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Flexible and Safe Heavy-Duty Fixings in Tall Buildings

高层建筑中安全的可调式重型固定装置

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Lars Grote graduated in civil engineering at the Technical University of Dortmund in Germany. Since 2006 he has been working for HALFEN GmbH in Langenfeld in Germany. During his time as a project engineer at HALFEN he developed a number of proposals for flexible heavy-duty cast-in channel fixings, among others for numerous international high-rise projects and visited professional consultants and designers for curtain wall façades, especially in the region of South East Asia. Since 2013 Lars has been working as a product manager for HALFEN cast-in channels and accessories.

Lars Grote毕业于德国多特蒙德技术大学土木工程系。从2006年开始，Lars Grote一直就职于德国朗根菲尔德的哈芬有限责任公司。在哈芬担任项目工程师期间，Lars为世界许多高层建筑设计了大量的预埋式重型槽钢构件，并拜访过多位建筑幕墙的专业顾问和设计师 (尤其在东南亚地区) 。从2013年至今，Lars一直担任哈芬预埋式槽钢装置及其配件的产品经理。

Abstract

More than any other structure tall buildings need a significant number of heavy-duty fixings, e.g. for the fixing of elevator guide rails or curtain-wall façades. For such applications cast-in channel fixing systems offer the possibility of a fast, 2-dimensional adjustable, clean and safe assembly under highest load conditions. Furthermore the installation does not need any power tools, saves time and energy. At the same time cast-in channels offer a very flexible connection which can be re-used for a new assembly even after many years. This paper demonstrates the before mentioned features, showing examples of HALFEN's outstanding projects around the world.

Keywords: Cast-In Channel Fixings, Flexible Heavy Duty Fixings, Fastening Technology

摘要

与其他结构相比，高层建筑需要大量的重型固定装置，例如固定电梯导轨或者幕墙外立面的固定装置。对于这类应用，预埋槽钢固定系统能够在最高负载条件下提供快速、二维可调节、清洁和安全的组装形式。此外，安装过程无需电动工具，节省了时间和能源。与此同时，预埋槽钢是一种非常灵活可调的连接方式，甚至在使用多年后也可以进行重新组装。本文展示了上述特点，提供了哈芬在全世界的优秀项目示例。

关键词: 预埋槽钢固定装置; 可调式重型固定装置; 紧固技术

Flexible and Safe Heavy-Duty Fixings in Tall Buildings

Tall building structures need a significant number of heavy duty fixings, for example for the connection of elevator guide rails or for the support of curtain wall façades. These connections are subject to different load conditions, e.g. to dynamic and fatigue relevant loads when fixing elevator rails, or seismic and impact loads (bomb blast) when fixing curtain wall façades.

Generally it is a common practice in the fastening technology to attach fixtures to concrete structures by welding to cast-in steel plates or by using post drilled anchors.

Like any other fixing method the two above mentioned methods provide some advantages but also include disadvantages and difficulties that may occur on site. In general, both methods are very costly and time consuming. In case of post drilled anchors, a hole must be drilled into the concrete first before the actual anchor can be installed. Hitting rebar during the drilling process is often unavoidable, which ultimately leads to the anchor having to be placed in a position different to that originally planned. This can lead to the whole connection having

高层建筑中 安全的可调式 重型固定装置

高层建筑结构需要大量的重型固定装置，例如用于连接电梯导轨或者支撑幕墙外立面。这些连接件会承受不同的荷载，例如安装电梯导轨时需要承受动态载荷和疲劳载荷，固定幕墙外立面时需要承受地震载荷和冲击载荷 (炸弹爆炸) 。

紧固技术中常见的做法是通过在预埋钢板上的焊接或者使用钻孔锚栓，把固定物连接到混凝土结构上。

与其他固定方法一样，上述两种方法有其优点，但也存在缺点和施工现场可能出现的问题。一般来说，此两种方法价格昂贵而且耗时。如果使用钻孔锚栓，安装锚栓之前，必须在混凝土内先钻孔。打孔过程中，有时打孔位置会跟钢筋产生不可避免的冲突，而这样有可能会导致锚栓位置与之前设计的位置不同。有时甚至需要重新设计整个连接件。这些都会产生额外的费用并导致项目整体延迟。

通过预埋板进行焊接连接时，质量通常难以保证，这是因为现场操作人员一般不是训练有素的专业焊接人员。此外，通过对焊接处进行喷涂防腐处理时，也经常会产生质量问题，导致腐蚀的产生。

to be redesigned again. Finally this will generate additional costs and time delay for the project as a whole.

The execution of welded connections to cast-in steel plates is often of questionable quality, as the personnel on site is not always very well trained in welding. Furthermore the quality of the corrosion protection by painting the welded connection can be incorrect, which may lead to corrosion.

The use of flexible bolted connections provided by cast-in channels presents an excellent alternative. Cast-in channels can transfer high loads, while at the same time they allow a fast and flexible installation of the fixtures and offer a lot of additional benefits to the designer, installer and owner of the building.

Cast-in Channels: Different Types and Use

Cast-in channels are available in hot-dip galvanized or stainless steel in different lengths, profile sizes and types to suit a wide range of applications. The range of products available in the market includes cast-in channels for various load ranges and different load directions (e.g. tension-, shear- and longitudinal loads) as well as cast-in channels for different load types like fatigue or seismic loads. Cast-in channel profiles are manufactured as standard with factory-riveted or welded anchors, providing the anchorage in the concrete.

The raw material used for the cast-in channel production usually contains post-consumer and pre-consumer recycled steel, so that iron ore resources are protected.

There are two main manufacturing methods to produce cast-in channels. One is to shape the channel profile from a flat steel coil, which means that the cast-in channel is cold-formed. The other, more advanced method is to roll the profile under high temperature directly from a glowing steel billet, so that the cast-in channel is hot-rolled. Both cast-in channel types, cold-formed and hot-rolled, can be used for static tension and transverse shear loads.

Due to the above mentioned manufacturing procedure hot-rolled cast-in channels offer a much better performance than cold-formed cast-in channels do. In contrast to cold formed cast-in channels the inherent material stress of hot-rolled cast-in channel profiles is reduced to a minimum due to the hot rolling production process. This has the effect that the fatigue strength of hot-rolled cast-in channels is significantly higher than it is for cold-formed cast-in channels.

Due to this, hot-rolled cast-in channels are normally preferred for fixing applications for elevators, machines or cranes, where fatigue relevant (dynamic) loads occur.

Because of the manufacturing process of hot-rolling it is possible to produce cast-in channels with an optimized geometry, with increased material thicknesses where necessary, while cold-formed channels usually only have a constant material thickness (see Figure 1).

Depending on the installation and load situation loads can occur which are acting in longitudinal direction of the cast-in channel. For this purpose, special serrated, hot-rolled cast-in channels are available in the market. In combination with a corresponding serrated T-bolt the longitudinal loads can be carried safely into the cast-in channel profile and from there into the concrete structure by the welded or riveted anchors of the channel.

使用预埋槽钢，提供的灵活螺栓连接是一种很好的替代。预埋槽钢能够传递高载荷，同时能够快速、灵活安装固定物，并且能够为设计师、安装工人和业主提供更多额外的益处。

预埋槽钢: 不同类型和用途

不同长度、剖面尺寸和类型的热镀锌或不锈钢预埋槽钢，可以满足各种应用的需要。市场上提供的产品范围包括用于不同载荷范围和不同载荷方向的预埋槽钢 (例如拉力、剪力和轴向力)，以及用于不同载荷类型的预埋槽钢 (例如疲劳载荷或者地震载荷)。预埋槽钢具有标准化的断面尺寸，锚腿可以通过铆接或焊接固定，将构件与混凝土结构可靠地连接起来。

用于预埋槽钢生产的原材料一般是消费前和消费后回收钢材，这样铁矿资源就得到了保护。

生产预埋槽钢的方法主要有两种。第一种是使用钢板轧制而成，称为冷弯。另一种更先进的方法是使用灼热的钢坯直接在高温下轧辊而成，这种方法称为热轧。不管是冷弯还是热轧的预埋槽钢，都可以用于承受静态拉力和剪力。

根据上述不同的生产程序，热轧预埋槽钢与冷弯成型槽钢相比，性能更好。跟冷弯相比，热轧工艺使得钢材的内部应力降到最低，所以热轧预埋槽钢的抗疲劳强度要比冷弯成型槽钢高得多。

因此，通常将热轧预埋槽钢用于会有疲劳 (动态) 荷载产生的电梯、机器或者起重机的固定。

热轧工艺可以使得槽体截面尺寸得到很好的优化，比如在最需要的地方增加槽体的厚度，而冷弯槽钢的截面材料厚度通常是固定的。(见图1)

根据不同的安装和载荷情况，载荷可能作用在预埋槽钢的纵向。因此市场上会找到特制带齿、热轧预埋槽钢。而与相应的带齿T形螺栓配套，纵向载荷就能够安全传递到预埋槽钢剖面，然后通过槽钢的焊接或者铆接锚腿，将载荷传递到混凝土结构。在大多数情况下，使用相应的光滑或者带齿T形螺栓将固定物与预埋槽钢进行连接。图1显示了上述提到的不同预埋槽钢类型和相应的T形螺栓。其他将固定物与预埋槽钢连接的方法也是可行的，例如使用锁板 (或者槽钢螺母) 和六角螺栓。

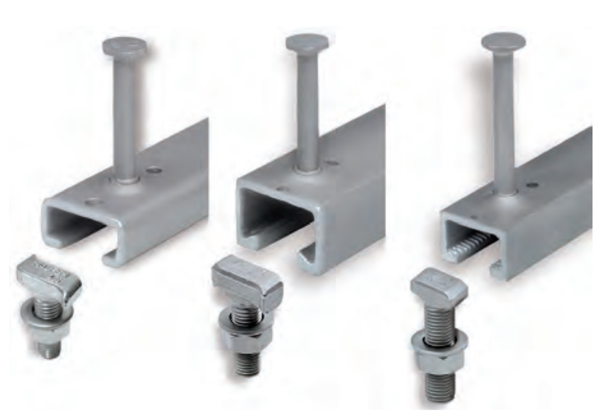

Figure 1. Illustration of different cast-in channel profiles, the anchors provide anchorage in the concrete, corresponding T-bolts are used to connect the fixture.
Cold-formed cast-in channel with rounded corners and constant material thickness (left); hot-rolled sharp edged profile with optimized geometry and increased resistance of the channel lips (middle); hot-rolled sharp edged profile with serration on channel lip (right) (Source: HALFEN GmbH)
图 1: 不同预埋槽钢断面的插图，锚腿提供混凝土中的锚固作用，使用相应的T形螺栓连接到固定物。
带圆角、的材料厚度不变的冷弯成型预埋槽钢 (左); 优化几何结构和槽钢槽口承载力得到加强的热轧槽钢断面 (中); 槽口带齿的热轧槽钢 (右) (来源: HALFEN GmbH)

Corresponding smooth or serrated T-bolts are used to connect a fixture to the cast-in channels in the vast majority of cases. Figure 1 is showing the before mentioned different cast-in channel types and corresponding T-bolts. Other methods to attach the fixture to the cast-in channel are also feasible, for example using female locking plates or channel nuts combined with hex-head bolts.

Before pouring the concrete in the precast plant or on site the cast-in channel is fixed to the formwork.

As soon as the concrete has cured and the formwork has been stripped the filler protecting the inner section of the channel can be removed and threaded T-bolts can be inserted into the channel. Accuracy is ensured as the fixture can be installed anywhere along the whole length of the channel. Slotted holes in the fixture allow an adjustment of the fixture perpendicular to the longitudinal axis of the cast-in channel. So a 2-dimensional adjustment is possible which means that construction tolerances can be compensated easily (see Figure 2).

Cast-in Channels: Design and Safety Concept

As for many other structural verifications in the construction industry the design of heavy duty cast-in channel fixings unfortunately is not subject to one worldwide uniform and global standard. Because of different safety awareness and safety requirements, the design and safety concept varies from country to country.

For example, the design of todays modern cast-in channel systems in Europe is based on the safety concept of the partial safety factors. This means in general that the value of the design action Ed must not exceed the design value of the resistance Rd. Ed is the result of the characteristic actual load value multiplied by a partial safety factor γ. At the same time the value of the design resistance Rd on material side is the result of the characteristic material resistance Rk divided by a material safety factor γM. The following equation shows the before mentioned relation:

$$\gamma \cdot E_k = E_d \leq R_d = \frac{R_k}{\gamma_M}$$

The design principle according to ACI, for example, is a little bit different. The ACI demands that the required strength must not exceed the design strength. The required strength is the acting load multiplied by a load factor which is normally greater than 1. The design strength is the nominal strength multiplied by a strength reduction factor φ, which is smaller than 1. The following equation shows the before mentioned relation:

$$\textit{required strength} \leq \textit{design strength} = \textit{nominal strength} \cdot \varphi$$

Depending on national regulations the above mentioned partial safety factors as well as the material safety and material reduction factors γM and φ can be different from country to country. The factors γM and φ also depend on the failure mode of the different cast-in channel system components. The failure of the channel-anchor connection or the local flexure of the channel lips are typical examples for steel failure under tension and shear loads. Concrete cone failure or splitting under tension load or concrete edge or pry-out failure under shear load are typical examples for concrete failure.

The nominal strength can be calculated individually for the particular failure mode of the cast-in channel system and is influenced by many factors. Among others the nominal concrete strength for example is

在预制厂或施工现场混凝土浇筑之前，将预埋槽钢固定到模板上。

混凝土养护完成并且脱模之后，就可以去除保护槽钢内部断面的填充物，然后把带螺纹的T形螺栓插入槽钢内部。由于可以在槽钢任何位置安装固定物，因此可以确保精度。固定物自带的长孔能够使其在垂直于槽钢纵轴的方向上进行调整。这样可以实现二维双向调整，从而可以轻松补偿施工公差(参见图2)。

预埋槽钢: 设计和安全理念

与建筑行业其他众多结构验证一样，由于不同的安全意识和安全要求，不同国家的设计和安全理念不同，目前重型预埋槽钢固定装置的设计并没有统一的全球标准。

例如，欧洲当今的现代预埋槽钢系统的设计基于分项安全系数的安全理念。这表示，一般情况下荷载的设计值Ed不能超过承载力设计值Rd。Ed是载荷标准值乘以分项安全系数γ所得出的结果。与此同时，材料的承载力设计值Rd是材料承载力标准值Rk除以材料安全系数γM所得出的结果。以下等式显示了上述关系:

$$\gamma \cdot E_k = E_d \leq R_d = \frac{R_k}{\gamma_M}$$

另外，比如符合ACI的设计原则则略有不同。ACI要求，要求强度不得超出设计强度。要求强度为作用载荷乘以载荷系数(通常大于1)。设计强度为标称强度乘以强度降低系数φ(通常小于1)。以下等式显示了上述关系:

$$\text{要求强度} \leq \text{设计强度} = \text{标称强度} \cdot \varphi$$

根据不同国家的规定，上述部分安全系数γM和材料下降系数φ可能因国家而异。系数γM和φ也取决于不同预埋槽钢系统组件的破坏形式。槽钢锚腿连接处破坏或者槽口破坏是受拉和受剪作用下钢材破坏的典型例子。混凝土锥体破坏、拉伸载荷下的劈裂、剪切载荷下的混凝土边缘破坏或者拔出破坏是混凝土失效的典型例子。

虽然钢槽不同形式的破坏荷载是可以通过计算得出的，但是有很多因素会对结果产生影响。混凝土等级、配筋或者预埋槽钢的边距，都会对设计结果产生重大影响。

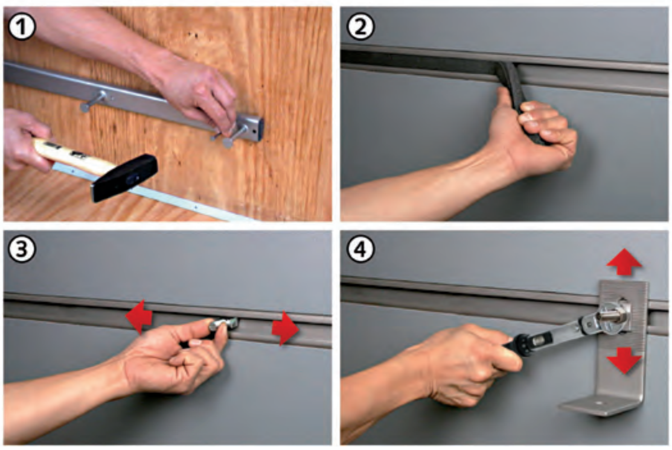

Figure 2. Illustration of installation: 1. Fix cast-in channel to formwork and pour concrete; 2. Remove channel filler after formwork has been stripped; 3.Insert T-bolt in cast-in channel and turn around 90 degrees; 4.Adjust fixture at required position and tighten the T-bolt (Source: HALFEN GmbH)

图2: 安装插图: 1.把预埋槽钢安装到模板上并浇筑混凝土; 2.拆掉模板后，取掉槽钢填充物; 3.把T形螺栓插入预埋槽钢并旋转90度; 4.将固定物调整至所需位置并拧紧T形螺栓(来源: HALFEN GmbH) controlled by the planned concrete grade, the planned reinforcement or the planned edge distance of the cast-in channel. All these aspects have a significant influence on the design result.

However, for certain failure modes it is not possible to calculate the nominal strength precisely. In such cases it is necessary to conduct tests to determine the particular material resistances, which then can be found in the corresponding country specific technical approvals of the cast-in channel manufacturers. Besides the material resistances, the technical approvals contain also all relevant data (e.g. anchoring depth, minimum edge distance, etc.) which are necessary for the design according to the particular country specific calculation standard. For this design and so for a safe and economical cast-in channel fixing the leading manufacturers offer special free design software which helps the engineer to calculate and verify the connection in a quick and easy way.

Example of Typical Connections in Elevator Shafts

The fixing of the sliding door motors and gears (see Figure 3) as well as the fixing of the elevator guide rails and spreader beams (see Figure 4) are among the most common applications in elevator shafts. Because of the lift cabin running along the guide rails the fixings of the guide rails are subject to fatigue relevant (dynamic) loadings so that hot-rolled cast-in channels should be used. In contrast to short buildings tall building structures often use double deck elevators to increase the passenger capacity of an elevator shaft. Due to the increased cabin capacity the loads acting on the guide rails and ultimately on the cast-in channels are higher than the loads in a short building using smaller cabins. At the same time tall buildings are often serviced by high speed elevators, which means that the frequency and finally the total number of load cycles acting on the guide rail and cast-in channel is increased. So generally cast-in channels used in tall buildings normally are subject to higher statical and fatigue loading than cast-in channels used in short buildings. Furthermore cast-in anchor channels are also generally used and suitable for structural connections in the elevator shaft (see Figure 5); they can also be used to fix further installation equipment like cables or pipes and keep the structure flexible for future upgrade. Corresponding T-bolts are used to connect the fixtures to the cast-in channels. A notch at the end of the T-bolt shaft serves as a marker to ensure the T-bolt is correctly installed and positioned in the channel.

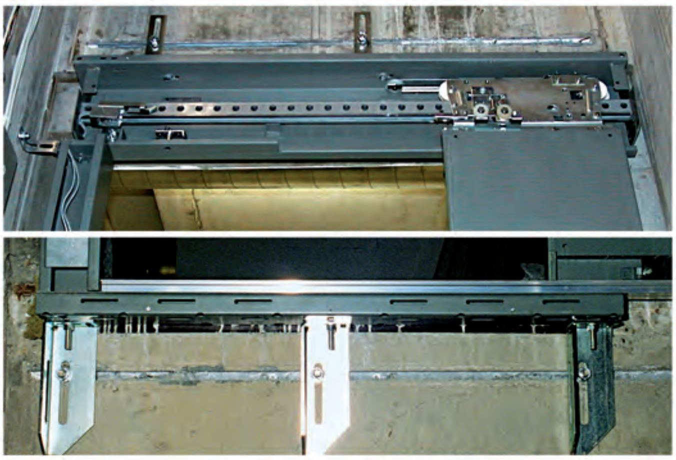

Figure 3. Door unit fixed with T-bolts to hot-rolled cast-in channels. The cast-in channels together with slotted hole brackets provide a fully adjustable installation in horizontal and vertical direction (Source: HALFEN GmbH)
图3: 使用T形螺栓将门固定到热轧预埋槽钢。预埋槽钢和带长孔的转接板的组合使用使得安装时，水平和竖直方向的位置调整都很方便 (来源: HALFEN GmbH)

Figure 4. Elevator guide rail fixed to hot-rolled cast-in channel (left); spreader beam fixed to hot-rolled cast-in channel (right) (Source: HALFEN GmbH)
图4: 安装在热轧预埋槽钢上的电梯导轨 (左)；安装在热轧预埋槽钢上的分布梁 (右) (来源: HALFEN GmbH)

Figure 5. Hot-rolled cast in channels and corresponding T-bolts used for the connection of structural elements in an elevator shaft (Source: HALFEN GmbH)
图5: 用于连接电梯井内结构构件的热轧预埋槽钢和相应T形螺栓 (来源: HALFEN GmbH)

然而，对于某些特定的破坏形式，是很难准确计算的。在这种情况下，有必要进行测试，以确定特定材料的承载力 (可以从预埋槽钢制造商的相应国家特定技术认证中得到)。除了材料承载力之外，技术认证也包含所有其他相关数据 (例如锚固深度、最小边距等)，这些数据对于根据不同国家特定计算标准进行设计十分必要。对于该设计以及安全、经济的预埋锚固安装，行业领先的制造商能够提供专业的免费软件，能够帮助工程师进行简单快速的计算和验证。

电梯井内典型连接件示例

滑动门电机和齿轮的安装 (参见图3) 以及电梯导轨和分布梁的安装 (参见图4) 是电梯井内最常见的应用。由于轿厢沿导轨运行，因此导轨的固定装置需要承受疲劳 (动态) 荷载，所以需要使用热轧预埋槽钢。与低层建筑相比，高层建筑结构通常使用双层电梯，以增加电梯井的载客量。由于轿厢容量增加，作用在导轨上的载荷以及最终作用在预埋槽钢上的载荷要高低层建筑内于使用较小轿厢的载荷。与此同时，高层建筑通常使用高速电梯，这意味着，频率以及最终作用在导轨和预埋槽钢上的负载循环总数增加。因此，与低层建筑内的预埋槽钢相比，高层建筑内的预埋槽钢一般要承受更高的静态载荷和疲劳载荷。此外，预埋槽钢锚固通常用于电梯井内的结构连接件 (参见图5)；预埋槽钢也可用于固定其他安装设备 (例如电缆或者管道) 并且保持结构灵活，以便将来升级。使用相应的T形螺栓将固定装置与预埋槽钢相连接。T形螺栓杆末端的缺口作为标记，确保正确安装T形螺栓并且在槽钢中位于正确位置。

One World Trade Center in New York, Case Study of Cast-in Channel Connections in Elevator Shafts

The One World Trade Center (see Figure 6) in New York, United States of America (designed by David Childs), is currently still under construction but has already reached it's final height with 541.3 meter (1,776 feet) so that today it already is the tallest building in the U.S. and the fourth-highest in the world. The height of 1,776 feet refers back symbolically to the year 1776 , the year of the Declaration of Independence of the United States of America.

The 104 -story building is served by 71 elevators, 5 of these running with a maximum speed of 9 meters per second. To attach the elevator guide rails to the highly reinforced high strength concrete elevator shafts, post drilled anchor solutions were already excluded in a very early design stage due to concerns over possible problems when drilling into the highly reinforced high strength concrete (see Figure 7).

Additionally a fast and accurate mounting of the elevator guide rails was required, so that the choice ultimately fell on the use of hot-rolled cast-in channels.

Figure 6. One World Trade Center in New York, 541.3 meter (1,776 feet) high (Source: HALFEN GmbH)
图6: 纽约世贸中心一号楼，541.3米 (1,776英尺) 高 (来源: HALFEN GmbH)

纽约世贸中心一号楼: 电梯井内预埋槽钢连接件的案例研究

美国纽约的世贸中心一号楼 (David Childs设计) (参见图6) 目前仍在施工当中，但是已经达到了其最终高度541.3米 (1,776英尺)，所以它是美国第一高楼和世界第四高楼。1,776英尺的高度代表1776年，即美国独立宣言发表的年份。

这栋104层的建筑物总共有71部电梯，其中5部电梯的最大速度为9米/秒。为了将电梯导轨固定到高强度混凝土电梯井，在早期设计阶段就已经排除了钻孔锚固解决方案，这是因为考虑到在高密度配筋的高强度混凝土中打孔可能带来的问题 (参见图7) 。

此外由于快速、精确安装电梯导轨的要求，使用热轧预埋槽钢成为无可替代的最终选择。

用于建筑幕墙的典型连接件示例

预埋槽钢有助于快速、安全、有效地完成幕墙安装，尤其在预制外立面构件装配方面。预埋槽钢的使用能够避免耗时而且昂贵的钻孔锚固，安装更快速，并且降低了项目预算超支以及相关违约成本的风险。

现场安装不再需要电动工具。与化学锚栓相比，预埋槽钢的安装不受天气和温度条件的影响。

此外，预埋槽钢不需要现场焊接，避免了火灾的风险。例如，2010年上海的一栋摩天大楼就因为焊接而起火。

由于不再使用钻孔螺栓，因此降低了噪声和粉尘污染，并排除了由于振动 (振动性白指) 而引起的受伤风险。因此这种安装方法对于工人健康没有损害。由于浇筑混凝土前进行预埋槽钢安装和T形螺栓安装 (安装固定装置时) 时不需要电动工具，因此也节约了能源。安装的预埋槽钢在多年之后还可以重新使用，例如建筑物需要翻新或者改变外立面时仍可使用。最后同样重要的是，预埋槽钢可为施工期间使用的板边护栏提供安全的临时固定，可以实现双重目的 (参见图8) 。

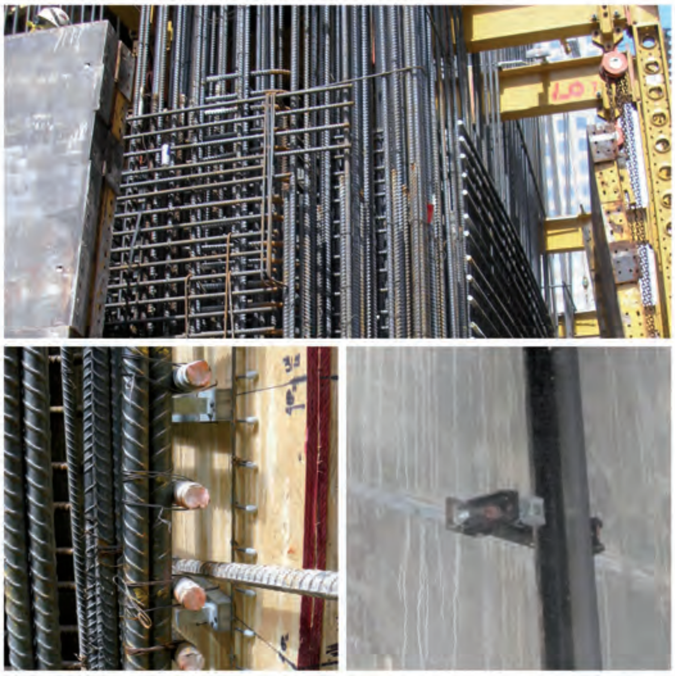

Figure 7. Highly reinforced elevator shaft (top); cast-in anchor channel fixed to the formwork before concreting (bottom left); elevator guide rail fixed to hot-rolled cast-in channel (bottom right) (Source: HALFEN GmbH)
图7: 高配筋率的电梯井 (顶部) ; 混凝土浇筑前安装在模板上的预埋锚固槽钢 (左下角) ; 安装在热轧预埋槽钢上的电梯导轨 (右下角) (来源: HALFEN GmbH)

Example of Typical Connections for Curtain-Wall Façades

Cast-in channels allow rapid, safe and efficient installation of curtain walls, especially in the assembly of prefabricated façade elements. They allow time consuming and costly drilled anchors to be avoided, leading to quicker installation and reduced risk of over-running the site program and associated cost penalties.

For installation on site no electrical tools are necessary and, in contrast to chemical anchor fixings, the installation is totally independent from any weather and temperature conditions.

Furthermore, cast-in channels avoid the requirement for on-site welding and the associated risk of fire. For example, in 2010 a skyscraper in Shanghai caught fire caused by fumes because of welding.

As drilled bolts are avoided, noise and dust pollution is reduced and the risk of injury due to vibration (vibration white finger) eliminated. Therefore this fixing method has no harmful influence on the workers' health. It also saves energy as no power tools are necessary for the installation of the cast-in channel before concreting as well as for the installation of the T-bolts when installing the fixture. Installed cast-in channels can be reused even after many years, for example when the façade has to be renewed or to be changed. Last but not least cast-in anchor channels can serve a dual purpose by providing a safe fixing for slab edge guard rails used during construction period (see Figure 8).

Generally façade fixings can be differentiated between front of slab fixings (FOS) and top of slab fixings (TOS) (see Figure 9). FOS fixings are mainly used for mullion-transom constructions (stick curtain wall) and TOS fixings are mainly used for prefabricated elements (unitized curtain wall).

Because of the better accessibility, the installation of TOS fixings is often easier than the installation of FOS fixings.

In most TOS cases one smooth cast-in channel is cast in parallel to the edge of the slab. The corresponding bracket is normally fixed by two T-bolts in slotted holes located in perpendicular direction so that a 2-dimensional adjustment of the connection is possible. To transfer the loads from bracket to the T-bolts the bracket needs e.g. a serration with a serrated washer (see Figure 10), so that the shear load in the bracket normally resulting from wind suction or wind pressure is transferred by a mechanical interlock of the bracket's and washer's serration directly into the shaft of the T-bolt. In this case the T-bolts are generally affected by bolt bending.

Alternatively, one or two serrated channels could be cast-in perpendicular to the edge of slab, so that the bracket needs two slotted holes parallel to the edge of the slab, which do not need any serration (see Figure 10). In this case the T-bolts are generally not affected by bolt bending.

Burj Khalifa in Dubai, Case Study of Cast-in Channel Connections for Curtain-Wall Façade

For the curtain wall façade of Burj Khalifa in Dubai, United Arab Emirates (designed by Adrian Smith), with 828 meter (2,716 feet) still the tallest building in the world, cast-in channels have been used to fix the more than 25,000 prefabricated glass façade panels (see Figure 11). The anchor channels have been cast-in into the face of the slab. Due to the limited height of the slab of only 200 millimeter (8 in) and due to very high characteristic tension loads with a maximum of 60 kN (13.48 kipf) acting on the cast-in channels resulting from wind suction it was necessary to change the anchorage from standard, smooth riveted bolt anchor to a 400 millimeter (16 in) long

Figure 8. Guard rail fixed to cast-in channel during construction period (Source: HALFEN GmbH)
图8: 施工期间安装在预埋槽钢上的护栏 (来源: HALFEN GmbH)

Figure 9. Front of slab (FOS) fixing (top); Top of slab (TOS) fixing (bottom) (Source: HALFEN GmbH)
图9: 侧埋 (FOS) (顶部) ; 顶埋 (TOS) (底部) (来源: HALFEN GmbH)

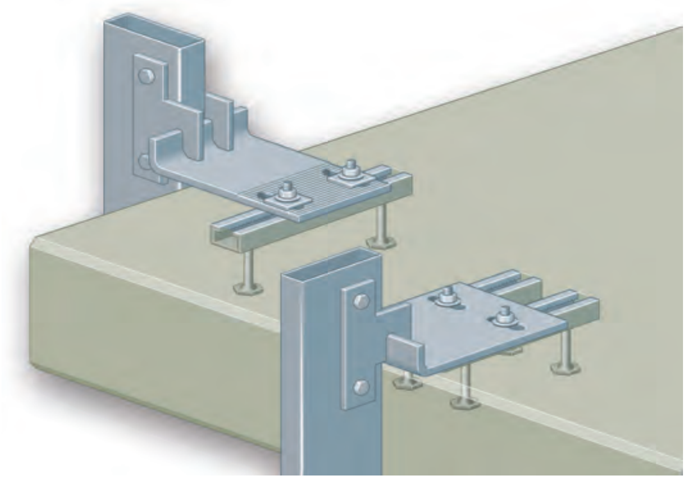

Figure 10. Smooth cast-in channel positioned parallel to edge of slab (left); serrated cast-in channels placed perpendicular to edge of slab (right) (Source: HALFEN GmbH)
图10: 平行于楼板边缘的光滑预埋槽钢 (左) ; 垂直于楼板边缘的带齿预埋槽钢 (右) (来源: HALFEN GmbH)

welded ribbed rebar with diameter 16 millimeter (#5) for the worst case, so that the tension load is transferred into the concrete by bonding and not by activating a concrete cone when using a smooth bolt anchor (see Figure 12 top). After concreting and removing the formwork the brackets for the façade panels could easily be adjusted and connected to the cast-in channels using the corresponding T-bolts (see Figure 12 bottom).

So the use of prefabricated façade panels in combination with cast-in channel fixings finally allowed a fast and safe installation process of the façade cladding for the tallest building in the world.

Figure 11. Burj Khalifa during the installation period of the more than 25,000 curtain wall façade panels (Source: HALFEN GmbH)
图11: 哈利法塔超过 25,000个幕墙单元板的安装 (来源: HALFEN GmbH)

一般而言，幕墙的固定方式分为侧埋 (FOS) 和顶埋 (TOS) (参见图9) 。FOS侧埋主要用于幕墙立柱和横梁构件 (构件式幕墙)，TOS顶埋主要用于预制构件 (单元式幕墙) 。

由于具有施工的便捷性，一般TOS顶埋安装比FOS侧埋安装更容易。

绝大多数TOS顶埋安装时，预埋槽钢将平行于楼板边设置。转接板通过位于长孔内的两个T型螺栓在槽钢的垂直方向上固定，由此提供连接件在平面内的二维调整。为了将载荷从转接板转移到T形螺栓，转接板需要带齿并且通过带齿的垫圈进行连接 (参见图10) ，这样转接板内的剪切载荷 (通常由风吸力或者风压力引起) 通过转接板和垫圈锯齿的机械咬合作用，直接传递到T形螺栓杆内。这种情况下，T形螺栓一般受到弯矩的影响。

或者可以垂直于板的边缘预埋一个或者两个带齿槽钢，而这样转接板则需要两个平行于板边缘的长孔 (不需要任何锯齿) (参见图10) 。这种情况下，T形螺栓一般不受弯矩的影响。

迪拜哈利法塔: 建筑幕墙预埋槽钢连接的案例研究

阿联酋迪拜的哈利法塔 (Adrian Smith设计) 高828米 (2,716英尺) 是世界上最高的建筑物，使用预埋槽钢固定超过25,000个预制玻璃幕墙单元板 (参见图11) 。预埋槽钢预先侧埋于楼板。由于楼板的厚度有所限制 (仅200毫米，也就是8英寸) 以及非常高的拉力标准值 (最大60kN，也就是13.48kipf) (由于风吸力作用在预埋槽钢上，因此有必要将标准的光面锚腿变为400毫米长 (16英寸) 的焊接螺纹钢筋 (最极端荷载情况下直径16毫米 (#5))，这样通过咬合力将拉力传到混凝土内，而不是使用光面锚腿时激活混凝土椎体的方式 (参见图12顶部) 。在浇筑混凝土并拆除模板后，可以轻松调整固定幕墙板的转接板，然后使用相应T形螺栓连接到预埋槽钢 (参见图12底部) 。

通过预制幕墙单元板与预埋槽钢装置的结合使用最终实现了世界上最高建筑物外立面维护结构的快速、安全安装。

Figure 12. Ribbed rebar welded to cast-in channel profile (top); brackets fixed to cast-in channels (bottom) (Source: HALFEN GmbH)
图12: 焊接在预埋槽钢上的螺纹钢筋 (顶部); 安装在预埋槽钢上的转接板 (底部) (来源: HALFEN GmbH)

Conclusion

In summary of this paper cast-in channel fixings offer the following benefits:

1. Flexible bolt connection, which allows rapid and efficient installation of elevator rails, curtain wall panels and other components in high-rise buildings.
2. Easy and safe installation without any drilling, no electricity on site is necessary.
3. No damage of existing reinforcement by drilling.
4. No welding necessary, so no risk of fire.
5. Connection can be reused even after many years for new components (e.g. when the façade is renewed).
6. Hot-rolled cast-in channels available, which have an increased channel lip capacity and are suitable for fatigue relevant loads.
7. Serrated hot-rolled channels available, which can carry also highest loads in longitudinal channel direction.
8. Quick and easy design with special free software

结论

作为本文的总结，预埋槽钢固定装置有下列好处:

1. 灵活的螺栓连接，实现高层建筑内电梯导轨、幕墙面板和其他组件的快速、有效安装。
2. 无需钻孔就可以实现简单、安全的安装。现场不需要电力设备。
3. 不会出现由于钻孔导致的钢筋损坏。
4. 不需要焊接，因此没有火灾风险。
5. 多年后连接件仍然可以用于新的组件 (例如建筑外立面翻新时) 。
6. 热轧预埋槽钢具有增强的槽钢凸缘，从而提高了槽钢槽口的承载力，可适用于疲劳载荷工况下。
7. 带齿热轧槽钢在纵向上能承担最重的载荷。
8. 专业的免费软件提供简单、快速的设计。