DOI: 10.1002/stco.202200024

Alfonso Fuente-García, Miguel Ángel Serrano-López, Carlos López-Colina, Fernando López-Gayarre

ARTICLE

Slip-resistant connections subjected to freeze-thaw cycles

There are many examples of steel structures subjected to severe environmental conditions with bolted connections directly exposed to climatic agents such as steel bridges, mining transfer towers, wind towers etc. In this experimental research, non-slip joints with M16 and M20 bolts have been studied. The specimens were subjected to fourteen 12 h freeze-thaw cycles, with periodic immersion in water and temperature oscillation. Subsequently, the connections were subjected to a slip test under monotonic load. The results were compared with other equal joints not subjected to freeze-thaw cycles and kept at room temperature for the same time. Some interesting conclusions are extracted from this piece of research. It was observed that freeze-thaw cycles negatively affect the slip resistance of non-slip joints with GB + ZE surfaces, even with a slight increase in clamping force. Samples with SR and GB surfaces increase in their slip resistance was observed.

Keywords freeze-thaw cycles; preloaded bolts; slip critical connections; surface treatment

1 Introduction

Generally, steel structures are formed of typically linear elements that must be joined together in order to transmit reliably the forces between the bars. The joining systems used are welding, rivets or bolts. Whereas welding and rivets are fixed connections, bolted connections allow the transport and handling of assemblies or disassembly for maintenance or service purposes. When these connections are exposed to reverse loading, or when deformation over time is critical, then slip-resistant joints should be used.

Non-slip or slip-resistant joints are joints with a low probability of sliding throughout the life of the structure, which increases the service capacity of the structure under dynamic, vibratory loads or with changes in the direction of the load. These joints are especially prescribed when it is required to limit the deformations generated by vibrations due to seismic, cyclic, wind or impact loads. The design of joints in steel structures is regulated by Eurocode 3 Part 1.8 [1]. According to Eurocode 3 (2.6.), those joints, whose slip is not acceptable, must be solved using preloaded bolts. In Section 3.4.2, the code establishes five categories of bolted connections, three for shear connections (A, B and C) and two for tension connections (D and E).

For each category, there are several verification criteria to verify the connection. Non-slip bolt joints belong to categories B and C. Due to their higher cost, compared to other bolts connections, non-slip connections made with preloaded bolts should be used only when slip in the joints is expected to affect the serviceability of the structure or to reduce the resistance of it.

Many steel structures are exposed to climatic agents. Joints, as a part of the structure, are also subjected to the same environmental conditions. Sometimes the working conditions of the joints are extreme with below zero temperatures, with the presence of high humidity, even ice. Some examples of this type of structure are steel bridges, mining transfer towers and wind towers. Thus, it is worthy asking how non-slip joints behave under these climatic situations. There are investigations that prove the loss of preload of the bolts in steel structures in outdoor installations [2].

The objective of this research is to find out how freeze-thaw cycles affect non-slip bolted joints with M16 and M20 (10.9), steel plates S275, with three types of surfaces: surface as rolled (SR), grit-blasted Sa $2^1/_2$ (GB) and grit-blasted Sa $2^1/_2$ and painted with zinc epoxy (GB + ZE). Similar tests without freeze-thaw cycles can be found in the literature such as [3–5].

2 Slip-resistant joints

Slip-critical or slip-resistant joints owe their resistance to the clamping force that presses the contact surfaces and to the preparation of the contact surfaces in order to obtain a slip coefficient that generates resistance to slip. The clamping force is achieved by prestressing the bolt, which is usually high strength.

In bolted slip-resistant joints, the aim is to take advantage of the friction between the joined pieces to provide rigidity to the connection that prevents the relative sliding of the pieces. The friction between the pieces is produced by imperfections, generally microscopic, on the surfaces of both part of pieces. There are two factors that affect the resistance capacity of the joints that are the type of contact surface and the clamping force between parts. When the tightening is applied to the bolt, an axial force is produced in it; the corresponding reaction of which produces a compression in the plates, generating friction forces between the contact surfaces that prevent their relative movement. Therefore, the shear stress must be supported by the friction between the plates. In a non-slip joint, the bolts are not exposed to shearing, so it is not necessary to check the bolt shank for this type of stress (Fig. 1).

2.1 Design slip resistance

To obtain the design slip resistance of a bolt, class 8.8 or 10.9 according to Eurocode 3 (EN 1993-1-8:2005-3.9.1) [1] provides the following equation:

$$F_{\mathrm{s,Rd}} = \frac{k_{\mathrm{s}} \cdot n \cdot \mu}{\gamma_{\mathrm{M3}}} \cdot F_{\mathrm{p,C}} \qquad (1)$$

where k_s is a parameter of hole type ($k_s = 1$ for normal round hole); n is the number of friction planes, μ is the slip factor obtained by specific test for the friction surface, γ_{M3} is the partial safety factor and $F_{p,C}$ is the preload force in bolt.

2.2 Preload

The bolt is subjected to a tension that is found in the elastic zone of the steel used, and it is generally accepted that is a 70 % of the elastic limit of the material. The expression that Eurocode 3 [1] provides to determine this force is the following:

$$F_{\mathrm{p,C}} = 0.7 \cdot f_{\mathrm{ub}} \cdot A_{\mathrm{s}} \qquad (2)$$

where f_{ub} is the ultimate tensile strength of the bolt steel and A_s is the net cross section of the bolt in a screw zone.

At this point, it should be noted that the screws to be used in prestressed joints have specific characteristics, in relation to the class and the geometry of the different elements (bolt, nut and washers). Thus, both Eurocode 3 (EN 1993-1-8) [1] and the UNE EN 1090 [6] standard establish that the bolts to be used in these joints must comply with the requirements established in the standard EN 14399-1 [7] that defines the characteristics of the assemblies bolted to be preloaded. The set of EN 14399 standards includes two systems of HR (high resistance – UK Environment) and HV (Hochfest Vorspannbar – German Environment) bolted assemblies; both composed of a screw, a nut and two washers. The HR system has thicker nuts, longer thread lengths and the ductility of the assembly is produced by the elongation of the shank. Besides, the HV system has thinner nuts, shorter threaded lengths and the ductility is produced by the deformation of the nut threads; this makes them require a greater control in the application of the tightening. For the HR system, it allows the use of classes 8.8 and 10.9 in both bolts, nuts and washers. On the other hand, HV system only allows the use of class 10.9 in all the components. The HR typology is widely used in the UK and French markets, while the HV is more widespread in countries such as Germany, Portugal or Spain (Fig. 2).

For instance, according the theory dimensions of the M16 and M20 bolts detailed in the EN 14399-4 [8] standard for

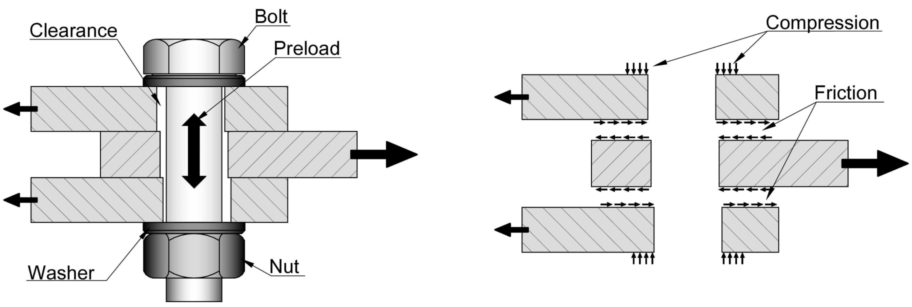


Fig. 1 Transfer of forces in slip-resistant joints

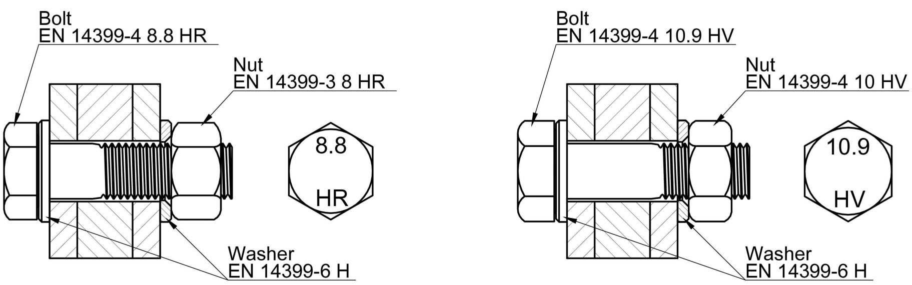


Fig. 2 Differences between HR and HV systems

HV system, we can obtain the theoretical preload forces shown in Tab. 1.

2.3 Surface treatment

According Eq. (1), another parameter necessary to determine the slip resistance of an anti-slip joint $F_{s,Rd}$ is the friction coefficient μ characteristic of the contact surfaces. Although this parameter should be determined empirically for the surfaces involved in the design of the slip-resistant joint [15–17], codes usually provide reference values that allow its direct application. Thus, for example, in the Section 8.4 of EN 1090-2 [6] code, it provides the slip factors shown in Tab. 2.

In the case of US codes, the Section 5.4 of RCSC [9] standard also supplies values for different surfaces as summarised in Tab. 3.

It can be verified that the slip factors are similar between both standards. It should be noted that both codes consider the possibility of using uncoated surfaces obtained from direct lamination and subsequently cleaned. However, this surface is not usually used due to the corrosion problems that it could cause in the joint, especially if it is not protected from environmental agents. In practice, zinc-based surface protections are widely specified, which provide high resistance against aggressive, industrial and marine locations, as well as high temperatures. Zinc epoxy resins, whose ease of application is highly regarded, are especially used. Inorganic zinc silicate coatings are also widely used, which can even provide greater resistance to slip, although drying and curing processes are more susceptible to relative humidity in the environment.

Tab. 1 Theory preload for M16 and M20 bolts (10.9) (HV)

	f_{ub} [N/mm^2]	A_s [mm^2]	$F_{p,C}$ [kN]
M16	1000	157	110
M20	1000	245	172

3 Experimental programme

3.1 Test programme

The research carried out requires to expose half of the specimens to a series of freeze-thaw cycles in a climatic test chamber. Due to its dimensions, it was decided to reduce the dimensions of the standardised specimens in the EN 1090 [6] specification, and to carry out a compression test like RCSC [9], instead of tension test, with single bolt connections, maintaining the bolts and plates thicknesses indicated in the European code.

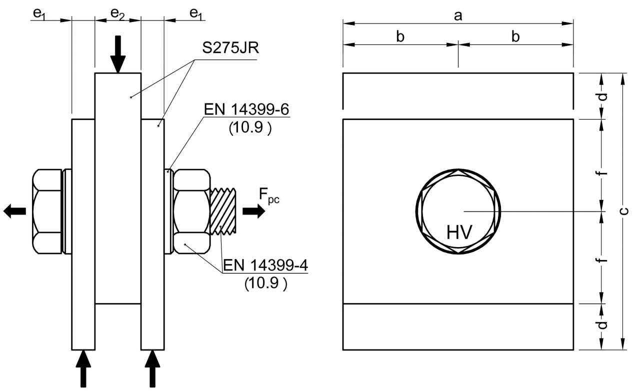
Two types of assemblies were considered to be analysed: with M16 and M20 bolts. M16 assemblies are formed with a 16 mm thickness central plate and two 8 mm thickness outer plates, both with steel grade S275JR according to EN 10025 [10] specification. The total width of the plates was 80 mm. Bolts were M16×60 (10.9) according to EN 14399-4 (HV) [8] and the holes in plates were 18 mm of diameter. The nut and washers used were class 10.9 ac-

Tab. 2 Classifications that may be assumed for friction surfaces according to EN 1090-2 (2018)

Surface treatment	Class	μ
Surfaces blasted with shot or grit with loose rust removed, not pitted.	A	0.50
Surfaces hot dip galvanised to EN ISO 1461 and flash (sweep) blasted and with alkali-zinc silicate paint with a nominal thickness of 60 µm.	B	0.40
Surfaces blasted with shot or grit:	B	0.40
a) coated with alkali-zinc silicate paint with a nominal thickness of 60 µm		
b) thermally sprayed with aluminium or zinc or a combination of both to a nominal thickness not exceeding 80 µm.		
Surfaces hot dip galvanised to EN ISO 1461 and flash (sweep) blasted (or equivalent abrasion method)	C	0.35
Surfaces cleaned by wire brush or flame cleaning, with loose rust removed	C	0.30
Surfaces as rolled	D	0.20

Tab. 3 Faying surfaces according RCSC (5.4)

Surface	Class	μ
a) Unpainted clean mill scale steel surfaces	A	0.30
b) Surfaces with class A coatings on blast-cleaned steel or hot-dipped		
c) Galvanised and roughened surfaces		
a) Unpainted blast-cleaned steel surfaces	B	0.50
b) Surfaces with class B coatings on blast-cleaned steel		



Dimensions (mm)	Assembly	
	M16	M20
Bolt	M16x60	M20x75
a	80	100
b	40	50
c	120	120
d	25	20
e_1	16	20
e_2	8	10
f	35	40

Fig. 3 Dimensions of specimens

cording to EN 14399-4 and EN 14399-6 [4] specifications, respectively. In the case of the M20 assemblies, the thicknesses used were 20 mm for the central plate and 10 mm for the outer, also made of S275JR steel, with a total width of 100 mm. Bolts were M20×75 (10.9) according to the EN 14399-4 (HV) [8] and the size of holes was 22 mm of diameter. The nut and washers used were also class 10.9 according to EN 14399-4 and EN 14399-6 [11], respectively (Fig. 3).

For each type of joint (M16 and M20), three types of surface treatment were considered to be analysed: rolled steel surface (SR), shot-blasted surface (GB) and shot-blasted surface with subsequent coating (GB + ZE). The SR surfaces were cleaned with acetone to remove any oil residue. The absence of mill scale was verified. The GB surface was obtained by blasting with triangular shot until obtaining a cleanliness degree Sa $2^1/_2$ (deep abrasive blast cleaning) according to the SIS 055900 [12] Swedish standard (transferred to the European standard ISO 8501-1 [13]). Finally, for the GB + ZE surface, a shot blasting was carried out under the same conditions as the GB surface, and subsequently was painting with two-component zinc epoxy (HEMPADUR ZINC17340) system with a nominal thickness of 70 µm according to the manufacturer's specification (HEMPEL). For painting, it was used an airless paint sprayer.

Two series of equal preparation were compared. One of them was subjected to freeze-thaw in a climatic test chamber. The other series was kept at room temperature during the same time. Subsequently, a short-term sliding test was carried out on all models in a universal testing machine. Tab. 4 summarises the series tested. Three models were studied for each of the surfaces considered.

3.2 Tightening method

For the application of preload, EN1090 [6] standard includes four methods: torque method, combined method, HRC (high resistance calibrated) tightening and direct tension indicator (DTI). In the investigation, the method of torque applied by means of a torque wrench was used. To determine the existing relationship between the torque set in the torque wrench and the preload generated

Tab. 4 Series of test

Series	Bolt	Surface	Freeze-thaw cycles
10	M16 (10.9)	Sr [a)]	No
11	M16 (10.9)	GB	No
12	M16 (10.9)	GB + ZE	No
20	M16 (10.9)	SR	Yes
21	M16 (10.9)	GB	Yes
22	M16 (10.9)	GB + ZE	Yes
50	M20 (10.9)	SR	No
51	M20 (10.9)	GB	No
52	M20 (10.9)	GB + ZE	No
60	M20 (10.9)	SR	Yes
61	M20 (10.9)	GB	Yes
62	M20 (10.9)	GB + ZE	Yes

[a)] SR: surface as rolled; GB: grit-blasted Sa $2^1/_2$; GB + ZE: grit-blasted Sa $2^1/_2$ and painted with zinc epoxy

in the bolt, previously calibrated bolt strain gauges were used to determine their deformation curve (Figs. 4 and 5).

Three strain gauges were calibrated on M16×60 bolts and other three gauges on M20×75 bolts. Subsequently, the jump values of the wrench were adjusted to the mean values of the nominal tension indicated on the gauges. Two torque wrenches were used, one for M16 bolts and one for M20 bolts. Before applying preload to all specimens, bolts and nuts were greased.

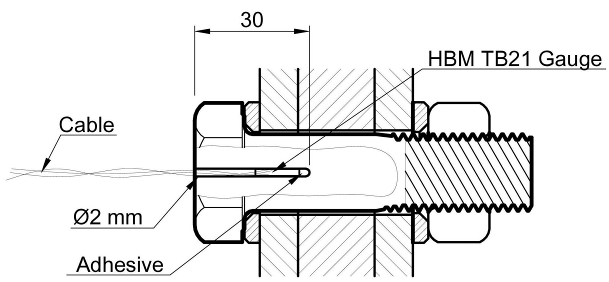


Fig. 4 Strain gauge set detail

Fig. 5 Torque wrench calibration

3.3 Freeze-thaw cycles

According Tab. 4, the 20, 21, 22, 60, 61 and 62 series were subjected to freeze-thaw cycles in a chamber (Fig. 6). In the absence of a specific standard reference for freeze-thaw cycle tests on elements of steel structures, it was decided to use the UNE-CENTS 12390-9EX [14] reference for concrete structures. This standard provides a temperature curve that tries to replicate the extreme environmental conditions that structural components may be subjected to. The samples were subjected to 14 freeze-thaw cycles of 12 h each according to the temperature curve of Fig. 7.

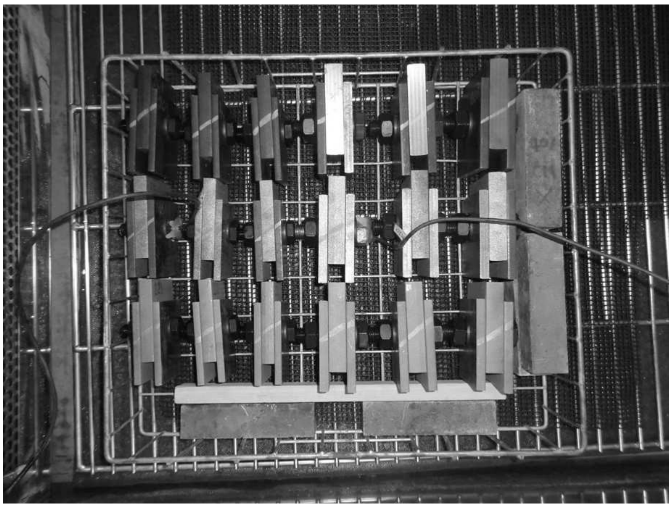


Fig. 6 Set in freeze-thaw chamber

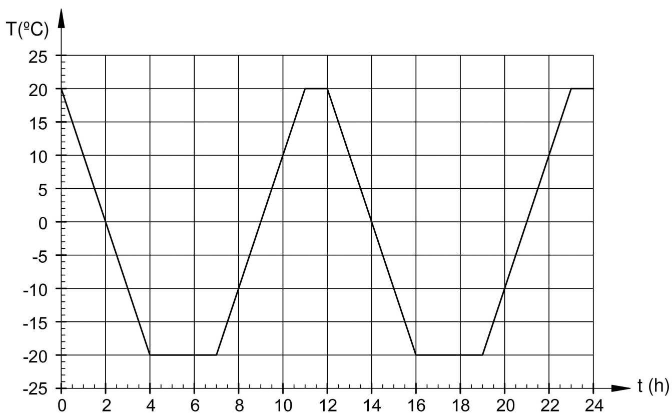


Fig. 7 Temp. Curve – UNE 12390-9EX [9]

3.4 Slip test

All specimens were subjected to a quasi-static slip short-time test on a universal testing machine (Fig. 8). An incremental compressive force was applied to the joints under displacement control at a speed of 0.1 mm/min. Simultaneously, relative displacements between joint plates were recorded using a CTOD (crack tip opening displacement) extensometer (Fig. 9). The tests were stopped once the slip of 0.5 mm was overcome. For each surface, three specimens were tested. The results obtained were averaged and plotted in force-slip curves.

The measurement position allows an accurate slip measurement because the measurement is less affected by the longitudinal deformation of the plates. It must be taken into account that the longitudinal deformation according to the proposed solution affects a length of less than 15 mm.

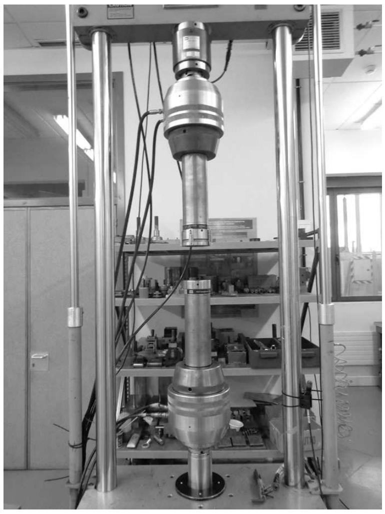


Fig. 8 Universal testing machine

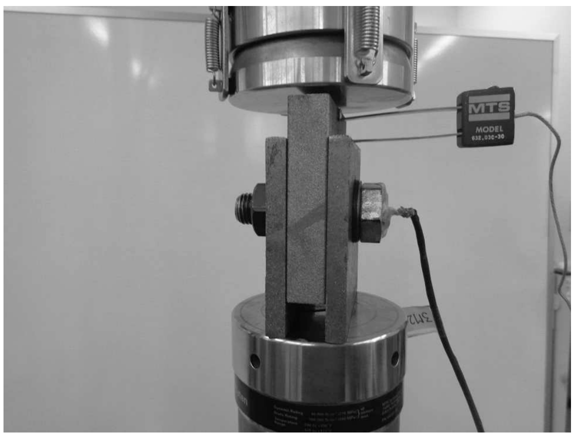


Fig. 9 Slip measuring

Tab. 5 Clamping force variation after 168 h

Bolt	Freeze-Thaw thaw cycles	$\Delta F_{p,C}$ (168 h)	$F_{p,C}$ at start of slip test
M16 (10.9)	No	+1.23 %	111.9 kN
M20 (10.9)	No	−0.96 %	170.2 kN
M16 (10.9)	Yes	−0.40 %	109.4 kN
M20 (10.9)	Yes	+4.21 %	164.3 kN

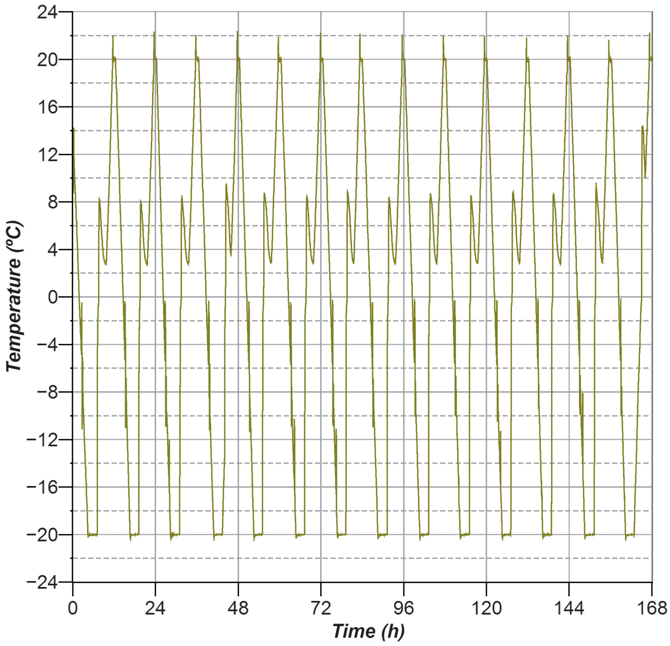


Fig. 10 Temp. curve for freeze-thaw cycles

4 Results

4.1 Clamping force variation

In order to know the variation of the bolt preload after and before the freeze-thaw tests, strain gauges were included in two of the specimens subjected to freeze-thaw cycles. Clamping force variation values were compared with equal specimens not subjected to cycles (Tab. 5). Fig. 10 shows the temperature variation through the time of analysis.

4.2 Load-Slip test

The main aim of this experimental research was not obtaining the slip factor for different surface treatments, but rather the comparison between the load-slip curves obtained in the samples subjected to freeze-thaw cycles and those not subjected to this process. The results of 36 compression slip tests are presented in this document. The results of the three average tests are shown in Fig. 11 for series 10-11-12 and 20-21-22 (M16) and Fig. 12 for series 50-51-52 an 60-61-62 (M20).

Tab. 6 to 8 compare slip capacity of the joints subjected to freeze-thaw cycles with those not subjected to them, for each type of surface.

4.3 Superficial degradation

Apart from the above, it is important to note that, once the sliding tests were completed and the specimens unbolted, a significant degradation of the contact surfaces was observed in the series subjected to freeze-thaw cycles. This phenomenon was not quantified analytically,

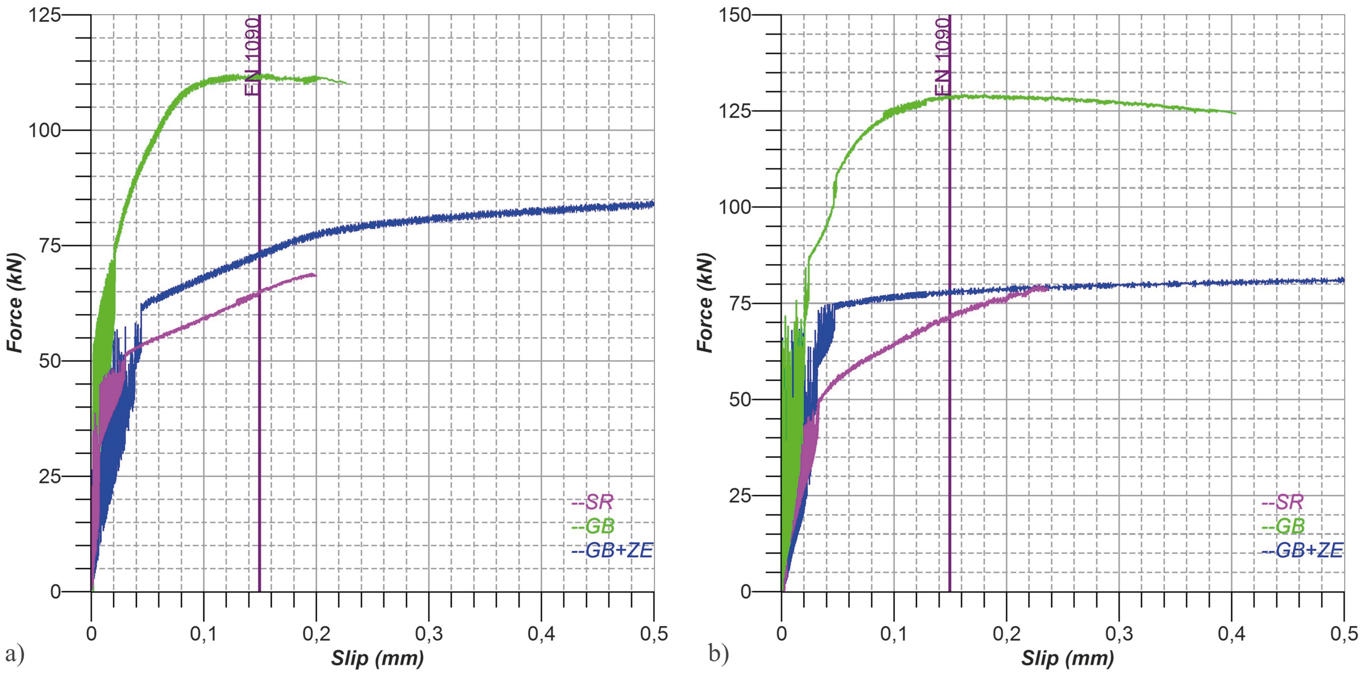


Fig. 11 Load-slip curve comparative for M16 series: a) no freeze-thaw cycles M16 (series 10-11-12); b) freeze-thaw cycles M16 (series 20-21-22)

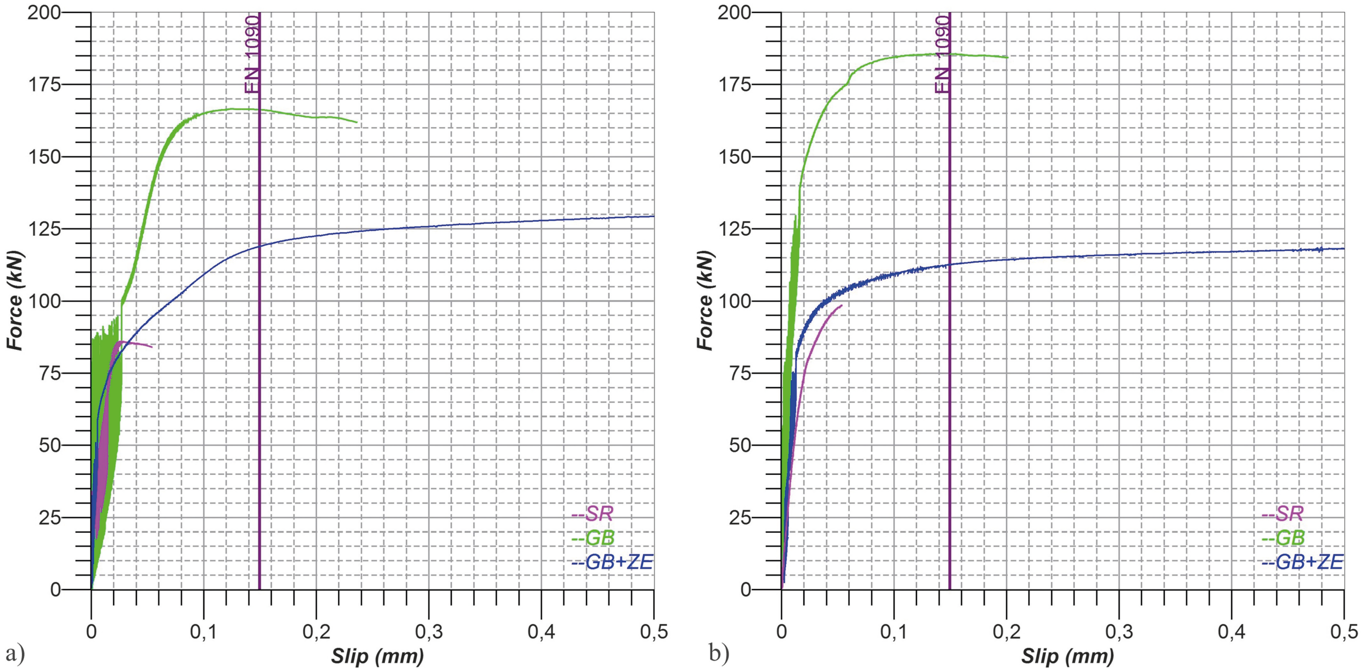


Fig. 12 Loadslip curve comparative for M20 series: a) no freeze-thaw cycles M20 (series 50-51-52); b) freeze-thaw cycles M20 (series 60-61-62)

Tab. 6 Comparative of load capacity (kN) for SR surfaces

Series	Slip				
	0.02 mm	0.05 mm	0.10 mm	**0.15 mm**	0.20 mm
10	47.10	53.92	59.12	65.22	68.41
20	33.92 (−28 %)	55.48 (+3 %)	64.43 (+9 %)	71.46 (+10 %)	76.11 (+11 %)
50	81.25	84.42	–	–	–
60	74.26 (−9 %)	97.72 (+16 %)	–	–	–

Tab. 7 Comparative of load capacity (kN) for GB surfaces

Series	Slip				
	0.05 mm	0.10 mm	**0.15 mm**	0.20 mm	0.40 mm
11	95.22	110.26	111.50	111.21	–
21	109.08 (+15 %)	124.53 (+13 %)	128.46 (+15 %)	128.70 (+16 %)	124.56
51	132.59	165.02	166.30	163.59	–
61	172.58 (+30 %)	184.44 (+12 %)	185.51 (+12 %)	184.35 (+13 %)	–

Tab. 8 Comparative of load capacity (kN) for GB + ZE surfaces

Series	Slip				
	0.05 mm	**0.15 mm**	0.30 mm	0.40 mm	0.50 mm
12	65.53	73.16	80.40	82.86	84.26
22	74.33 (+19 %)	78.16 (+7 %)	79.93 (−1 %)	80.46 (−3 %)	81.17 (−4 %)
52	93.00	118.86	125.83	127.88	129.33
62	102.28 (+10 %)	112.59 (−5 %)	116.01 (−8 %)	117.10 (−8 %)	118.15 (−9 %)

although, qualitatively, a generalised deterioration of these samples was observed with the presence of moisture, oxide, even water in the GB + ZE samples (see Fig. 13).

5 Conclusions

The main conclusions obtained from the research carried out are as follows:

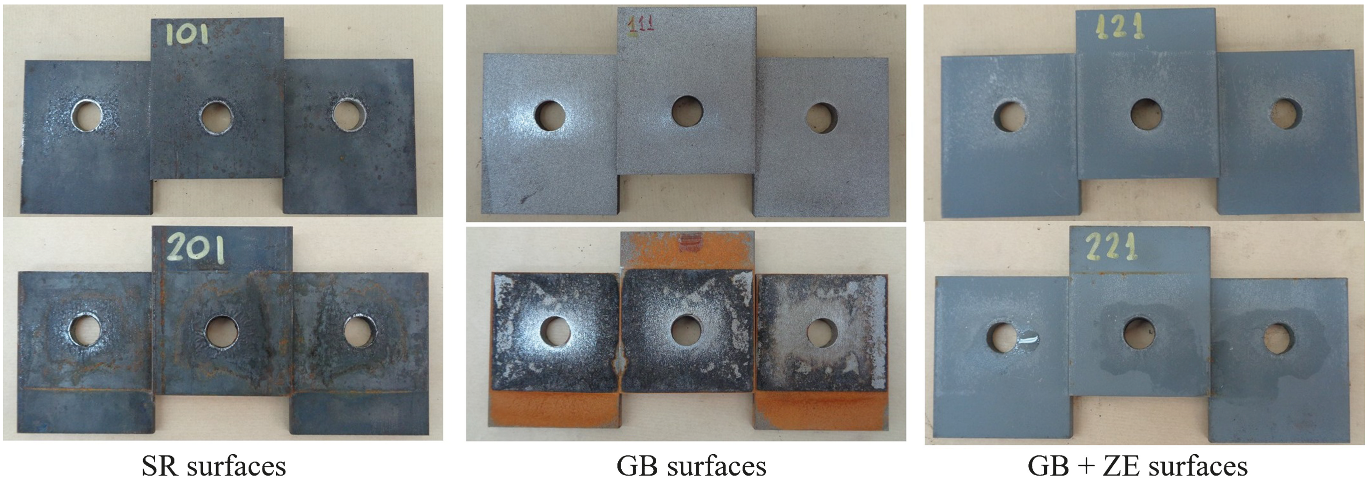


Fig. 13 Surface comparative with no freeze-thaw cycles (up) and freeze-thaw cycles (down)

1. As it was reported in previous studies, the preload force varies with time. After 168 h of freeze-thaw cycles, variations in preloading were observed between the initial and final values of −0.40 % and +4.21 % for the M16 and M20 joints, respectively. For the joints not subjected to freeze-thaw cycles, the variations in clamping force between the initial and final values for a time of 168 h were +1.23 % and −0.96 %. These variations are small, and no conclusions can be drawn from them.
2. Joints with SR surfaces subjected to freeze-thaw cycles showed detachment of metallic particles and the appearance of rust. These joints increased their slip resistance for values greater than of 0.05 mm (Tab. 6). It must be taken into account that, due to the low slip resistance capacity of this type of surface, the values obtained for small displacements are not significant due to settlements in the test.
3. Joints with GB surfaces subjected to freeze-thaw cycles showed detachment of metallic particles and blackened areas. In load slip test, all the specimens show a clear increase in slip resistance (Tab. 7).
4. On GB + ZE surfaces subjected to freeze-thaw cycles, a deterioration of the paint layer was observed with loss of consistency of it. The areas of painting closest to the hole had a rubbery state and more deteriorated state than the rest. In the sliding tests, specimens showed a generalised increase of slip capacity for low values (≤ 0.15 mm), but showed reductions of up to 9 % for values greater than 0.15 mm (Tab. 8).
5. It was observed that the samples with M16 and SR surfaces maintained resistance with slip values of up to 0.20 mm. In the case of M20 samples, although their capacity is greater, they did not resist sliding greater than 0.05 mm. These results were observed for samples subjected and not subjected to freeze-thaw cycles (Tab. 6).
6. M16 samples with non-freeze-thawed GB surfaces have strength to 0.20 mm, compared to non-freeze-thaws that provided strength to 0.40 mm. In the case of the M20 samples, both provided slip resistance up to 0.20 mm (Tab. 7).
7. Samples of M16 and M20 with GB + ZE surfaces subjected to and not subjected to freeze-thaw cycles provided resistance capacities up to 0.5 mm (Tab. 8).
8. On a whole, it is observed that freeze-thaw cycles negatively affect the slip resistance of non-slip joints with surfaces blasted and coating with zinc epoxy, even with a slight increase in clamping force. For the joints, only cleaned or only shot blasted, a generally increase in their slip resistance was observed [15–17].

References

[1] Eurocode 3 (2011) *Design of steel structures. Part 1.8: Design of joints.* Brussels, Belgium: European Committee for Standardization.

[2] Ebert, A.; Dörre, M.; Glienke, R. (2017) *Behaviour of lock-bolts in slip-resistant connections for steel structures.* Steel Construction 10, No. 4, pp. 295–309. https://doi.org/10.1002/stco.201710043

[3] Annan, C.-D.; Chiza, A. (2014) *Slip resistance of metalized-galvanized faying surfaces in steel bridge construction.* Journal of Constructional Steel Research 95, pp. 211–219. https://doi.org/10.1016/j.jcsr.2013.12.008

[4] Nah, H.-S.; Kim (2011) *Establishment of slip coefficient for slip resistant connection.* Journal of civil engineering and architecture 5, pp. 112-120. https://doi/10.17265/1934-7359/2011.02.003

[5] Maiorana, E.; Zampieri, P.; Pellegrino, C. (2018) *Experimental tests on slip factor in friction joints: Comparison between European and American standards.* Frattura ed Integrità Strutturale 43, pp. 205–217. https://doi.org/10.3221/IGF-ESIS.43.16

[6] (2018) *EN 1090-2 Execution of steel structures and aluminium structures – Part 2: Technical requirements for steel structures.* Brussels, Belgium: European Committee for Standardization.

[7] EN 14399-1 (2015) *High-strength structural bolting assemblies for preloading – Part 1: General requirements.* Brussels, Belgium: European Committee for Standardization.

[8] EN 14399-4 (2015) *High-strength structural bolting assemblies for preloading – Part 4: System HV – Hexagon bolt and nut assemblies.* Brussels, Belgium: European Committee for Standardization.

[9] RCSC (2009) *Specification for structural joints using high-strength bolts.* Chicago, USA: Research Council on Structural Connections Committee.

[10] EN 10025 (2004) *European standards for structural steel (1–6).* Brussels, Belgium: European Committee for Standardization.

[11] EN 14399-6 (2015) *High-strength structural bolting assemblies for preloading – Part 6: Plain chamfered washers.* Brussels, Belgium: European Committee for Standardization.

[12] SIS 055900 (2015) *Rust grade booklet.* Swedish Standard Institute.

[13] ISO 8501-1 (2015) *Preparation of steel substrates before application of paints and related products – Visual assessment of surface cleanliness – Part 1: Rust grades and preparation grades of uncoated steel substrates and of steel substrates after overall removal of previous coatings.* Geneva, Switzerland: International Organization for Standardization.

[14] UNE-CEN/TS 12390-9 EX (2006) *Ensayos de hormigón endurecido. Part 9: Resistencia al hielo-deshielo. Pérdida de masa superficial.* Madrid, Spain: Asociación Española de Normalización.

[15] Stranghöner, N. et al. (2022) *Gleitfeste Verbindungen mit Imperfektionen.* Stahlbau 91, No. 7, pp. 442–453. https://doi.org/10.1002/stab.202200028

[16] Ebert, A.; Glienke, R.; Dörre, M. (2019) *Ultra-long-term slip-resistance and comments to the test procedure determining the slip factor.* Journal of Constructional Steel Research 161, pp. 171–186. https://doi.org/10.1016/j.jcsr.2019.06.013

[17] Stranghöner, N. et al. (2017) *Optimization of the test procedure for slip factor tests according to EN 1090-2.* Steel Construction 10, No. 4, pp. 267–281. https://doi.org/10.1002/stco.201710040

Authors
Alfonso Fuente-García (corresponding author)
UO272385@uniovi.es
University of Oviedo
EPS Engineering, Department of Construction
Campus de Viesques
West Department Building, Module 7, Floor 1
33203 Gijón
Spain

Prof. Miguel Ángel Serrano-López
serrano@uniovi.es
University of Oviedo
EPS Engineering, Department of Construction
Campus de Viesques
West Department Building, Module 7, Floor 1
33203 Gijón
Spain

Carlos López-Colina
lopezcarlos@uniovi.es
University of Oviedo
EPS Engineering, Department of Construction
Campus de Viesques
West Department Building, Module 7, Floor 0
33203 Gijón
Spain

Fernando López-Gayarre
gayarre@uniovi.es
University of Oviedo
EPS Engineering, Department of Construction
Campus de Viesques
West Department Building, Module 7, Floor 1
33203 Gijón
Spain

How to Cite this Paper
Fuente-García, A.; Serrano-López, M. Á.; López-Colina, C.; López-Gayarre, F. (2024) *Slip-resistant connections subjected to freeze-thaw cycles*. Steel Construction 17, No. 3, pp. 155–163.
https://doi.org/10.1002/stco.202200024

This paper has been peer reviewed. Submitted: 11. August 2022; accepted: 19. October 2023.