ROBUST – Renovation of Buildings Using Steel Technologies

Vertical steel extension – Connection systems

Final Document

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Issues regarding connecting vertical steel extensions

INTRODUCTION

When refurbishing a building and/or extending it, some questions are raised regarding the design of the new extended structure but also the older one including the connection between the two frames (older and new one). In refurbishing/extension projects the structural connection between steelwork and other materials, as concrete, masonry, older steel components, shall deeply been regarded and appraised in way not to overlap specific connection problems in terms of structural integrity, services extensions and code requirements.

This document is an attempt to list connections characteristics and requirements for building vertical extensions.

1. APPRAISAL

1.1. Heavy or light refurbishing/vertical extension

There are many factors that influence the choice of a connection detail in vertical extension, high or light duty connection. One is the importance of the extension considered as a refurbishing: is this extension a heavy or light construction work? (This is different of high duty or light duty connection!)

This should be appraised not only in terms of structural frame but also in terms of service organization, circulation rules, services continuation, safety procedures, etc.

The regulations situations vary between countries. It depends also of the size of the building, urban or county-site, residential, commercial or office buildings.

France situation:

In general "In France" refurbishing a building will induce some specific questions/topics:

Design issue: Question: design with new code, "Eurocode” as example, or the older code "CM66" as example?

The appraisal is governed by the following question:

Is it light or heavy refurbishing? This question is usually not clearly answered.
Facade change is clearly heavy refurbishing!
Roof changing "at same load" is not clearly stated, can be stated as light, not affecting the frame, as for example replacing asbestos roofs with steel sheeting's roofs,
Roof changing with loading effects can be stated as heavy refurbishing, it affects the frame,
Change of affectation can be heavy "change from office to residential as example" or light "change in partitioning in residential buildings",
Change in structural affectation can be regarded as heavy refurbishing!
Change in safety procedures is regarded as heavy refurbishing,
Vertical extensions shall be considered as heavy refurbishing.

In any case, if the codes and state rules does not confirm the requirement, this shall be stated in the call for tendering documents.

**Consequences:**

**Heavy refurbishing:**

The new building shall conform with the regulation in force at time of refurbishing. The consequence can be important:

This affect:

- the loading of the building (whole building and not only the extension),
- The code and methods used for the structural design of the building,
- The safety code used: fire resistance, safety evacuation route and corridors planning,
- Lift organization and needs of lifts systems,
- Energy code for thermal requirements as passing from "no code before the 60' to RT2005 in 2007" (France),
- Energy consumption,
- Comfort requirements: air circulation, acoustic,
- Electric design,
- Water supply and brown water evacuation, drainage,
- Heating systems,
- Ventilation systems if useful,
- Health codes,
- Etc,

All shall be reviewed in lights of the changes between old and new code.

**Light refurbishing:**

The design shall be made for the changed works in light of new codes and requirements but the rest of the former design is not affected.

**Construction material**
Note that nevertheless requirements on material resistance shall be met and laboratory testing shall confirm that the expected material resistance is met for the new design.

**Others**

In any case some requirements shall be met during a refurbishing operation: light or heavy:

- Asbestos eradication,
- Lead eradication,
- Hazardous fumes and solvents,
- Etc.

**1.2. Requirement**

One of the issues to be appraised are the connections between steel and other material at the interface of the vertical extensions and the former building. It can be formulated in several questions:

**Issues regarding loading:**

What are the new loadings to be transmitted at the interface?

- New horizontal loading: wind especially that are greater in new codes,
- New vertical loading: dead weight, variable loadings,
- Local loading, service interface,
- Etc.

Note that several heavy loads as "lift system loading" can affect the interface at high rate. The requirement is not structural but has big consequence on the structural frame.

**Issues regarding structural resistance:**

Checking shall be made for material resistance in:

- The new extension,
- The interface connection,
- The frame of the older building.

Connection details should include the physical characteristics of both steelwork and the material to which the steelwork is connected.

**Issues regarding fire resistance:**

Need of survey regarding the necessary requirements levels for fire resistance of vertical extension and transfer of fire between dwellings within the extension/old building interface.

- Structural fire safety in relation with the total height of the building and existing or new building,
CTICM – Vertical extensions

- Aspect related to the possibility of fire spread between compartments,
- Other fire safety aspects such as problems with regards to escaping route out of the building.

**New loads:**

As a combined example, the following figure shows vertical extension in a residential building in Boulogne, near Paris.

The lifts have been added due to circulation requirement: "a lift shall be included in the building for building of more the 3 Storeys (4 levels)". In this case, the old building was 6 storeys (30's construction) but two extra vertical extensions have induced the need of lift systems that have been fixed on the facade of the building. Moreover the older building frame was not strong enough and extra columns have been added. The extra lift frame is included in the mechanical system of the lift and is only point connected to the older building.

*Figure 01: Building with vertical extensions in steel (1990’s – Boulogne – Paris)*
Another example refers to the refurbishing /extension of an office tower at “La Defense” district in Paris.

In that case also, refurbishing and extensions are considered as heavy refurbishing and new wind loads shall be considered in the new structural design of the tower.
Issue regarding urbanism code: the gauge requirement

1.3. **Connection "in general" between extended steel frame and original frame "steel or other"**

Interface between older structure and new extension – Structural frame

*The new extension is assumed steel!*

Where structural steelwork is used to connect with other structural materials, this shall be regarded as: (from the new extension in steel):

- Steel columns connections to the older frame structure as point connection; Steel to steel,
- Steel columns connections to the older frame structure as point connection; Steel to concrete,
- Steel beam connections to concrete panel walls,
- Steel beams connections to concrete columns and beams,
• Steel beams connections do masonry walls,
• Steel to steel connection “with different material characteristics”.

The older structural frame can be:

• Steel: the best for us but usually really not the case, **point connection**,
• Concrete: linear columns and beams, structural frame including RBars useful for steel connection, **point connection**,
• Concrete: linear columns and beams structural frame including RBars useful for steel connection, **linear connection**, as for concrete panel wall,
• Concrete: plain concrete panel walls including RBars not useful for steel connection, **point connection**,
• Concrete: plain concrete core walls including RBars not useful for steel connection, **point connection**,
• Blocks or stones: from my personal point of view, cannot be used for a heavy connection. One opportunity is **vertical anchors** but will need heavy internal work in the old building and valid only for light vertical extensions (to be discussed),
• Masonry walls including every type of masonry material as plain bricks and blocks, simple hollow core bricks, multy hollowcore bricks “as thermally efficient material”,
• Lightweight concrete blocks “Ytong, ….”

Connection details shall take provisions for the physical characteristics of the steel and the support material to be connected.
2. Design consideration

Considerations that influence the structural design of connection include the following topics:

- Structural resistance and safety,
- Load transfer distribution,
- Construction tolerances,
- Dimensional variations, can differ between materials,
- Buildability,
- Fire résistance and fire interface,
- Future maintenance and connection access,
- Costs.

Factors to be addressed are:

- Installation conditions in concrete on site,
- Drilling methods and drill bit diameter,
- Bore hole cleaning,
- Installation tools, access for,
- Long term sustained and variable loads on the fastener,
- Variable load on the concrete structure, cracks cycling,
- Crack width in concrete structure,
- Environmental conditions such as air pollution, alkalinity, aggressive environment, humidity, concrete installation temperature, service temperature, …
- Location of fastener in the concrete component,
- Minimum dimension of the structural component.

Consideration shall also be done on skill and experience of the building personnel. Note that CEN/TS 1992-4-1 [9] states for an installation safety factor $\gamma_{\text{inst}}$, a partial factor that accounts for the sensitivity of a fastener to installation inaccuracies on its performance. CEN/TS 1992-4-1 states for post-installed fasteners the following values $\gamma_{\text{inst}}$:

$$\gamma_{\text{inst}} = :$$

Tension loading:  
- $= 1.0$ for systems with high installation safety,
- $= 1.2$ for systems with normal installation safety,
- $= 1.4$ for systems with low but still acceptable installation safety.

For shear loading: $\gamma_{\text{inst}} = 1.0$.

2.1. Consideration about type of material (existing building) and mechanical quality of the support

Information from reference [9]
In the region of the fastening, the concrete may be cracked or non-cracked. The condition of the concrete should be determined by the designer. In general, it is always conservative to assume that the concrete is cracked.

Non-cracked concrete may be assumed if it is proven that under service conditions the fastener with its entire embedment depth is located in non-cracked concrete. This will be satisfied if the following equation is observed (compressive stresses are negative):

\[
\sigma_L + \sigma_R \leq \sigma_{adm}
\]

- \(\sigma_L\) stresses in the concrete induced by external loads including fastener loads,
- \(\sigma_R\) stresses in the concrete due to restraint of intrinsic imposed deformations (e.g. shrinkage of concrete) or extrinsic imposed deformations (e.g. due to displacement of support or temperature variations). If no detailed analysis is conducted, then \(\sigma_R = 3\) N/mm² should be assumed,
- \(\sigma_{adm}\) admissible tensile stress for the definition of non-cracked concrete.

The stresses \(\sigma_L\) and \(\sigma_R\) should be calculated assuming that the concrete is non-cracked. For connection members which transmit loads in two directions the equation shall be fulfilled for both directions. [9].

The value of \(\sigma_{adm}\) may be found in a Country's National Annex. The recommended value is \(\sigma_{adm} = 0\).

The surface of the reinforced concrete elements can deteriorate due to either carbonation or corrosion of the embedded reinforcement. It is therefore important that connection are made into the body of the elements, to a depth where the concrete has appropriate strength and long-term integrity. [1].

### 2.2. Consideration about connection positioning

Care should be taken to ensure that the erection operations can be carried out reliably, on program 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 [1].

Connections between structural steelwork and other structural building elements are often therefore based upon steel connection supports shims and brackets. These shims and brackets are installed in advance of erection operations [1].

Connection 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 can then be located to avoid the reinforcement (slotted holes or alternative fixing positions can be provided for this purpose). Alternatively, special brackets can be designed with pre-determined fixing positions that really avoid the reinforcement [1].

### 2.3. Consideration about connection arrangement
2.3.1. Considerations about fasteners and fastening arrangement

*Information from reference [9]*

The **minimum edge distance** is set to avoid damage to the concrete during installation of the fasteners. They are given in European Technical Specification. The **minimum member thickness**, in which a fastener can be installed, is also given in the European Technical Specification.

The configuration of fasteners and the steel end plate are show in figure 04 and shall conform the following requirements:

\[
\begin{align*}
&c_1 \leq 10h_{ef}\quad \text{or} \quad 1c_1 \leq 60d_{nom} \\
&c_2 \leq 10h_{ef}\quad \text{or} \quad 1c_2 \leq 60d_{nom}
\end{align*}
\]

\(c_1\) is in the direction of the shear load, \(c_2\) is the direction perpendicular to the shear load.

\(h_{ef}\) is the effective embedment depth and \(d_{nom}\) the outside diameter of the fastener.

1 shows fastener, 2 shows steel plate, a) fastening without hole clearance for all edge distances, b) fastening with hole clearance situated far from edges, c) fastening with hole clearance situated near to an edge.

*Figure 04: Configuration of post-installed fasteners, edge distances*
The minimum spacing of fastener distances are measured centerline to centerline and are given from European Technical Specification.

Give specification? No: Too much consideration for this summary!

In general the **minimum embedment depth** should be $h_{ef} > 40$ mm (very small for structural frame but this is the base from the code CEN/TS 1999-4-1) or taken from relevant European Technical Specification.

Fasteners are usually in the diameter range from 12 mm to 24 mm. Minimum diameter is 6 mm (min thread size).

**Type of post-installed fasteners, also named anchors [9]**
Post-installed anchors can be of several types such as expansion anchors, undercut anchors, concrete screws, bonded anchors, bonded expansion anchors and bonded undercut anchors. Figure 07 gives examples of such fasteners.

![Figure 07: Post-installed fasteners types](image)

- Torque controlled fastener, sleeve type,
- Torque controlled fastener, wedge type,
- Deformation controlled fastener,
- Undercut fastener type 1,
- Undercut fastener, type 2,
- Concrete screw,
- Bonded fastener,
- Bonded expansion anchor.

Fastener systems are designed for Ultimate Limit State with appropriate partial safety factors. They shall not deform to an inadmissible degree that will affect the use for which they required. In general actions in the fixture may be calculated ignoring the displacements of the fastener. However, the effect of the displacement of the fastener shall be taken into account for fastener with soft behavior or for particular stiff elements fixed by the fastener.

**Hole clearance [9]**

The following table from prCEN/TS 1992-1-4 [9] gives hole clearance for fixing the rods and fasteners. For shear action consideration the fastener can be set into a sleeve (b) or not (a). $d$ is given for non sleeve disposition and $d_{nom}$ for sleeve disposition.

<table>
<thead>
<tr>
<th>External diameter $d$ (a) or $d_{nom}$ (b) in (mm)</th>
<th>6</th>
<th>8</th>
<th>10</th>
<th>12</th>
<th>14</th>
<th>16</th>
<th>18</th>
<th>20</th>
<th>22</th>
<th>24</th>
<th>27</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter $d_f$ of clearance in fixture (mm)</td>
<td>7</td>
<td>9</td>
<td>12</td>
<td>14</td>
<td>16</td>
<td>18</td>
<td>20</td>
<td>22</td>
<td>24</td>
<td>26</td>
<td>30</td>
<td>33</td>
</tr>
</tbody>
</table>
(a): if bold bears against the fixature  (b): if sleeve bears against fixature

Table 01: Hole clearance

2.3.2. Consideration about the connection

- Point connection,
- Linear connection,
- Podium,
- Pinned connection,
- Rigid connection.

Any gap between the fastener and the fixture is filled with mortar of sufficient compression strength or eliminated by other suitable means (e.g. Epoxy material, …).

2.4. Consideration about tolerances

Dimensional variations associated with concrete material are significantly greater than those associated with steel construction. The expected dimensional variation should be reflected in the amount of adjustment that is provided with the connection detail.

Tolerances can be classified as: (see definition of tolerances in ISO 1803 and Pr EN 1090-2).

**Essential tolerances:** Basic limits for a geometrical tolerance necessary (upper limit) to satisfy the design assumptions for structures in terms of mechanical resistance and stability,

**Functional tolerances:** Geometrical tolerances which might be required to meet a function other than mechanical resistance or stability, e.g. appearance or fit up,

**Special tolerances:** Geometrical tolerances which are not covered by the tabulated types and values of tolerances given in pr EN 1090, and which need to be specified for a particular case,

**Manufacturing tolerances:** Permitted range in the size of a dimension of a component resulting from the component manufacture.
This is common to consider that the cm is the scale for masonry and concrete construction while mm is for the steel construction. Nevertheless this is not as simple and the following list can be set as reference for tolerances [1].

Acceptable margins in variation from nominal dimensions can be set for each type of material and connections shall be able to adjust to accommodate building tolerances. Material prone to large dimensional variations require connections that have greater potential for adjustment (masonry and concrete) than other material may require (steel).

**Steelwork:**

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

**Concrete:**

- General permitted deviation of concrete surfaces: +/- 15 mm
- Cross section of columns, walls, up to 1 meter: +/- 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:**

<table>
<thead>
<tr>
<th>Depending of the length of the wall</th>
<th>300 mm – 2 m</th>
<th>2 m – 5 m</th>
<th>5 m – 10 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position on plan</td>
<td>+/- 5 mm</td>
<td>+/- 10 mm</td>
<td>+/- 15 mm</td>
</tr>
<tr>
<td>Cross section</td>
<td>+/- 5 mm</td>
<td>+/- 10 mm</td>
<td>+/- 15 mm</td>
</tr>
<tr>
<td>Level</td>
<td>+/- 5 mm</td>
<td>+/- 10 mm</td>
<td>+/- 15 mm</td>
</tr>
</tbody>
</table>

Note:

From UK document (SCI), should be reviewed in the light of new Eurocode tolerances document:

- pr EN 1090 for steel structures,
- pr EN 1990, section 4 for concrete structures,
- Add other documents and national codes.

The amount of adjustment actually provided should reflect the assumptions stated for the structural design of the building.

Tolerances can be taken up by slotted holes, shims or other devices. Brackets designed to accommodate particularly large tolerances can be problematic, in that they sometimes results in large level of eccentricity at the point of load transfer from one element to another [1].
2.5. **Consideration about movements**

When designing new steel extension in existing buildings, it is important to have an understanding of the in which the structure cope with movements. Structural movements have a variety of causes, including changes in loading, environmental effects and changes in the dimensions of materials over time. The magnitude and direction of these movements must be determined [1]. See also Design for Movements in Buildings (Alexander S.J. and Lawson R.M.; CIRIA technical note 107, 1981).

2.6. **Consideration about load transfer**

Loading on fastening can be static, cyclic causing fatigue failure and seismic.

Seismic considerations are not taken into account in this document but fatigue loading shall be well considered at the interface between concrete and steel and especially in the concrete boundary of the fastening. Concrete is hardly stresses during boring, gripping, pressing, while this volume of concrete is usually altered by climatic loadings, humidity, pollution, temperature variation,....

Aspects of load transfer that should need to be considered include [1]:

- The effect of concentrated load on supporting elements,
- The effect of eccentricities on the supported and the supporting elements (design consideration and assumptions),
- 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.

Weak supporting structure should require more close and numbered connections. This is often the case for deteriorated concrete supporting elements. It is therefore important to investigate in the structural quality of the supporting material and take provisions to ensure and secure load transfer on the older structure. It is important that connections are **made into the body of elements**, to a depth where the concrete has appropriate strength and long term integrity. It is also important that RBars shall be integrated in the connection volume, thus connection devices shall reach RBars cage to be fully efficient.

2.7. **Consideration about durability and maintenance**

The durability of the connection shall be regarded with [1]:

Design with regards to service and environmental conditions including moisture. Where connections are subject to moisture they should be particularly resistant to corrosion and special care shall be taken to avoid bimetallic action. A useful system to avoid moisture is to design the connection on elevated end plate and to ventilate correctly the volume where the connection is set. Follow up and maintenance should be stated for the future building management.
Connection should be able to resist all erection and service loads (that can be greater than final loading) without deforming excessively, or being damaged.

2.8. Consideration about fire resistance

Connections must be fire resistant for a period at least equivalent to that of the least fire resistance of the elements that they connect. Resin anchors tend to soften or lose strength prematurely when exposed to fire, and must be fire protected. Maintenance work will conduct to use removable fire protection material in place of definitive fire protection as sprayed or blanket type [1].

2.9. Consideration about final aspect of the joint “aesthetic”

Need development!

2.10. Consideration about rectitute and urbanism code – “Urbanism gauge”

Need development!

2.11. Consideration about air/water and chemical behavior of the joint

Need development!

2.12. Consideration about cost

Usually extension connections are more expensive than basic steel connection as they shall perform specific tolerance and interface characteristics. They shall perform adequate displacements without overloading the supporting and supported structures and thus are more costly. High quality connections provide a good level of adjustment, safe positioning, rapid and reliable construction that will save money on site construction (men hours) even more expensive at manufacture factory.

2.13. Consideration about extension construction process

There are distinct operations to process to achieve a structural connection and extension frame [1]:

- Construction or erection of the supporting element, and installation of any connection brackets,
- Pre alignment of brackets and seatings,
- Construction or erection of supported elements,
• In-Situ adjustment of brackets and seatings,
• Temporary attachment of the supported and supporting elements prior to a permanent connection being made;
• Permanent connection of the structural elements.

2.14. Consideration about buildability

At any stage of the design process, the connection shall be sized and designed in view of the mounting process, in particular attention shall be set on the possibility, or non possibility, of access for boring, engaging, bolting, screwing, adjusting the various elements of the connection.

2.15. Consideration about safety

Safety procedures shall also be regarded about as the connection will be erected at dangerous edges of buildings.

Connection of the steel elements usually start at crane hooks operation with a rapid simple initial connection, crane hook is then released and further bolts are then introduced for complete connection [1].

3. Extensions with modular construction

Using a modular construction system can save on lots of aspects.

A fast site construction is of prime importance, especially in urban environment. This will save on costs, reduce congestion on the site and environment of the site "streets, cities, roads, ".

A modular approach can also result in much safe works, less surfaces for stocks and less waste material and all related materials.

Using modular construction is requiring more skilled workers and more contacts between the designer, producer, provider, erector, architect.

The provider should manage all the needs from the client and its architect representative. This includes requirements for customization as:

- Floor Plans,
- Space Programming,
- Program Design,
- Site Layout Input,
- Architectural Design & Specifications,
- Budgetary and Scheduling Information.

The Design Engineering Team is staffed do adapt construction process to the client customizing needs.

Technological Systems
Service systems are pre set on each module at factory plans for fast and simple settlement on site. This includes:

- Water connection and distribution,
- Electrical wire, both power and communications,
- Waste water systems, water drainage if any,
- Air circulation systems and/or air conditioning,
- Heating systems,
- Etc.

### 3.1. 3D modular construction

Based on an industrial process, the 3D modular constructions are generated on 3D metallic units modules assembled from bottom to top by juxtaposition or stacking to create successive floors and horizontal combination for large rooms and flats. The module frame is usually made of hot rolled steel sections or from thin gauge galvanized steel sections.

The construction of the modules and the pre-assembly are made in factory. Small rolled section and/or light steel framing is generally used to form structural frame of the module.
4. Tentative for connection design loads

4.1. Parametric considerations

Considering a top extension from a 6 levels building (roof at 30 meter vertical position) a loading tentative can be set for a 1 to 3 levels extension and a flat roof.

Figure 08: Loading tentative

Horizontal area: 30m x 12m: 360 m²
High of extension: 3 time 3 m.

Building extension; Structural loading: 4200 N/m² at each level: including a 15 cm concrete slab.

Wind load: Dynamic pressure: 1000N/m², Extreme wind: *1.75

<table>
<thead>
<tr>
<th>Component</th>
<th>Pressure</th>
<th>Depression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Façade</td>
<td>550 N/m²</td>
<td>350 N/m²</td>
</tr>
<tr>
<td>Roof</td>
<td>550 N/m²</td>
<td>350 N/m²</td>
</tr>
</tbody>
</table>

Snow: Roof: 450-800 N/m².

Building: Frame: 350 N/m², (estimated)
Envelope: 1000 N/m², (estimated)
Partitioning: 1000 N/m². (estimated)

Live load: (residential): 1500 N/m².

Loading: vertical balance: Downloading:
Uplifting:
Moment loading:

Safety factors on loading: 1.00, 1.35, 1.50, 1.42

Parametric factors are as follow:
1, 2 or 3 level extensions (3 cases)  

The roof (assumed to be flat) of the existing building can be used as first floor of the extension or not (60 cm new floor system if not); (2 cases)  

Pinned of rigid connection (2 cases)  

Longitudinal span made of one single frame or two successive frames with one intermediate column (2 cases)  

| Figure 09: Total design cases: 24. |

The range of moment loading on the frame connection (M expressed in N*m/m width) for rigid connection (0 N*m/m in case of pinned connection) are:

- from the order of 21000 N*m/m for the small size case, one level, 2x6 m span,
- passing to 62000 N*m/m for the medium size case, one level, 1x12 m span,
- and 43000 N*m/m, for 3 level extension, 2 x 6 m span,
- to 120000 N*m/m in case 3 levels, 12 m span, the most heavy case.

Globally a moment range from one to five!

From this parametric calculation assuming transverse spans of 3 m and 6 m:

- Beams are chosen from steel section from IPE “all range of IPE” from IPE 220 to IPE 500. Note that if we limit the parameter to 2 x 6 m longitudinal spans and 3 m transversal span, steel section ranges from IPE 220 to IPE 300.
- Column sections can be chosen from HEA 280 to HEA 500. Buckling has been considered. Note that if we limit the parameter to 2 x 6 m longitudinal spans and 3 m transversal span, steel section ranges from HEA 200 to HEA 300.

Connection devices should be chosen, appreciated and designed within this range. Steel connection shall be considered but also, and mainly, the supporting material shall resist this loading. This is important to estimate the range of loads applied on the connecting device and to design in due case.

Note 1: Connection between members shall be compatible and special look should be made on width of elements. Usually the connection is chosen with HEB’s width >= IPE Width= IPE high/2, (HEAxxx >= IPExxx/2).
Note 2: The size of the columns should be in correspondence with the thickness of the supporting element e.g. the thickness of a core plain concrete panel wall. This can be a problematic issue as those walls are usually thin at about 20 cm thickness.

Connection on those types of wall can be considered as top connection with special care and investigation or otherwise should be considered with lateral devices connections (see later in this document).

4.2. Design consideration

Top connection can be considered on columns and beams provided that the width of the supporting element is able to support the end plate of the steel section. In that case consider a square end plate at section size * 1.5.

The opportunity to consider the connection as fixed or pinned is an important issue.

Technical requirement on concrete connection, access to Rebars, disposal of rods etc, conduct to the following requirements:

**Pinned connection:** Two lateral rods at the centre of the support, no problem as for as the Rbars cage can be reached. This is the usual simple connection.

1: HEA Column  
2: Lower slab  
3: Column end plate  
4: Anchor bar  
5: Sleeves
**Fixed connection:** Must perform a moment resistance and need level arm between rods. Rods shall penetrate the Rbars cage:

\[ > 2 \times (4 \text{ cm distance from the outer face of the concrete}), + 2 \times (\text{the Rbars diameters, 12 mm assumed}), - 1 \times \text{diameter of the rods (20 mm assumed)}. \]

This conduct to a lever arm limit of: With of the support – 124 mm.

In the case of a 200 mm thick concrete panel wall this conduct to 76 mm lever arm. This is quite not sufficient to provide a moment resistance and fixed type connection. Nevertheless in the continuation of this document, we will discuss this type of connection as the wall thickness can be greater than 200mm.

---

**4.3. Summary of investigations**

Table 02 and 03 give for each parametric case the type of frame:

- The maximum moment in the beam for a 1m slice of the building length, leading to the choice of the beam section, for 3 m / 6 m transverse span width.
- The maximum normal load in the column for a 1 m slice of the building, leading to the choice of the column section, for 3 m / 6 m transverse span width.
<table>
<thead>
<tr>
<th>Type of Frame</th>
<th>Mmax (N*m/m)</th>
<th>Section Beam 3m/6m width</th>
<th>Nmax (N/m)</th>
<th>Section Column 3m/6m width</th>
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<td>HEA280/HEA360</td>
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Table 02: Results summary: Loads on section /m width (One single longitudinal span)
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<th>Type of Frame</th>
<th>Mmax (N*m/m)</th>
<th>Section Beam 3m/6m</th>
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<th>Section Column 3m/6m</th>
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</tr>
</tbody>
</table>

Table 03: Results summary: Loads on section /m width (two longitudinal spans)
Figure 12: Design summary from Eurobuild project as cross reference
5. Connections

5.1. Type of connection situation

Depending of the arrangement of the existing building, the column will induce different balance of connection loading.

For example:

In the case of acroterion a), even with pinned connection, the loading at the base of the acroterion will be: Normal load, Shear load and MOMENT than can be relatively high in a weak area of the existing building. Moreover if we try to make a fixed connection, the loading moment will be more higher. The base zone of the acroterion shall be considered as altered by moisture and alkalinization.

In the case of a simple external wall, the support zone of the existing building is usually more clean, the structural zone is also more rigid due to the horizontal slab, beam, and the MOMENT loading on the connection is zero for pinned connection. For fixed connection a little more greater than in the acroterion case connection but not so much.

In the case of “middle of the slab” situation c), the balance of moment between left side and right side of the spans “building” at the support will lead to balanced moment and low moment loading on the connection. This case is applicable to a double span portal frame at the intermediate support.

![Several type of situation for connection](image)

5.2. Loading

Three types of loading shall be regarded for the connection (Load transfer is given for concrete base):

1. Normal loading:
When using steel/concrete connection the compression between the steel element (usually a steel plate base) and the concrete shall be checked. Concrete is usually altered and low strength characteristics due to long time whether exposure. Tension is transferred by the threaded rods and loads shall be anchored in the concrete core within the reinforcing bars cage.

2. Moment loading:

Bending moments are resisted by the rods loaded in traction and the balanced concrete loaded in compression.

3. Shear:

Transversal shear can be transferred by the connecting device, rods, anchors, fastener loaded in shear, and/or by friction between the base-plate and the grout/concrete or by alternative devices as a spade welded to the bottom of the base-plate.

*Figure 13: Load path diagram of a joint loaded in axial compression and bending moment. Top cap column joint and beam/wall joint.*

**Installation operation [1]**

Operation involved in achieving a structural connection between steel and other support material can be stated as:

- Preparing the support element, material, and installation of connection brackets if any,
- Pre-alignment of brackets and seatings,
- Construction or erection of the supported elements,
- In-situ adjustment of brackets and seatings,
- Temporary attachment of the supported and supporting elements prior to a permanent connection to be made,
- Permanent connection of the structural elements.
5.3. **Steel to steel interface: Point connection**

Steel frame as the support frame of the new structure:

1. Heavy frame, rolled section and end plate connections. The steel frame will serve as structural foundation for the extension: rolled sections or light gauge elements.
2. Heavy frame, light gauge sections for the vertical extension.

Figure 14 shows a proposed example with end plate connection, typical of steel frames. No installation problem for this type of connection, this is usual of steel construction.

![Figure 14: Steel-Steel joint on vertical elements](image)

![Figure 15: Steel to steel connection](image)
One end plate shall be fixed on the former structural steel frame and one end plate at the bottom of the structural element of the extension. For beams, the joint can be simply pinned or fixed as show in Figure 15

- Remove roof,
- Access steel frame,
- Fix end plate on the former frame, welding of steel plates,
- Fix next vertical extension,
- Complete vertical extension.

**Design:**

Design end plates connections with Eurocode 3 part 1-8: design of joints.
Confirm load capacity of the supporting structural frame: old building for the new loading path.

**Type of connection: End plates**

![Figure 16: Joint with lateral sleeves](image)

5.3. **Steel to reinforced concrete interface**

5.3.1. **Linear frame: Point connection**

5.3.1.1. **Concrete frame connection: Column top “Pile cap” or concrete beams.**

Concrete frame as the support frame of the new structure.

Concrete/Steel end plate connection:

Bolds and anchors are typically used to attach structural members to the concrete base. Light gauge steel tracks can be attached to the bold with washers and nuts.
Often oversized holes are drilled in the steel base plate to adapt tolerance between the steel structure and the concrete base and permit any type of horizontal adjustments. Washers are used to overlap the oversized holes and shall be designed for. If oversize holes are quite large, washer shall be designed for loading and bending resistance.

Vertical adjustment, prior to grouting, is by steel shims between the base plate and the concrete. Grouted basement will adjust flat base for the end plate of the steel section.

To adapt for tolerances, where foundations are constructed from mass concrete, bold holes in column base-plate should be sized as follows:

- bold diameter + 4 mm for holes up to 16 mm,
- bold diameter + 6 mm for holes over 16 mm.

Holes can also be of extended dimension in one direction (slotted hole) to adjust for large tolerances in one direction. This will require the use of specific washers to be designed for bending and shear.

![Figure 17: Base plate design with oversized and slotted holes for adjustment](image)

![Figure 18: Concrete/steel connection: Frictional, end plate, anchors](image)

The details show threaded rods used to bolt the column base plate to the foundation. Rods can be:

- Long grouted threaded rods with frictional resistance between the rod and the concrete. The rod act as a Rbar with enough length to anchor the base plate. Special grouting material with fluidity and resistance characteristics shall be used to connect...
the rot and the concrete. Design following Eurocode 2 “concrete” rules for anchoring of Rbars.

- Fixed/welded threaded rods with connection between the rod and the Rbars. The rod act as a Rbar to transfer loads to the base plate. Special grouting material with fluidity and resistance characteristics shall be used to connect the rot and the concrete. Design following Eurocode 2 “concrete” rules for Rbars.
- Expansion anchors: Design from Eurocode 2 Part 4-4: Design of fastening for use in concrete – Post installed fasteners – Mechanical systems [12] or from commercial tables – as an example HILTI design table and catalog [4],[5],[6].
- Chemical anchors: Design from Eurocode 2 Part 4-5: Design of fastening for use in concrete – Post installed fasteners – Chemical systems [13] or from commercial tables – as an example HILTI design table and catalog [4],[5],[6].

Using diamond drill provides smooth surface of the concrete in the hole. This is not really adequate for connection between the rod and the concrete. The side of the core hole shall be roughened and chemical stuff can be used for. Epoxy in drilled hole to enhance the bonding between the rod and the concrete to provide adequate strength. Take care for fire resistance characteristics.

Procedure:

System 1: Frictional anchors

- Access concrete frame and check or repair for concrete structural characteristics,
- Drill hole in concrete to introduce the anchor system, need frictional characteristics,
- Insert anchor,
- Grout the hole for fixing the anchor system, special grouting ciments, high strength and fluidity,
- Positioning shim at the correct level,
- Set columns base plate, *
- Fix the vertical extension,
- Fill space between concrete and the end plate with non-shrinking grout or drypack.

System 2: Treaded rods concrete end plating and Rbars/Rods connection

- Access concrete platform frame,
- Reach and access Rbar on top of the concrete column, remove top concrete,
- Work Rbars with threading for bolts and fix end plate for connection,
- Can also be site welded,
- Add rod,
- Rework concrete topping to finish the work,
- Positioning shim at the correct level,
- Set column base plate, *
- Fix the vertical extension,
- Fill space between concrete and the end plate with non-shrinking grout or drypack.

System 3: Chemical and expansion connection (not useful for heavy section, used for light gauge systems).
• Drill hole in concrete to introduce the anchor system,
• Insert anchor,
• Fit anchor, follows instruction from the fabricator,
• Note that expansion anchors system should check for the concrete splitting if any,
• Positioning shim at the correct level,
• Set columns base-plate,
• Fix the vertical extension,
• Fill space between concrete and the end plate with non-shrinking grout or drypack.

• Note *: The space between the base-plate and concrete is filled with non-shrinking grout or drypack. Adequate arrangement should be done to permit air escaping from the bottom of the base-plate and confirm that grout has fully full this volume. Small holes drilled in the base-plate can confirm that the volume below the base-plate is fully filled.
• Note **: The base-plate should be fitted with oversized or “oblong” hole to fit with concrete tolerances for rods. Treaded rods are normally grouted and/or fixed in place before the steel work is erected [1].
• Note ***: Temporary support of the steel column needed during erection. Bracing shall be adequate both for safety and verticality of the columns.

Note: Particular attention for:

• Checking for local resistance of the concrete, old concrete are generally altered by weather exposition and should be improved or concrete characteristics should be changed in regards of the local situation,
• Checking for splitting of the concrete and special attention shall be paid to edge distance to prevent bursting of the concrete (see [4] and [6] and [9] to [16] for design consideration,
• Check design of Rbars for connection and load transfer resistance,
• Check older previous frame for structural design.

Figure 19 shows a proposed type of connection on a large base. Figure 21 show other proposed arrangements for smaller widths. In these cases the connection cannot be considered as fixed.
Figure 19: Proposed type of connection

Figure 20: Several type of connections situation
**Figure 21: Concrete/steel connection – Point connection on concrete column frame**

**Design:**


**Load path:**

*Figure 22: Load path*
5.3.2. **Concrete columns: Steel beam connection**

This system to connect a steel beam to an existing column. The system is based on a connection using rods or anchors and is operated in the same way as in 5.3.1. A bracket is used to rest the beam. All the considerations listed in 5.3.1. are still valid,… tolerances. The bracket is fixed first on the column and the steel beam is fixed (simply resting) + bolds on the bracket. This will allows for pinned connection. If extra stiffness shall be met, semi-rigid connection can be performed by using an end-plate welded at the end of the beam. Extra connection can be set at top of the end-plate and between the two flanges.

Note 1: this semi-rigid connection shall correctly be considered regarding buildability. Introduction of the rods into ten end-plate could be problematic for small (or large scale sections) and care shall be taken during erection.

Note 2: Access to bolds (and use of the bold wrench) shall be considered especially for small size sections.

![Figure 23: Concrete column: steel beam joint](image)

5.4. **Steel beam to reinforced concrete beam interface - point connection**

![Figure 24: Steel beam to reinforced concrete beam connection](image)
5.5. **Steel to reinforced concrete interface - panel walls**

This kind of concrete walls was very useful in France and very productive in the 60's and later. Most of the residential buildings for HLM are made in that way. This thickness of the wall is relatively thin (20cm) and in most of the case top connection cannot be used. Lateral connection systems shall then be used.

If possible a point connection could be proposed but usually due to sizing this is not usually the case. A core wall is usually 20 cm thick, reinforcing cover at least 15 mm each site, and Rbars 12 mm diameter, holds ?? 20 mm. The lever arm could be at a maximum of 110 mm. This is quite small and uncertain on tolerances !!!

**Other option**

This type of wall usually need a continuous connection at top or lateral edge of the wall and heavy connection devices.

5.5.1. **Top connection (if possible)**

- Remove roof,
- Reach top of wall, check thickness and concrete quality,
- Fix linear rolled U section on top of the wall. Chemical screws or mechanical screws. Need careful fixing devices as usually concrete is not at its best quality on top of these walls and wall are not really thick. Carefully done will not damage concrete or Rbars.
- Fix next vertical extension,
- Complete vertical extension,
- Check design for wall resistance for connection and load transfer resistance,
- Check older previous frame for structural design.
CTICM – Vertical extensions

Figure 25: Top connection on concrete core walls

1 - concrete (existing)  
2 - reinforcement bars (existing)  
3 - steel column (HEA)  
4 - plate  
5 - anchor shank  
6 - wedges  
7 - insulation and watertightness (existing - to be refined)

For thin walls  
For ticker walls  
Pinned connection
Figure 26: Vertical connection on concrete core wall including part of the slab, Steel columns

Note: This type of connection performs only for pinned connection. Usual concrete panel walls are not thick enough to provide for rigid connection.

5.5.2. Twin lateral plate connection

5.5.2.1. Top twin lateral plate connection for column joints

This kind of connection is performed as twin linear lateral plate connection on both sides of the wall. It can be of better resistance while checking shear resistance. Note also that urbanism requirement can limit this kind of opportunity. Volumetric occupancy of the building is larger than the supporting building.

Procedure

- Access concrete frame and check or repair for concrete structural characteristics.
- Drill hole in concrete to introduce the rods system, need frictional characteristics,
- Insert rods, note that the rods shall access to the Rbar cage,
- Grout the hole for fixing the anchor system, special grouting cement, high strength and fluidity,
- Fix lateral plate and use flasher,
- Use flasher,
- Fix the vertical extension to the lateral plates,
- Fill space between concrete and the end plate with non-shrinking grout or drypack.

Figure 27: Top linear joints – Twin lateral plate connection
Note 1: The size of the structural steel element of the vertical extension, shall fit the space between the two vertical plates, flasher can be use for adjustment. It shall be smaller or at most the same dimension as the wall thickness. If lower use shims to adjust, (small adjustment are acceptable, large adjustment are not), between the wall thickness and the section size. A plate, flange connection is required.

Note 2: This system performs pinned connection well but is rather limited for rigid connection for two reasons:

- The maximum size of the structural element is limited to the thickness of the wall (<20 cm),
- The wall Rbars and internal lever arm are even more limited at around 10-12 cm between two faces of the concrete core panel wall. High bending moment can induce longitudinal cracking. This kind of wall is not designed for bending resistance as isolated element.

Note 3: It is advised to grout the interface of the steel and concrete after erection. Special care shall be regarded against water infiltration between the plate and drainage consideration shall be advised.

5.5.2.2. Intermediate lateral plate connection for beams joints

a) Pinned joint
In this system, the internal plate is fitted (welded) with angle, one for resting the beam and a second for fixing the beam web.

Note: Lower angle as resting plate for the beam

*Figure 29: Twin lateral connection on concrete core wall, beams*

*Figure 29-b: Other type of pinned beam – wall joint*
b) Fixed joint (tentative)

In that case a twin angle flange connections shall be made. In fact end plate connection is not feasible due to tolerances in the concrete wall and difficulties to engage the beam in the joint system. The following is a fixing procedure, even complicated that can perform fixed connection of a steel beam on a concrete wall.

- The two end plates are fixed to the concrete wall using only the lower line of drilled holes.
- The lower angle comes with the inner plate, the upper angle comes with the beam.
- The beam rest on the lower angle.
- The angle coming with the beam is fixed to the wall, internal plate and external plate.
5.5.3. Angle top connection

This system is similar in concept to the previous one except that the top of the wall can be accessed. In that case the plate can be extended on top of the wall and participate in the resting of the joint. The joint is showed in Figure 32 with thick wall but the systems work also on thin wall with an external steel plate as in the previous drawing. Figure 32 shows a pinned joint. To create a fixed joint, only connect the upper wed of the beam to the upper part of the wall, using a plate (Figure 33).
5.5.4. Top linear connection

Note: for this type of connection – Big torsion moment to be expected on the wall.
This type of connection is used for continuous supporting walls. This type of walls are mostly from light gauge framing as steel prefabricated panel walls (from steel construction modular industry), see Arcelor proposal! Planja, etc.

In these systems a continuous connection is advisable, in fact every post member shall be fixed at +/- 60 cm step, leading to continuous support assumption.

Only pinned connection is assumed at the base of the post as the load resistance of the element is longitudinal along the wall, contrary to the portal framed structure where the loading is transverse to the wall.

System

The proposed connection system as described in several literature documents is composed of a U section (channel), laminated or light gauge, resting on top of the concrete wall. This will form a plate platform for the rest of the steel wall element. The U channel is fixed with rods fixed into the concrete core.

- The boring into the concrete is performed first,
- then the rod and ciment are introduced into the hole and a certain period is awaited for curing of ciment, rod can be replaced by anchors.
- While the rod is fixed, then the U section can be fixed, including a vertical angle or not.
- The vertical angle will allows for fixing the post with classical screwing techniques for light gauges construction.

![Figure 34: Point connection for continuous connection on a concrete walls](image)

While all posts are fixed, the wall can be completed using usual techniques.

Care shall be taken due to possible water infiltration at the joint. The best arrangement possible shall drain water to the exterior. See building envelope techniques.
CTICM – Vertical extensions

Figure 35: Details of composition of point connection on concrete continuous walls

Figure 36: Continuous top extension

5.6. Steel to reinforced concrete interface - Platform connection

1 - Existing wall / slab
2 - reinforced bars (existing)
3 - steel column
4 - plate / rail
5 - anchor shank
6 - wedge / rail
7 - insulation and watertightness (existing - to be retied)
The platform (need of an existing platform) will serve as structural foundation for the extension: rolled sections or light gauge elements.

**Roof as structural element**

Keep it or remove it? Could be used for the vertical extension as supporting structure?

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<tr>
<th>Roof Type</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal concrete platform roof</td>
<td>Yes: used as platform: need redesign</td>
</tr>
<tr>
<td>Horizontal double skin steel roof</td>
<td>No: Cannot be used. Not structural</td>
</tr>
<tr>
<td>Slope steel framed roof</td>
<td>Maybe: Redesign</td>
</tr>
<tr>
<td>Slope tiles roof</td>
<td>No: New frame to be reconstructed</td>
</tr>
</tbody>
</table>

**Procedure**

- Remove roof, if any,
- Access concrete platform frame and check or repair for concrete structural characteristics,
- Drill hole in concrete to introduce the rods system,
- Insert rods,
- Fix steel plate at ceiling of the platform and temporary fix end plate at top of platform,
- Set columns on line and level using steel shims,
- Fix,
- Fix next vertical extension,
- Complete vertical extension,
- Check design of Rbars for connection and load transfer resistance, of the platform,
- Check older previous frame for structural design.

**5.6.1. Concrete platform as foundation for the new frame, Rolled section as column - joint**
NOTE: This system will introduce heavy local load transfer at support (local moment and shear) and adequate checking shall be made at supports for the resistance of the platform.

**Design:**


**5.7. Steel to blocks or stones frame interface**

Need anchor systems that will reach slabs or surf ram system below the stone wall. Very heavy work that will interfere with use of the old building. Seem not to be applicable.

**NO MOMENT RESISTANCE**

**5.8. Steel to masonry walls interface**
Proper distribution of the beam reaction onto the masonry.

Figure 39: Connection to brick walls

Figure 40: Connection to brick walls, Pocket system for beams - 1
5.9. **Steel to expended concrete blocks walls interface**

*Figure 41: Connection do brick walls, Pocket system for beams - 2*
6. Connecting Facades

External walls are curtain or semi-curtain walls. Thermal insulation is fixed on the curtain wall and as a whole, the frame is considered as thermal isolated. Inner parts of the external wall are built from slabs to slabs on sub-structural frames (cold formed sections) and are made with plaster boards.

![Diagram of connecting facades](image)

**Figure 42: concept, external wall and the supporting slab**

All the components of the system are common and well distributed on the market. They are heavily prepared in workshops and the site work can be deeply reduced. This system uses intensively cold formed sections for all the wall substructures (external and internal).
7. Connecting Balconies

Connecting balconies can be made on a base of metal section support frame and point connections if the old building has sufficient strength. Note that moment resistance connections are needed if no traction rods are used.
Figure 44: Connecting balconies
8. Design consideration about fasteners


Document CEN/TS 1992 4-1. Design of fastenings for use in concrete - Part 4-1: General is currently into voting procedure at the CEN level for final approval and is expected to be future design code within EUROCODE frame. Thus, this information is at the front edge of design for fasteners connections systems. The content is composed of 5 documents, this one as a base, + 4 documents for specific fastening system:

8.1. Design of fastening system

In general actions in the fixture may be calculated ignoring the displacement of the fasteners. However, the effect of the displacement of the fasteners may be significant when a statically indeterminate stiff element is fastened and should be considered in these cases.

Derivation of forces acting on fasteners [9]

The actions acting on a fixture shall be transferred to the fasteners as statically equivalent tension and shear forces. When a bending moment and/or a compression force act on a fixture, which is in contact with concrete or mortar, a friction force will develop. If a shear force is also acting on a fixture, this friction will reduce the shear force on the fastener. However, it will not alter the forces on the concrete. As it is difficult to quantify with confidence the effect of friction on the resistance, the friction forces are usually neglected in the design of the fastenings. This simplified assumption is conservative. However, in case of fastenings shear loaded towards the edge and concrete edge failure the friction develops between the edge and the fastener with the smallest edge distance. Then friction may yield premature spalling of the edge and unfavourably influence the resistance of the fastening.

Eccentricities and prying effects should be explicitly considered in the design of the fastening (see Figure 45). Prying forces C arise with deformation of the fixture and displacement of the fasteners. Prying forces are avoided by using rigid fixtures.
1 eccentricity  
a) eccentricity  
b) prying action

Figure 45: Example for eccentricity and prying action

In general, elastic analysis may be used for establishing the loads on individual fasteners both at ultimate and serviceability limit states. For ultimate limit states plastic analysis for headed and post-installed fasteners may be used, if the conditions of Annex B of CEN/TS 1992-4-3 are observed.

Tension loads

The design value of tension loads acting on each fastener due to the design values of normal forces and bending moments acting on the fixture may be calculated assuming a linear distribution of strains across the fixture and a linear relationship between strains and stresses. If the fixture bears on the concrete with or without a grout layer, the compression forces are transmitted to the concrete by the fixture. The load distribution to the fasteners may be calculated analogous to the elastic analysis of reinforced concrete using the following assumptions (see Figure 46):

a) The axial stiffness $E_s A_s$ of all fasteners is equal. In general $A_s$ may be based on the nominal diameter of the fastener and $E_s = 210\,000\,\text{N/mm}^2$. For threaded fasteners the stressed cross section according to ISO 898 should be taken.

b) The modulus of elasticity of the concrete may be taken from EN 1992-1. As a simplification, the modulus of elasticity of concrete may be assumed as $E_c = 30\,000\,\text{N/mm}^2$.

c) In the zone of compression under the fixture, the fasteners do not take forces.

Figure 46: Load path for design of fasteners
For fastener groups with different levels of tension forces $N_{E2J}$ acting on the individual fasteners of a group, the eccentricity $e_N$ of the tension force $N_{E2d}$ of the group with respect to the centre of gravity of the tensile fasteners influences the concrete cone resistance of the group. Therefore this eccentricity should be calculated (see Figures 46 and 47). If the tensioned fasteners do not form a rectangular pattern (see Figure 47c) for reasons of simplicity the group of tensioned fasteners may be shaped into a rectangular group to calculate the centre of gravity. It may be assumed as point 'A' in Figure 47c). This simplification will lead to a larger eccentricity and a reduced concrete resistance.

The assumption of a linear distribution of strains is valid only if the fixture is rigid and does not deform significantly. The base plate should remain elastic under design actions and its deformation should be compatible with the displacement of the fasteners.

1) compressed area
2) neutral axis
3) centre of gravity of tensile fasteners
4) point of resulting tensile force of tensile fasteners
5) point 'A'
   a) eccentricity in one direction, all fasteners are loaded by a tension force
   b) eccentricity in one direction, only a part of the fasteners of the group are loaded by a tension force
   c) eccentricity in two directions, only a part of the fasteners of the group are loaded by a tension force
Shear loads

The load distribution depends on the effectiveness of fasteners to resist shear loads. Based on the assumption that the diameter in the hole of the fixture is not larger than the value \( d_f \) given in Table 05 the following cases are distinguished:

- All fasteners are considered to be effective if the fastening is located far from the edge and if fastener steel or concrete pry-out are the governing failure modes.
- Only fasteners closest to the edge are assumed to be effective if the fastening is located close to the edge and concrete edge failure governs.

<table>
<thead>
<tr>
<th>External diameter ( d ) (a) or ( d_{f,\text{rem}} ) (b) in (mm)</th>
<th>6</th>
<th>8</th>
<th>10</th>
<th>12</th>
<th>14</th>
<th>16</th>
<th>18</th>
<th>20</th>
<th>22</th>
<th>24</th>
<th>27</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter ( d_f ) of clearance in fixture (mm)</td>
<td>7</td>
<td>9</td>
<td>12</td>
<td>14</td>
<td>16</td>
<td>18</td>
<td>20</td>
<td>22</td>
<td>24</td>
<td>26</td>
<td>30</td>
<td>33</td>
</tr>
</tbody>
</table>

(a): if bold bears against the fixture (b): if sleeve bears against fixture

Table 05: Hole clearance

For groups without hole clearance this approach might be conservative in the case of concrete break-out failure. The fastener is not considered to be effective if the diameter \( d_f \) in the fixture is exceeded or the hole is slotted in the direction of the shear force. Slotted holes may be used to prevent fasteners close to an edge from taking up shear loads and to prevent a premature concrete edge failure (Figure 50).
Determination of loads

The design value of the shear forces of the individual fasteners of a group resulting from shear forces and torsion moments acting on the fixture may be calculated using the theory of elasticity assuming equal stiffness for all fasteners of a group and statics. Equilibrium has to be satisfied. Examples are given in Figures 51 and 52.

Independent of the edge distance the calculation of the design value of the shear forces on each fastener due to shear loads and torsional moments acting on the fixture should be carried out to verify steel and pry-out failures.

Shear loads acting away from the edge do not significantly influence the concrete edge resistance. Therefore for the proof of concrete edge failure these components may be neglected in the calculation of the shear forces on the fasteners close to the edge.
a) group with three fasteners in a row
b) quadruple fastening
c) quadruple fastening under inclined load
d) quadruple fastening under torsion moment

Figure 51: Determination of shear loads when all fasteners are effective (steel and pry-out failure),

\[
V_{\text{flecker}} = \frac{\tau_{\text{flecker}}}{z_p} \left[ \left( \frac{z_1}{2} \right)^2 + \left( \frac{z_2}{2} \right)^2 \right]^{0.8} \quad \text{with: } \ z_p = \text{radial moment of inertia (here: } z_p = z_1^2 + z_2^2 \text{)}
Key

a) group with two fasteners loaded perpendicular to the edge;
b) group with two fasteners loaded parallel to the edge;
c) quadruple fastening loaded by an inclined shear load

Figure 52: Determination of shear loads when only the fasteners closest to the edge are effective (concrete edge failure), examples

Edge effect

In case of fastener groups where only the fasteners closest to the edge are effective the component of the load acting perpendicular to the edge is taken up by the fasteners closest to the edge, while the components of the load acting parallel to the edge, due to reasons of equilibrium, are equally distributed to all fasteners of the group (Figure 52c)).

Design of fasteners

Fastener shall be designed considering traction and shear loads, results from load distribution analyze as here before. Compression is not considered as design criterion for fasteners.

The design of the fastener shall be considered taking count of the possibility of lever arm acting in the fastener or non lever arm acting on the fastener.

Shear force with non lever arm action

Shear loads acting on fastenings may be assumed to act without a lever arm if all of the following conditions are fulfilled:

1) The fixture must be made of metal and in the area of the fastening be fixed directly to the concrete without an intermediate layer or with a levelling layer of mortar with a compressive strength $\geq 30 \text{ N/mm}^2$ and a thickness $\leq d/2$. 
2) The fixture is in contact with the fastener over a length of at least 0.5·t\textsubscript{fix}, see Figure 54.

3) The diameter d\textsubscript{f} of the hole in the fixture is not greater than the value given in Table 5, line 2.

Key

1 grout layer
2 fixture
3 fastener
4 concrete

*Figure 53: Fixture with grout layer*

*Figure 54: Bearing area of fastener*

**Shear load with lever arm action**

If the conditions for non lever arm design action are not fulfilled, it should be assumed that the shear load acts with a lever arm according to Equation.
Figure 55: Design of fastener with lever arm

\[ l = a_3 + e_1 \]

with:

- \( e_1 \): distance between shear load and concrete surface
- \( a_3 \): 0.5 \( d \), see Figure 56,
  - 0 if a washer and a nut are directly clamped to the concrete surface, or if a levelling grout layer with a compressive strength \( \geq 30 \text{ N/mm}^2 \) and a: thickness \( t_{\text{Grout}} > d/2 \), is present,
- \( d \): diameter of the bolt or thread diameter, see Figure 55

The design moment acting on the fastening is calculated according to Equation:

\[ M_{\text{Ed}} = V_{\text{Ed}} \frac{l}{a_M} \]

The value \( a_M \) depends on the degree of restraint of the fastening at the side of the fixture of the application in question and should be determined according to good engineering practice. No restraint \((a_M = 1.0)\) should be assumed if the fixture can rotate freely (see Figure 56a)). Full restraint \((a_M = 2.0)\) may be assumed only if the fixture can, not rotate (see Figure 56b)) and the fixture is clamped to the fastening by a nut and washer and cannot rotate (see Figure 56b)).

Figure 56: Examples of fasteners without and with full restraint of the fastener at the site of the fixture.
If restraint of the fastening is assumed, the fixture and/or the fastened element must be able to take up the restraint moment.

**Verification of concrete at ultimate limit state**

It shall be demonstrated that Equation: \( E_d < R_d \) is fulfilled for all loading directions (tension, shear, combined tension and shear) as well as all failure modes (see Figures 57 and 58). When using plastic analysis additional checks are required.

Both minimum edge distance and spacing should only be specified with positive tolerances. If this requirement cannot be met, then the influence of negative tolerances on the design resistance shall be taken into account in the design.

**Key**

- a1) pull-out failure
- a2) pull-out failure (bond failure)
- b1), b2), b3) concrete cone failures
- b4) concrete blow-out failure
- c) splitting failure
- d) steel failure

*Figure 57: Failure modes under tensile loading*
Verification of fatigue limit state

This type of verification is not considered in this document while it should be checked that fatigue action does not occur for building vertical extensions.
9. FROM HILTI COMPANY (Extract)

Installation of column base plates on packing shims using the HSL anchor (all versions):

When a column base is to be erected using packers and under the base plate grout, this information needs to be considered by the Specifier or Responsible Engineer before the anchor is selected.

When the column is plumb, grout under the baseplate with an appropriate non-shrink grout and allow to cure.

Working with the opposing pairs of bolts, sequentially tighten all the bolts incrementally to the full tightening torque required for the anchors.

Installation sequence.

1. Position the column baseplate in the required location with the requisite packers in place underneath.
2. With the column temporarily supported drill through the base plate and clean out in accordance with the anchor setting instructions.
3. Tap the anchors into the prepared holes making sure that the anchor is embedded into the structural concrete at least as far as the minimum depth of embedment mark and the washer of the anchor is in contact with the baseplate.
4. Tighten the bolts up sequentially to the required tightening torque to fully set the anchors.
5. To Plumb the column slacken off the bolts on the low side of the baseplate. This will slacken off the tension in all the bolts.
6. Tighten the bolts on the high side of the baseplate. If a significant amount of movement is required this will result in the operation of the collapsible sleeve component of the anchor. This will be felt by the operator as a sudden reduction in tightness of the fixing. It is then possible to tighten the bolt further and pull the column vertical. Partially tighten the bolt on the opposite side of the baseplate to secure the baseplate in place.
7. If necessary repeat this procedure to plumb the column in the perpendicular direction.

IMPORTANT NOTICE

1. Construction materials and conditions vary on different sites. If it is suspected that the base material has insufficient strength to achieve a suitable fixing contact Technical Advisory Service.
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