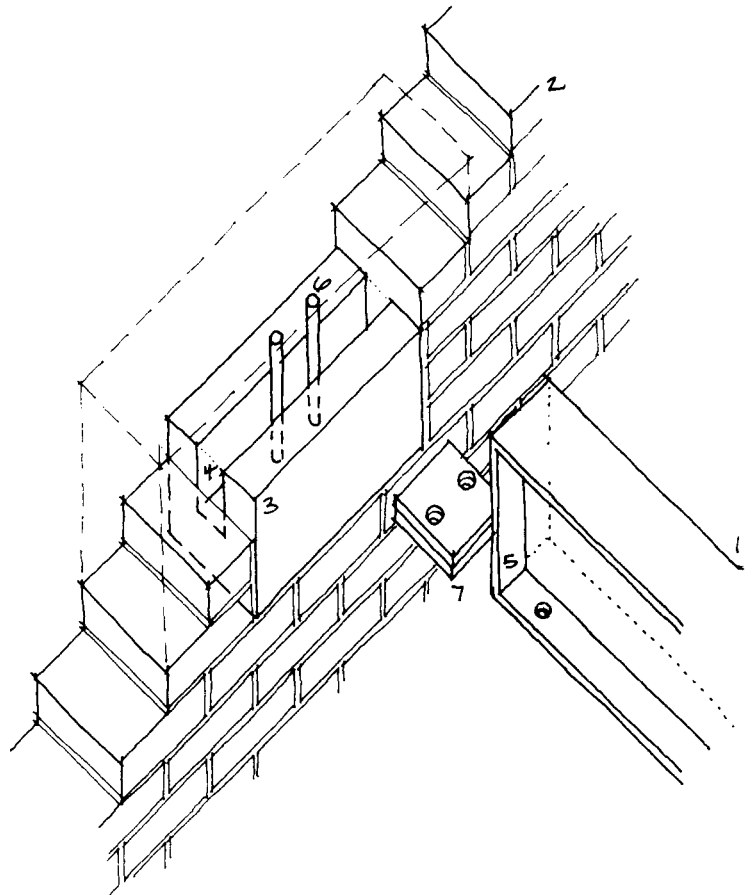
An opening is formed in the brickwork wall to accommodate a suitable padstone and allow for installation of the steel beam (Figure 17).

The padstone incorporates a cast-in slot and is set to line and level on a mortar bed. The steel beam is located on shims and fixed using bolts grouted into the slot in the padstone. The detail is completed by infilling the remaining opening with masonry. If lateral restraint is required to the beam flange, it is important to ensure that masonry is packed tightly around the beam.



1. Steel beam
2. Masonry wall
3. Padstone
4. Cast-in slot
5. End plate
6. Grouted bolt
7. Shims

Figure 17
Schematic arrangement



Adjustments

- Vertical adjustment is by steel shims between the padstone and the beam flange.
- Horizontal adjustment is by the bolt position in the padstone slot.
- Adjustment along the main member is by the bolt position and possible slotted holes in the beam flange.

Load paths

1. Load on beam
2. Load on connection
3. Vertical reaction
4. Nominal tie force capacity

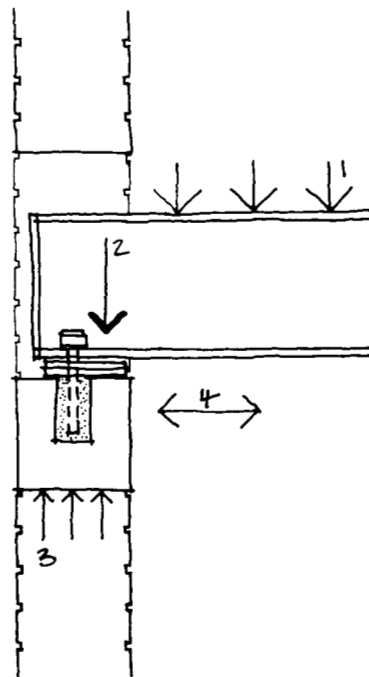


Figure 18
Load path diagram

Critical appraisal

The padstone should be sized to achieve proper dispersion of the beam reaction into the masonry. Where possible, the size of the padstone should be limited to allow safe installation by two operatives.

In party walls the depth of the opening and of the padstone should be limited to half the wall thickness and the effect of local eccentricities should be considered. Padstones can be difficult to place in existing walls.

Design checklist

Buildability

| | |
|-----------------|--|
| Site Operations | <ol style="list-style-type: none"> 1. Concrete padstone is installed. 2. Beam is positioned on shims. 3. Beam is bolted in position and grout is introduced. 4. Infill masonry is constructed. |
| Setting Out | Generally not critical Care required at party walls |
| Skill Level | Normal |
| Handling | Opening in wall should be large enough to manoeuvre beam into place. Consideration should be given to the weight of the padstone |
| Safety | Padstone provides positive seating |

In-situ Adjustment

| | |
|-------------------|--|
| Horizontal | Cast-in slot |
| Vertical | Shims |
| Along Main Member | Cast-in slot and possible slots in beam flange |

Load Transfer

| | |
|-------------|--------------------------------|
| Compression | Nominal |
| Tension | Nominal |
| Shear | M - H limited by wall capacity |
| Moment | Not recommended |

Special Notes: Consider wall stability and local strength of party walls. Small local shims may be used in conjunction with grout, to replace full sized shims illustrated.

2.11 Steel Beam to Masonry Wall 3

Applications

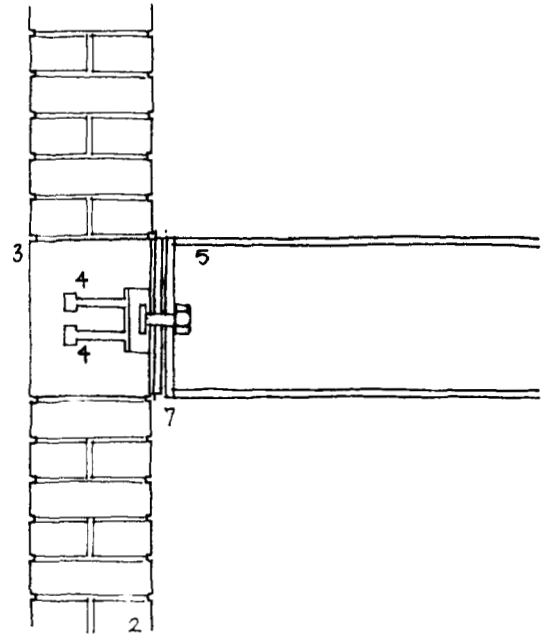
- Connection of simply supported steel beams to load-bearing masonry walls

Construction

A padstone, with toothed channels on the exposed face is either built into the brickwork (new construction); or is installed into a specially formed opening in the masonry (refurbishment). Padstones may be constructed in-situ or may be pre-cast. Bolted connections to the toothed channels provide vertical shear transfer (Figure 19).

Eccentric loading is resisted by the push/pull reaction of the beam end plate and the tensile action of the bolts used to attach the beam to the channels.

Through bolts may be considered for single brick or party walls, where the padstone may not have sufficient depth to support channel details.



1. Steel beam
2. Masonry wall
3. Padstone
4. Cast-in toothed channel
5. End plate
6. Slot in end plate
7. Finger packs to channel
manufacturers' recommendations

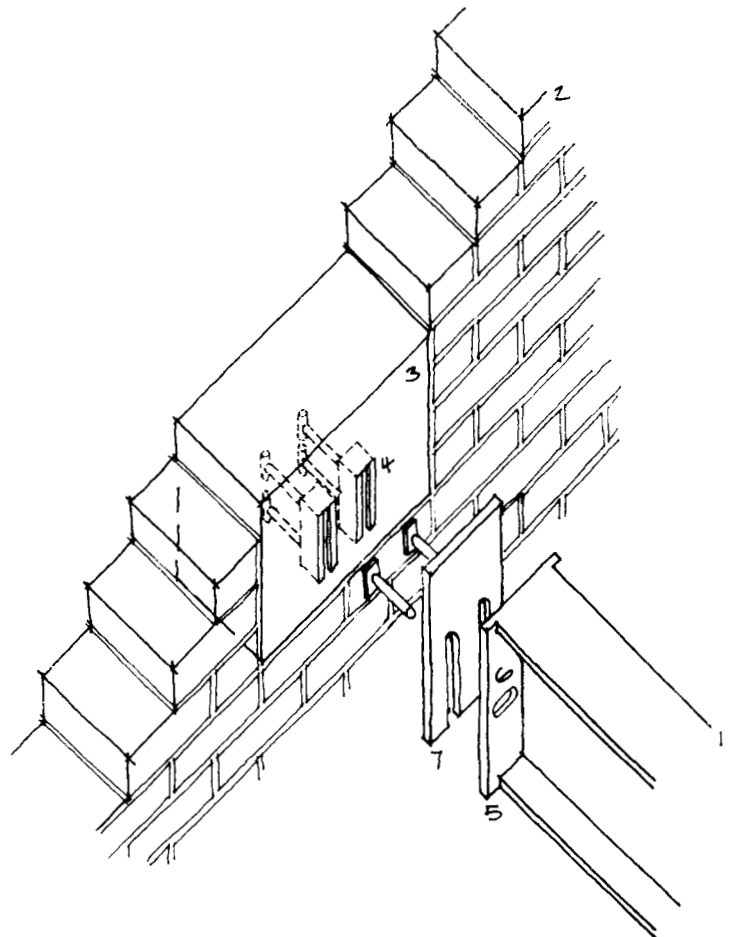


Figure 19
Schematic arrangement

Adjustments

- Vertical adjustment is by toothed channels.
- Horizontal adjustment is by slotted holes in the beam end plate.
- Adjustment along the main member is by finger packs between the end plate of the beam and the face of the padstone.

Load paths

Vertical load transfer is limited by shear in the bolts and the capacity of the toothed channels (Figure 20).

1. Load on beam
2. Load on connection
3. Vertical reaction
4. Shear at connection
5. Nominal tie force capacity

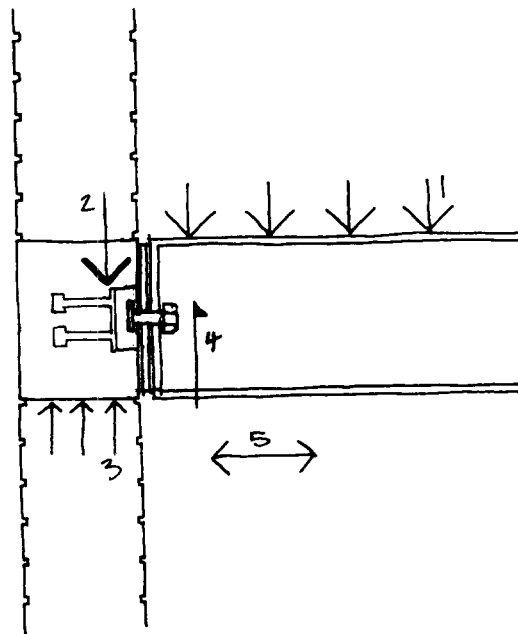


Figure 20
Load path diagram

Critical appraisal

The detail is only recommended where the wall is narrow or where it may be necessary to remove the beam.

The padstone should be sized to achieve proper dispersion of the beam reaction into the masonry. Where possible, however, the size of the padstone should be limited to allow safe installation by two operatives. Adjustment of the position of the beam once the padstone has been installed can be relatively limited.

In party walls, the depth of the opening and of the padstone should be limited to half the wall thickness, and local eccentricities should be considered.

The beam must be supported temporarily prior to being bolted in place.

Design checklist

Buildability

| | |
|-----------------|---|
| Site Operations | <ol style="list-style-type: none"> 1. Concrete padstone is installed. 2. Beam is positioned and temporarily supported. 3. Beam is bolted in place. |
| Setting Out | Horizontal placing of padstone is most critical |
| Skill Level | Normal |
| Handling | Consideration should be given to the weight of the padstone. |
| Safety | Consider installation of padstone |

In-situ Adjustment

| | |
|-------------------|--------------------|
| Horizontal | Slots in end plate |
| Vertical | Toothed channels |
| Along Main Member | Finger packs |

Load Transfer

| | |
|-------------------------------|---|
| Compression | L limited by wall |
| Tension | Nominal |
| Shear | L limited by capacity of bolts and toothed channels |
| Moment | Not recommended |
| Connection stiffness/strength | Low |

Special Notes: Consider wall stability and local strength of masonry walls.

2.12 Steel Beam to Existing Concrete Column 1

Applications

- Connections of steel beams to existing reinforced concrete columns.
- Connections of steel beam to existing reinforced concrete walls.

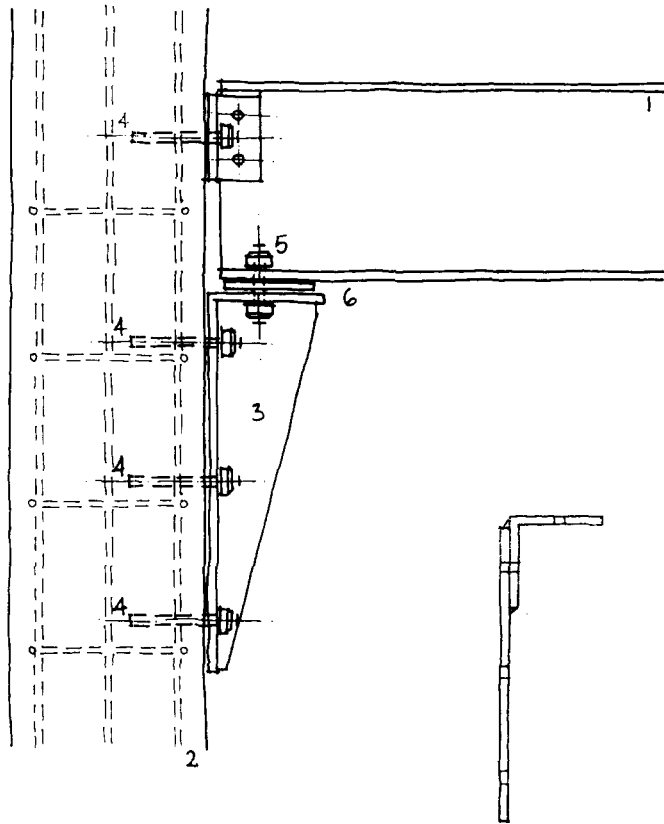
Construction

Anchor holes are set out using a template, and are positioned to avoid reinforcement (see Section 1.3).

A pre-fabricated seating bracket set on an epoxy bed is bolted to the column face, using drilled and grouted bolts, or expanding anchors (Figure 21). Edge distances must be considered particularly where expanding anchors are used, owing to the forces that they induce in the concrete.

The steel beam is placed on the bracket and bolted down. Restraint cleats are located using expanding anchors. Alternatively, the face plate may be extended and a welded web cleat incorporated into the design.

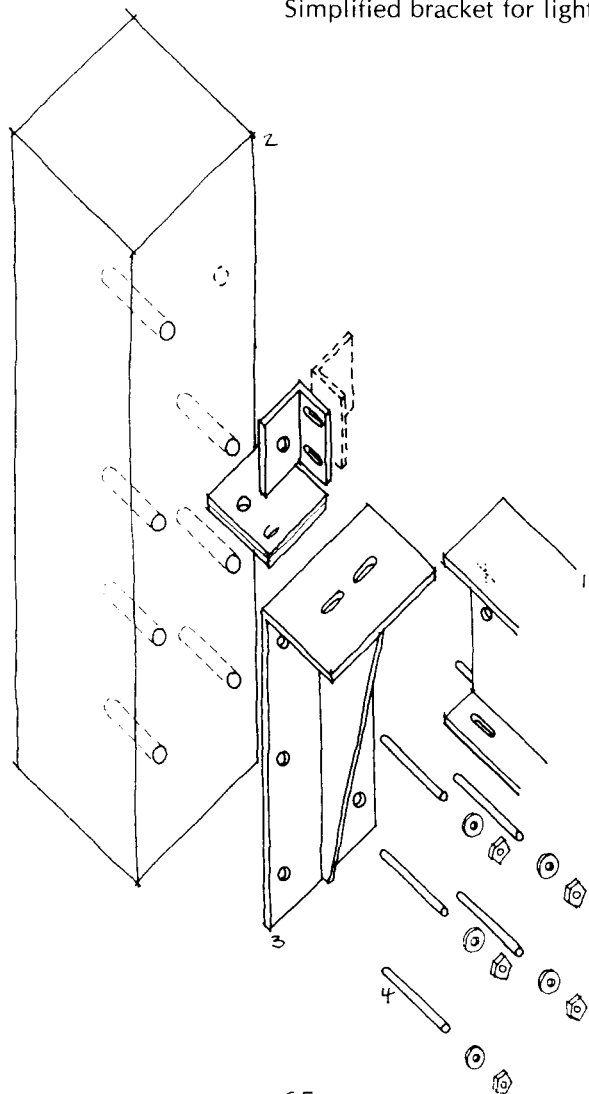
The seating bracket may be fabricated from plate (as illustrated), or from cut rolled sections. Alternatively, a horizontal angle welded to a plate may be appropriate for lighter loads.



Simplified bracket for light load

1. Steel beam
2. Concrete column
3. Seating bracket on epoxy bed
4. Drilled and grouted bolts or expanding anchors
5. Bolts
6. Shims

Figure 21
Schematic arrangement



Adjustments

- Vertical adjustment is by shims between the beam flange and the seating bracket.
- Horizontal adjustment is by slotted holes in the top plate of the seating bracket.
- Adjustment along the main member is by slotted holes in the beam.

Load paths

The number of expanding anchors determines the ability for shear transfer (Figure 22).

1. Load on beam
2. Load on connection
3. Shear on anchors
4. Pull-out due to eccentricity
5. Compression due to eccentricity
6. Lateral restraint
7. Tie forces (if required) by anchor tension or concrete bearing.

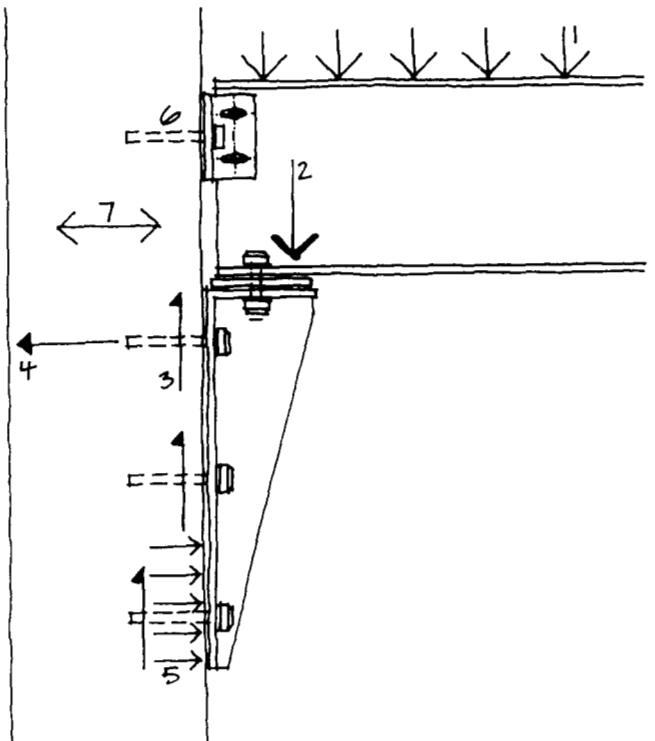


Figure 22
Load path diagram

Critical appraisal

For a given load, the principal influences on the size of the seating bracket will be the necessary anchor spacings and edge distances. Where it is possible to diamond core to the opposite face of the column, through bolts may be used in grouted holes. These tend to reduce the size of the connection.

If possible, the column reinforcement arrangement should be established before preparing working drawings and fabricating brackets. If this is not possible, then redundant holes may be drilled in the seating bracket. Redundant holes do, however, increase the depth of the bracket.

Design checklist

Buildability

| | |
|-----------------|---|
| Site Operations | <ol style="list-style-type: none"> 1. Holes are drilled for expansion anchors. 2. Connection bracket is installed. 3. Beam is located on shims. 4. Bolts are installed. |
| Setting Out | Column reinforcement should be located and brackets designed accordingly |
| Skill Level | Normal |
| Handling | Consider the weight of the seating bracket. Seating minimises crane hook time |
| Safety | Provides positive seating during construction |

In-situ Adjustment

| | |
|-------------------|--------------------------|
| Horizontal | Slots in seating bracket |
| Vertical | Shims |
| Along Main Member | Slots in beam |

Load Transfer

| | |
|-------------------------------|----------------------------------|
| Compression | Nominal with HSFG bolts |
| Tension | Nominal with HSFG bolts |
| Shear | M - H limited by anchor capacity |
| Moment | Not recommended |
| Connection stiffness/strength | Nominal rotation stiffness |

2.13 Steel Beam to Existing Concrete Column 2

Applications

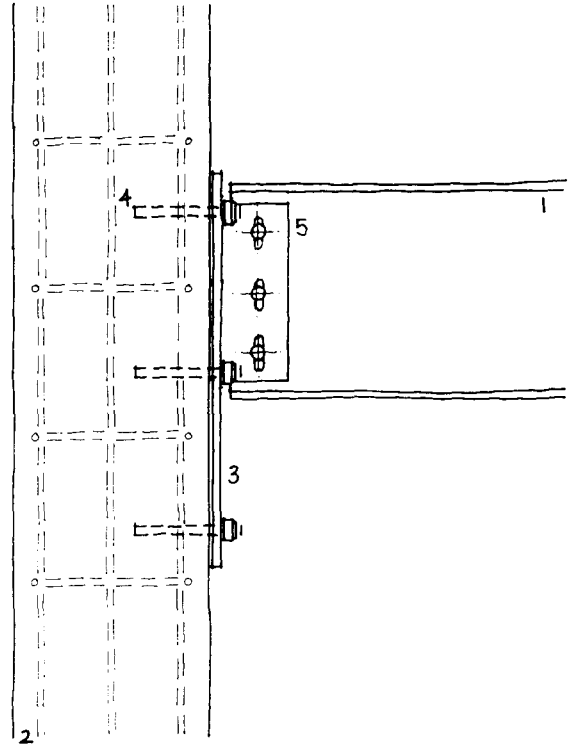
- Connection of steel beams to existing reinforced concrete columns.
- Connection of steel beams to existing reinforced concrete walls.

Construction

Steel reinforcement in the column is located using a covermeter and confirmed by pilot drilling or chasing the column face. Anchor holes are set out using a template and positioned to avoid reinforcement (Figure 23).

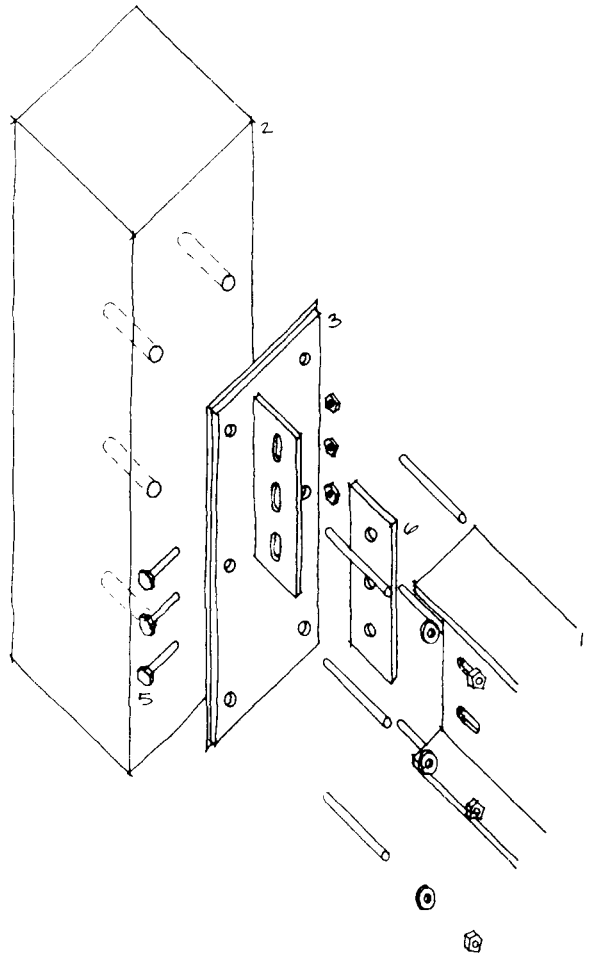
A pre-fabricated steel connection plate set on an epoxy bed is bolted to the column face, using expanding anchors. The steel beam is connected to one side of a welded web cleat and positioned using shims. The beam is bolted in place using high strength friction grip (HSFG) bolts.

INTERFACES



1. Steel beam
2. Concrete column
3. Connection plate on epoxy bed
4. Expanding anchors
5. HSFG Bolts
6. Shims

Figure 23
Schematic arrangement



Adjustments

- Vertical adjustment is by slotted holes in the fin plate.
- Horizontal adjustment is by shims between the fin and beam web.
- Adjustment along the main member is by slotted holes in the beam web.

Load paths

If friction grip bolts (HSFG) are used, consideration needs to be given to the additional forces arising from the connection rigidity.

1. Load on beam
2. Load on connection
3. Shear on anchors
4. Pull-out due to eccentricity
5. Compression due to eccentricity
6. Tie forces (if required) by anchor tension or concrete bearing.

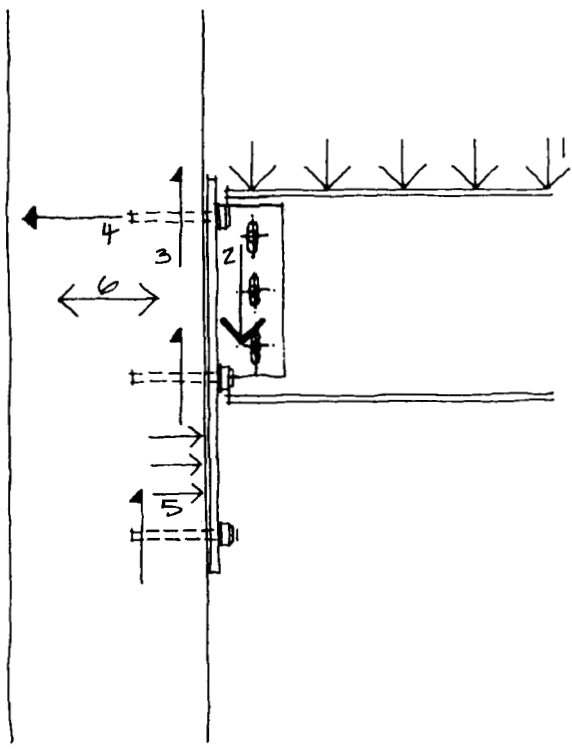


Figure 24
Load path diagram

Critical appraisal

For a given load, the principal influence on the size of the connection plate will be the recommended anchor edge distances and spacings. Where it is possible to diamond core to the opposite face of the column, through bolts may be used in grouted holes. These tend to reduce the size of the connection.

If possible, the column reinforcement arrangement should be established before preparing working drawings and fabricating brackets. Only limited adjustment is possible once the plate and fixings are located.

Design checklist

Buildability

| | |
|-----------------|--|
| Site Operations | <ol style="list-style-type: none"> 1. Holes are drilled for expansion anchors. 2. Connection is installed. 3. Beam is positioned using shims and bolted in place. |
| Setting Out | Column reinforcement should be located and brackets designed accordingly |
| Skill Level | Normal |
| Handling | Consider the weight of the bracket |
| Safety | Care must be taken when temporary bolting is used to ensure that bolts do not move in slotted holes |

In-situ Adjustment

| | |
|-------------------|--------------------|
| Horizontal | Shims |
| Vertical | Slots in beam |
| Along Main Member | Slots in fin plate |

Load Transfer

| | |
|-------------------------------|----------------------------------|
| Compression | L - M limited by column |
| Tension | Nominal |
| Shear | M - H limited by anchor capacity |
| Moment | Nominal |
| Connection stiffness/strength | Nominal rotational stiffness |

Special Note: A seating cleat may be incorporated to facilitate easier erection.

2.14 Steel Hanger from Existing Concrete Beam

Applications

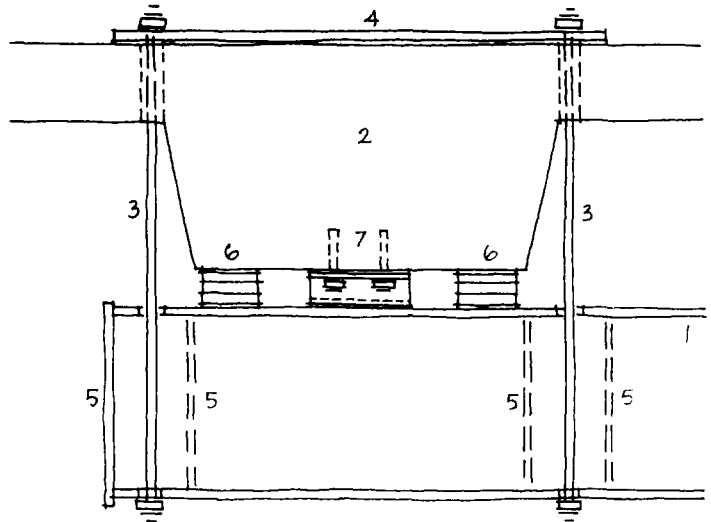
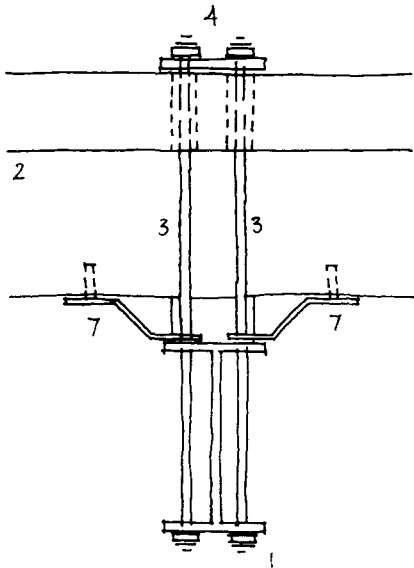
- Connection of new steel beams to existing concrete beams.

Construction

Hangers are bolted to a large steel plate set across the top of the concrete beam on an epoxy bed (Figure 25). Two smaller plates (one for each set of hangers) may be used for lighter loads.

The steel beam is attached to the hangers and set to level using shims between the top flange of the beam and the concrete soffit. Where the clamping action is not considered adequate to restrain the shims, these shims should be tack-welded to the beam.

If lateral restraint is required at the connection, a simple folded plate bracket may be used to connect the beam to the concrete soffit. Web stiffeners may be needed at the hanger locations.



1. Steel beam
2. Concrete beam
3. Steel hangers, lock nuts and plate washer
4. Thick plate on epoxy bed
5. Stiffeners
6. Shims
7. Restraint bracket (post fixed folded plate) if required.

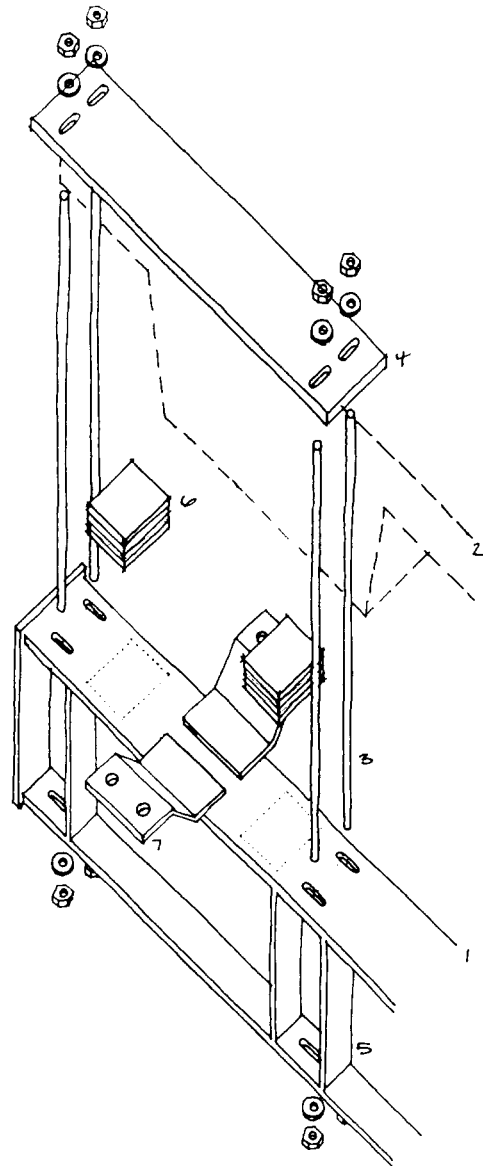


Figure 25
Schematic arrangement

Adjustments

- Vertical adjustment is achieved by altering the length of the hanger and packing the hanger connection using shims.
- Horizontal adjustment is by slotted holes in the top plate and oversized holes in the concrete through which the hangers are suspended.
- Adjustment along the main member is by slotted holes in the beam flange.

Load paths

Vertical load transfer is via the rods. Longitudinal load transfer is mainly achieved by the clamping forces between the steel and concrete beams.

1. Load on beam
2. Tension in hangers
3. Concrete bearing
4. Lateral restraint (if required)

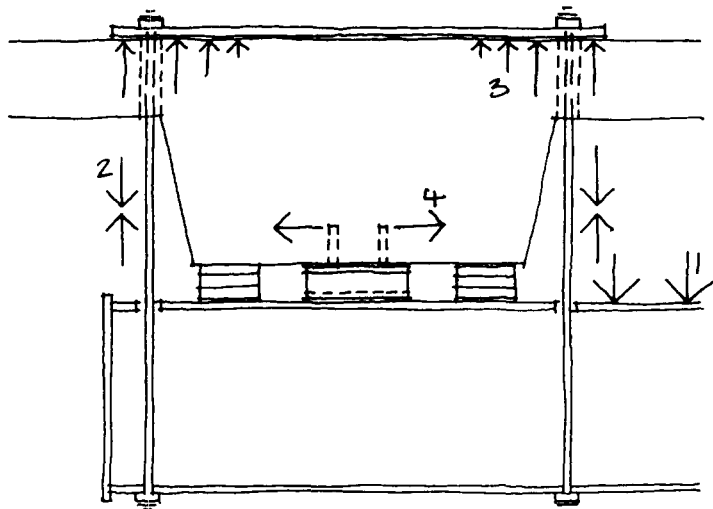


Figure 26
Load path diagram

Critical appraisal

The connection is relatively simple. The length of the connection is determined by the beam width.

The gap between the top of the steel beam and the bottom of the concrete beam should not be so large that the shims or packers become unstable. A maximum gap of 50 mm is suggested.

Consideration should be given to the influence of beam rotation on the distribution of forces between the two pairs of hangers. Tension in the member nearest the centre of the beam may increase to balance the compression in the outer shims.

Design checklist

Buildability

| | |
|-----------------|--|
| Site Operations | <ol style="list-style-type: none"> 1. Holes are drilled for hangers. 2. Hangers and top plate are installed. 3. Beam and shims are installed. |
| Setting Out | Normal procedures |
| Skill Level | Normal |
| Handling | Consider the weight of the top plate. Temporary support may be required for the steel beam. Raising a beam under an existing floor may pose particular handling problems. |
| Safety | Care must be taken if vertical drilling into the floor soffit is required. The design of any temporary support for the steel beam must be carefully considered. |

In-situ Adjustment

| | |
|-------------------|-----------------------------|
| Horizontal | Oversized holes in concrete |
| Vertical | Shims |
| Along Main Member | Slots |

Load Transfer

| | |
|-------------------------------|---|
| Vertical - up | Through existing construction |
| Vertical - down | Through rods |
| Horizontal | Through clamping action |
| Moment | Not usually required |
| Connection stiffness/strength | If hangers are clamped to the beam, some fixity is provided |

Fire Protection

| | |
|---------|-------------------------------|
| General | Ensure top plate is protected |
|---------|-------------------------------|

2.15 Steel Prop to Existing Concrete Floor

Applications

- New steel columns to support existing concrete floors or beams.

Construction

The steel column is installed directly onto the floor slab or beam. Non-structural screeds may need to be broken out at the column base. Bolt fixings at the top and bottom are for location and to resist nominal horizontal loads (Figure 27).

The column is set to line and level using steel wedges or shims under the baseplate. Subsequently, locating bolts at the top of the column are installed and hand tightened, and an epoxy or mortar bed is formed between the top plate and the concrete soffit. Alternatively, the epoxy or mortar bed may be applied to the top plate prior to the column being levelled, and may be compacted by the levelling operation.

When the top bed joint has cured sufficiently, the upper locating bolts are tightened, and the connection is completed by installing the lower locating bolts, and grouting the bottom bed joint.

Column base plates may be designed with oversized holes, or additional redundant holes to allow locating bolts to be positioned to avoid existing reinforcement in the concrete slabs.

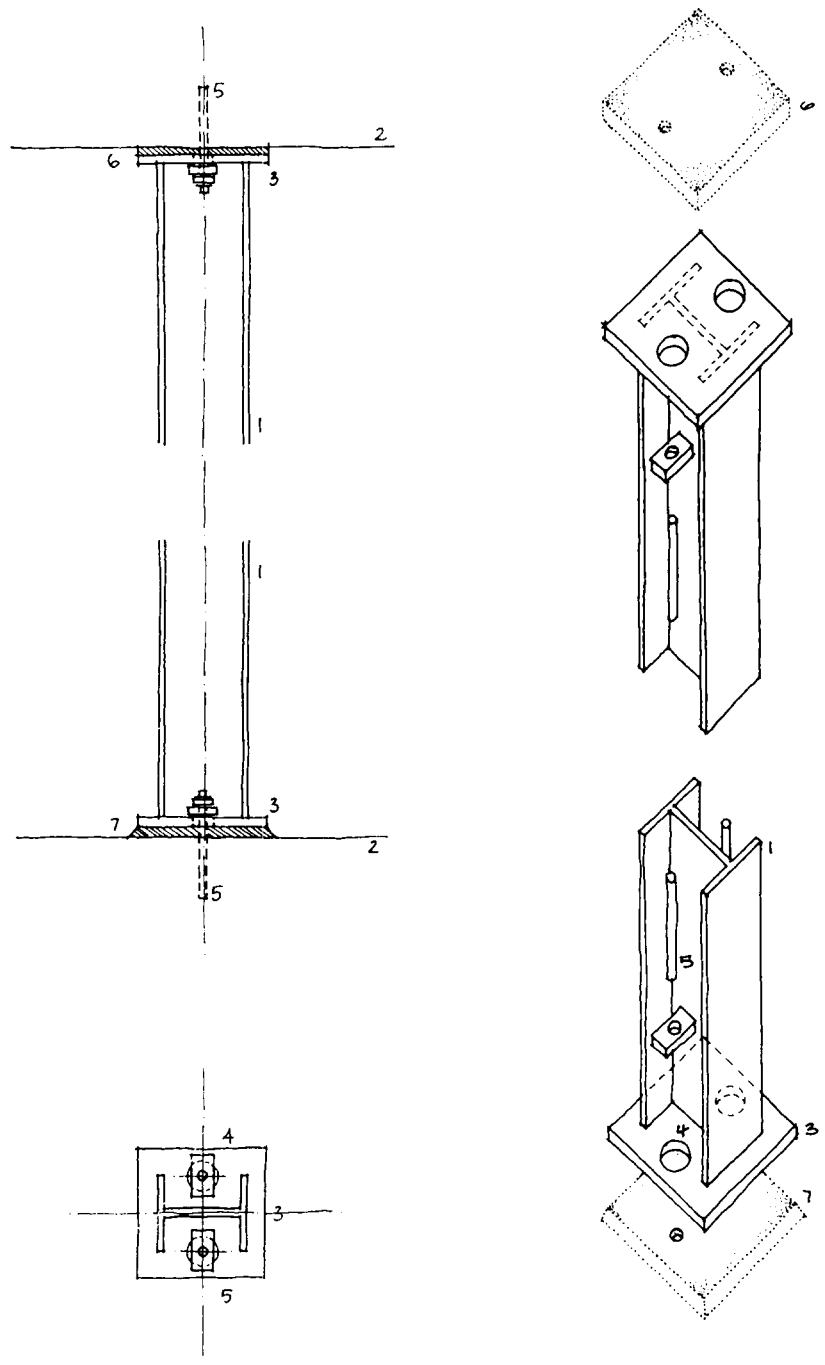


Figure 27
Schematic arrangement

1. Steel column
2. Concrete slab
3. Base plate
4. Oversized hole
5. Post drilled anchor with plate washer
6. Epoxy or mortar bed
7. Shims and epoxy or grout

Adjustments

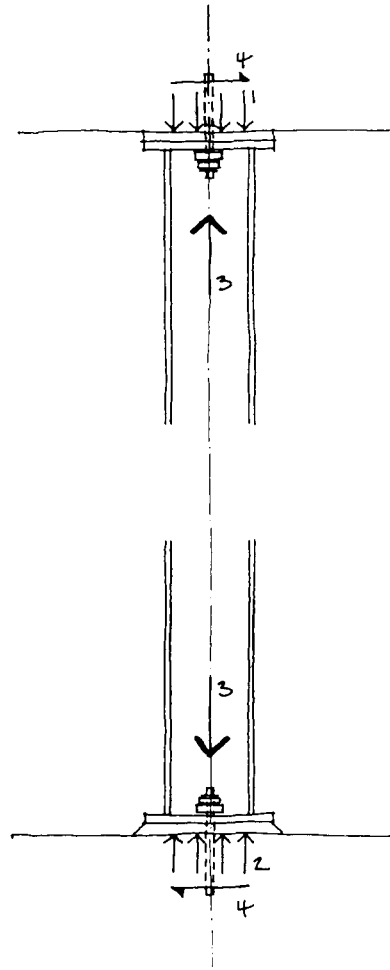
- Horizontal adjustment in the two orthogonal directions is by oversized holes or use of redundant holes.
- Vertical adjustment is by steel shims (or wedges) between the lower column baseplate and the concrete slab.

Load paths

Unless the column is jacked, or otherwise stressed, to achieve precompression, significant load transfer will generally only occur after the floor, or beam, above the column has displaced under loading.

1. Load on column
2. Bearing
3. Compression in column
4. Lateral restraint (frictional resistance and possible shear of bolts)

Figure 28
Load path diagram



Critical appraisal

This is a very simple detail with a minimum number of components. The principal forces are transferred by direct bearing. Consideration should be given to the thickness of bed joints, in order to achieve a reasonable standardisation of column lengths, and allow the column to be lifted from the horizontal to the vertical position without the top plate hitting the concrete soffit. As a guide, the top bed should be in the range 10 mm - 25 mm and the lower bed should be in the range 25 mm - 50 mm. The total gap should exceed $w^2/2\ell$, where w is the width of the end plate and ℓ is its length.

Where controlled load transfer is required, flat jacks may be installed between the lower base plate and the structural slab level. These jacks ensure that the column is pre-compressed against the floor and therefore no further movement is required before load transfer takes place. Flat jacks may be injected with epoxy grout and left in place. Alternatively arrangements can be made for the jacks to be removed after packing and grouting.

Design checklist

Buildability

| | |
|-----------------|---|
| Site Operations | <ol style="list-style-type: none">1. Holes are drilled in the concrete structure for fixings.2. Column is set to line and level using wedges.3. Anchors are installed at the column head and an epoxy or mortar bed is formed.4. Column is jacked up and anchors are installed at the column base5. A second epoxy or mortar bed is formed beneath the column base. |
| Setting Out | A template may be used for locating bolt holes |
| Skill Level | Normal or special if flat jacks are used |
| Handling | Column lengths should normally allow the member to be manoeuvred from horizontal to vertical without hitting ceiling |
| Safety | Consider temporary use of the locating bolts |

In-situ Adjustment

| | |
|------------|-----------------|
| Horizontal | Oversized holes |
| Vertical | Shims |

Load Transfer

| | |
|-------------------------------|---------------------------------|
| Compression | M - H |
| Tension | Not usually required |
| Shear | Nominal, through locating bolts |
| Moment | Not normally required |
| Connection stiffness/strength | A robust detail |

APPENDIX A - Fixings in Concrete and Masonry

CIRIA Technical Note 137: 1991, *Selection and use of fixings in concrete and masonry: Interim update to CIRIA Guide 4*, reviews the types of fixings available, and discusses their behaviour and use. Some recommendations based on this guide are given below:

GENERIC TYPES OF FIXINGS

1. Cast-in fixings

- internally threaded sockets
- externally threaded projecting studs
- hot formed (thick wall) channel insets
- cold formed (thin wall) channel insets.

2. Expanding fixings

The expanding action of sleeves or wedges exerts a radial force to produce a combination of indentation and friction against the sides of a drilled hole. Most fixings have to be tightened to a correct torque. The different forms of fixings may be classified by the means of clamping action that they achieve. Fixing diameters (expressed in terms of the shank) are typically in the range of 8 to 25 mm. The different types are:

- loose metal shell or sleeve
- thick metal shell or sleeve
- thin metal shell or sleeve
- double expanding cone
- plastic or rubber sleeve
- under-ream (or undercut).

Undercut fixings are often preferred in cracked concrete but require a more complex drilling operation to form the undercut. A wide range of proprietary fixings is available.

3. Resin or grouted fixings

Anchorage is achieved principally by the bonding action of an adhesive against the sides of a drilled hole. Some interlocking between the hardened adhesive and irregularities in the hole profile adds mechanical keying to the total strength of the anchor. Full bond can only develop when the bonding surfaces are clean

and free of loose dust. The three basic types of resin anchor are:

- encapsulated (glass or plastic phials) resin
- cementitious grout
- proprietary injection system.

BEHAVIOUR UNDER LOAD

In most applications the loading is either in the form of shear, or a combination of shear and tension. Few applications will be pure tension (commonly called pull-out). Indeed, creep effects on expanding anchors mean that their behaviour under sustained pure tensile load requires a high factor of safety to be applied. Manufacturer's technical data is generally however based upon pull-out tests.

Load capacity depends on the:

- strength and condition of the base material
- embedment length
- fixing spacing when in a group
- distance to the edge of the base material
- use of slotted holes
- whether a static or cyclic load is applied.

A factor of safety of about 3.5 is usually applied to obtain the safe working load (or 2 to obtain the design capacity for factored load design).

DISPLACEMENT

Load/displacement characteristics have three sequential stages:

- initial fixity
- first slip, not recoverable
- displacement to failure. •

The performance of fixing assemblies should generally be based on the tensile load at which first slip occurs. Limits for displacement used for calculating safe working loads for products certified by the British Board of Agrément are 0.1 mm (tensile loading) or 1.0 mm (shear loading).

TEMPERATURE

At elevated temperatures, particularly those associated with fire, resin anchors tend to soften or lose strength. In such cases, the anchors should be insulated by surface protection. Expansion anchors generally lose strength at the rate similar to that of

the materials that they connect (i.e. steel and concrete) and so special measures are not usually required.

DRILLING HOLES

- Covermeters may be used to estimate the location of reinforcement.
- Pilot drilling or chasing may be used to confirm the location of reinforcement prior to connections being installed.
- Smooth hole profiles, arising from the use of diamond drills, may need to be roughened particularly where resin anchors are used.
- Drills should be matched to drilling machines to ensure maximum drilling efficiency and correct hole shapes.

TESTING

The relevant standard for testing fixings is:

BS 5080: Structural Fixings in Concrete and Masonry:

Part 1: 1993 Method of test for tensile loadings.

Part 2: 1993 Method for determination of resistance to loading in shear.

The scope of testing is a matter of engineering judgement related to the assumptions made in the design, and the likely consequences of connection failure.

It is important to distinguish between tests used to confirm a design (which should be regarded as prototype testing) and tests used to verify that correct installation has been carried out.

APPENDIX B - Grouts and Resins

Grouts and resins are used extensively in the connection of steel to concrete and masonry:

- as part of a fixing (see Appendix A)
- to transfer loads (e.g. under a column base plate)
- as bedding between steel and concrete
- to seal gaps for fire resistance.

GENERIC TYPES

1. Proprietary systems

These fall into two main groups and are available in low strength, high strength and creep resistance grades.

(i) Non-shrink Cementitious

These are generally pre-batched, dry-bagged products based on cement and sand, with a range of admixtures to help control workability, shrinkage and strength. Defined quantities of water are added on site.

Dry mix proportions are controlled by the manufacturer and can be customized to meet specific project requirements. The resulting grouts can be either pourable or spreadable grades. They are generally used as an alternative to dry pack, as bearing surfaces, or in conjunction with anchor systems.

(ii) Resins

These are generally two-part epoxy-based chemical products. The constituents parts are mixed together on site to start a chemical setting process. The 'pot life' of resins can be relatively short.

Encapsulated products have their constituents proportioned by the manufacturer and sealed in a glass or plastic phial. Where proportioning is carried out on site, effective quality control is essential.

These products are generally more expensive than cementitious grouts, and tend to be used in

small quantities as part of anchor assemblies. Handling instructions given by manufacturers must be followed.

Low temperatures during construction may influence the reaction and curing of resins, leading potentially to poor bond and loss of strength.

2. Simple grouts

These are grouts mixed on site from traditional building materials: sand, cement and water. In some circumstances cement replacement products may be used (e.g. pfa) or chemical admixtures. It is difficult to control batching quality and consistency and so simple grouts tend to be used in non-critical locations.

3. Dry pack

This is typically mixed on site from sharp sand and cement. The minimum amount of water necessary to achieve the hydration reaction is used. The mixture is rammed into place to give a high degree of compaction. Dry pack has very low shrinkage characteristics.