Hilti S-BT Screw-in threaded studs

Specifications

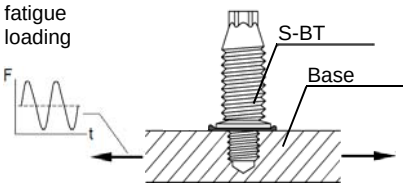
July 2017

5.6 Effect of S-BT threaded stud fastenings on the fatigue strength of the base material structural steel

Report No. 2017-38X by Prof. U. Kuhlmann an Prof. H.-P. Günther from the University of Stuttgart: Fatigue classification of the constructional detail "Structural steel base material with Hilti S-BT screw-in threaded studs", (2017) [4]
Report No. 5214011585/e, No. 5214013022/e_corr. and 5214014601/e Swiss Federal Laboratories for Materials Science and Technology (2016 and 2017) [1], [2], and [3]

General comments

When using Hilti S-BT fasteners installed into structural steel elements that are subjected to cyclic loading, the effect of the fastener on the fatigue strength of the steel base material has to be considered. Hilti has completed a comprehensive fatigue test program in order to classify the constructional detail "Structural steel base material with Hilti S-BT screw-in threaded studs" in compliance with different fatigue codes and standards, namely EN 1993-1-9 [5], AWS D1.1/D1.1M [6], ABS [7], BV [8], DNVGL-RP-C203 [9] and BS 7608 [10]. A corresponding evaluation was made by Prof. U. Kuhlmann and Prof. H.-P. Günther from the University of Stuttgart (Report No. 2017-38X, [4]).



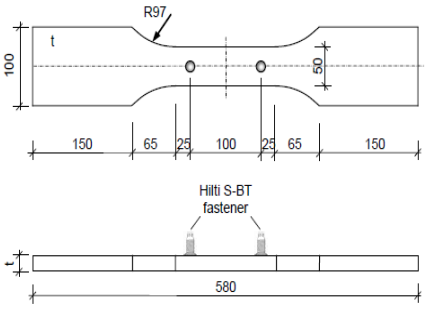
Hilti S-BT fastening system under cyclic loading

Test Concept

7 different test series were carried out varying the following parameters which can influence the fatigue resistance:

- 4 different plate thickness' (t = 3, 4, 6, 8 and 20 mm),
- 2 different stress ratios (R = +0.1 and +0.3),
- 2 different installation conditions (correctly installed and fastener removed),
- 2 different fastener materials (stainless steel and carbon steel)

In any case the S235JR steel base material is used acc. to EN 10025-2. Higher strength and fine grain steel shows in general better fatigue resistance in the non-welded condition.

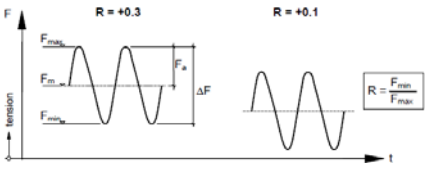


Shape and dimension of the test specimen

Name of series	Thickness t [mm]	Stress ratio R [-]	Installation condition	# of test specimens	Report
235-03-01-ci	3	+0.1	stud correctly installed	10	[2]
235-04-01-ci	4	+0.1	stud correctly installed	10+2*	[1], [3]
235-04-01-io	4	+0.1	stud installed and overwound	7*	[3]
235-06-01-ci	6	+0.1	stud correctly installed	10	[1]
235-06-03-ci	6	+0.3	stud correctly installed	10	[3]
235-08-01-ci	8	+0.1	stud correctly installed	11+2*	[1], [2], [3]
235-08-01-ip	8	+0.1	stud installed and pulled out	9	[2]
235-08-03-ci	8	+0.3	stud correctly installed	6	[2]
235-20-01-ci	20	+0.1	stud correctly installed	10	[2]

Steel base material grade: S235JR
Standard fastener type: S-BT-MR M8/7 SN6 (stainless steel)
* Fastener type: S-BT-MF M8/7 AN6 (carbon steel)

Table 1: Overview of the test program

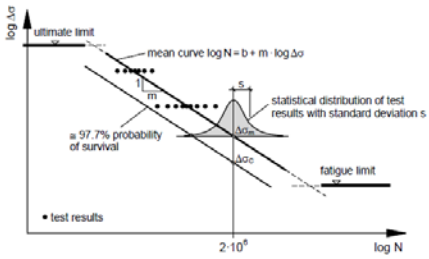


Loading condition of test specimens

Test results and evaluation procedure

The statistical evaluation of the test results and the final set-up of a fatigue reference class and S-N curve were done in three steps.

1. Determination of linear regression line (mean S-N curve) of fatigue test series
2. Determination of a characteristic design S-N curve with a certain probability of failure based on the requirements with regards to the statistical intervals (confidence level, probability of survival) as given in the specific codes and standards.
3. Recommendation of a final design S-N curve and fatigue reference class based on the afore mentioned statistical evaluation and engineeringjudgment taking into account the specific S-N curve types and classes as given in the relevant codes and standards.



Statistical evaluation acc. to EN 1993-1-9 (EC 3)

Table 2 summarizes the results of a statistical evaluation acc. to EN 1993-1-9 combining all test results with regards to the base material thickness, stress ration R, installation condition and fastener material.

Base material	Thick-ness t [mm]	Stress ratio R [-]	Instal-lation*	No. of test speci-mens	No. of data points	No. of run-outs	Slope of S-N curve m [-]	Standard deviation s [-]	k-factor [-]	Fatigue strength at N = 2·10⁶ mean value $\Delta\sigma_m$ [N/mm²]	Fatigue strength at N = 2·10⁶ detail category $\Delta\sigma_c$ [N/mm²]
S235JR	3…20	0.1-0.3	ci, io, ip	83	79	4	5.17	0.373		136.3	102.0

* ci…stud correct installed io…stud installed and overwound ip…stud installed and pulle-out

Table 2: Statistical evaluation combining all test results

In Figure 1, all test data and the statistically evaluated design S-N curve are plotted in comparison to the detail category 100 (m_1 = 5) as given in EN 1993-1-9 [5] and the IIW-Recommendations [11]. Both curves fit very well, which means that the fatigue strength of Hilti S-BT fastening system can be well described by the detail category 100 (m_1 = 5).

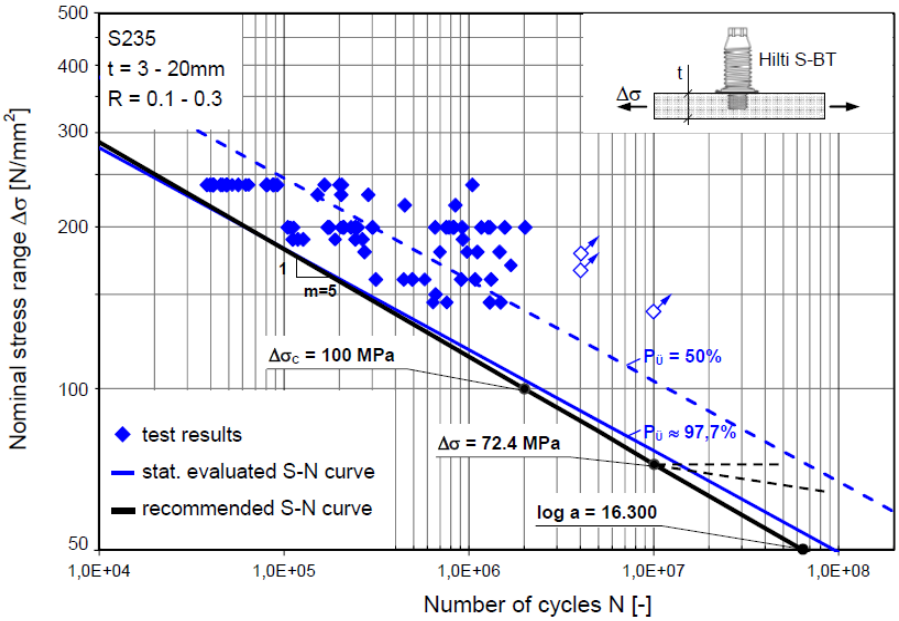


Figure 1: Statistical evaluation of all test results


Test facility for fatigue test


Specimen for fatigue test


Fracture surface

Recommendation of a design S-N curve according to different codes

On the basis of the existing test results and a statistical evaluation of these test data according to the provisions given in EN 1993-1-9:2005 (Eurocode 3) it is recommended to use following general design S-N curve for the Hilti S-BT fastening system. The structural steel grades S235 up to S355 acc. to EN 10025-2, EN 10025-3 and EN 10225 are covered.

$$\log N = \log a - m \cdot \log S$$

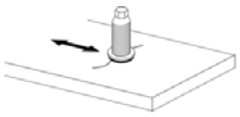
with

log N	logarithm to base 10 of corresponding number of cycles to failure N
log a = 16.300	intercept on the log N axis
m = 5.0	negative slope of S-N-curve being linear on a log-log basis
log S	logarithm to base 10 of stress range $\Delta\sigma$

Number of load cycles N	Stress range $\Delta\sigma$ [MPa]
$1 \cdot 10^5$	181.9
$1 \cdot 10^6$	114.8
$2 \cdot 10^6$	100.0
$5 \cdot 10^6$	83.2
$1 \cdot 10^7$	72.4
$1 \cdot 10^8$	45.7

EN 1993-1-9:2005 (Eurocode 3)

It is recommended to use the following design S-N curve respectively detail category given in Table 3 for the constructional detail “Steel base material with Hilti S-BT screw-in threaded studs”.

Detail category	Construction detail	Description	Requirements
100 m = 5		Hilti S-BT screw-in stainless and carbon steel threaded studs with pre-drilled hole in structural steel base material. Imperfect fastener installations as e.g. overwound or pulled-out fasteners are covered.	$\Delta\sigma$ to be calculated by the gross cross-section. Installation, static loading and spacing of fasteners only in accordance with the requirements given in [1] or [2]. Plate thickness $t \geq 3$ mm. Steel base material S235 and S355 according to EN 10025-2 and EN 10025-3.

[1] Hilti S-BT screw-in threaded studs. Specification Binder, Edition 01/2017
[2] Hilti Direct Fastening Technology Manual. Edition 12/2016. S-BT product pages.

Table 3: Recommendation of fatigue S-N curve and detail category acc. to EN 1993-1-9:2005

AWS D1.1/D1.1M:2015

It is recommended to use the following design S-N curve respectively stress category termed “S-BT” given in Table 4 for the constructional detail “Steel base material with Hilti S-BT screw-in threaded studs”.

Stress Category	m [-]	C_f for [ksi]	C_f x 329 for [MPa]	F_{TH} [ksi]	F_{TH} [MPa]
A	3.0	250×10^8	8.225×10^{12}	23.9	165.0
B	3.0	120×10^8	3.948×10^{12}	16.0	110.0
B'	3.0	61×10^8	2.007×10^{12}	12.0	83.0
C	3.0	44×10^8	1.448×10^{12}	10.0	69.0
D	3.0	22×10^8	7.238×10^{11}	7.0	48.0
E	3.0	11×10^8	3.619×10^{11}	4.5	31.0
E'	3.0	39×10^8	1.283×10^{11}	2.6	18.0
F	6.0	150×10^{10}	1.650×10^{17}	8.0	55.0
S-BT	**5.0**	**6065×10^{10}**	**1.995×10^{16}**	**12.6**	**87.0**

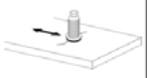
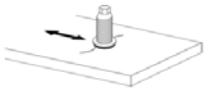
Description and requirements	Stress Category	Constant C_f ksi [MPa]	Threshold F_{TH} ksi [MPa]	Slope m	Potential crack initiation	Illustrative Example
Hilti S-BT screw-in stainless and carbon steel threaded studs with pre-drilled hole in structural steel base material. Imperfect fastener installations as e.g. overwound or pulled-out fasteners are covered. $\Delta\sigma$ to be calculated by the gross cross-section. Installation, static loading and spacing of fasteners only in accordance with the requirements given in [1] or [2]. Plate thickness $t \geq 3$ mm. Steel base material up to yield strength 355 MPa.	S-BT	6065×10^{10} [1.995×10^{16}]	12.6 [87.0]	5.0	At the edge or tip of the pre-drilled hole	
[1] Hilti S-BT screw-in threaded studs. Specification Binder, Edition 01/2017 [2] Hilti Direct Fastening Technology Manual. Edition 12/2016. S-BT product pages.						

Table 4: Recommendation of fatigue S-N curve and stress category acc. to AWS D1.1:2015

ABS:2014

It is recommended to use the following design S-N curve respectively stress category termed “S-BT” given in Table 5 for the constructional detail “Steel base material with Hilti S-BT screw-in threaded studs”.

Curve Class	A for [MPa] units	A for [ksi] units	m	for [MPa] units	for [ksi] units	r	N_Q	S_Q for [MPa] units	S_Q for [ksi] units
B	1.01×10^{15}	4.48×10^{11}	4.0	1.02×10^{19}	9.49×10^{13}	6.0	1.0×10^7	100.2	14.5
C	4.23×10^{13}	4.93×10^{10}	3.5	2.59×10^{17}	6.35×10^{12}	5.5	1.0×10^7	78.2	11.4
D	1.52×10^{12}	4.65×10^{9}	3.0	4.33×10^{15}	2.79×10^{11}	5.0	1.0×10^7	53.4	7.75
E	1.04×10^{12}	3.18×10^{9}	3.0	2.30×10^{15}	1.48×10^{11}	5.0	1.0×10^7	47.0	6.83
F	6.30×10^{11}	1.93×10^{9}	3.0	9.97×10^{14}	6.24×10^{10}	5.0	1.0×10^7	39.8	5.78
F2	4.30×10^{11}	1.31×10^{9}	3.0	5.28×10^{14}	3.40×10^{10}	5.0	1.0×10^7	35.0	5.08
G	2.50×10^{11}	7.64×10^{8}	3.0	2.14×10^{14}	1.38×10^{10}	5.0	1.0×10^7	29.2	4.24
W	1.60×10^{11}	4.89×10^{8}	3.0	1.02×10^{14}	6.54×10^{9}	5.0	1.0×10^7	25.2	3.66
S-BT	**1.995×10^{16}**	**1.28×10^{12}**	**5.0**	**1.995×10^{16}**	**1.28×10^{12}**	**5.0**	**1.0×10^7**	**72.4**	**10.50**

Description and notes on mode of failure	Class	Explanatory comments	Example including failure modes
Hilti S-BT screw-in stainless and carbon steel threaded studs with pre-drilled hole in structural steel base material. Imperfect fastener installations as e.g. overwound or pulled-out fasteners are covered. Potential crack initiation at the edge or tip of the pre-drilled hole.	S-BT	$\Delta\sigma$ to be calculated by the gross cross-section. Installation, static loading and spacing of fasteners only in accordance with the requirements given in [1] or [2]. Plate thickness $t \geq 3$ mm. Steel base material up to yield strength 355 MPa.	

Parameter of design S-N curve class S-BT									
Curve Class	A for [MPa] units	A for [ksi] units	m	for [MPa] units	for [ksi] units	r	N_Q	S_Q for [MPa] units	S_Q for [ksi] units
S-BT	1.995×10^{16}	1.28×10^{12}	5.0	1.995×10^{16}	1.28×10^{12}	5.0	1.0×10^{7}	72.4	10.50

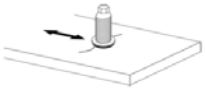
[1] Hilti S-BT screw-in threaded studs. Specification Binder, Edition 01/2017
[2] Hilti Direct Fastening Technology Manual. Edition 12/2016. S-BT product pages.

Table 5: Recommendation of fatigue S-N curve and fatigue class acc. to ABS-(A):2014

BV:2016

It is recommended to use the following design S-N curve respectively stress category termed “S-BT” given in Table 6 for the constructional detail “Steel base material with Hilti S-BT screw-in threaded studs”.

Curve	FAT	First slope		Slope intersection		Second slope		Reference thickness t_{ref} [mm]	Thickness exponent n
	ΔS [MPa]	m_1	$\log_{10}(K_1)$	N cycles	ΔS_q [MPa]	m_2	$\log_{10}(K_2)$		
B	150.00	4.0	15.0056	10^7	100.32	7	21.0105	25	0
C	123.81	3.5	13.6260	10^7	78.19	6	18.3589		see Sec. 10, Tab. 2 of BV
D	91.25	3.0	12.18.18	10^7	53.36	5	15.6363		
E (1)	80.31	3.0	12.0153	10^7	46.96	5	15.3588		
F (1)	68.10	3.0	11.8004	10^7	39.82	5	15.0007		
F2 (1)	59.95	3.0	11.6345	10^7	35.06	5	14.7241		
$P_\perp$	91.25	3.0	12.1818	10^7	53.36	5	15.6363		
$P_\parallel$	100.00	3.0	12.3010	10^7	58.48	5	15.8350		
S-BT	100.00	5.0	16.3000	10^7	72.40	5	16.3000	25	0

Joint and detail description	Curve	Geometry	Requirements
Hilti S-BT screw-in stainless and carbon steel threaded studs with pre-drilled hole in structural steel base material. Imperfect fastener installations as e.g. overwound or pulled-out fasteners are covered. Potential crack initiation at the edge or tip of the pre-drilled hole.	S-BT		$\Delta\sigma$ to be calculated by the gross cross-section. Installation, static loading and spacing of fasteners only in accordance with the requirements given in [1] or [2]. Plate thickness $t \geq 3$ mm. Steel base material up to yield strength 355 MPa.

Parameter of design S-N curve S-BT								
Curve	FAT	First slope		Slope intersection		Second slope		Thickness exponent n
	ΔS [MPa]	m_1	$\log_{10}(K_1)$	N cycles	ΔS_q [MPa]	m_2	$\log_{10}(K_2)$	
S-BT	100	5.0	16.300	10^7	72.40	5.0	16.300	0

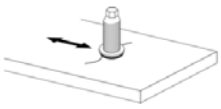
[1] Hilti S-BT screw-in threaded studs. Specification Binder, Edition 01/2017
[2] Hilti Direct Fastening Technology Manual. Edition 12/2016. S-BT product pages.

Table 6: Recommendation of fatigue design S-N curve and stress category acc. to BV:2016, air

DNVGL-RP-C203:2016

It is recommended to use the following design S-N curve respectively stress category termed “S-BT” given in Table 7 for the constructional detail “Steel base material with Hilti S-BT screw-in threaded studs”.

S-N curve	$N \leq 10^7$ cycles		$N > 10^7$ cycles $\log a_2$ $m_2 = 5.0$	Fatigue limit at 10^7 cycles [MPa]	Tickness exponent k
	m_1	$\log a_1$			
B1	4.0	15.117	17.146	106.97	0
B2	4.0	14.885	16.858	93.59	0
C	3.0	12.592	16.320	73.10	0.05
C1	3.0	12.449	16.081	65.50	0.10
C2	3.0	12.301	15.835	58.48	0.15
D	3.0	12.164	15.606	52.63	0.20
E	3.0	12.010	15.350	46.78	0.20
F	3.0	11.855	15.091	41.52	0.25
F1	3.0	11.699	14.832	36.84	0.25
F3	3.0	11.546	14.576	32.75	0.25
S-BT	5.0	16.300	16.300	72.4	0

Detail category	Construction detail	Description	Requirements
S-BT		Hilti S-BT screw-in stainless and carbon steel threaded studs with pre-drilled hole in structural steel base material. Imperfect fastener installations as e.g. overwound or pulled-out fasteners are covered.	$\Delta\sigma$ to be calculated by the gross cross-section. Installation, static loading and spacing of fasteners only in accordance with the requirements given in [1] or [2]. Plate thickness $t \geq 3$ mm. Steel base material up to yield strength 355 MPa.

Parameter of S-N curve for detail category S-BT

Detail category	$N \leq 10^7$ cycles		$N > 10^7$ cycles $\log a_2$ $m_2 = 5.0$	Fatigue limit at 10^7 cycles [MPa]	Thickness exponent k
	m_1	$\log a_1$			
S-BT	5.0	16.300	16.300	72.4	0

[1] Hilti S-BT screw-in threaded studs. Specification Binder, Edition 01/2017
[2] Hilti Direct Fastening Technology Manual. Edition 12/2016. S-BT product pages.

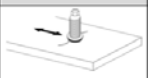
Table 7: Recommendation of fatigue S-N curve and detail category acc. to DNVGL-RP-C03, air

BS 7608:2014

It is recommended to use the following design S-N curve respectively stress category termed “S-BT” given in Table 8 for the constructional detail “Steel base material with Hilti S-BT screw-in threaded studs”.

Class	C_o	$\log_{10}C_o$	m	SD Stand. Deviation of $\log_{10}N$,	C_2	S_{gc} ($N=10^7$ cyc.) N/mm²	S_{oy} ($N=5\cdot10^7$ cyc.) N/mm²
B	$2.343\cdot10^{15}$	15.3697	4.0	0.1821	$1.01\cdot10^{15}$	100	67
C	$1.082\cdot10^{14}$	14.0344	3.0	0.2041	$4.23\cdot10^{13}$	78	49
D	$3.988\cdot10^{12}$	12.6008	3.0	0.2095	$1.52\cdot10^{12}$	53	31
E	$3.2893\cdot10^{12}$	12.5171	3.0	0.2509	$1.04\cdot10^{12}$	47	27
F	$1.726\cdot10^{12}$	12.2371	3.0	0.2183	$6.32\cdot10^{11}$	40	23
F2	$1.231\cdot10^{12}$	12.0902	3.0	0.2279	$4.31\cdot10^{11}$	35	21
G	$5.656\cdot10^{11}$	11.7526	3.0	0.1793	$2.48\cdot10^{11}$	29	17
G2	$3.907\cdot10^{11}$	11.5918	3.0	0.1952	$1.59\cdot10^{11}$	25	15
S1	$5.902\cdot10^{16}$	16.7710	5.0	0.2350	$2.00\cdot10^{16}$	46 (10^8 cyc.)	46 (10^8 cyc.)
S2	$3.949\cdot10^{16}$	16.5965	5.0	0.3900	$6.55\cdot10^{15}$	37 (10^8 cyc.)	37 (10^8 cyc.)
S-BT	$5.902\cdot10^{16}$	16.7710	5.0	0.2350	$2.00\cdot10^{16}$	74.2	52.5

Design S-N curve: $\log N = \log_{10}C_o - 2\cdot SD - m\cdot\log S$

Product form	Location of crack	Detail	Manufacturing requirements	Special requirements	Design stress area	Class	Notes	Sketch
Rolled steel plates and sections	At the edge or tip of the pre-drilled hole	Hilti S-BT screw-in stainless and carbon steel threaded studs with pre-drilled hole in structural steel base material.	Installation, static loading and spacing of fasteners only in accordance with the requirements given in [1] or [2].	Plate thickness t ≥ 3mm. Steel base material up to yield strength 355 MPa.	Net cross section	S-BT (S1)	Imperfect fastener installations as e.g. overwound or pulled-out fasteners are covered.	

Parameter of S-N curve for detail class S-BT							
Class	C_o	$\log_{10}C_o$	m	SD Stand. Deviation of $\log_{10}N$	C_2	S_{oc} (N=10^7 cyc.) N/mm²	S_{oy} (N=$5 \cdot 10^7$ cyc.) N/mm²
S-BT	$5.902 \cdot 10^{16}$	16.7710	5.0	0.2350	$2.00 \cdot 10^{16}$	74.2	52.5

[1] Hilti S-BT screw-in threaded studs. Specification Binder, Edition 01/2017
[2] Hilti Direct Fastening Technology Manual. Edition 12/2016. S-BT product pages.

Table 8: Recommendation of fatigue S-N curve and detail category acc. to BS 7608:2014

Literature:

[1] EMPA: Test Report No. 5214011585/e. Swiss Federal Laboratories for Materials Testing and Research (EMPA), April 26th 2016.
[2] EMPA: Test Report No. 5214013022/e_corr. Swiss Federal Laboratories for Materials Testing and Research (EMPA), June 29th 2017.
[3] EMPA: Test Report No. 5214014601/e. Swiss Federal Laboratories for Materials Testing and Research (EMPA), April 11th 2017.
[4] Kuhlmann, U., Günther, H.-P.: Fatigue classification of the constructional detail “Structural steel base material with Hilti S-BT screw-in threaded studs”. Universität Stuttgart, Institut für Konstruktion und Entwurf, June 30th, 2017, Nr. 2017-38X.
[5] EN 1993-1-9: Eurocode 3: Design of steel structures - Part 1-9: Fatigue, European Committee for Standardization.
[6] AWS D1.1: Structural Welding Code – Steel, American Welding Society.
[7] ABS: Guide for Fatigue Assessment of Offshore Structures. American Bureau of Shipping. 2003, Updated version February 2014.
[8] BV: Guidelines for Fatigue Assessment of Steel Ships and Offshore Units. Bureau Veritas. September 2016.
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