FASTENING ON STEEL: HILTI STUDS AND BEAM CLAMPS COMPARISON

In this article two technologies for fixing elements to steel will be compared, that are an alternative to the traditional fixing methods (welding and bolting): studs (find out more about Hilti's solutions for studs here) and beam clamps. This comparison will be done for the different stud solutions shown in Figure 1, beam clamps related to base plates and struts shown in Figure 2 and beam clamps related to threaded rods shown in Figure 3. The following parameters are considered in the comparison: base material requirements, loads, corrosive environments, approvals, vibration, fatigue, seismic behaviour and fire resistance. In the end of the technical comparison, real examples will be shared (justifying the best solution for this cases) and also a total installed cost analysis (that includes labour cost besides the material) will also be presented.

Topics related to a direct connection to fastening elements such as pipe clamps, pipe shoes or thermal expansion elements are not included in this article.

Figure 1 – Hilti stud solutions for Fastening on Steel: X-BT, S-BT-MR HL and F-BT-MR SN (from left to right).

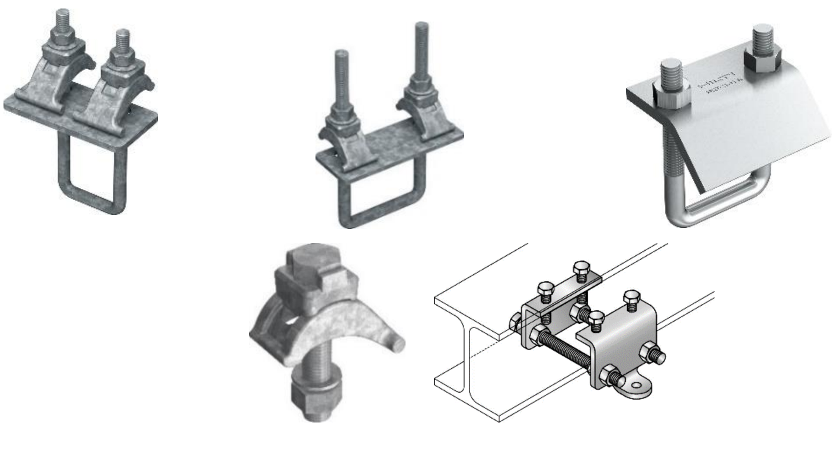

Figure 2 – Hilti beam clamps solutions related to base plates and strut, from left to right: MT-BC-GS T OC, MT-BC-GXL T OC, MQT-21-41-R, MI-SGC M16, MQS-IB.

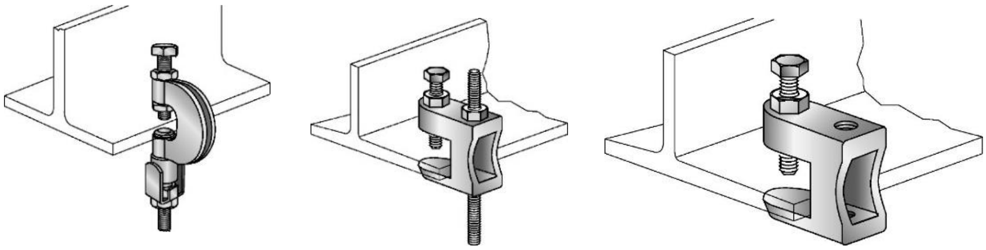

Figure 3 - Hilti beam clamp solutions related to threaded rod connection from left to right: MQT-G, MAB, MAB-M.

Base material requirements

When it comes to the base material, it's important to compare the **range of the base material**, **the steel grade**, and the **scope of applications** (like profile types, direction, among others).

Fastening on steel **studs can be used from a thickness of 4 mm on**, and in some solutions like Hilti S-BT HL and X-BT we **don't have defined a maximum base material thickness**. When it comes to steel grades, these can be applied from **S235 on**, but we have a maximum limit that varies from S460 (F-BT) to S960 (X-BT).

Hilti beam clamps can also be used on steel grades **from S235** onwards and, in case of beam clamps related to base plates and strut, **in steel profiles with a minimum flange thickness from 3 mm**. **The maximum flange thickness** Hilti offers **is 36 mm**. In Table 1 it is possible to find a summary of these limits for the portfolio we are comparing.

Table 1 - comparison on base material thickness and steel grade.

			Min base material thickness	Max base material thickness	Min Steel Grade	Max Steel Grade
Studs	all	X-BT*	8 mm	N/A	S235	S960
		S-BT HL*	6 mm	N/A	S235	S500
		F-BT*	4 mm	30 mm	S235	S460
Clamps	strut / girder	MT-BC-GS T OC	3 mm	36 mm	S235	N/A
		MT-BC-GXL	3 mm	36 mm	S235	N/A
		MQT-21-41-R	3 mm	23 mm	S235	N/A
		MI-SGC	3 mm	36 mm	S235	N/A
		MQS-IB	6 mm	28 mm	S235	N/A
	threaded rod	MQT-G	N.A.	17 mm	S235	N/A
		MAB	N.A.	28 mm	S235	N/A
		MAB-M	N.A.	28mm	S235	N/A

* The studs can be applied in thinner base materials, however no backside damage can not be guaranteed

Regarding base material, fastening on steel **studs can be applied on coated steel** without rework, while **with beam clamps a touch up of the coating is needed** after the application to guarantee protection against corrosion. Furthermore, it is important to point out that **a steel profile with a flange is required for application when using beam clamps**.

Fastening on steel **studs** (S-BT and X-BT) also **provide a solution for passive fire protected (PFP) steel**, when used in combination with standoff couplers.

When it comes to **studs, the installation is overall more flexible**, allowing **fixing on more directions** (e.g. floor) and a wider range of profiles, namely square, rectangular, and circular hollow sections (for circular sections the minimum diameter must be verified) or, when it comes to the shipbuilding industry, fixing in a bulkhead, for instance. Also, Fastening on Steel **studs do not require access to both sides of the base material** for installation. However, if the **fixing is not meant to be perpendicular to the surface** of the base material (if there is an angle different than 90°), **only beam clamps provide a solution** (e.g. MQT-G). In case a solution is needed to be flexible related to the orientation of the beam, a sandwiched solution (in which a support plate is placed on the other side of the beam to give support) could be a viable alternative as well.

Hilti's portfolio also includes adapters and an installation tool for the **fixing of studs to passive fire protected structures**, allowing for a safer and more productive installation. **For beam clamps, the fixing on passive fire protected coated steel is not recommended.**

As previously mentioned, **Hilti studs offer a broader range of profiles and material thicknesses** in base materials. While Hilti beam clamps provide a flexible solution for threaded rod connections and are not restricted by maximum steel grade, **Hilti studs cover most of the steel grades commonly used in construction, energy, and industry projects**.

Loads

Regarding loads, we consider the design resistance of **shear and tension**. The performance in shear is very similar between the two technologies (the studs go up to 6 kN and the beam clamps go up to 7,50 kN). However, when it comes to **tension, the performance of the beam clamps can go up to significantly higher values** (45 kN for MT-BC-GXL) – see Table 2.

Studs are bonded directly to the steel base material. Clamps on the other hand are fastened to the coating which can be damaged or deform over time. Consequently, studs are more suited to coated base material. **For beam clamps, a coating damage needs to be avoided, with that reduction factors depending on the coating need to be considered which can be up to 50% driven by friction on painted steel surface** [1]**.** Also, for beam clamps, **a loss of pre-tension should be considered**, that will lead to **lower long-term resistances.**

In summary, for applications involving **coated steel, studs are preferable** as it does not harm the quality of the coating. However, when the primary considerations are **load capacity and orientation**, and the **base material is non-coated steel**, beam clamps for base plates offer superior load-bearing capabilities due to the use of thicker threads compared to studs.

Table 2 - Design resistance for shear and tension for the FoS studs and beam clamps.

			Max Shear Load (S275 steel)	Max Tension Load (S275 steel)
Studs	all	X-BT	6,00 kN	5,00 kN
		S-BT HL	5,70 kN	5,10 kN
		F-BT	5,00 kN	11,20 kN
Clamps	strut / girder	MT-BC-GS T OC*	5,40 kN	22,50 kN
		MT-BC-GXL*	7,50 kN	45,00 kN
		MQT-21-41-R	0,78 kN	8,40 kN
		MI-SGC	2,85 kN	24,00 kN
		MQS-IB**	N.A.	N.A.
	threaded rod	MQT-G	N.A.	1,5-2,5 kN***
		MAB	N.A.	5,5 kN
		MAB-M	N.A.	5,5 kN

*For the Shear Load in the beam clamps, it is considered the shear direction parallel to the substructure to be fixed

**MQS-IB to be used under Seismic sprinkler specific conditions only

*** Load varies related to angle being smaller or bigger than 25°

Corrosive environments

When it comes to corrosion, ISO 12944 :2018 [2] classifies the main environments to which steel structures are exposed. There are 6 different atmospheres of corrosivity:

- C1 – very low;
- C2 – low;
- C3 – medium;
- C4 – high;
- C5 – very high;
- CX – extreme;

In the Table 3 it's possible to see the maximum corrosivity atmosphere and the corresponding life expectancy. If the products are applied in lower corrosive environment, the life expectancy increases. According to the information on the table, **beam clamps for base plates can mostly be used up to C4 environments** (industrial areas and onshore areas of medium salinity), and in the case of MQT-R, it can be used up to C5. **Stud solutions can mostly be applied in more aggressive environments**, such as C5 (industrial areas of high humidity and aggressive atmosphere and onshore areas of high salinity), or even CX (for more details reach out to Hilti). Also **studs have higher life expectancies** (up to 40 years for X/S-BT in C5 atmosphere).

It's also important to refer that, in **commercial segments**, most of the MEP (Mechanical, Electrical and Plumbing) applications only require C1-C2 corrosion protection, which are covered by the beam clamps. For higher corrosive environments, studs are the preferred solution.

Table 3 - maximum corrosive environment per product.

			Max Corrosive Environment	**Life expectancy**
Studs	all	X-BT	C5	40 years
		S-BT HL	C5	40 years
		F-BT	C5	25 years
Clamps	strut / girder	MT-BC-GS T OC	C4	15 years
		MT-BC-GXL	C4	15 years
		MQT-21-41-R	C5	25 years
		MI-SGC	C4	15 years
		MQS-IB	C1-C2	25 years
	threaded rod	MQT-G	C1-C2	25 years
		MAB	C1-C2	25 years
		MAB-M	C1-C2	25 years

Approvals

For non-standardized construction products (such as concrete or steel material products), the European Technical Assessment (**ETA**) [3] provides an independent Europe-wide assessment of the essential performance characteristics. Besides the ETA, a construction product can be assessed also by other external entities, like the Bureau Veritas [4], American Bureau of Shipping [5], RINA [6], various Sprinkler insurance companies (VdS, FM or UL) [7] [8] [9]. These approvals by external entities are important for different reasons, namely quality assurance, compliance, risk mitigation or building insurance.

In the table 4 we can see the different approvals for the beam clamps and studs as per June 2024.

Table 4 - Approvals overview for studs and beam clamps.

			ETA	American Bureau of Shipping	Bureau Veritas	DNV Type Approval	RINA	LR - Lloyds Register	Sprinkler (VdS, FM, UL)
Studs	all	X-BT	Yes	Yes	Yes	Yes	Yes	Yes	No
		S-BT HL	Yes	Yes	Yes	Yes	Yes	Yes	VdS in Progress
		F-BT	No	Yes	Yes	No	No*	No	No
Clamps	strut / girder	MT-BC-GS T OC	Yes	No	No	No	No	No	No
		MT-BC-GXL	Yes	No	No	No	No	No	No
		MQT-21-41-R	No	No	No	No	No	No	No
		MI-SGC	In Progress	No	No	No	No	No	No
		MQS-IB	No	No	No	No	No	No	FM
	threaded rod	MQT-G	No	No	No	No	No	No	VdS, FM
		MAB	No	No	No	No	No	No	VdS, FM, UL
		MAB-M	No	No	No	No	No	No	VdS, FM, UL

* F-BT has a Welding Procedure Qualification for RINA, but not a Type Approval

Beam clamps have a LABS/PWIS statement [10], which could be relevant for projects in the automotive industry. S-BT HL also have a LABS statement.

As per the information on the table, it's fair to refer that **fastening on steel studs have an overall wider range of approvals, while beam clamps have approvals that could be relevant for sprinkler applications** (like the FM approval).

Vibration

Vibration is the mechanical oscillations of an object about an equilibrium point. Vibration commonly occurs when any physical system is displaced from its equilibrium state and allowed to respond to the forces that restore equilibrium.

Multiple sources can lead to vibration on fastening on steel studs, namely turbomachinery, conveyers, or wind loads. It's also important to understand that in this chapter we are addressing vibration and not fatigue (this will be addressed in the next chapter). Vibration is different from fatigue in the sense that the endurance limit of the material is not reached and does not lead to the fatigue failure of the fastener but may potentially lead to a rotation of the nut/screw – see Figure 4.

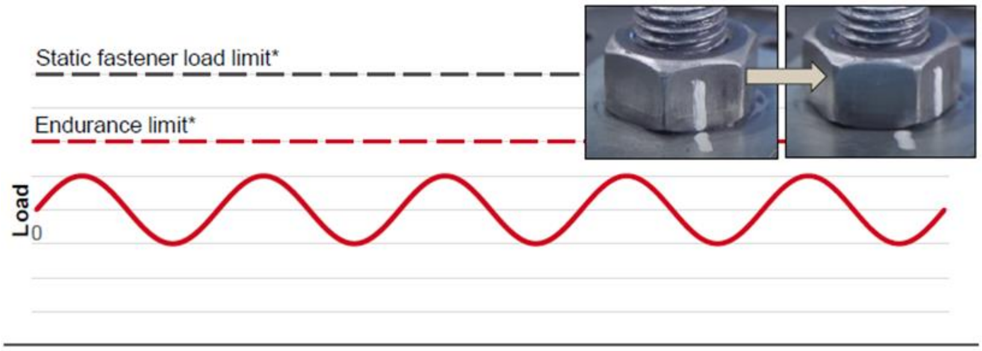

Figure 4 - Visual representation of load on a fastener from vibration.

Hilti has analysed the fastening on steel studs (X-BT and the old generation of S-BT) to vibration. To do that, we recorded and collected data for more than 100 hours to gain a deeper understanding of the expected vibration parameters, namely frequency and amplitude of movements.

Hilti has developed a test that evaluates the performance of a threaded connection in a vibration-rich environment when a nearby source is causing the fixed material to oscillate. To represent the real application, a cantilever connection is used, where a mass is fixed to the end of the lever arm – See in Figure 5 a representation of the test. **Each fastener is marked to observe any loosening that may occur from rotation of the screw element (vibration effect).**

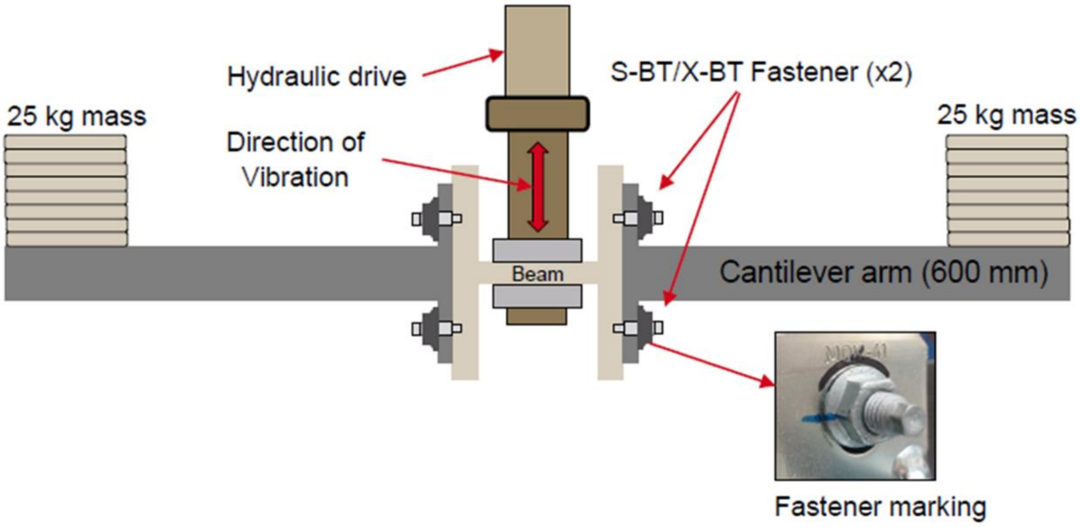

Figure 5 - Schematic representation of the vibration test developed by Hilti.

In the tests concluded, **no rotation of the nut/screw, no loosening and no slip of the fastened cantilever was observed, showing good retention of pretension/clamping force**. As so, the results indicate the **suitability of the studs tested and the provided flange nuts to the covered environments**.

Regarding beam clamps, MI-SGC have been tested with 2 base plates (8 beam clamps) as well as 4 base plates (16 beam clamps), with 1 Mio load cycles in each case. Those test results are taken into consideration, **to issue Engineering Judgements** (EJs) for this beam clamps, based on project specifics.

In summary, if vibrations are expected, **stud solutions are very suitable**. If **beam clamps are being used, an Engineering Judgment is required.**

Fatigue

It is very complex to assess if a specific source of dynamic loading is causing fatigue loading or vibration in the connection, because it depends on different parameters, namely frequency, amplitude, distance from excitation source, among other parameters.

When it comes to studs, the main purpose of dynamic testing of fasteners is to examine the fundamental robustness of the fastener anchorage in steel base material and to confirm the resistance to the variable portions of imposed loads in quasi-static design. Furthermore, the motivation of these tests is to show that the characteristic number of load cycles at service load level of the fastener clearly exceeds the threshold value of 10'000 below which the actions may be considered as not fatigue relevant. For the rare cases where **Fatigue design is required**, **an Engineering Judgement should be performed**, based on testing or by means of the numerical simulation of the structural detail [11].

Very similar to the vibration field, **beam clamps were not tested for fatigue loading**, and are **not recommended when fatigue loading is expected**.

Seismic

Regarding seismic performance, the X-BT and the S-BT HL studs were tested according to the AC70 standard [12] and ASTM E1190 [13]. The test results prove the robustness and the suitability of the studs to resist seismic loading. Based on these investigations, no load reductions in the North American approvals [12] will be necessary in tension and slight reduction are made to the seismic shear loads. **For Europe, the respective seismic product qualification process (EAD for seismic loading) as well as European rules for design of powder-actuated fasteners under seismic actions are not yet in place**. Based on the existing provisions on anchor design [14] [15], conclusions by analogy were made as follows:

- The current recommended tension load values of the X-BT and S-BT given in the Specification Manual (and Hilti Direct Fastening Technical manual [16], respectively) are applicable for design under seismic actions of Type B connections (**connections of non-structural elements**) applying performance category C1 according to Technical Report TR45;
- In case of the shear loads, slight adjustments are necessary (10% resistance reduction can be assumed) based on the results of the tests performed by Hilti [17].

Regarding **beam clamps**, Hilti provides a **seismic approved bracing solution for sprinkler applications**, with the MQS-IB that is covered by an FM approval.

Fire resistance

The **X-BT studs were tested to evaluate the temperature resistance**. The test concept was as follows: X-BT studs were fastened to a steel plate and placed in a chamber until the fastener and the base material reached a specific target temperature. Different temperatures were tested, from -50°C (5 samples) to higher temperatures, namely 200°C, 400°C and 600°C (10 samples each) [18]. After the base material reaches the defined temperature, a pull-out test is performed. The results of this tests can be seen in Figure 6.

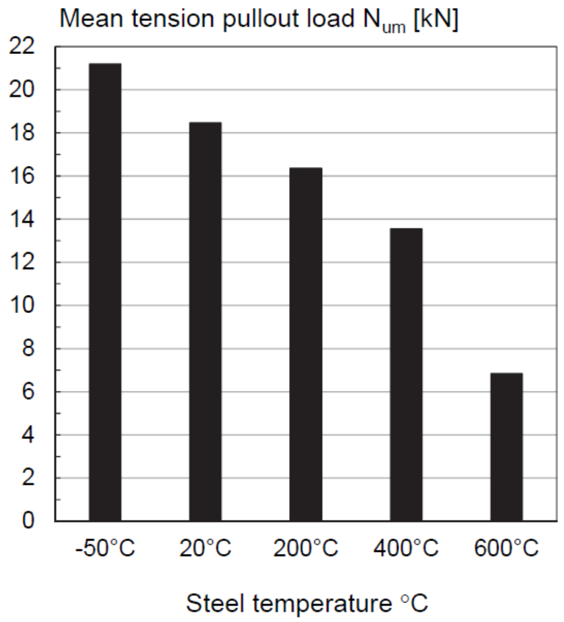

Figure 6 - Mean tension pullout load for different temperatures for the X-BT studs.

Given the test results achieved, we can conclude that **if the fastener is used on fire protected steel structures** (with steel temperature typically less than 600°C in case of a fire), **the characteristic resistances at high temperature allows for fastener design in case of a fire as per ETA-20/1042**, Annex C3 [19] [20].

Also, the S-BT HL and X-BT studs were tested regarding their application on fire rated boundaries in shipbuilding facilities, to understand the effect of the fasteners on the mechanical resistance of the steel base material (bulkheads, decks). Tests were performed according to the requirements of IMO Resolution MSC.307(88), Fire Test Procedure Code, 2010, part 3 [21], where multiple studs were installed in the unexposed face of two different bulkheads subjected to fire.

Both bulkheads passed the performance criteria of IMO Resolution MSC.307(88), FTP Code, 2010 for "A-0" bulkheads. The installed S-BT studs didn't affect the fire resistance of steel bulkheads, and the studs were able to maintain their loads for a period of 60 minutes. Based on the test results, in the S-BT HL Specifications document [22] it's possible to find the recommended loads, and also the conditions in which these loads apply.

When it comes to fire resistance on beam clamps a case-by-case Engineering judgment is recommended to be done as a single fire resistant for such steel fasteners without considering the overall application might lead to misleading results. For this case we offer a case-by-case assessment if being needed.

Application examples

After comparing both technologies in different fields, namely the base material, loads, corrosive environments, approvals, vibration, fatigue, seismic and fire resistance, we will now analyze different real examples and explain the best Hilti solution for each.

Example 1 – Integrated Floor System for a Yacht (shipbuilding)

In this example the goal was to fix the structure of a raised floor in the construction of a yacht. The base material is S235 steel. A schematic representation (section view) of the application can be seen in Figure 7.

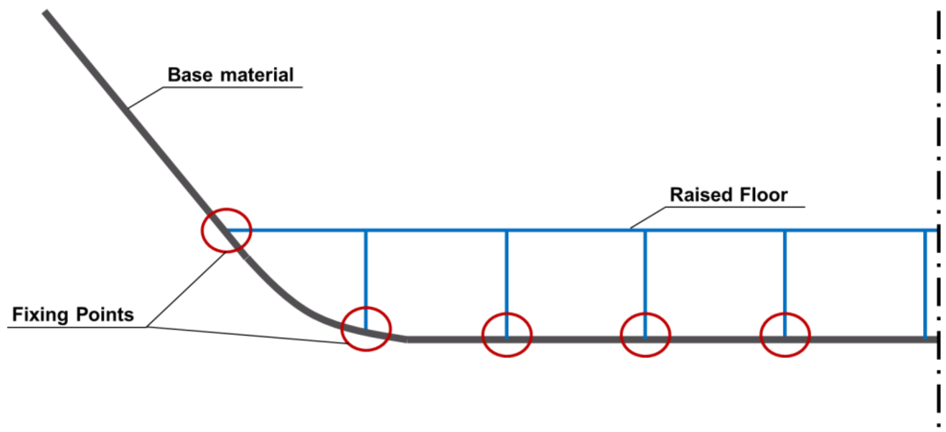

Figure 7 – Schematic representation (section view) of a raised floor in a yacht.

In this case, the **structure needs to be fixed to the floor**, and since the base material is a **continuous steel structure (only have a flange in some cases)**, beam clamps are not an option, so we needed a **stud solution**. In this case, the stud with a **broader scope of approvals in the Shipbuilding industry** (namely RINA) is **F-BT**, so it's the best Hilti solution for this application. The F-BT stud enables a faster and safer solution (traditional welding was avoided in the shipyard).

Example 2 – Handrail fixing on an Energy project

The following example is on a Power Plant project, where a handrail needed to be fixed to a steel beam. A schematic representation of this application is shown in Figure 8.

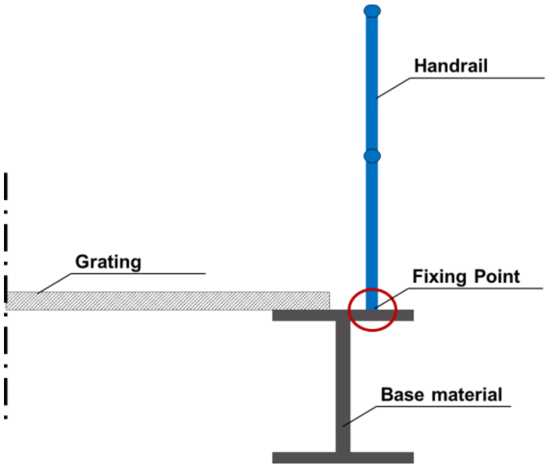

Figure 8 – Schematic representation of a handrail application on a steel base material (section view).

As shown in Figure 8, on one side of the beam the access was limited, due to grating. Because of that, beam clamps were not possible, also allied with the fact that the vibration and the higher corrosive resistance make studs the better solution. As so, X-BT was the selected solution, and a load capacity test was done with the customer. With this, the customer had a productive solution, avoiding hot work (traditional welding).

Example 3 – Modular cable tray in a Mining project

In this example, we have a modular cable tray support in a Mining project. A schematic 3D view of a similar structure is shown in Figure 9.

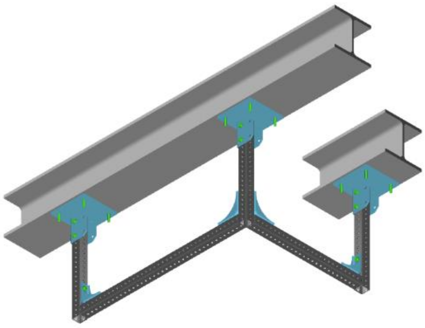

Figure 9 - 3D schematic view of a similar structure to the one being fixed in a Mining project.

These structures had to be fixed to steel beams. The main goal of the customer was to maximize efficiency (so traditional welding was not an option) and there were also vibration requirements, so studs are most suited. Since it was an application with high loads, F-BT, being the stud with highest resistance in tension, was the selected solution.

Example 4 – Modular support bridge in chemical industry

This example shows a retrofit expansion in a chemical plant where no perforation or scratching of the beam was allowed by the Owner. With that as well as based on the high tension load and connection mechanism being needed, beam clamps were the right choice to cover the project requirements. A 3D scheme of this solution is shown in Figure 10.

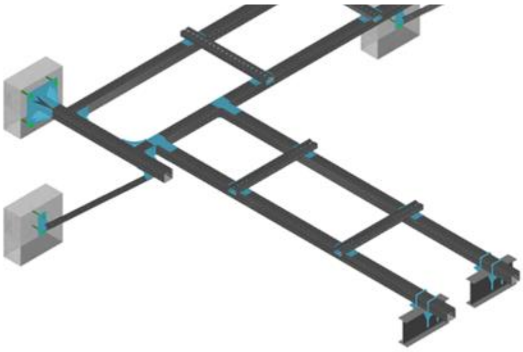

Figure 10 - 3D scheme of a solution on a chemical plant.

Example 5 – Roof drainage piping – riser support in Automotive

In this example a new automotive production hall was built, where a negative pressure roof drainage system needs to be mounted on existing steel and concrete structure. To support vertical pipes accordingly, the open struts need to be mounted on a specific direction towards the pipe, which requires a special orientation to the steel structure. Due to the flexible orientation between the strut and the existing steel structure, beam clamps were the easiest to install solution – see Figure 11. In addition, LABS / PWIS conformity was requested to be offered as well.

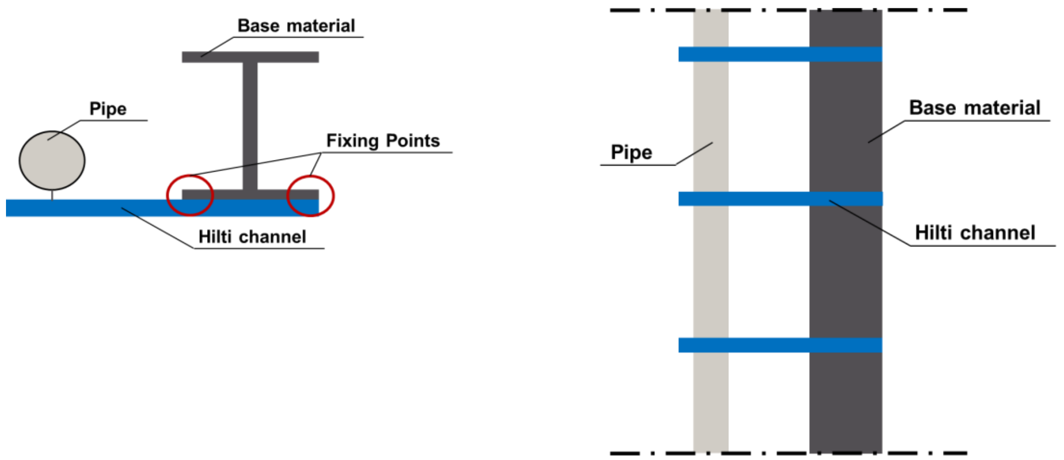

Figure 11 – schematic representation of the application: section view (left) and elevation view (right).

Total Installed Cost Analysis

The analysis and comparison done so far provides you relevant data to better define the fastening on steel technology from a technical perspective. However, it's also important to **compare the solutions from a cost perspective** for general applications – a total installed cost analysis. For this, multiple costs should be considered, namely labour cost, the cost of the consumables (studs, beam clamps and other accessories – henceforth referred to as hardware) and the cost of the tools used for the application.

Different general configurations were considered – see Figure 12:

- Headrail application – channel directly fixed to the steel structure;
- Trapeze on rod;
- Heavy trapeze;
- Cantilever.

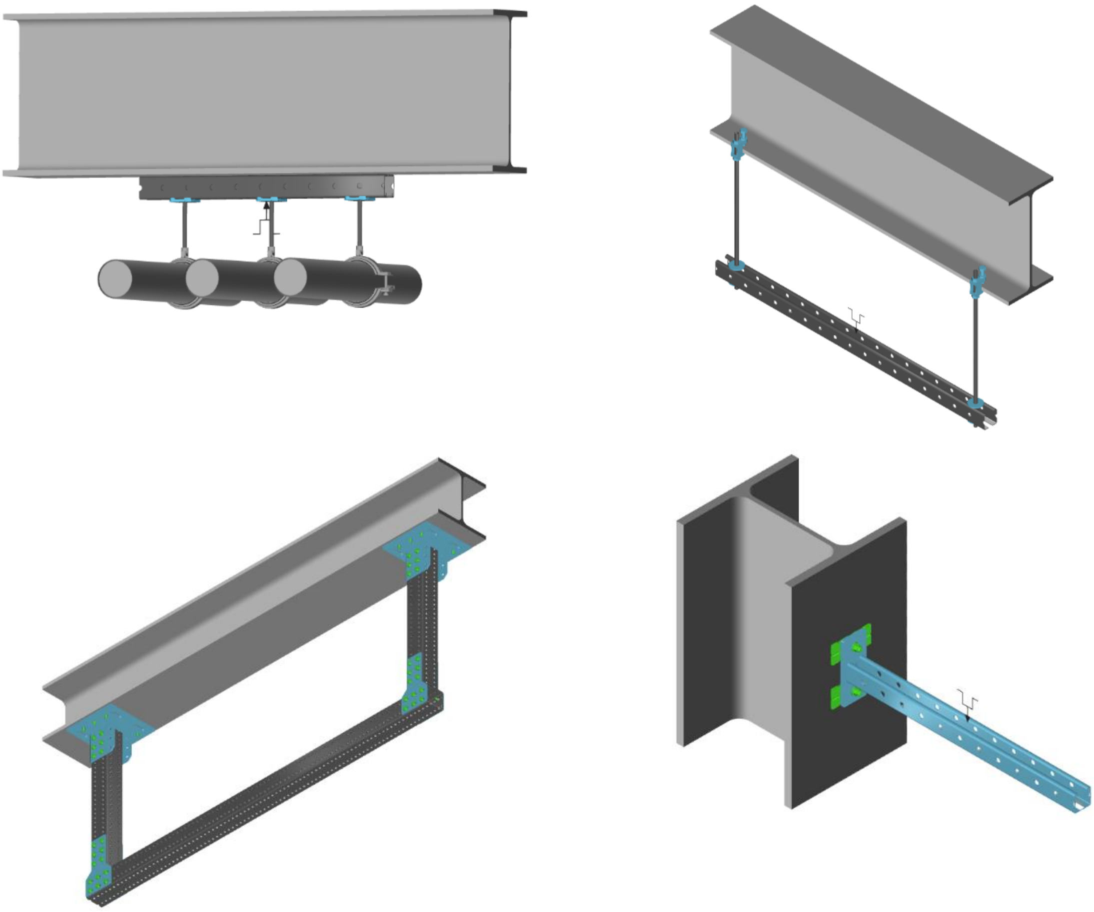

Figure 12 - Different configurations considered: headrail (top left), trapeze on rod (top right), heavy trapeze (bottom left), cantilever (bottom right).

The four configurations were executed in a lab in Hilti's Headquarters by a user that was trained on both technologies, ensuring that the influence of the installer can be neglected. The following total installed cost analysis considers the following:

- A labour cost of 38 €/h was assumed – we estimate this value to be an average in Germany;
- For the cost of hardware and tools, we considered also the mean values for the market in Germany;
- For the tools, a cost per fixing point was estimated based on the lifetime of the tool;
- For the results of the comparison shown below, the costs presented (namely on hardware) only refer to the fixing part of the structures (i.e. the cost of the cantilever channel, for example, is not included in the hardware cost since this would not be relevant for the comparison – same for both technologies);
- It's important to refer that the results shown below apply to the referred assumptions, meaning that different market conditions will lead to different results.

Regarding the **headrail application**, the S-BT HL was the solution considered for the studs and the MQT-21-41 the one considered for beam clamps. The **solution with studs is the most economical** (see Figure 13 – left). Even though the tool investment is higher on the studs, the application is faster (lower labour cost) and the hardware is more economical.

For the **trapeze on rod** application, also the S-BT HL was the stud solution and for the beam clamps, the MAB-M10 was the one considered for this exercise. The application took roughly the same time for both technologies, so the labour cost is the same. The difference is in the fact that the studs need an adapter to connect to the threaded rods, making the hardware more expensive. As so, **beam clamps are the more economical solution** for this configuration – see Figure 13 on the right.

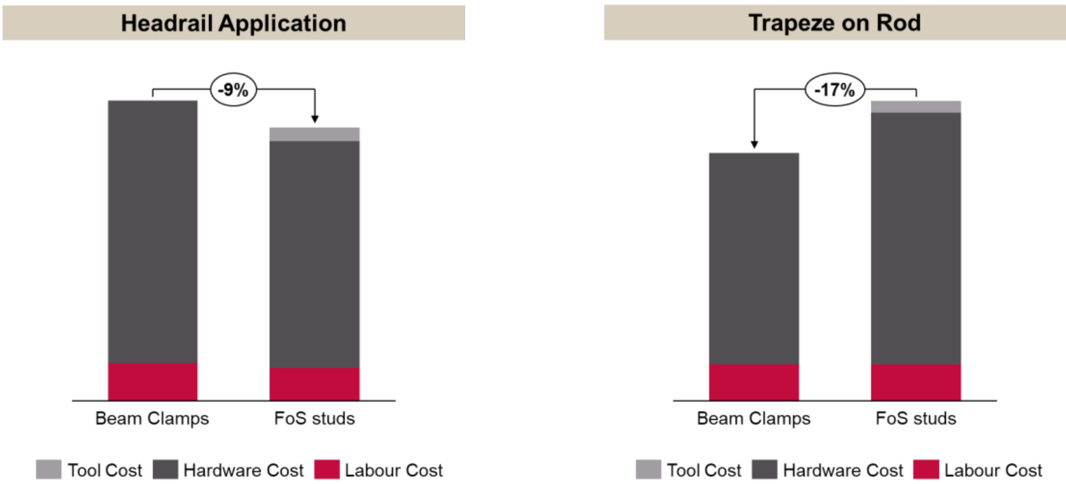

Figure 13 - Overview on the comparison of the total cost of installation for the headrail application (left) and the trapeze on rod configuration (right).

The **heavy trapeze** is the configuration that takes more time to install. In this case, the considered beam clamps were the MI-SGC M16 and the studs were the F-BT MR M10 with the sealing washer. In this analysis it was considered the same number of connectors (4 studs and 4 beam clamps) because MI-SGC M16 have a higher resistance to tension loads but F-BT studs have a higher resistance to shear. The beam clamps are faster to install and have a lower tool cost but the studs have lower cost of hardware, making the total cost of this configuration balanced between both technologies – see Figure 14 on the left.

For the **cantilever** configuration, we need a substructure to fix it with beam clamps (channel fixed with MQT 21-41), having an impact on the hardware cost. For the studs, the F-BT MR M10 stud with sealing washer was considered, being the application with the studs also faster for the cantilever configuration. This makes the **studs the most economical solution for the cantilever** configuration – see Figure 14 on the right.

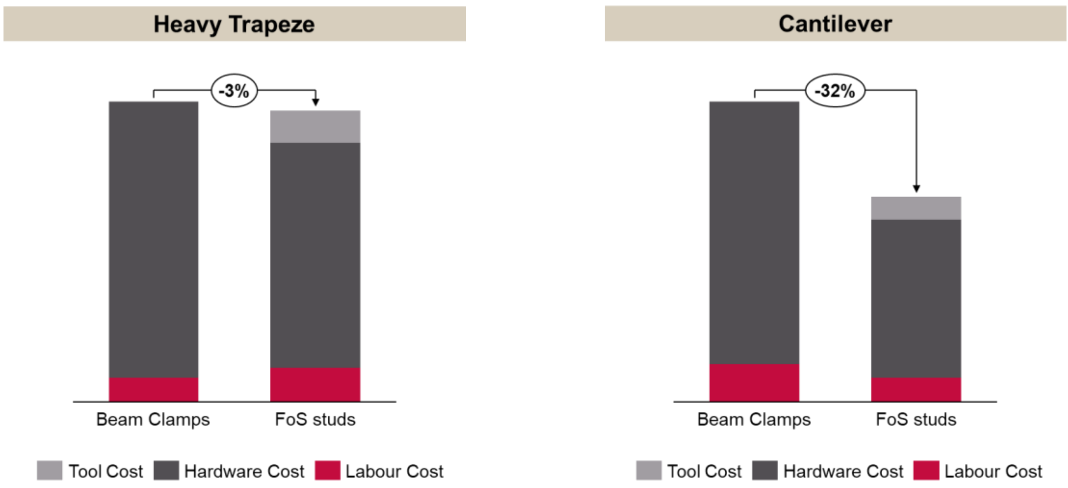

Figure 14 - Overview on the comparison of the total cost of installation for the heavy trapeze (left) and the cantilever (right) configurations.

Summary

The purpose of this document is to help on selecting the best technology (between Hilti studs and Hilti beam clamps) for the multipurpose fastening on steel application. With this in mind, a comparison was done based on different parameters, concluding on the following:

- **Hilti studs are best suited for fastening to coated steel** (no rework on the coating after application), **can be applied on Passive Fire Protected** (PFP) steel (S-BT and X-BT) and on **steel profiles without a flange** (like a rectangular hollow section);
- **Hilti beam clamps allow non-perpendicular fixing** to the base material;
- Both technologies have **similar performance in shear**, and beam **clamps can reach higher tension loads**. However, in terms of **beam clamps applied to painted steel some reduction factors can impact the resistance**;
- **Hilti studs can be applied in C5** (CX in some cases) **environments**, while Hilti **beam clamps can be installed in C4** (C5 in some cases) corrosive environments;
- **Hilti studs have a wider scope of approvals**, while Hilti **beam clamps have relevant approvals for sprinkler applications**;
- **Hilti studs are suitable for applications under vibration**, and the **MI-SGC beam clamps were tested up to 1 Mio load cycles with positive results**;
- **Hilti studs** show **robustness under fatigue and seismic loading;**
- **The Hilti beam clamp MQS-IB can be used under seismic conditions for sprinkler applications;**
- **Hilti studs were tested to fire resistance and on fire rated boundaries, with promising results;**
- Hilti **studs provide the most economical solution for headrail and cantilever applications**, when compared to Hilti beam clamps;
- Hilti **beam clamps provide the most economical solution for trapeze on rod applications**, when compared to Hilti studs.

A summary table is presented below.

		FoS Studs	Beam Clamps
Base material	Galvanizeo and black steel w/o rework		
	Painted steel w/o rework		
	Passive Fire Protected Steel		
	Section w/o flange (e.g. square hollow section)		
	Stud not perpendicular to the surface of the base material		
Corrosive environment	Up to C4		
	C5 environment		i)
Approvals	ETA	ii)	ii)
	Bureau Veritas		
	American Bureau of Shipping		
	RINA		
	Lloyds Register		
	FM/Vds/UL	iii)	
Dynamic Loading	Vibration		iv)
	Fatigue		
	Seismic		v)
Fire	Fire tested		

i) Not all the solutions available in C5
ii) Not all the solutions have ETA
iii) VdS in progress for S-BT HL
iv) MI-SGC tested for 1 Mio load cycles
v) MQS-IB is part of system approval for sprinkler according to COLA and FM in seismic conditions

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