Case Studies in Structural Engineering 6 (2016) 63–75

Contents lists available at ScienceDirect

Case Studies in Structural Engineering

journal homepage: www.elsevier.com/locate/csse

Current UK trends in the use of simple and/or semi-rigid steel connections

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ARTICLE INFO

Article history:
Received 22 March 2016
Accepted 10 May 2016
Available online 16 June 2016

Keywords:
Steel
Connections
Simple
Survey
Fabrication
Industry

ABSTRACT

This paper presents the findings of an internet based survey conducted on members of the UK steel construction industry. The survey was in the form of an online questionnaire that was open from April to October of 2015. The purpose of the survey was to aid the development of a programme of full scale dynamic testing on UK standard simple and/or semi rigid steel connections. The information that was obtained is of use to both the wider academic community and the steel industry itself. Findings of the survey indicate how often tubular box sections are used on projects, the most popular methods of connecting open sections to box sections, preferred choice of fasteners in blind connections, preferred methods of connecting open section beams to open section columns, how often stainless steel bolts are currently being used on construction projects and finally some additional comments on the design of simple and/or semi-rigid connections are presented that were provided by survey respondents.

1. Introduction

Simple and/or semi-rigid steel connections are commonly used to connect structural members together in the construction of steel framed buildings within the UK. The terms ‘simple’ and ‘semi-rigid’ refer to the connection being designed to resist shear and axial forces only (i.e. assumption of pin-joint behaviour and no bending moments). The term semi-rigid is used to cover scenarios where the size of connecting and/or connection elements may be such that the connection is classified as semi-rigid in accordance with BS EN 1993-1-8 [1], but is still designed without consideration of any bending moments that might be present due to the lever-arms in the bolt rows or as a result of the partial fixity attracted by an increased joint stiffness.

From April to October of 2015, an online based questionnaire survey was carried out on the steel construction industry to try to establish common practices and trends in the design, specification and fabrication of such connections. The motivation behind the survey was to inform the development of a dynamic testing programme for industry standard simple connections typically found in the UK based design guidance, commonly termed ‘The Green Book’ [2]. This testing programme is being developed to study the behaviour of such connections in blast and/or impact scenarios and forms part of a PhD study into the resilience of simple and/or semi-rigid connections under highly transient loading conditions. The information obtained from the survey may also be of use to both the academic and industry based communities.

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http://dx.doi.org/10.1016/j.csse.2016.05.004

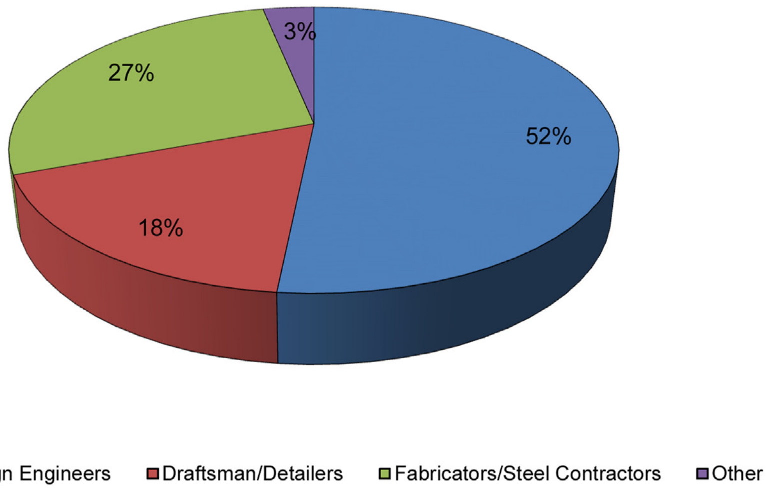

Fig. 1. Demographic of industry survey respondents.

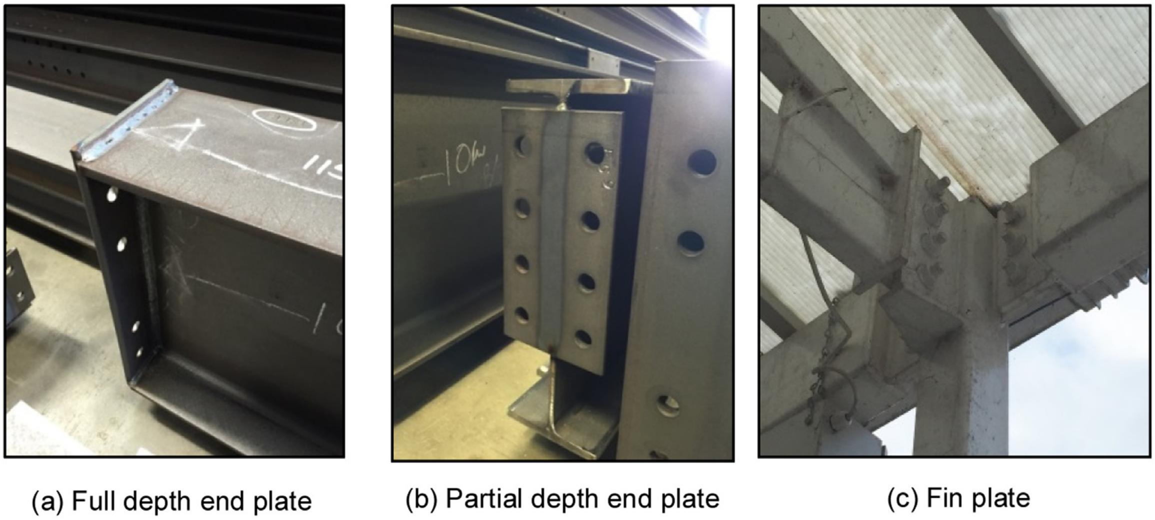

Fig. 2. Most common three connections forms typically found in the UK.

All *relevant* members of the UK Steel Construction Institute (SCI) and the British Constructional Steel Association (BCSA) were contacted (via email) about the survey. This amounted to 227 companies and from this 62 individual responses were obtained. Each company had the purpose of the survey explained to them and were provided with a hyperlink to the URL of the online survey page, assurance of anonymity was also given. No respondent was able to view any findings of the survey at any stage in the process to avoid any potential influence on question response. Feedback on the findings could be requested by the respondent providing an email address at the end of the survey, respondents that did this are to be sent a more detailed findings report post publication of this paper.

It was important to categorise the results of the survey by occupation of the respondents to capture different occupational points of view. This was achieved by making the first question of the survey about what role or position that the respondent held within the steel construction industry. The occupational demographic of the respondents was as shown in Fig. 1.

The 3% 'other' category comprised one quantity surveyor and one technical manager of a cold rolled manufacturer; this was deemed too low to be representative and therefore was neglected. It should be noted that the findings of this survey should not be taken as given fact but rather as a quantification of mass opinion. They (the findings) may be used as a guide to academics and industry practitioners on what some of the common trends are and the reasons such trends exist from a practical and economical view point.

The three most common standardised simple beam to column connection details that are used in the UK are shown in Fig. 2. These are the connection details that are discussed throughout the paper.

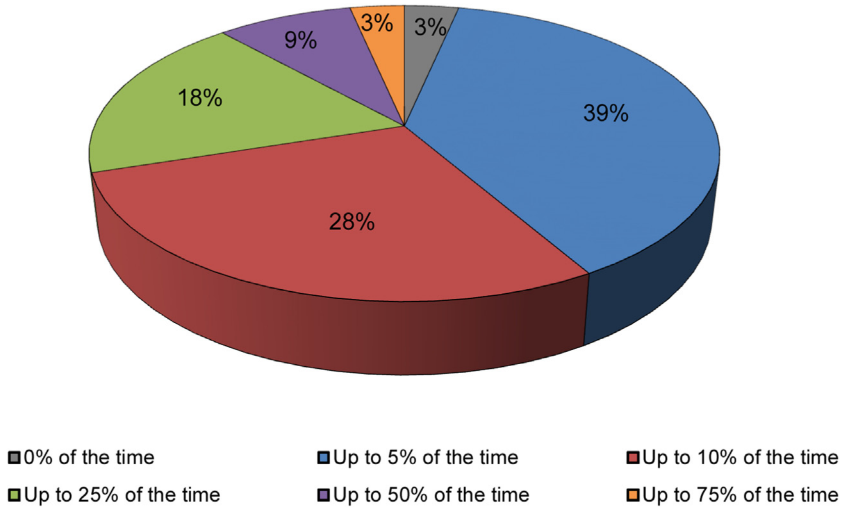

Fig. 3. How often the survey respondents have encountered projects where box sections were the primary columns.

2. Use of tubular box sections as primary columns

One of the purposes of the survey was to establish how often box sections (SHS's and RHS's) are used as the primary structural columns in steel frames to establish if it would be a wise use of research funding to test connections adjoining open sections with box sections. Overall the survey indicated that a total of 97% of the survey population encountered projects in which box sections were the primary columns however, as expected, the usage was low as can be seen in Fig. 3.

The reasoning behind the low occurrence of use is likely to be attributed to the practicality and complexity of connecting primary beams (open or closed) to the closed column section as well as a connection cost factor. Fin plate details are a common method of connecting to box section columns but extra care is required during the erection process because eccentricities can accumulate and induce torsional stresses into the fin plate, acting around its weak axis, which would not have been accounted for in the connection design. The use of end plates would relieve this concern but carries a cost implication. Two plates would be required per connection (one welded to the beam, and one welded to the box section) rather than just one (welded to the beam) if connecting to an open section column and they would have to be over-sized plates to accommodate ordinary bolts. If blind fixings were to be used, then only one plate (welded to the beam) would be required but there is a different cost implication to consider. A quick online price check, depending on supplier and order quantity, can show that the for the same cost, four times the amount of ordinary bolts can be purchased than blind fixings. It is also not possible to visually inspect blind fixings after installation as only the bolt head is visible, yet correct installation is critical to their functionality. Connecting box section beams to box section columns using fin plate details is possible but this carries a greater cost implication as three sections of plate material are required per connection (one welded to the column, and two welded together perpendicular to one another then welded to the beam). Box sections also possess lesser facility to accommodate the installation of stiffeners, meaning larger connection components are usually required to provide additional strength. From a practical point of view it is more difficult for an erector to work around a box section than an open section as there are no real edges on a box section to grab hold of for balance.

In situations where box sections were used as primary columns, it was found from the survey that the most popular method of forming a connection between them and open sections was to use a fin plate connection (Fig. 4). The second most popular method was to weld a stub to the box section that mirrors the incoming connecting beam cross-section to enable a splice connection to be achieved (Fig. 5), 19% of the survey population indicated this to be their favoured option in this situation.

If Fig. 4 is to be broken down again with the respondents categorised by occupation then the Design Engineers, Draftsmen/Detailers and Fabricators/Steel Contractors contained populations of 55, 91 and 88% respectively for the preference of using fin plates. For welding on a stub, the same occupational breakdown was 32, 0 and 6% respectively. Respondents were also asked what their reasoning was for their choice of answer. Some of the most common reasons are summarised in Table 1.

Design Engineers were the only occupational group to contain a population who indicated their preferred method of connecting an open section to a box section to be scenario dependent, i.e. rather than have a set preferred connection detail in mind, the survey respondent prefers to assess a design situation on its own merit and choose a connection detail best suited for that particular situation as appropriate.

The option of connecting an open section to a box section using either a partial depth end plate or full depth end plate made up very little of the responses. If, however, this connection detail was unavoidable, it was asked of the survey respondents

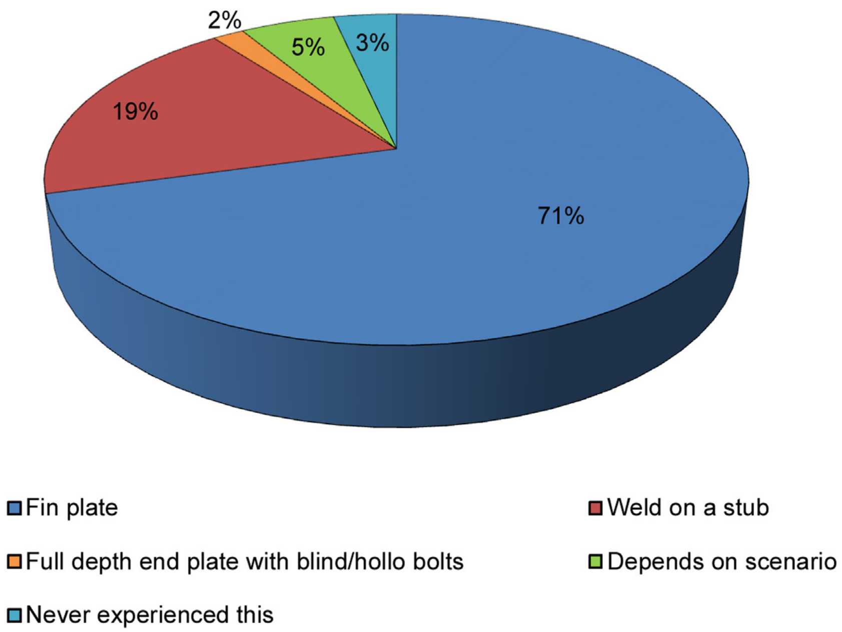

Fig. 4. Preferred method of connecting an open section beam to a rectangular or square box section column.

Table 1
Summarised reasons provided by survey respondents for using a fin plate to connect primary open sections to box section columns.

Design Engineers Reasons	Draftsmen/Detailers Reasons	Steel Contractors/Fabricators Reasons
Ease of fabrication	Cheap and simple	Cheapest option
Simplicity	To aid erection	Ease of fabrication
Cheapest option	Ease of detailing	Ease of erection
Convenience on site	Least amount of welding	Minimal amount of welding
Avoiding difficulty of through bolts	Least amount of cutting & drilling	–

Table 2
Summarised reasons provided by survey respondents for preference of specifying the use of Hollo-Bolts in a blind connection.

Design Engineers Reasons	Draftsmen/Detailers Reasons	Steel Contractors/Fabricators Reasons
More simple to design	More contact area than blind bolts	Blind bolts susceptible to being pulled out if rotated
Preference of fabricator	Higher strength capacity	Blind bolts not manufactured to ISO specification
Previous experience of premature failure of blind bolts	–	Readily available technical information
Ease of ensuring correct installation	–	Cover any lack of fit better
Hollo-bolts have the backing of their manufacturer	–	–
Readily available technical information	–	–
Higher strength capacity	–	–
Experience of 'toggle' when using blind bolts	–	–

whether they preferred to use Hollo-Bolts or Blind Bolts (Fig. 7) as fasteners. These are the two standard products used for blind fixings in the UK, and design information for both is contained within The Green Book. The overall finding for preference of Blind Bolts or Hollo-Bolts is shown in Fig. 6.

Little reason was given by the survey respondents for the use of Blind Bolts, one respondent stated that there is a reduced hole diameter in the hollow section supporting member when Blind Bolts are used and another stated that their preference of using Blind Bolts was down to bad experiences on site with Hollo-Bolts in the past. The reasons respondents gave for preferring Hollo-Bolts were much more thorough and have been summarised in Table 2.

Some of the respondents stated that Hollo-Bolts are a propriety product by a single manufacturer (Lindapter) that has readily available technical information on their website [3] which complies with ISO standard quality assurances. Some went further to say that Blind Bolts are made by any number of manufacturers and therefore technical properties of the bolt may vary from manufacturer to manufacturer and that a contractor may use a cheap alternative to one of the ISO standard quality manufacturers. In 2009, the Blind Bolt Company commissioned the SCI to carry out testing on their products to verify their load capacities against capacities derived using BS5950-1 [4] & BS EN 1993-1-8 [1]. The capacities of blind bolts were derived from this testing and a copy of the testing report [5] can be found on the Blind Bolt Company website [6]. It also contains

Fig. 5. Typical stub detail for connecting an open section beam to a box section column.

design procedures for engineers to use. Users of Hollo-Bolts should also bear in mind that only the type HB Hollo-Bolt, which is the original expansion type Hollo-Bolt, is CE marked at the time of writing.

3. Connecting open section beams to open section columns

Question eight of the survey was related to the preferred method of connecting an open section beam to an open section column. The survey respondents were asked '*when connecting an I/H shaped beam to an I/H column, do you prefer to use/specify*. . .' and the options were listed as:

- Full depth end plate
- Partial depth end plate
- Fin plate
- Web cleats
- Scenario dependent

The overall response to question eight was not as clear cut as it was for preferred methods of connecting to box sections. Fig. 8 shows the percentage of the overall survey population that chose each connection method listed above:

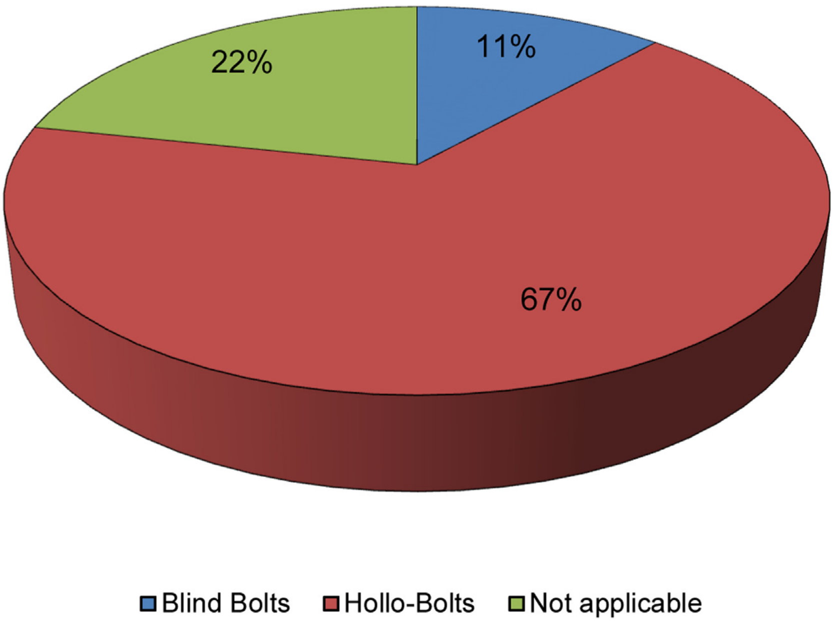

Fig. 6. Survey respondent's preference for specifying Hollo-Bolts or Blind Bolts on blind connections.

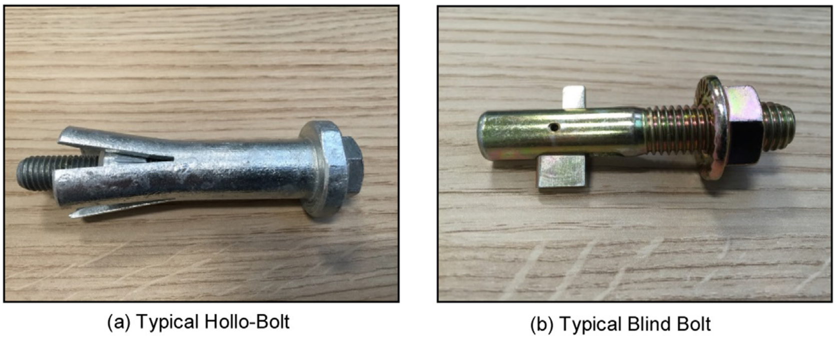

Fig. 7. Main standardised blind fixings used in the UK for fastening steel elements together.

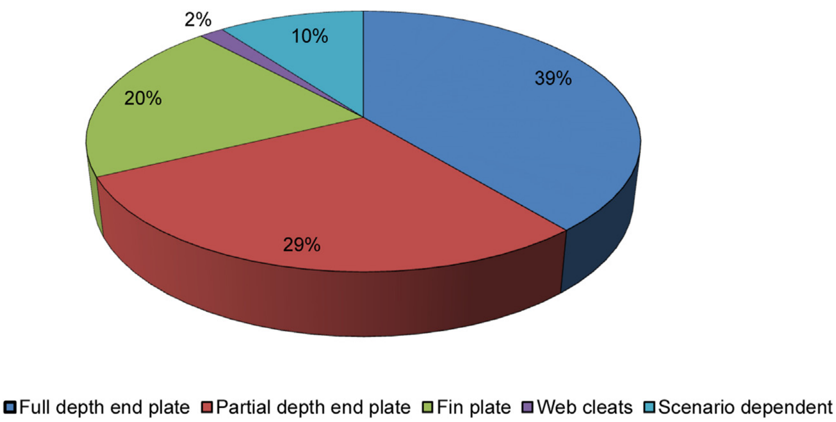

Fig. 8. Survey respondents preferred method of connecting an open section beam to an open section column.

Table 3
Approximate guide of how much welding work is required to achieve a given leg length [12].

Leg length of weld (mm)	Minimum number of passes required to achieve leg length
6	1
8	1 (2 by lesser skilled welder)
10	3
12	5
15	8

Table 4
Summarised reasons provided by survey respondent's for using a full depth end plate connection to connect an open section beam and an open section column.

Design Engineers Reasons	Draftsmen/Detailers Reasons	Steel Contractors/Fabricators Reasons
Integrity/Robustness	Additional strength	Stability during erection
Restraint against torsion	Integrity/Robustness	Restraint against torsion
Ensures square connection	Eliminates risk of fixing beam on wrong side of fin plate (as does use of Partial Depth End Plate)	–
–	Easier for fabricator to ensure end plate is square	–

Web cleats were included as an option to try to gauge how often they are still being used. They are no longer deemed as standard connection details as they have fallen out of favour with Steel Contractors/Fabricators due to the requirement that they need to have their finishing coatings (i.e. paint or galvanising) applied separately to the members that they connect. This creates more logistical considerations within fabrication shops that can be eliminated by using any of the other standard connection forms. Some existing research studies [7,8] have shown the performance of web cleated connections to be very good under blast or sudden column loss scenarios due to their inherent flexible nature lending itself to ductility performance.

The occupational breakdown for choice of connection method when connecting open sections together indicated that Design Engineers and Draftsmen/Detailers both preferred to use full depth end plates followed by partial depth end plates and then fin plates as a third choice (split 40, 22, 19% for the Design Engineers & 64, 27, 9% for the Draftsmen/Detailers respectively). The response from steel contractors and fabricators indicated that their preferred connection was to use a partial depth end plate followed by a fin plate and then a full depth end plate as a third choice (split 44, 31 and 19%). Note that the remaining percentages for the Design Engineers were made up of a 16% respondent population who chose the 'Scenario dependent' option and a 3% respondent population who chose web cleats as their preferred connection method. The remaining 6% for the Steel Contractors/Fabricators was made up of a population that chose the 'Scenario Dependent' option.

It is important for the reader to understand that welding is usually what governs the fabrication cost of a connection and not the cost of material, punching/drilling of bolt holes or the cutting of material lengths. Material tends to be bought in bulk by fabricators from stock holders who in turn buy in larger bulk direct from a main source (e.g. TATA steel in the UK). At the time of writing (early 2016), the price of structural steel is around £400–£500/tonne from TATA Steel in the UK [9], which has dropped over the last 10 years. In 2007 the price was around £900–£1000/tonne [10]. Punching or drilling of bolt holes and cutting material to length is seldom carried out manually by humans. CNC machines linked with CAD carry out these tasks in an automated process, requiring only an operator of the machinery. The welding part of the fabrication process is usually carried out manually by a human, costing around £10/h rising to £15/h for higher skilled welders [11] and on top of this an allowance for overheads should be made. It should be born in mind how much work is actually required by a welder to achieve a specified weld. Table 3 is an **approximate** guide for the minimum amount of 'passes' or times a weld torch needs to pass over the parent material to achieve the specified leg length of a standard fillet weld.

The survey response indicated by the Steel Contractors/Fabricators is likely to be due to the amount of welding involved in the fabrication of full depth end plates as they require a weld all the way around the profile of the beam to which the end plate is attached (a full profile weld). The response indicated by the Design Engineers and the Draftsmen/Detailers are most likely to be due to the amount of structural integrity and spare capacity the full depth end pate offers as a result of it being attached to the connecting beam with a full profile weld.

Some of the reasons that were given for choosing a full depth end plate, partial depth end plate or fin plate connection stated by the survey respondents have been summarised in Tables 4–6.

UK industry design guidance (The Green Book) [2] highlights that full depth end plates will provide an increased resistance to tying and an enhanced vertical resistance compared with partial depth end plates as a result of the profile weld. If the detailing rules outlined by the UK guidance are adhered to then the connection will be classified as 'simple' or 'nominally pinned'. These detailing rules are such that the material of the end plate should be grade S275 steel, bolts should be a maximum size of M20 (8.8), fillet welds should have a leg length of 6 mm or 8 mm and plate thickness should not exceed 12 mm. Specification of components outside of these limits would likely result in a connection becoming 'semi-rigid'. Standard UK practice is to use fully threaded non pre-loaded bolts that are 60 mm in length. This enables bulk orders of one diameter of bolt by steel contractors and fabricators to be made and hence bolts of one size and length can then be used on a wide

Table 5
Summarised reasons provided by survey respondent's for using a partial depth end plate connection to connect an open section beam and an open section column.

Design Engineers Reasons	Draftsmen/Detailers Reasons	Steel Contractors/Fabricators Reasons
Simplicity of design	Less fabrication cost (compared to full depth end plate)	Ease of fabrication
Tidiness	Simple to detail	Economics
Can take more load than a fin plate but similar amount of fabrication required	–	Stability during erection

Table 6
Summarised reasons provided by survey respondent's for using a fin plate connection to connect an open section beam and an open section column.

Design Engineers Reasons	Draftsmen/Detailers Reasons	Steel Contractors/Fabricators Reasons
To ensure excessive moment is not transferred into the column	Cheap to fabricate	Cheapest connection
Ease of detailing	To aid erection	To aid erection
Quick to design	–	–
Easy to fabricate	–	–
Cheapest option	–	–

range of different connections. This is opposed to using traditional shanked bolts (commonly known as 'black bolts' or 'shop bolts') where a portion of the bolt is unthreaded. This portion of the bolt (termed the shank) is designed to pass through the thickness of connecting steel plates and therefore no threaded portion of the bolt is in bearing or shear. Past research [13] has shown there to be no significant effect on the performance of a typical joint due to the marginal increase in bearing deformation with fully threaded bolts [2].

Stability during erection was highlighted as a reason for choosing both full depth and partial depth end plates by Steel Contractors/Fabricators. The Green Book highlights that any connection using end plates will possess little ability to accommodate on-site adjustments during erection and shorter beams with various thicknesses of packs should be detailed at regular intervals to accommodate for on-site tolerance. Two-sided connections can also create erection difficulties when end plates are used, for example, in situations where one group of bolts is shared between two beams connecting into a column web. In these situations, beams are normally erected in pairs with accompanying temporary support, usually in the form of landing cleats or an extra top row of bolts (or even a single bolt) that is only to be used for erection purposes. A common way to eliminate this problem all together is to use fin plate connections. Table 6 presents a summary of reasons provided by survey respondents for the use of fin plates.

Design Engineers should bear in mind some additional considerations when specifying fin plates. The research done by Moore and Owens [14], which developed a design methodology for fin plates (eventually adopted by the UK steel construction industry), recommended that long fin plates should never be used to support unrestrained beams due to the twist induced in the fin plate that might result from lateral torsional buckling of the connecting beam. Additionally, the positioning of the line of action of shear force through the connection, used in the design method, is a reasonably safe assumption for short fin plates, but for long fin plates it is highly conservative. Moore and Owens described it as 'unwise' to specify the use of fin plates based on their design method when forming a connection to support beams deeper than 610 mm without very careful analysis or further testing as the safety factor for their proposed design method against experimental results reduced from 3.57 down to 1.57 with increasing beam depth.

The Green Book states that for beams over 610 mm deep, the span to depth ratio of the supported beam should not exceed 20 and, in addition, the distance between the extreme bolts should not exceed 530 mm. Long fin plates may be used but the fin plate must be checked for lateral torsional buckling. Plate sizes and bolt spacings are recommended for depths of supported beam $\leq$610 mm and >610 mm with lines of either 1 or 2 bolts that should be adhered to, otherwise the connection may not behave as nominally pinned (a simple connection).

It is also common for the bottom flange of the supported beam to be removed or chamfered locally to aid erection on site when fin plates are used. This enables the beam to be safely lowered into positon rather than 'swung-in' thus risking the connecting beam web colliding side-on with the plate.

Where respondents gave a reason for choosing the 'Scenario Dependent' option for connecting an open section beam to an open section column they have been presented in Tables 7 and 8. No Draftsmen/Detailers chose this option.

It is true that each connection should be designed according to its own individual situation, the design loads, ease of erection, stability, economics and fabrication should all be considered. If fabrication cost was the only driving force behind connection selection, then fin plates and partial depth end plates would always be used. Where structural integrity is a major driving force behind connection selection, particularly in heavy high rise construction or situations where disproportionate collapse is an important design consideration, full depth end plates are more likely (but not exclusively) to be used.

4. Use of stainless steel bolts

It was of interest to attempt to capture how often stainless steel bolts are used on construction projects as the overall PhD, for which this survey forms a part of, is to investigate the dynamic resistance of connections. It has been shown in previous

Table 7
Reasons Design Engineers chose 'Scenario Dependent' option when connecting an open section beam to an open section column.

Design Engineers Reasons
'Simple connections would be fin plate, RSA cleats or partial depth end plate, subject to member local capacities and the applied loads. Semi-rigid connection full depth end plate'
'In a nutshell: Crowded connections, loads (shear/tying), column buckling, EC3 vs. 5950. The cheapest default connection to fabricate is a fin plate. However, if you weld fin plates into column webs then your bolts may become difficult to access if columns are small. Also of note is that column buckling is most likely to occur in the minor axis, i.e. buckling loads are that are to be resisted are at right angles to the column web. This leads your default web connection to be an end-plate type detail. Whether you use a partial end plate or a full depth end plate depends on the loads present (high tying may necessitate a full depth end plate), or the specification may require it (for example EC3 requires full end plates for the Green Book)'
'It is dependent on the loads. It may also depend on the finishes – if the steelwork is exposed the visual effect of the connection might be important. The dimensions of the connections are also important – is the beam eccentric on the column – an endplate might be better than a fin plate'
'I have used all of the first three and others using a t-section welded into the column and an end plate on the beam. Differs depending on site conditions and loads and contractor's preference'

Table 8
Reasons Steel Contractors chose 'Scenario Dependent' option when connecting an open section beam to an open section column.

Steel Contactors/Fabricators Reasons
'Generally, these will be full depth end plates however, connections can be provided with all of the first three'
'Generally, choice is dependent on the applied design forces, stability issues, architectural requirements as well as financial reasons'

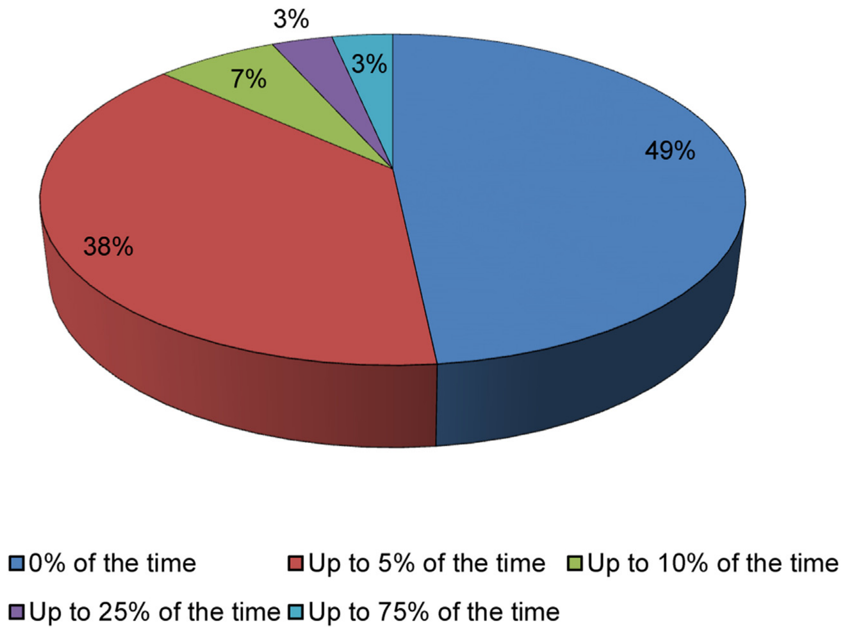

Fig. 9. Breakdown of how often survey respondents have encountered the use of stainless steel bolts.

research studies [15] that stainless steel bolts are much more resistant to high strain rate loading than ordinary bolts. This property of stainless steel bolts alone is not deemed a good enough reason for common application of them throughout the entire steel construction industry and their use is somewhat exclusively reserved. The reasons for this come down to cost and availability. Various internet price checks can show that the cost of $1N^0$ ordinary zinc coated, fully threaded bolt compared to $1N^0$ fully threaded stainless steel bolt can increase by a factor that starts at around 1.3 to as much as 3.2 depending on supplier, bolt length and the bulk quantity of the order. In addition, not all suppliers readily stock stainless steel bolts, and those that do may only stock a limited number of diameters and lengths.

With the above information in mind, it is unsurprising that the majority of the survey population (49%) indicated that they have encountered the use of stainless steel bolts 0% of the time and that 38% of the survey population indicated that they have encountered their use up to just 5% of the time (Fig. 9).

The occupational breakdown for this question indicated that 71% of Steel Contractors/Fabricators & 46% of Draftsmen/Detailers have encountered the use of stainless steel bolts 0% of the time. 44% of Design Engineers indicated they have encountered the use of stainless steel bolts up to 5% of the time, followed by a population of 37% of Design Engineers who have encountered their use 0% of the time. The Draftsmen/Detailers contained a fairly even divide between encountering their use 0% of the time and up to 5% of the time, with a split of 46% and 45%, respectively. The survey respondents were

Table 9
Summarised reasons provided by survey respondents for the use of stainless steel bolts.

Design Engineers	Draftsmen/Detailers	Steel Contractors/Fabricators
Nuclear power station design	For architectural metalwork done	Corrosive environments
Marine & Coastal environments	Corrosive environments	Fixings for glazing
Used as holding down bolts	As aesthetic features	To satisfy architectural requirements
Ethane tank design	External pins	As a pin within a structure
As fixings in areas that are inaccessible (i.e. cavities)		
Connections at interfaces with other materials such as RC & timber		
Swimming pool connections		
Fixings on architectural features such as stairs, balustrades and canopies		

Table 10
Additional comments by Design Engineers on simple connection design.

Design Engineers Additional Comments
'Semi-rigid design, though not well catered for in current design codes is the way forward. By designing full depth end plates to take say 10% of free span moment a reduction in beam size is possible and a practical connection results — as opposed to fully rigid'
'Connections should be kept simple and easy to fabricate, don't forget that someone has to manufacture and more importantly erect these structures and simple and swift applications make safer and cost effective solutions'
'The choice of any given connection is often decided by the scale of the structure and its elements as well as the nature of adjacent connections'
'Fabrication and erection considerations should influence design more than is currently the case'
'Fin plates are not really as good as partial depth end plates in fire situations, part of my business, in addition to general consulting, is connection design for small fabricators with no design department. They demand fin plates and as long as they comply with Building Regs and that's all they care about. Main project structural engineers don't seem to pick up on poor performance of fin plates in fires'
'The ease of manufacture/cost of connections is seldom if ever considered by consulting engineers. The majority of consulting engineers grossly over specify the design loads. There is also considerable confusion and ignorance on the difference between a tie force and an axial load resulting from real loads'

Table 11
Additional comments by Draftsmen/Detailers on simple connection design.

Draftsmen/Detailers Additional Comments
'Although I have a preference for partial depth end plates, if the beam is also supporting vertical bracing I use full depth end plates to accommodate any additional loads created by the bracing'
'When a beam to column connection has a beam section width that is similar to that of the column depth, i.e. 254 × 146UB beam into the web of a 152UC, a toe plate to the column is usually preferred for ease of installation'
'Toe plate connections are also commonly used. These are expensive to fabricate but are structurally better than fin plates and avoid the need to notch beams. Also easier for erectors as reduces problem of 'swinging-in''

Table 12
Additional comments by Steel Contractors/Fabricators on simple connection design.

Steel Contractors/Fabricators Additional Comments
'Endplates are traditionally the more popular as can take more loading but fin-plates would be the preferred option where possible'
'Integrity aside, the cost of a connection is mostly in fabrication time, which is related to cutting and welding as opposed to material costs. 'Simple' is the key.'

also asked in what sort of situation, if at all, they had encountered the use of stainless steel bolts. Table 9 summarises the responses received.

5. General comments from industry

The final question of the survey was worded '*if you have any thoughts/comments you wish to make yourself on the different types of simple beam-column connections then please do so below*:' and a subsequent text box was provided. The purpose of gathering respondent's additional comments was to try to gauge a free thinking opinion from members of the industry to enable any concerns or suggestions to be raised relating to the topic of the survey. Not all respondents chose to do this, but in cases where they did, Tables 10–12, show the extrapolated additional comments that were provided.

As one Design Engineer respondent highlights in Table 10, the use of true semi-rigid design, whereby a portion of the in-span free bending moment is redistributed into the connection is not common place, (one exception to this is in portal frame design where a portion of base fixity is often catered for to reduce horizontal deflections). Simple connections do often become semi-rigid when connection components outside the limitations in The Green Book are used, however as highlighted earlier, they are still only designed by considering shear and/or axial force as necessary. Another respondent highlights that there is confusion between a prescribed tensile force (or 'tie force') and an axial force resulting from real loads. The difference is that the purpose of a prescribed tie force is to satisfy any disproportionate collapse requirements and it should be checked in its own load case without consideration of any shear forces acting at the same time as the Green Book states, '*The check for tying resistance in entirely separate to the check for vertical shear resistance – the two design forces do not occur in the same design situation and therefore should not be considered at the same time*'. An axial force that results

Fig. 10. Typical crowded connection where a Draftsman/Detailers input or use of 3D BIM may be invaluable.

from the in-span 'real' loads should be checked in combination with any vertical shear reactions that may be present. The prescribed tie force has a magnitude that is calculated in accordance with the procedures set out in SCI P391 [16] for steel framed buildings (this procedure is in accordance with Approved Document A of the Building Regulations [17]) and is not a reaction force resulting from the in-span 'real' loads acting on the structure.

The view of Draftsmen/Detailers is vital as they will often pick up on practical/buildability issues that may not be apparent to a Design Engineer carrying out structural calculations. These sorts of things may include, bolt spacing clashes with incoming bracing members or adjoining connections, available plate sizes stocked by a Steel Contractor/Fabricator, ease of access to tighten bolts, any issues with erection that may arise etc. . . The advances in building information modelling (BIM) have enabled the complete visualisation of any complex connection configuration in 3D, and therefore Draftsmen/Detailers are now able mitigate such issues well in advance of physical fabrication. An example of a crowded connection, where 3D BIM is of valuable use is shown in Fig. 10.

Two of the Draftsmen/Detailer respondents highlighted the use of toe plate connections in certain situations where in which a plate is welded across the top and bottom flanges (the toes) of a beam, for the incoming member to attach to. A stiffener is usually added behind the plate also along the centre line of the beam to create a 'T-stub' (Fig. 11). If geometry lends itself, then the T-stub may also be formed by cutting one flange off of an open section and welding the remaining section into position.

Toe plate connections are not classed as standard connections and have no standard design check procedure, however, as the respondents in Table 11 point out, they are commonly used to avoid notching or reducing a beam size to fit between

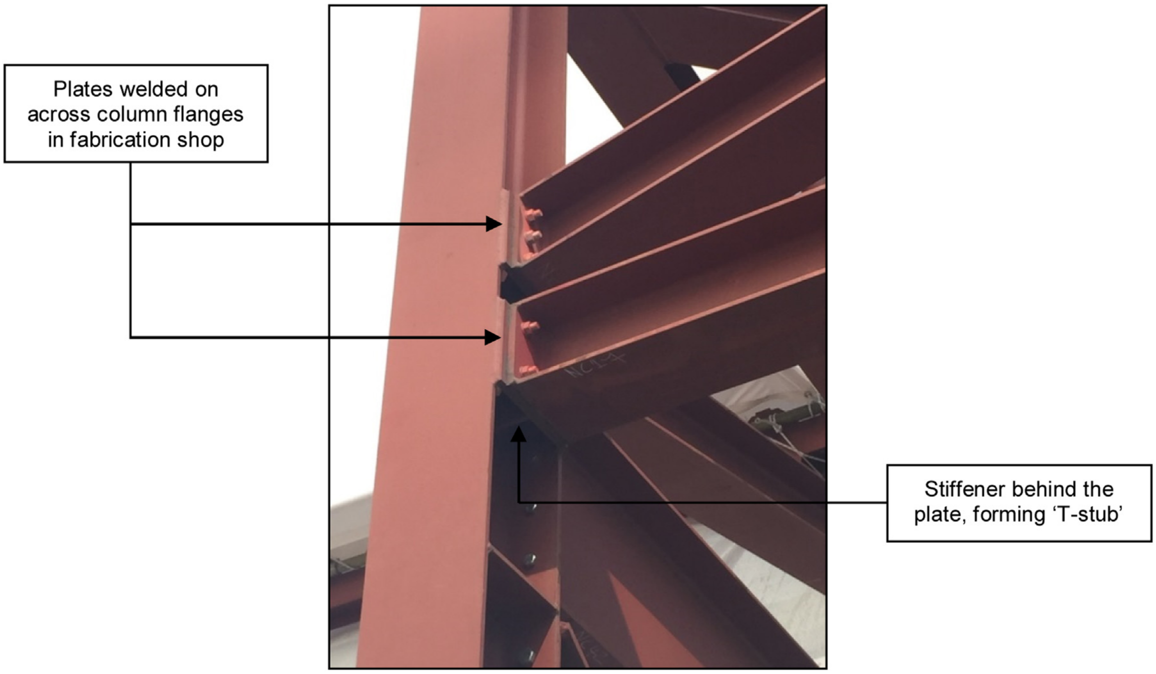

Fig. 11. Typical toe plate connection.

flanges of a supporting member. Engineering judgement and basic design checks to calculate plate thickness, number of bolts and weld thickness are used to determine their appropriateness and suitability for a given situation. For single sided beam-beam connections, the supporting beam would also need to be capable of resisting the torsional shear stresses induced by the eccentricity of the supported beam.

6. Conclusion

It was the intention of the survey to try to establish some common practices in the design, specification and fabrication of simple and/or semi-rigid structural steel connections in the UK. This has been achieved and the information obtained has been quantified and presented within this paper. The importance of this information being published is such that it will not only help to bridge the gap between the academic research community and industry, when considering future research on such structural connections, but also provide a useful practical insight to the community within the steel construction industry as a whole. From the survey results, the following points can be inferred:

- Steel box sections (SHS's & RHS's) are not commonly used as primary columns on construction projects. A total of 88% of the respondents have encountered their use on projects 25% of the time or less.
- On projects where tubular box sections are the primary columns, the preferred method of connecting an incoming open section to them is a fin plate connection.
- If a 'blind' connection is absolutely necessary, the survey indicated that Hollo-bolts were the preferred fastener to use (as opposed to Blind Bolts).

The preferred choice for connecting an open section beam to an open section column was overall highlighted as a full depth end plate (39% of the survey population), followed by a partial depth end plate (29% of the survey population) and then a fin plate (20% of the survey population). A portion of the survey respondents (10%) also indicated that their choice of connection between open sections would be scenario dependent. The remaining 2% of the respondents indicated their preferred method of connecting open sections would be to use web cleats (now withdrawn as standard connections).

Stainless steel bolts are rarely used on construction projects, 49% of the survey respondents stated that they have never encountered their use on construction projects and 38% stated that they had only encountered them up to 5% of the time.

These points will help devise a full scale testing programme in which standardised details from the Green Book will be subjected to a range of dynamic tests. The purpose of this testing is to propose a design methodology for the standard connection details that can be used to calculate the dynamic capacity of such connections with greater confidence than simply applying dynamic increase factors. Currently, only the static design capacity is catered for within the Green Book. Static tensile capacities of the standard connections are provided and are used to satisfy the tying requirements set out in Approved Document A [17]. These capacities and the concept of 'tying' provide a safety net against collapse but overlook the dynamic nature of a progressive collapse. Inertia, rapid rotational force and any strain rate effects that could be encountered during a collapse event are not considered by the Green Book. It is the intention of the overall PhD study mentioned to output peer reviewed research findings that can be used to progress the development of the standard connection dynamic capacities with due consideration to structural and material dynamic behaviour.

Acknowledgements

The corresponding author would like to thank all of the survey participants for taking the time to complete the survey questions. All of the input received was of great value and people's kindness and level of voluntary helpfulness is greatly appreciated. This research is funded by the Engineering and Physical Sciences Research Council (EPSRC reference EP/L505018/1) and the Institution of Structural Engineers Research Fund Research Award for 2015.

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