Journal of Constructional Steel Research 234 (2025) 109667

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

journal homepage: www.elsevier.com/locate/jcsr

A rotation-based method for bolt and Belleville Spring preloading for seismic friction sliding structural connections☆

Shahab Ramhormozian [a,*], G. Charles Clifton [b], George P. Davet [c]

[a] Auckland University of Technology, Auckland, New Zealand
[b] The University of Auckland, Auckland, New Zealand
[c] Solon Manufacturing Company, OH, United States

ARTICLE INFO

Keywords:
Seismic friction-sliding connections
Belleville Springs (BeSs)
Bolt tightening
Clamping force
Bolt preload
Slotted bolted connection

ABSTRACT

Seismic friction sliding structural connections have been a focus of research and development for over four decades, due to their potential to act as energy-dissipating fuses, dissipating energy through friction and limiting forces. One of the key challenges in the design and implementation of these connections is achieving accurate and precise clamping force through bolt tightening. An overestimated clamping force can lead to premature sliding, while an underestimated force can delay the onset of sliding and cause excessive damage during a severe earthquake. Achieving a precise clamping force during installation and maintaining it throughout the structure's lifetime is very important. Well-designed Belleville Springs (BeSs) have been identified as a significant component in enhancing the seismic behaviour of these connections, by ensuring stable sliding behaviour and maintaining clamping force under both static and dynamic conditions. Despite their effectiveness, there is a lack of standardized methods for tightening bolts with BeSs to reliably achieve a desirable level of bolt tension within the elastic range.

This paper presents findings from 69 bolt tightening experiments conducted on various configurations and BeS types and arrangements. Key parameters such as imposed torque on the nut, BeS deflection, and nut rotation were measured and analyzed. A nut rotation-based method is proposed to ensure that the desired level of bolt tension is consistently achieved, offering a practical solution for both on-site and workshop applications in seismic friction-sliding connections.

1. Introduction

Bolts and bolted connections are amongst the most common fastening components used across a wide range of industries to join materials and ensure structural integrity. Bolted connections typically consist of bolts, nuts, and washers, and are known for their ease of installation and removal, as they don't require permanent bonding like welding or riveting. Bolts are also adaptable to various materials and configurations, making them versatile for many applications. Their widespread use spans multiple sectors, from automotive and aerospace to manufacturing and infrastructure.

Bolt installation involves applying preload to the bolt assembly, generating tension within the bolt body (i.e. shank and threaded part under tension) and creating a compressive clamping force between the connection components. A variety of tools may be used to preload the bolt during installation, including spanners (or wrenches), impact wrenches, electromechanical or hydraulic torque multipliers, and hydraulic direct bolt tensioners. In addition, specialized devices or bolts, such as ultrasound bolt tension meters, Direct Tension Indicator (DTI) washers, and twist-off bolts (also known as Tension Control Bolts, or TCB), have been developed to ensure the required bolt tension is achieved at installation. These tightening methods or tools often rely on one or more parameters related to the achieved bolt tension, including the rotation angle of the nut relative to the bolt, axial strain in the bolt body, applied torque at the nut or a specific bolt cross-section, elastic or plastic material properties and/or geometry of the bolt, the pressure exerted by tools like hydraulic tensioners, and pressure applied to the DTIs. Each of these techniques has distinct characteristics, advantages, and limitations.

As in the construction industry, each standard for the design and

---

☆ This article is part of a Special issue entitled: 'Seismic-Resilient Structures' published in Journal of Constructional Steel Research.

* Corresponding author.
E-mail address: shahab.ramhormozian@aut.ac.nz (S. Ramhormozian).

https://doi.org/10.1016/j.jcsr.2025.109667
Received 28 February 2025; Received in revised form 20 May 2025; Accepted 24 May 2025

installation of structural bolted connections specifies allowable methods of bolt tightening that comply with its requirements. For example, according to New Zealand Steel Structures Standard NZS3404 [1], depending on the design requirements, there are two main allowable methods of tensioning the High Strength Friction Grip (HSFG) structural bolts, namely snug tightening, and full tensioning using the part-turn method. According to NZS3404, the torque-control method of tightening is allowed mainly for inspection and not as the primary method of tightening, and the use of DTIs instead of the part-turn method of tightening is allowed only under specific circumstances. There are other structural standards which have specified and allowed also torque-control, or the use of DTIs, or other methods of tightening e.g. [2,3].

For most of the conventional structural bolted connections in construction industry, in which the bolts are typically designed to deliver an ultimate capacity under shear, tension, or combined shear and tension, a precise level of the bolt preload achieved at the time of the installation is not critical to the performance of the connection, however a minimum level of bolt tension needs to be guaranteed to be achieved, following tightening, to satisfy the performance requirements. For example, the NZS3404 specified snug tightening method guarantees that the load-transmitting plies which are being connected, are brought into effective contact but without specifying a precise level of associated bolt tension. As for the NZS3404 specified Part-turn method of tensioning, it guarantees only a minimum bolt tension, exceeding the minimum proof loads given in AS/NZS 1252 [4], to be achieved at the time of installation. For friction-type (also known as slip-critical) connections design, where no sliding is expected between the plies under the associated performance criteria, a minimum bolt tension is required to be known, along with a conservative minimum coefficient of friction between the sliding surfaces of the plies. The safety factors to design such connections are suitably conservative, ensuring that the slip is prevented. However, the friction-type (or slip-critical) connections are different from the seismic friction-sliding structural connections of which the design philosophy necessitates an accurate and precise level of bolt tension to be achieved, as one of the key design parameters, in order to exhibit a desirable performance.

Seismic friction-sliding structural connections have been the focus of research and development for over four decades (e.g. [5–14]). One common type of these connections is the Slotted Bolted Connection (SBC), which consists of several metal plates clamped together by bolts. One or more of these plates include slotted holes to allow sliding to occur. SBCs act as energy-dissipating fuses within a structural system, i.e. they are designed to slide in a stable manner at a pre-determined sliding force during a severe earthquake. This sliding action dissipates input energy through friction, and limits the maximum force to a pre-set level (the SBC's sliding force), preventing overloading of the connected members. Examples of seismic-resistant systems using SBCs include the Rotational Slotted Bolted Connection (RSBC), FREE from DAMage (FREEDAM), and the Sliding Hinge Joint (SHJ) beam-column connection details for Moment Resisting Steel Frames [15–17]. The RSBC and FREEDAM details employ symmetric plate arrangements, while the SHJ uses an asymmetric arrangement for their SBCs.

Two critical parameters influencing the design and behaviour of friction-sliding structural connections are the clamping force provided by the bolts and the coefficient of friction at the sliding interfaces. An overestimated clamping force can lead to premature sliding under service conditions, while an underestimated clamping force may delay the onset of sliding in severe earthquake, resulting in an excessive damaging force being imposed on the members connected by the friction-sliding connection, and potentially leading to member or system failure. Therefore, it is crucial for these connections to achieve a clamping force, at the time of installation, as close as possible to the design value, and maintain it throughout the structure's lifetime. However, most bolt tightening methods specified by standards have not been specifically developed for seismic friction-sliding structural connections, but rather for conventional structural bolted connections, where, as mentioned earlier, achieving a precise level of bolt tension is not as critical.

Previous studies had demonstrated that seismic friction-sliding structural connections are prone to experiencing post-sliding clamping force loss (e.g. [8,9,15–19]). The improvements observed in several experiments using Belleville Springs (BeSs) suggested that further research was needed to explore and establish the use of BeSs in these connections. Ramhormozian et al. [20,21] conducted both analytical and experimental research to establish the design and implementation of (BeSs) as a key component for significantly improving the seismic behaviour of friction-sliding structural connections, which have also been implemented in practice [22,23]. They demonstrated that amongst the benefits of tightening bolts in their elastic range and implementing well-designed BeSs according to their recommendations, the BeSs effectively maintain the clamping force during and after sliding and provide more stable sliding behaviour. D'Antimo et al. [24] also experimentally demonstrated the benefit of using BeSs in short- and long- term retention of the clamping force.

However, there are no recommendations in the literature for a method of tightening bolts with BeSs, specifically in seismic friction-sliding structural connections, to consistently achieve a reliable level of installed bolt tension within the elastic range. As mentioned earlier, the primary available methods are mostly those specified in standards for conventional bolted connections to achieve a dependable minimum installed bolt tension; exceeding this in practice is not detrimental as it is with friction sliding connections. This presents challenges, particularly when following standards like NZS3404, which primarily recommend snug tightening, and subsequent full tensioning using the part-turn method of tightening. The former method can result in significant variation in the delivered clamping force, while the latter exceeds the elastic range of the bolt preload.

The primary goal of the research presented in this paper is to establish a feasible and reliable method for tightening bolts with BeSs within the elastic range of bolt preload, ensuring any desired level of bolt tension to be achieved at installation, whether on site or in a workshop.

2. Experimental testing plan

As shown in Fig. 1, a bolt tightening test setup was designed and secured on a solid bench, using a vice, to simulate a typical SBC. Four M20 High Strength Friction Grip (HSFG) Property Class (PC) 8.8 bolts were first snug tightened. Then, one M20 HSFG G8.8 bolt was removed and replaced with the target bolt/BeS assemblage for testing various configurations.

The following parameters were monitored during the bolt tightening experiments for different configurations of the bolt/BeSs, from the hand (finger) tight condition to the installed bolt tension:

- Bolt tension using a donut load cell,

Fig. 1. Bolt tightening test setup.

- Applied torque on the nut using a smart socket,
- Nut rotation, visually monitored by marking the nut and reading the angle against an angle gauge,
- Bolt length using a digital height gauge,
- BeSs deflection using the digital height gauge

3. Test components

3.1. Belleville Springs (BeSs)

Two types of Belleville Spring (BeS), supplied by Solon Manufacturing Co., were used in this research: type 1 and type 2. Three sets of experiments with BeSs were conducted, using different configurations of type 1, type 2, and a combination of both types. According to the BeSs manufacturer, the maximum linear deflection of type 1 and type 2 BeSs was 0.838 mm (at 124.7 kN) and 1.57 mm (at 110 kN), respectively. The characteristics of type 1 and type 2 BeSs are presented in Table 1 and Fig. 2. It is important to note that both BeS types were preset, and had a load capacity associated with their linear deflection which was greater than the target installed bolt tension. This follows the design procedure proposed by Ramhormozian et al. [20,21], which suggests that the BeSs should be partially deflected at installation. All BeSs configurations considered in this research were either single or series. The typical geometric design of a BeS and possible stacking configurations are explained in [20].

3.2. Bolt specimens and preparation

The HSFG PC 8.8 Structural M20 bolts complied with AS/NZS 1252 [4] and were purchased from a professional fastener supplier in New Zealand. The pitch of each HSFG PC 8.8 M20 bolt is 2.5 mm. Both ends of the bolts (tip and head) were prepared using a bench grinder to ensure they were flat and suitable for use with the digital height gauge. The length of each bolt was measured with the digital height gauge before installation. Bolt lengths were selected according to Clause 14.3.6.1.2 of NZS 3404 [1], ensuring that at least one clear thread was visible above the nut after tightening to ensure full engagement between the nut and the bolt body threads.

3.2.1. Free turn of nut test on the bolts

All of the received bolts were tested based on the “free turn of nut” check recommended by Ramhormozian et al. [25–27] and included in AS/NZS1252.2 [28], which states: “*Nuts shall run freely when part of a bolt/nut assembly. This shall be checked by running the nut along the bolt's threads by hand the full length of the thread before being used in a connection. Only bolt/nut assemblies that pass this test shall be used. Once a bolt/nut assembly has been so tested, neither component shall be substituted.*” Several bolts initially failed this check, primarily due to tiny zinc particles from galvanizing being stuck around the threads. However, using a metal handle brush to remove these particles upgraded most of the “almost-freely” bolts to the “free” category. This was done to minimize potential variations in the required torque for tightening the bolts.

3.2.2. Bolts lubrication

All the bolts were lubricated before the tightening tests by Molybond® GA50 paste containing 50 % molybdenum disulphide. The lubricant was applied along the threads, and the nut was then turned over the whole threaded part of the bolt to spread the lubricant all around the threads. This was done to minimize potential variations in the required torque for tightening the bolts.

Table 1
Geometrical characteristics of type 1 and type 2 Belleville springs.

	D (mm)	d (mm)	s (mm)	h (mm)
Type 1	52.705	20.75	6.013	0.838
Type 2	69.77	20.9	6.35	1.57

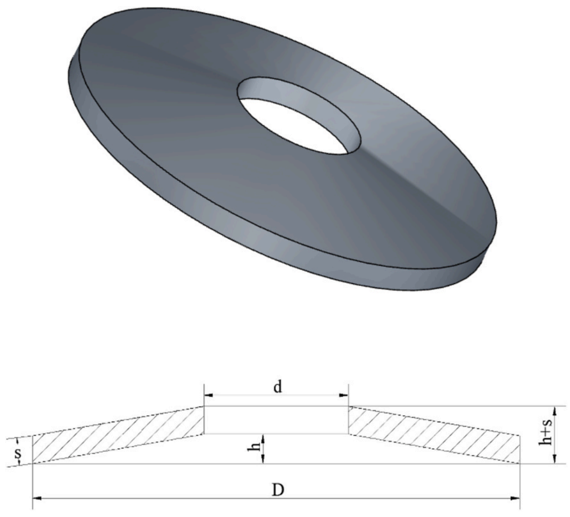

Fig. 2. Typical layout of a Belleville spring.

3.3. Plates and washers layouts

A set of three 16 mm thick and two 5 mm thick, 250 mm × 250 mm structural steel plates were designed to represent a typical SBC, such as an Asymmetric Friction Connection (AFC) in the Sliding Hinge Joint (SHJ) [21]. The 16 mm thick plates were made from Grade 350 structural steel, while the 5 mm thick plates were made from Raex 450 abrasion-resistant (high hardness) steel. All surfaces were sweep-blasted, following typical steel fabrication practices in New Zealand. Each plate contained four standard holes, except for the middle plate, which featured four slotted holes. Fig. 3 illustrates the layout of the plates used in the bolt tightening tests.

Appropriate Grade 350 structural steel washers were also designed and supplied to sandwich the load cells between them to maximize the accuracy of the load cell readings. Fig. 4 shows the layout of the washers used for the tests.

3.4. Measurements: load cell, digital height gauge, and smart socket

3.4.1. Load cell

A specialist donut load cell (LWO-60) was used to monitor and record the bolt tension during tightening (Fig. 5). The load cell was positioned between two washers, which were specifically designed and supplied to ensure reliable readings. The load cell was provided by *Transducer Techniques (TT)*, a U.S.-based load cell manufacturer.

The load cell was connected to the structural laboratory's data acquisition (DAQ) system, which continuously measured and recorded the clamping force applied to the load cell. This force was equal to the tensile load in the bolt during the tightening tests.

3.4.2. Digital height gauge

A Starrett electronic digital height gauge was customized and used to measure the required dimensions of the bolt assembly before, during, and after tightening. The customization involved mounting a strong magnet at the base of the gauge to ensure a fixed and secure position for the most reliable readings. The change in BeS deflection during tightening was also measured using the digital height gauge. Fig. 6 shows the digital height gauge with the LCD display used in the experiments.

3.4.3. RAD smart socket

A RAD specialist smart socket was supplied by a Canadian manufacturer (Fig. 7) and then customized for the specific needs of this

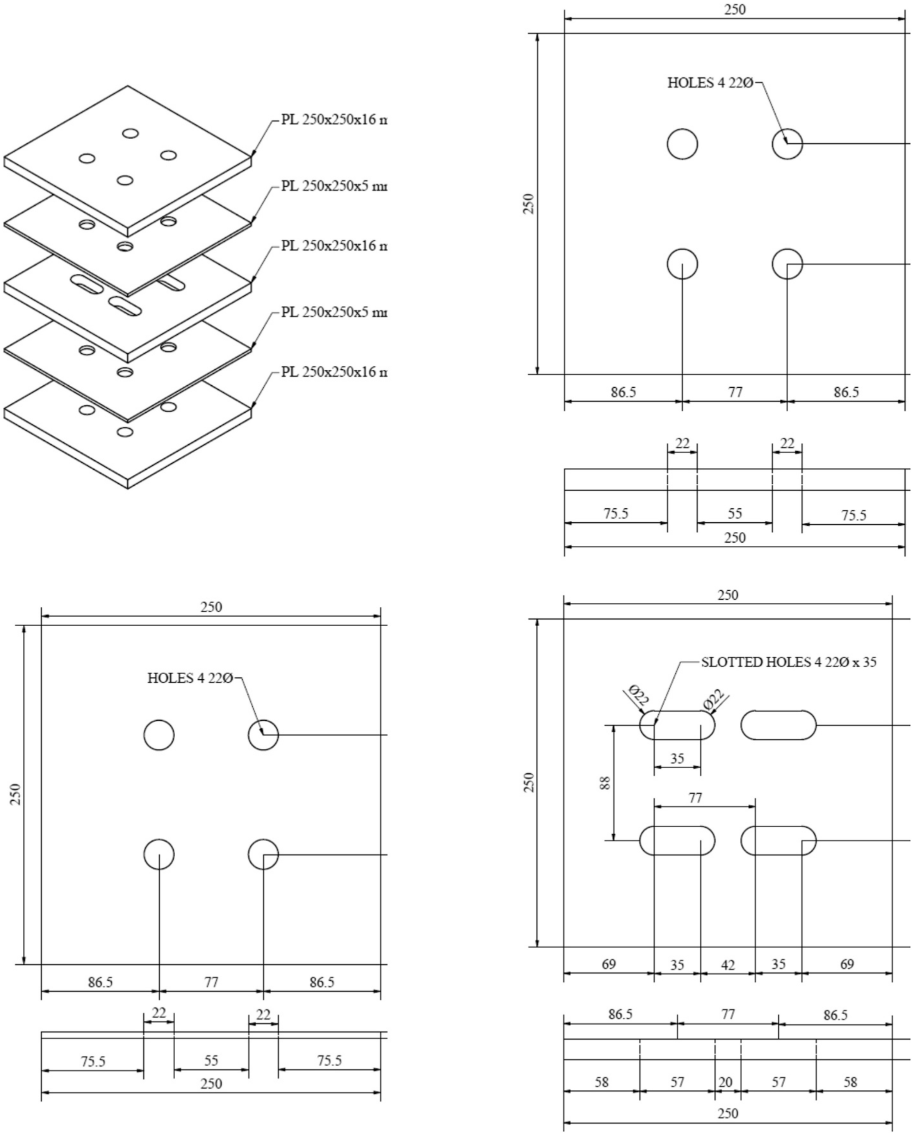

Fig. 3. Layout of the plates used for bolt tightening tests (dimensions in mm).

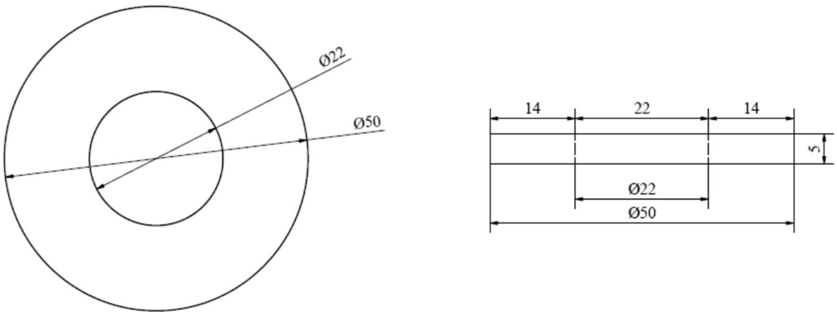

Fig. 4. Layout of the washers used to sandwich donut load cell (dimensions in mm).

research. The customization included providing adapters to match the bolt sizes used in the experiments. The smart socket enabled the recording of the peak torque applied to the nut, thereby generating a relationship between the applied torque and the installed tension measured by the load cell.

4. The tightening tests

Fig. 8 below shows the layout of the bolt in the tightening tests. The layout included three 16 mm thick and two 5 mm thick, 250 mm × 250 mm steel plates, the LWO-60 load cell set with two washers, and the bolt assembly configuration with BeSs. The number of BeSs on either the head or nut side of the bolt was 0, 1, or 3, using either type 1 and/or type

Fig. 5. TT LWO series donut load cells.

2 BeSs, as presented in Tables 2-4. This range of configurations was selected to cover a wide spectrum of BeS system stiffness values.

4.1. Bolt tightening test setup preparation

All five plates were fitted and clamped onto the solid bench using the vice, then firmly snug tightened with four bolts. One of the bolts was then removed and replaced with the target bolt, BeS(s), and donut load cell. Fig. 9 shows the detailed setup of this test, with the components labelled to represent an AFC in a SHJ.

According to Clause 14.3.6.3 of NZS 3404 [1], oil, dirt, loose scale, rust, fins, or any other defects on the contact surfaces that may prevent proper seating of the parts in the snug-tight condition must be removed. This was done in the tests.

4.2. Bolt tightening tests configurations

4.2.1. Bolt /nut/hardened washer without BeSs (T1)

The target tension was set at 130 kN, approximately 90 % of the bolt's proof load. Three tests were conducted on three new bolts without BeSs (T11, T12, and T13).

4.2.2. Type 1 BeSs (T2)

The target tension was 90 kN, approximately 72 % of the type 1 BeS flat linear deflection load. Three repetitions of each test configuration were conducted, using new bolts for each repeat.

4.2.3. Type 2 BeSs (T3)

The target tension was 90 kN, approximately 82 % of the type 2 BeS linear deflection load. Three repetitions of each test configuration were conducted, using new bolts for each repeat.

4.2.4. Combinations of type 1 and type 2 BeSs (T4)

The target tension was 90 kN, approximately 82 % of the weaker BeS's linear deflection load. Three repetitions of each test configuration were conducted, using new bolts for each repeat.

5. The test procedure

The following procedure was followed for each bolt tightening test:

Measuring bolt dimensions: The following bolt dimensions were measured before installing each target bolt using the height gauge:

- Total bolt length
- Shank length
- Thread length
- Head height
- Thickness of the hardened washer
- Nut thickness (height)

Hand tight: The target bolt was firmly hand (finger) tightened, and the following values were recorded:

- Bolt's tension using the donut load cell (continuously).
- Height of the top of the nut and the tip of the bolt relative to the cap plate (A), measured using the digital height gauge.

Snug tight: The bolt was tightened to snug-tight using a spanner, as specified by NZS 3404, which states: "*The tightness of a bolt is achieved by a few impacts of an impact wrench or by the full effort of a person using a standard podger spanner*." The bolt head was prevented from rotating

Fig. 7. The RAD smart socket.

Fig. 6. The digital height gauge.

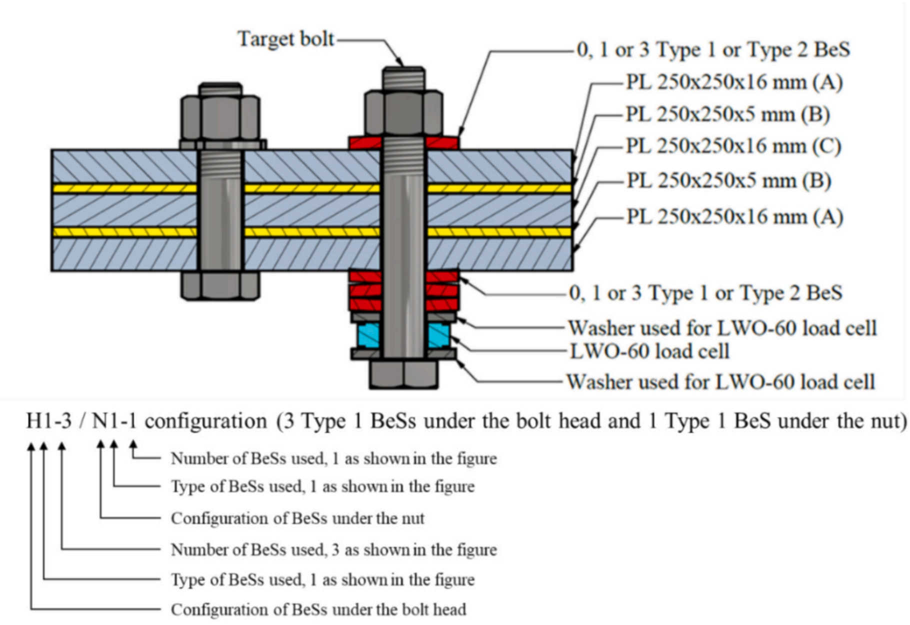

Fig. 8. Schematic layout of the tightening test setup and the target bolt.

Table 2
Tests configurations using type 1 BeSs (T2).

Configuration	Under bolt head		Under nut	
	Type of BeS	Number of BeSs	Type of BeS	Number of BeSs
H1–1/N1–1	1	1	1	1
H1–3/N1–3	1	3	1	3
H1–1/N0–0	1	1	N/A	0
H1–3/N0–0	1	3	N/A	0
H0–0/N1–1	N/A	0	1	1
H0–0/N1–3	N/A	0	1	3
H1–3/N1–1	1	3	1	1
H1–1/N1–3	1	1	1	3

Table 3
Test configurations using type 2 BeSs (T3).

Configuration	Under bolt head		Under nut	
	Type of BeS	Number of BeSs	Type of BeS	Number of BeSs
H2–1/N2–1	2	1	2	1
H2–3/N2–3	2	3	2	3
H2–1/N0–0	2	1	N/A	0
H2–3/N0–0	2	3	N/A	0
H0–0/N2–1	N/A	0	2	1
H0–0/N2–3	N/A	0	2	3
H2–3/N2–1	2	3	2	1
H2–1/N2–3	2	1	2	3

Table 4
Test configurations using combinations of type 1 and 2 BeSs (T4).

Configuration	Under bolt head		Under nut	
	Type of BeS	Number of BeSs	Type of BeS	Number of BeSs
H2–1/N1–1	2	1	1	1
H1–1/N2–1	1	1	2	1
H2–1/N1–3	2	1	1	3
H1–1/N2–3	1	1	2	3
H2–3/N1–3	2	3	1	3
H1–3/N2–3	1	3	2	3

while the nut was being turned. The following values were then recorded:

- Bolt's tension using the donut load cell (continuously).
- Height of the top of the nut and the tip of the bolt relative to the cap plate, measured using the digital height gauge.
- The angle of the nut's rotation from the hand-tight state, measured visually.

Reaching the maximum installed tension by turning the nut continuously using a V-RAD Electric torque multiplier: The nut was turned up to a maximum tension while the bolt head was being prevented from any potential rotation when the nut was being turned, and the following parameters were recorded:

- Bolt tension using the donut load cell (continuously).
- Height of the top of the nut and the tip of the bolt relative to the cap plate, measured using the digital height gauge.
- Maximum imposed torque on the nut using the smart socket once the maximum installed tension was reached.
- The angle of the nut's rotation from the snug-tight condition, measured visually.

After untightening and removing each bolt, the bolt length was measured by the digital height gauge. Additionally, the “free turn of nut” test was also carried out on all bolts after removing. These were to investigate if the bolts had potentially yielded or experienced any physical damage during tightening to the extent that may be captured by this physical test. Fig. 10 shows the donut load cell, standard spanner, smart socket, and torque multiplier used on the test setup.

6. The measurements and data processing

The bolt tension was continuously monitored and recorded over time by the donut load cell, including the bolt's hand-tight, snug-tight, and final (maximum) installed tension. Assuming a constant rotational velocity applied by the electronic torque wrench during the post-snug-tight turn, and a linear relationship between rotation and bolt tension in this phase, the rotation required to reach the target bolt load (which is typically less than the final installed tension) was calculated. Assuming a

Fig. 9. Bolt tightening test setup (left) and measuring scale for the nut turn (right).

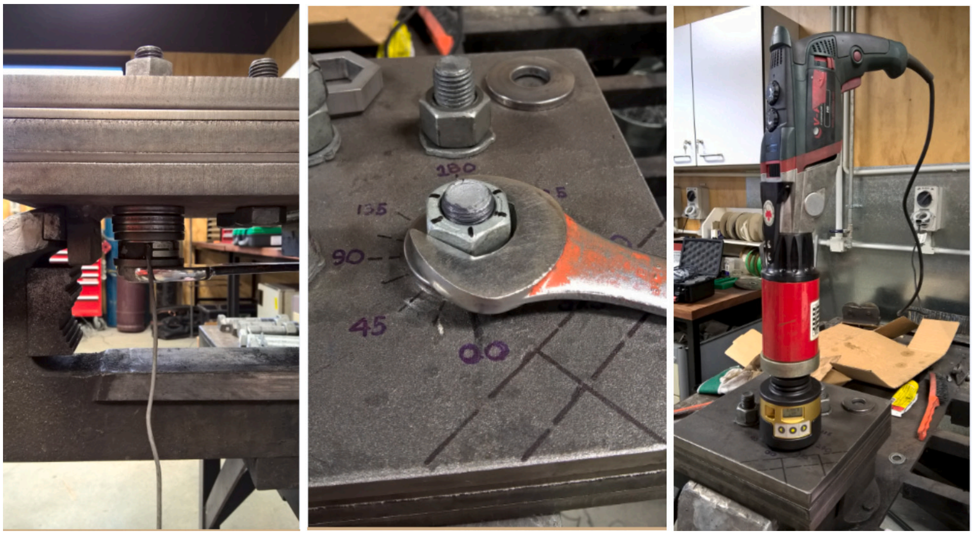

Fig. 10. The donut load cell (left), The standard spanner (middle), The electric torque multiplier with the smart socket (right).

linear increase in the applied torque on the nut from snug-tight to the final installed tension [29], the required torque on the nut to just reach the bolt target load was calculated. The deflection of the BeSs on the nut side, from hand-tight to snug-tight and from snug-tight to the final installed tension, was calculated based on the measured values. After completing the tightening, a small drop in bolt tension was recorded, as expected, before reaching the stable bolt tension. This reduction in bolt tension was also calculated as a percentage, with an average value of

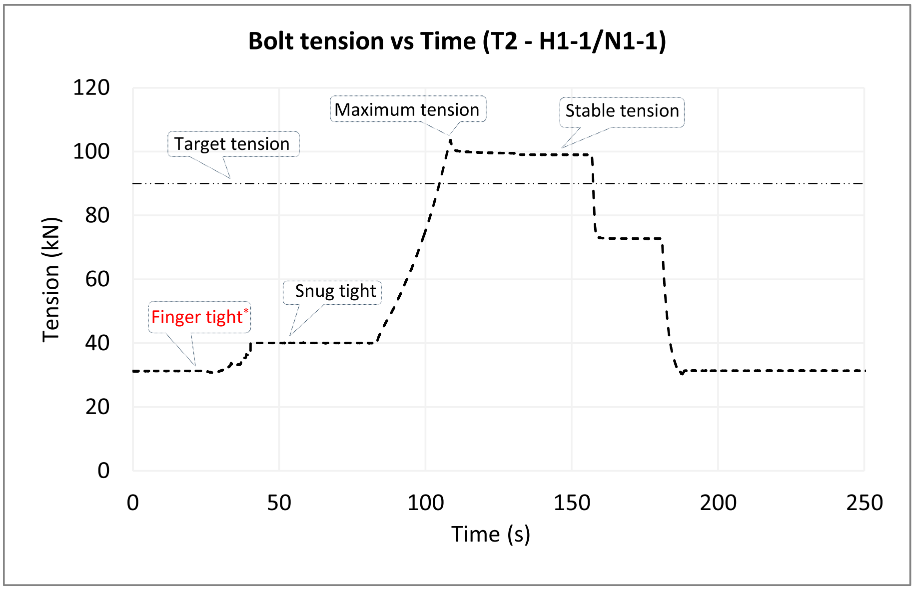

Fig. 11. Example of the bolt tension-time graph of one test (T2 – H1–1/N1–1).

approximately 2 % observed across all tests. Additionally, the length of the unloaded and loaded threads under tension, as well as the height of the top of the nut and the tip of the bolt relative to the cap plate, were all measured. It is worth noting that during the calibration of the donut load cells prior to the tests, it was observed that they were inaccurate at low load levels, up to approximately 30kN. As a result, the finger-tight bolt tension may not be accurately measured. However, this limitation does not impact the data analysis and/or the final recommendations of this paper. Fig. 11 and Table 5 show the recorded and processed data of one of the tests (T2 – H1–1/N1–1).

7. Results and discussions

The tightening tests were conducted on 69 HSFG PC 8.8 M20 bolts, sourced from a specialized bolt supplier based in New Zealand, as previously described. Two types of BeS, supplied by Solon Manufacturing Company, were used in various configurations, also as described previously. The processed data from the three tests conducted without BeSs (i.e. T1) are excluded from the data analysis and comparisons presented in this section.

7.1. *Tests T2 (Type 1 BeS)*

Fig. 12 shows the required nut turn to reach the target tension post-snug tight and post-hand tight, plotted against the BeS system nominal deflection normalized to the bolt thread pitch, for the configurations using type 1 BeS. The BeS system (total) nominal deflection was calculated based on the deflection associated with the target installed bolt tension, considering the manufacturer's data described in section 1.3.1. The general trend indicated that 0.36 turns should be added to (0.76 × BeS system nominal deflection, normalized to the bolt thread pitch) to determine the required post-hand tight turn to achieve the desired target installed bolt tension. Meanwhile, the required post-snug tight turn to reach the target installed tension was (0.5 × BeS system nominal deflection, normalized to the bolt thread pitch).

Table 5
Example of the recorded and processed data of one test (T2 – H1–1/N1–1).

Parameter	Value	Unit
Maximum installed bolt tension	103.6	kN
Stable bolt tension after initial drop	97.8	kN
Bolt tension drop after tightening	5.57	%
Snug tight bolt tension	40.06	kN
Hand (finger) tight bolt tension (*likely not accurate)	31.31	kN
Snug tight turn	180.00	Degree
Post-snug-tight turn (to reach maximum tension)	135.00	Degree
Total amount of turn	315.00	Degree
Required nut turn to reach the target tension (90kN)		
- After snug tight	106.09	Degree
- After hand tight	286.09	Degree
Torque at maximum installed bolt tension	484.03	Nm
Torque associated with snug tight	180.00	Nm
Torque associated with the target tension	418.92	Nm
Initial bolt length	141.01	mm
Bolt length after removing	141.03	mm
% of the bolt length change	0.01	%
Nut turn check after untightening	OK	
BeS total height at nut side		
- Hand tight	6.69	mm
- Snug tight	6.20	mm
- Final installed	5.96	mm
Length of the unloaded thread		
- Hand tight	13.23	mm
- Snug tight	14.37	mm
- Post-snug-tight turn	15.07	mm
Length of the thread under the tension		
- Hand tight	19.66	mm
- Snug tight	18.52	mm
- Post-snug-tight turn	17.82	mm
BeS deflection at nut side associated with the snug tight after hand tight	0.49	mm
BeS deflection at nut side associated with the target tension after snug tight	0.19	mm

Fig. 13 shows the required post-hand tight nut turn to reach the snug tight condition, normalized to the BeS system nominal deflection, and further normalized to the bolt thread pitch. As observed, in most cases, at least 50 % of the nut turn associated with the BeS system nominal deflection of the target bolt tension is needed to reach the snug tight condition.

Fig. 14 shows the measured post-hand tight nut-side BeS system deflection required to reach the target tension, normalized to its maximum nominal linear deflection, plotted against the BeS system nominal deflection normalized to the bolt thread pitch. It is important to note that cases with no BeS on the nut side were excluded from this part of the data analysis.

Fig. 15 shows the measured post-snug tight nut-side BeS system deflection required to reach the target tension, normalized to its maximum linear deflection, plotted against the BeS system's nominal deflection normalized to the bolt thread pitch. It is important to note that cases with no BeS on the nut side have been excluded from this part of the data analysis.

Fig. 16 shows the post snug tight and post hand tight required nut turn to reach the target tension versus (BeS system nominal deflection + bolt elongation) normalized to the bolt thread pitch. This is for type 1 BeS configurations. The BeS system nominal deflection is calculated based on the nominal deflection associated with the target installed bolt tension. The bolt elongation is calculated using the equation ($\frac{\text{bolt target tension}}{\text{bolt longitudinal stiffness}}$). The bolt longitudinal stiffness for these calculations is calculated using the equation proposed by Ramhormozian, Clifton [26], i.e. $K_{bolt} = \frac{A_s A_t E}{l_s A_t + l_t A_s}$ where A_S, A_t, l_S, l_t, and E are shank cross sectional area, thread cross sectional area, shank length, loaded thread length, and structural steel elastic modulus respectively. This equation considers the bolt shank and threaded part as two springs in series, and is a simplified version of the approach proposed by Ramhormozian et al. [20] to calculate the bolt longitudinal stiffness. The reason for using the simpler equation is that the axial stiffness of the plates is significantly larger than that of the BeS system or the bolt. Additionally, the contributions of the bolt head and nut stiffness values are minimal, which justifies the adequacy of the simpler approach. The nominal shank and threaded part cross sectional areas were used in the calculations i.e. 314 mm^2 and 245 mm^2 respectively. E = 205GPa was used. The Shank length was the actual shank length measured for each bolt. The loaded thread length was the bolt actual loaded thread length of the hand tight condition measured for each bolt. This is longer than the loaded thread of target tension, however given the flexibility of the bolt head and nut being neglected in the simplified bolt stiffness equation, this inaccuracy in calculating the bolt longitudinal stiffness is minimal. Given the plies are longitudinally much stiffer than the bolt, they are considered as rigid. It is worth noting that the BeS system deflection during tightening is considerably larger than the bolt and/or plies deformations, hence the BeS system deflection is expected to be governing in the calculations. However, it was intended to investigate if there is any potential increase in the accuracy of the predicting equations of required turn of the nut, to install the bolt with BeSs, by including the bolt deformation's parameters in the calculations.

The general trend shows that 0.32 turn is required to be added to (0.75 × "BeS system nominal deflection + bolt elongation" normalized to the bolt thread pitch) to find the required post hand tight turn of the nut, to reach the bolt to the target installed tension. The required post snug tight turn, to reach the bolt to the target installed tension is (0.5× "BeS system nominal deflection + bolt elongation" normalized to the bolt thread pitch).

Fig. 17 shows the imposed torque on the nut associated with target tension normalized to the average snug tight torque versus (BeS system nominal deflection + Bolt elongation) normalized to the bolt thread

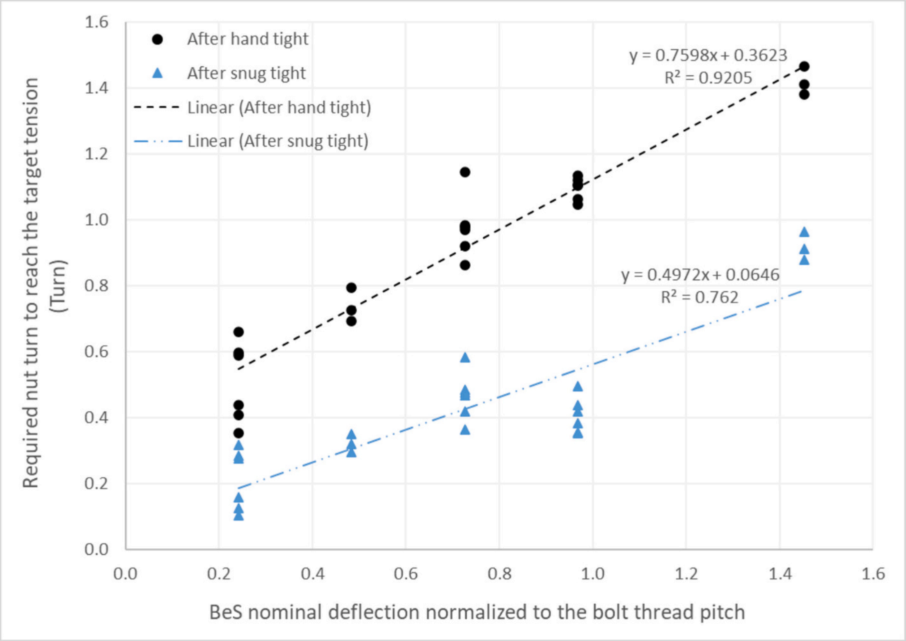

Fig. 12. The relationship between BeS system nominal deflection normalized to the bolt thread pitch and Required nut turn to reach the target tension.

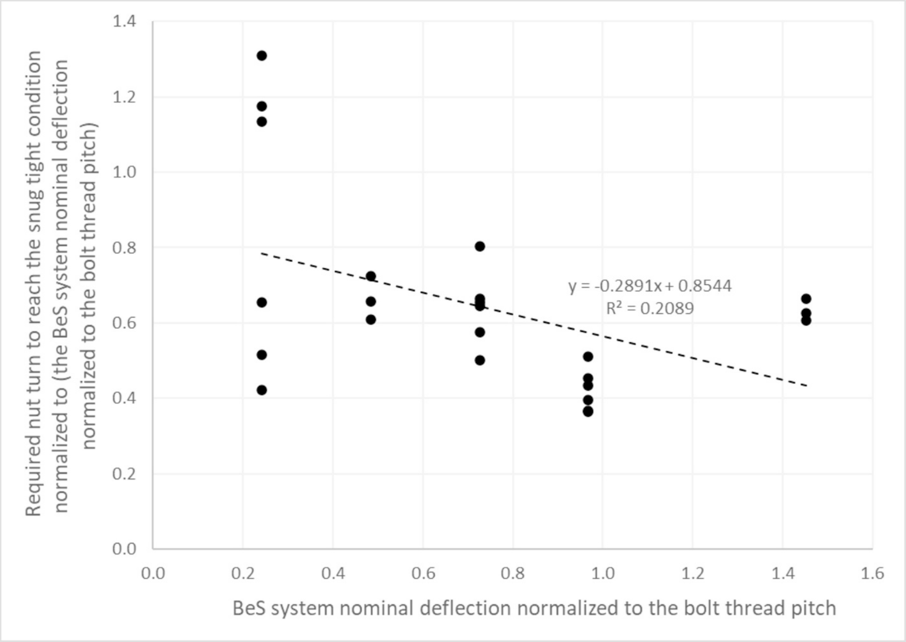

Fig. 13. The relationship between BeS system nominal deflection and Required nut turn to reach the snug tight condition.

pitch. The average snug-tight torque, identified during the experiments, was 180 Nm. This value was obtained using a digital torque wrench to snug-tight the bolts according to NZS 3404 [1], with three different individuals performing the task, each having varying physical strength.

Figs. 18 and 19 are based on extracted data from Figs. 12 and 16 respectively, for the configurations including only one or two BeSs.

7.2. *Tests T3 (Type 2 BeS)*

Fig. 20 shows the post snug tight and post hand tight required nut turn to reach the target tension versus BeS system nominal deflection normalized to the bolt thread pitch. This is for type 2 BeS configurations. The BeS system nominal deflection was calculated based on the deflection associated with the target installed bolt tension, considering the manufacturer's data described in section 1.3.1.

The general trend shows that 0.2 turn is required to be added to (0.98× BeS system nominal deflection normalized to the bolt thread pitch) to find the required post hand tight turn to reach the bolt to the target installed tension. The required post snug tight turn to reach the bolt to the target installed tension is (0.58× BeS system nominal deflection normalized to the bolt thread pitch).

Fig. 21 shows the required post hand tight nut turn to reach the snug tight condition normalized to (the BeS system nominal deflection normalized to the bolt thread pitch). As can be seen, for most of the cases, at least around 50 % of the nut turn associated with BeS system nominal deflection for the target bolt tension, is required to reach the

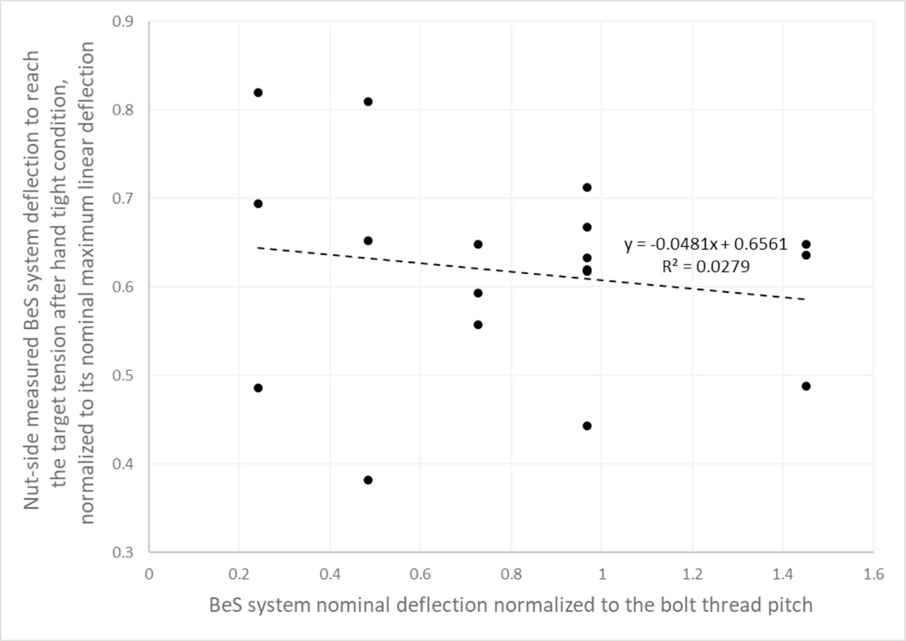

Fig. 14. The relationship between BeS system nominal deflection and nut-side BeS system deflection after hand tight condition.

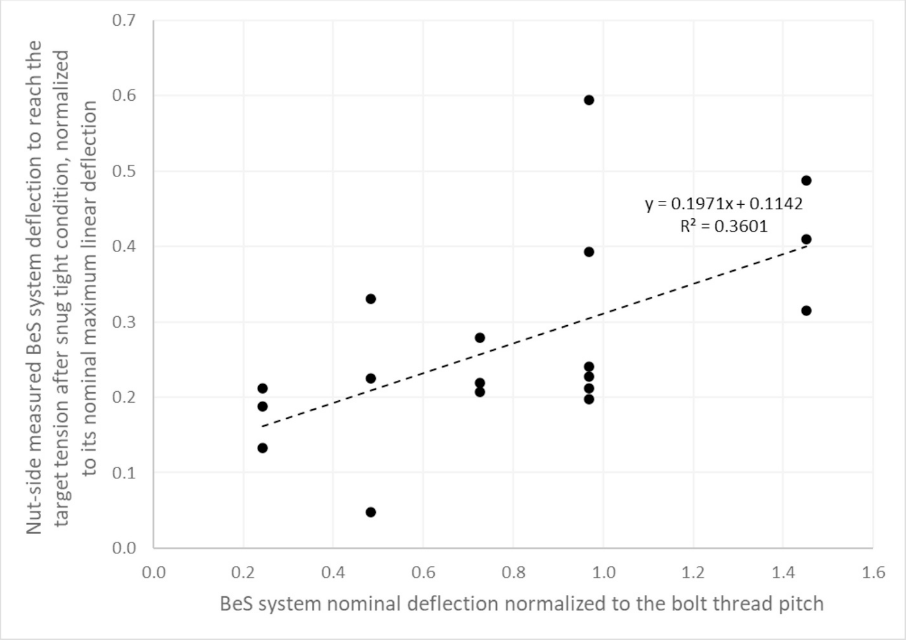

Fig. 15. The relationship between BeS system nominal deflection and nut-side BeS system deflection after snug tight condition.

snug tight condition.

Fig. 22 shows measured nut-side BeS system deflection to reach the target tension after hand tight condition, normalized to its nominal maximum linear deflection, versus BeS system nominal deflection normalized to the bolt thread pitch. The cases with no BeS at nut side have not been included in this part of the data analysis.

Fig. 23 shows the measured nut-side BeS system deflection to reach the target tension after snug tight condition, normalized to its nominal maximum linear deflection, versus BeS system nominal deflection normalized to the bolt thread pitch. The cases with no BeS at nut side have not been included in this part of the data analysis.

Fig. 24 shows the post snug tight and post hand tight required nut turn to reach the target tension versus (BeS system nominal deflection + bolt elongation) normalized to the bolt thread pitch for type 2 BeS configurations. The BeS system nominal deflection is calculated based on the nominal deflection associated with the target installed bolt tension. The general trend shows that 0.14 turn is required to be added to (0.97 × "BeS system nominal deflection + bolt elongation" normalized to the bolt thread pitch) to find the required post hand tight turn to reach the bolt to the desired target installed bolt tension. The required post snug tight turn to reach the bolt to the desired target installed bolt tension is (0.57× "BeS system nominal deflection + bolt elongation" normalized to the bolt thread pitch).

Fig. 25 shows the torque associated with target tension normalized to the average snug tight torque versus (BeS system nominal deflection + Bolt elongation) normalized to the bolt thread pitch.

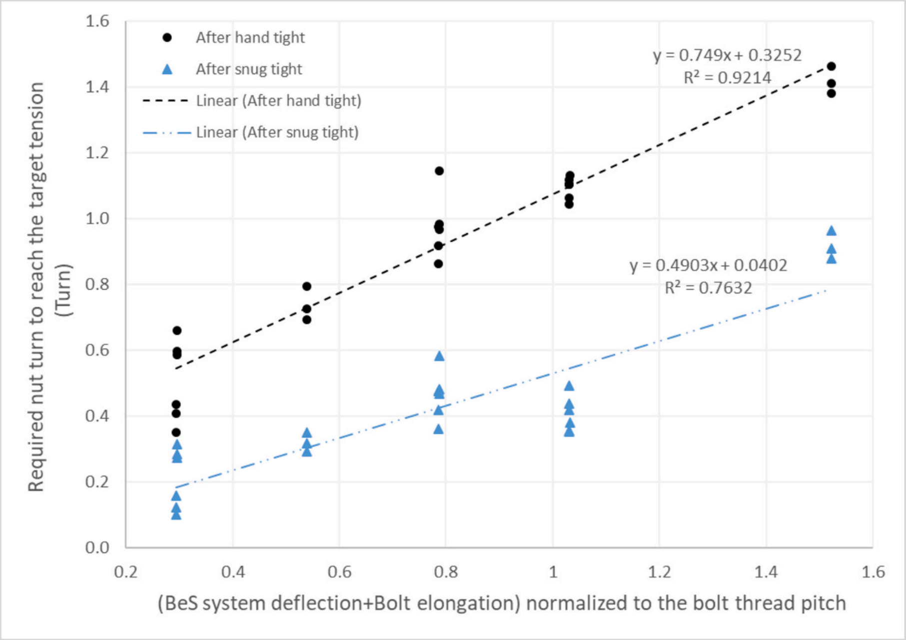

Fig. 16. The relationship between (BeS system nominal deflection + Bolt elongation) and Required nut turn to reach the target tension (Turn).

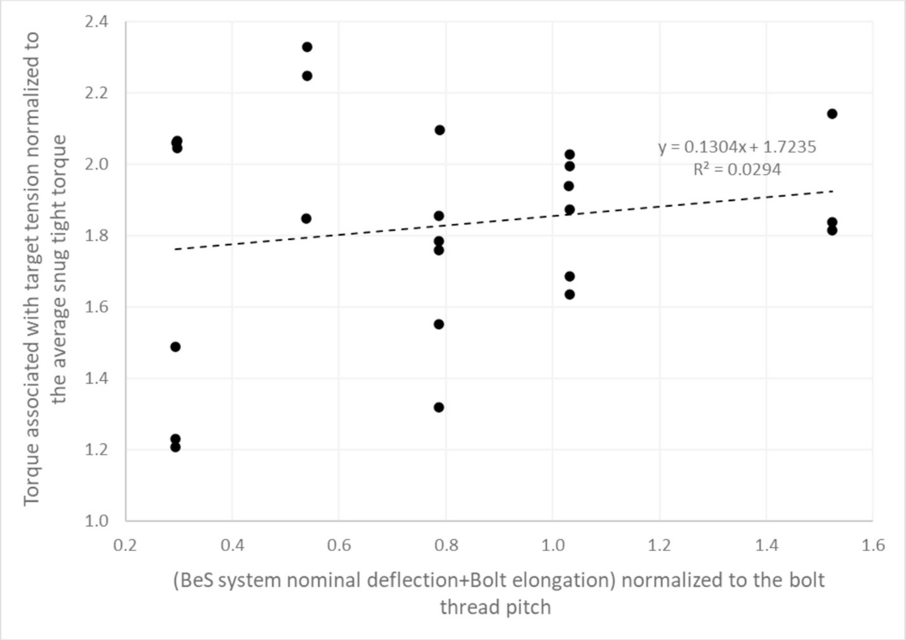

Fig. 17. The relationship between (BeS system nominal deflection + Bolt elongation) and imposed torque associated with target tension for tests T2.

Figs. 26 and 27 are extracted from Figs. 20 and 24 respectively, for the configurations including one or two BeSs.

7.3. Tests T4 (combinations of Type 1 and 2 BeSs)

Fig. 28 shows the post snug tight and post hand tight required nut turn to reach the target tension versus BeS system nominal deflection normalized to the bolt thread pitch. This is for the configurations using combinations of type 1 and 2 BeSs. The BeS system nominal deflection is calculated based on the nominal deflection associated with the target installed bolt tension. The general trend shows that 0.35 turn is required to be added to (0.86× BeS system nominal deflection normalized to the bolt thread pitch) to find the required post hand tight turn to reach the bolt to the desired installed bolt tension.

Fig. 29 shows the required post hand tight nut turn to reach the snug tight condition normalized to (the BeS system nominal deflection normalized to the bolt thread pitch). As can be seen, for almost most of the cases, at least around 50 % of the nut turn associated with BeS system nominal deflection for the target bolt tension, is required to reach the snug tight condition.

Fig. 30 shows the post snug tight and post hand tight required nut turn to reach the target tension versus (BeS system nominal deflection + bolt elongation) normalized to the bolt thread pitch. This is for the configurations that include combinations of type 1 and 2 BeSs. The BeS system nominal deflection is calculated based on the nominal deflection associated with the target installed bolt tension. The general trend shows

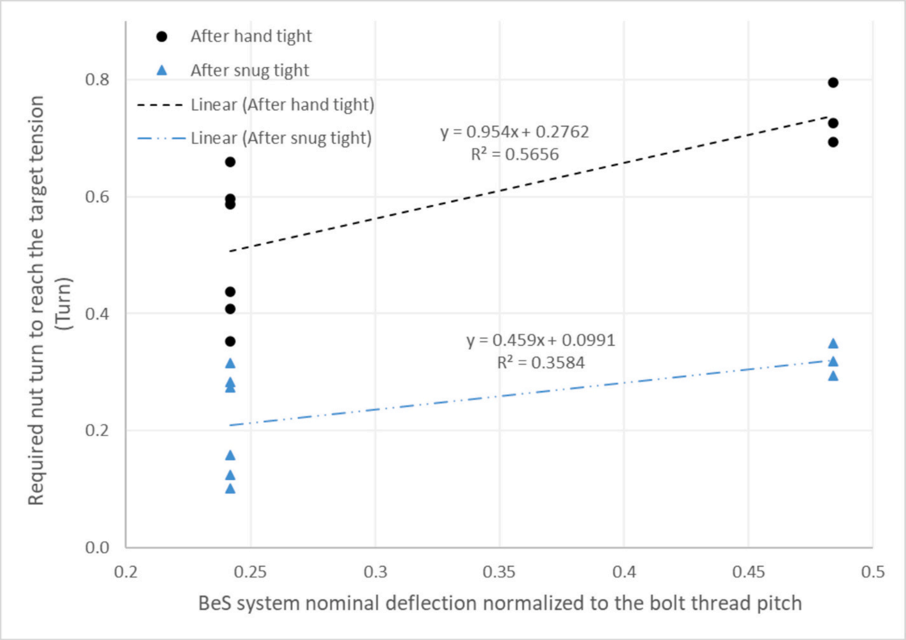

Fig. 18. The relationship between BeS system nominal deflection and Required nut turn to reach the target tension (Not more than two BeSs).

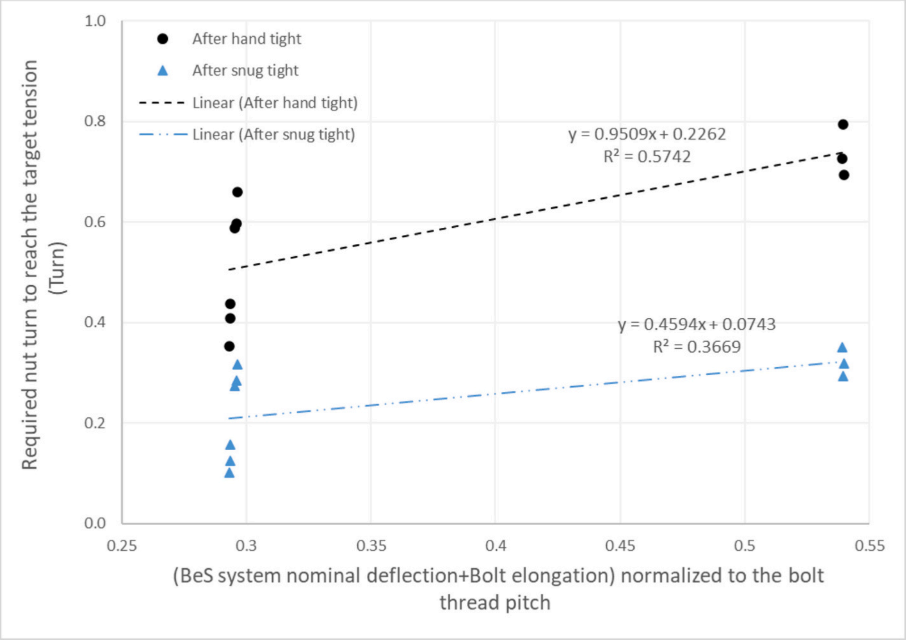

Fig. 19. The relationship between (BeS system nominal deflection + Bolt elongation) and required nut turn to reach the target tension (Not more than two BeSs).

that 0.3 turn is required to be added to (0.86 × "BeS system nominal deflection + bolt elongation" normalized to the bolt thread pitch) to find the required post hand tight turn to reach the bolt to the desired target installed bolt tension.

Fig. 31 shows the torque associated with target tension normalized to the average snug tight torque versus (BeS system deflection + Bolt elongation) normalized to the bolt thread pitch.

7.4. All BeS types and configurations

Fig. 32 shows the post snug tight and post hand tight required nut turn to reach the target tension versus BeS system nominal deflection normalized to the bolt thread pitch. This is for the whole experiments on type 1, type 2, and combined BeS configurations. The BeS system nominal deflection is calculated based on the nominal deflection associated with the target installed bolt tension. The general trend shows that 0.25 turn is required to be added to (0.93 × BeS system nominal deflection normalized to the bolt thread pitch) to find the required post hand tight turn to reach the bolt to the target installed tension. The required post snug tight turn to reach the bolt to the target installed tension is (0.5× BeS system nominal deflection normalized to the bolt thread pitch).

Fig. 33 shows the post snug tight and post hand tight required nut turn to reach the target tension versus (BeS system nominal deflection + bolt elongation) normalized to the bolt thread pitch. This is for the whole experiments on type 1, type 2, and combined BeS configurations.

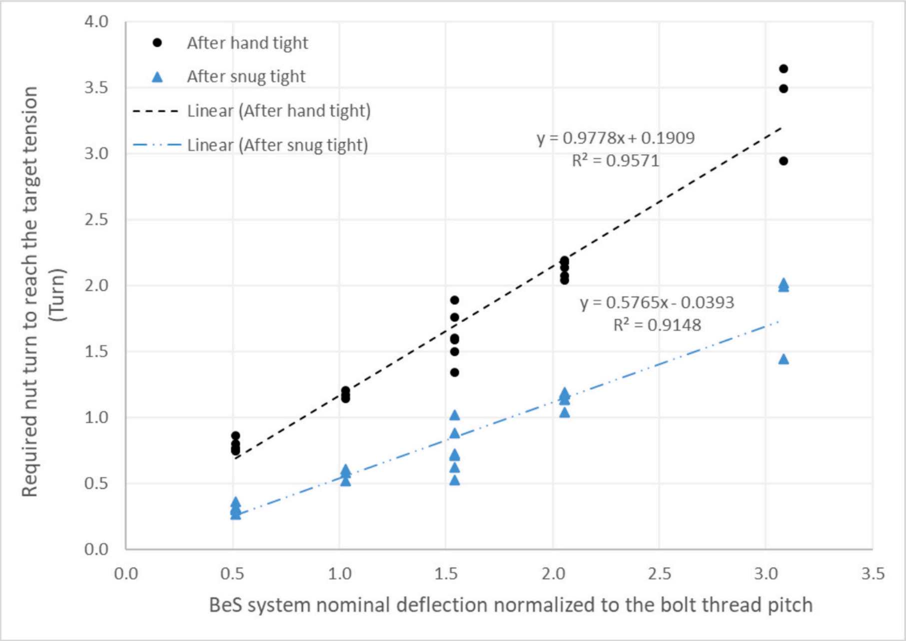

Fig. 20. The relationship between BeS system nominal deflection and Required nut turn to reach the target tension for the tests T3.

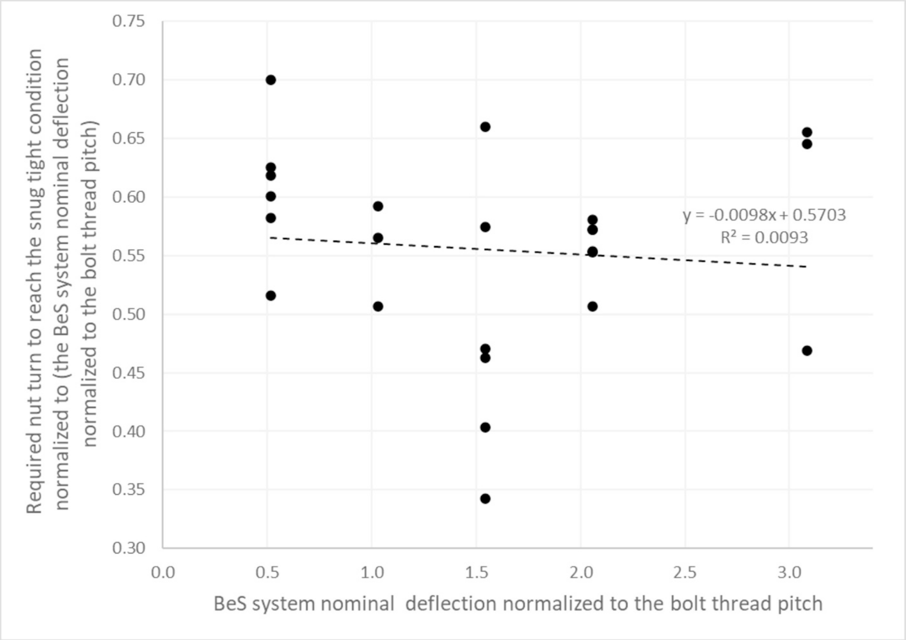

Fig. 21. The relationship between BeS system nominal deflection and Required nut turn to reach the snug tight condition for the tests T3.

The BeS system nominal deflection is calculated based on the nominal deflection associated with the target installed bolt tension. The general trend shows that 0.2 turn is required to be added to (0.92 × "BeS system nominal deflection + bolt elongation" normalized to the bolt thread pitch) to find the required post hand tight turn to reach the bolt to the target installed tension. The required post snug tight turn to reach the bolt to the target installed tension is (0.5× "BeS system nominal deflection + bolt elongation" normalized to the bolt thread pitch).

Figs. 34 and 35 are extracted from Figs. 32 and 33 respectively, for the configurations including one or two BeSs.

Figs. 36 and 37 are related to the data of the cases having two BeSs of the same type (type 1 or 2), one under the nut and one under the bolt head.

8. Conclusions and recommendations

1. It was not possible to propose a practical and reliable torque-based method of bolt tightening with BeS, at least for the HSFG bolt assemblies supplied in New Zealand, which are not specifically made for torque control tightening. The reason is variability of the required torque to reach a specific tension. The very low coefficient of determination (R^2) values of the associated graphs confirm this. This was observed in the experiments under the lab conditions on the bolts that had passed the "nut free turn" check, and with same method of bolt preparation and lubrication. In practice, the variability is expected to be much higher.

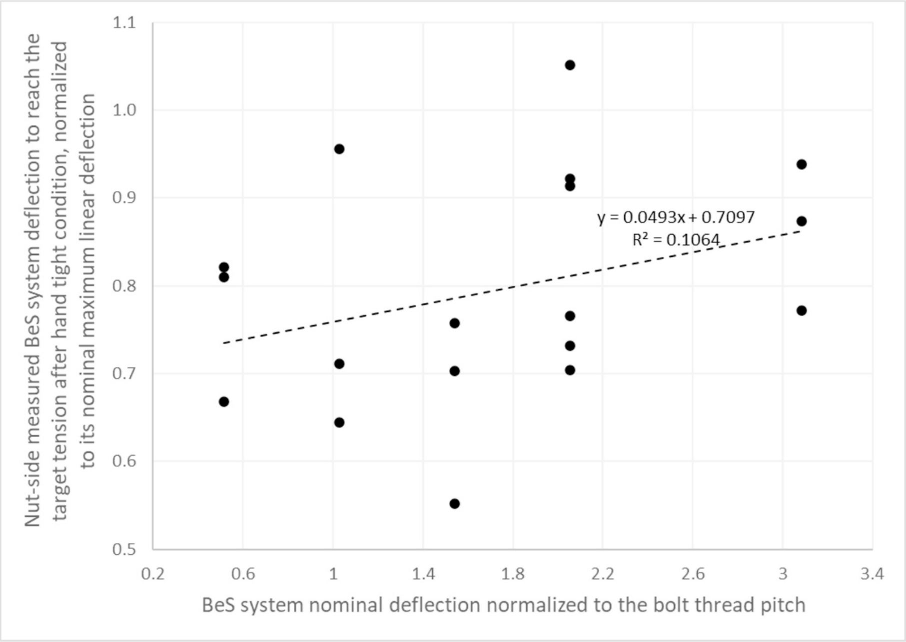

Fig. 22. The relationship between BeS system nominal deflection and nut-side BeS system deflection after hand tight condition for the tests T3.

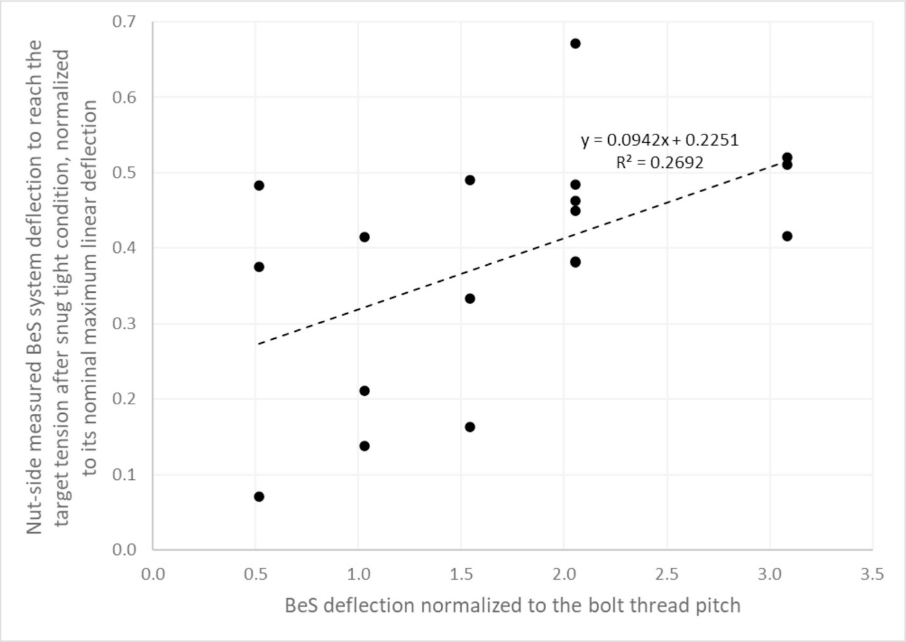

Fig. 23. The relationship between BeS system nominal deflection and nut-side BeS system deflection after snug tight condition for the tests T3.

2. It was not possible to propose a practical and reliable BeS deflection-based method for bolt tightening with BeS, as evidenced by the very low R^2 values of the associated graphs. This observation was consistent across experiments conducted under controlled lab conditions, even with the use of the most precise customized tools available. The reason is that the deflections are small and it is difficult to set a reliable and repeatable reference point to measure the BeS deflection. A further consultation with BeS manufacturers (e.g., Solon Manufacturing Co.) confirms that deflection measurements have been attempted for decades across various industries, with limited commercial success. While accurate measurement is theoretically feasible, it is considered impractical due to the high cost of specialized tools and fixturing. Hence, it is recommended not to use a BeS deflection-based method such as using a depth micrometre or a digital gauge, to install the bolts with BeS in practice, unless a robust working procedure is established to achieve this.
3. A nut rotation-based method proved to be a potentially reliable and consistent approach, demonstrating a strong tendency to follow a linear regression trend with high R^2 values. This method is not dependent on torque, which can be influenced by various factors such as surface conditions and coatings, and often requires specialized bolt assemblies. Additionally, it does not require direct measurement of the relatively small deflections in the BeS system. The main parameters to be correlated are the deflection of the BeS system and the pitch of the bolt. However, challenges to overcome include determining the amount of rotation, the starting point for applying

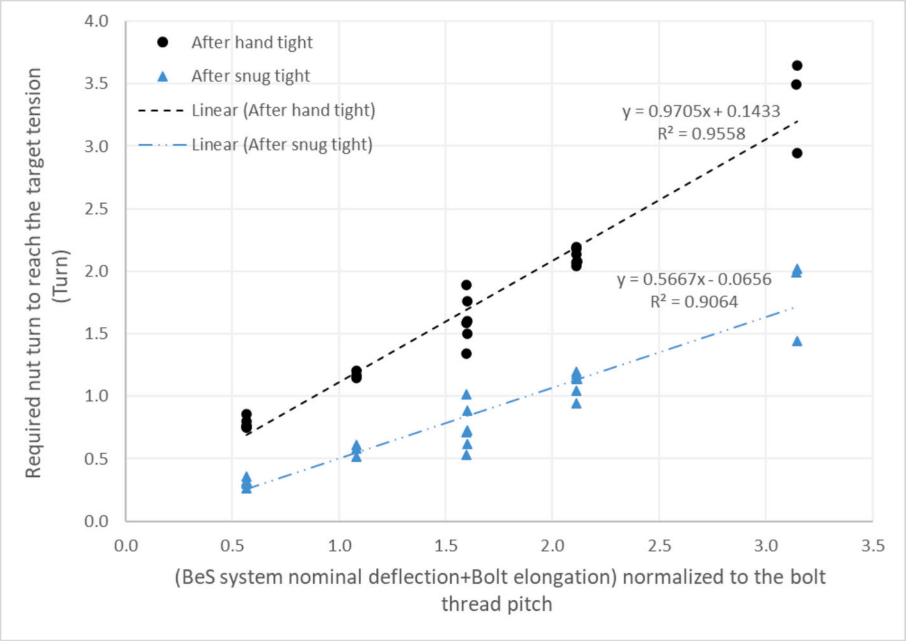

Fig. 24. The relationship between (BeS system nominal deflection + Bolt elongation) and required nut turn to reach the target tension for the tests T3.

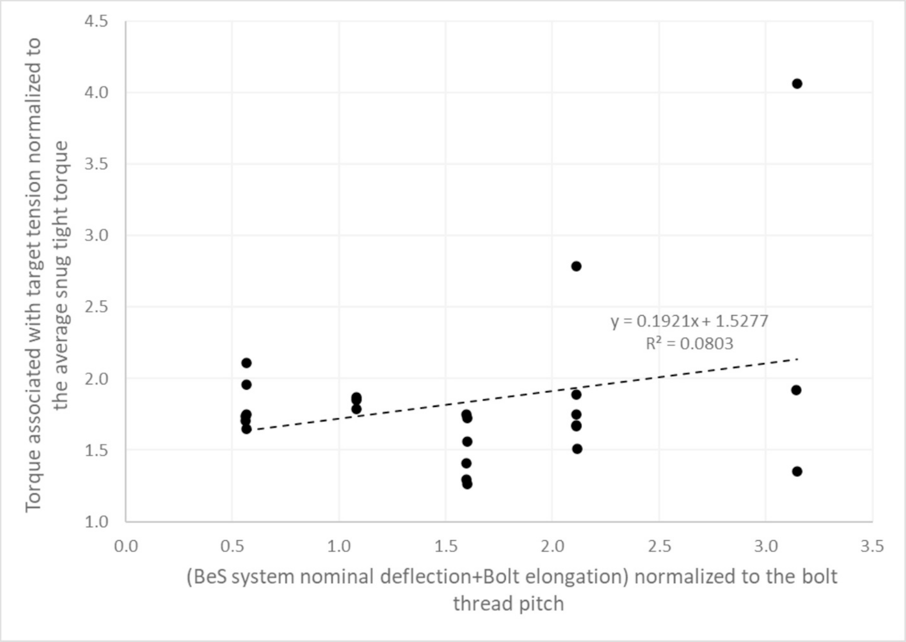

Fig. 25. The relationship between (BeS system nominal deflection + Bolt elongation) and Torque associated with target tension for the tests T3.

this rotation, and the correct order and procedure for tightening the bolts in a connection. The following nut rotation-based method is proposed for practical use in seismic friction-sliding structural connections:

i. Perform the “free turn of nut” check, explained in section 1.3.2.1, on each bolt/nut set and reject any that do not meet the criteria. Ensure that all bolt/nut sets are properly lubricated in accordance with code requirements, and apply lubrication if necessary. This step (i) ensures the bolt/nut sets are of sufficient quality to allow smooth nut rotation, effectively translating the applied torque and amount of turn into bolt tension without jamming.

ii. Snug-tighten the bolts according to the definition provided in NZS3404 [1] to achieve the tightness achieved by the full effort of a person using a standard podger spanner. For bolts with BeSs, this can be done by applying a rotation that may be approximately at least 50 % of the nominal calculated rotation required to compress the BeS system up to the target installed bolt tension. Hence it is advisable to inform the installer about the expected higher turn to reach the snug tight condition compared with the conventional practice. However, the snug tight definition is still valid and should be followed. In the case of small bolts, such as M12, where there is a risk of exceeding their elastic range during snug tightening, it is recommended to use a torque wrench and set a cut-off torque value on it. This value is recommended to

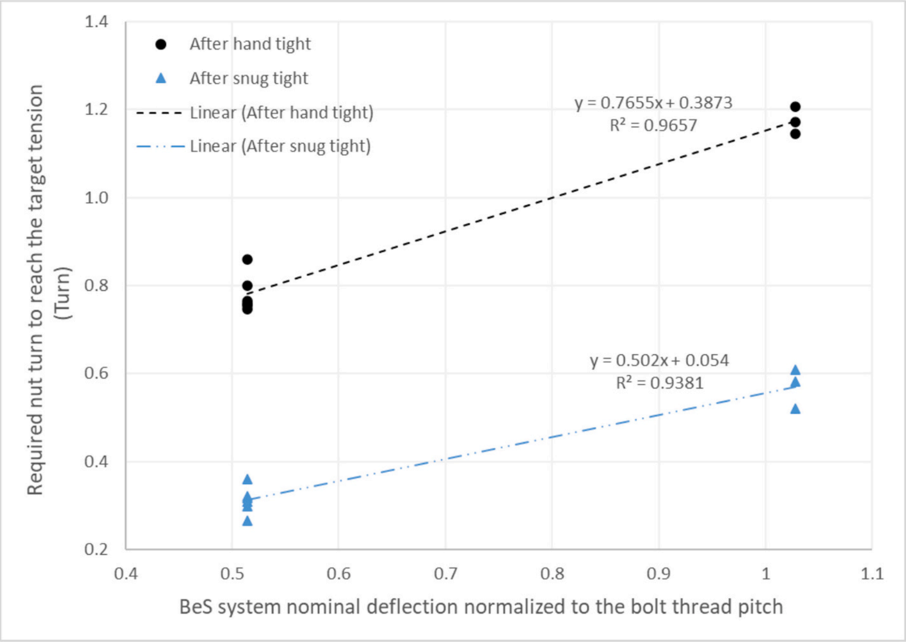

Fig. 26. The relationship between BeS system nominal deflection and Required nut turn to reach the target tension (Not more than 2 BeSs) for the tests T3.

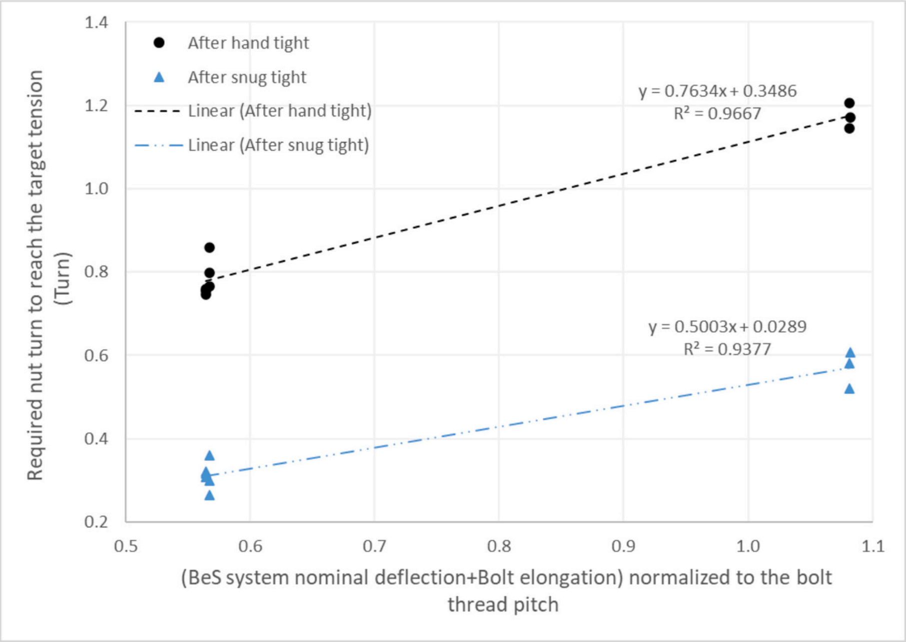

Fig. 27. The relationship between (BeS system nominal deflection + Bolt elongation) and Required nut turn to reach the target tension (Not more than 2 BeSs) for the tests T3.

correspond to approximately 70 % of the proof load tension of the bolt, according to the available charts provided by the supplier, serving as a safety measure to prevent overtightening at this stage. It is worth noting that multiple cycles of snug tightening may be required to ensure the snug-tight is achieved. This step (ii) ensures that all plies are brought into direct contact, with no gaps between them, and that the bolts remain within the elastic range.

iii. Then, one by one, loosen off the bolts, hand tighten each nut then turn to the specified amount of turn to achieve the target installed bolt tension. It is recommended to start with the bolts at the least stiff part of the connection, working back in towards the stiff part of the connection. The bolt head must remain fixed while the specified amount of nut rotation is applied. The required turn can be calculated as follows:

a) General case for all possible configuration of BeS:

$$0.25 + \left(0.93 \times \frac{\text{BeS system nominal deflection}^{*}}{\text{Bolt thread pitch}}\right)$$

This is based on $R^2 = 96$ % related to the whole data points. (Fig. 32)

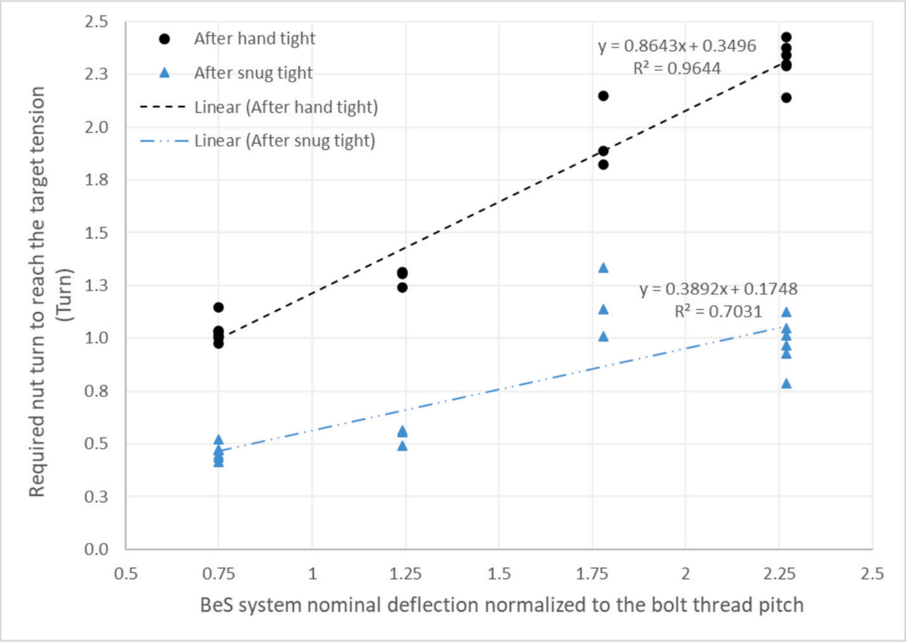

Fig. 28. The relationship between BeS nominal deflection and Required nut turn to reach the target tension for the tests T4.

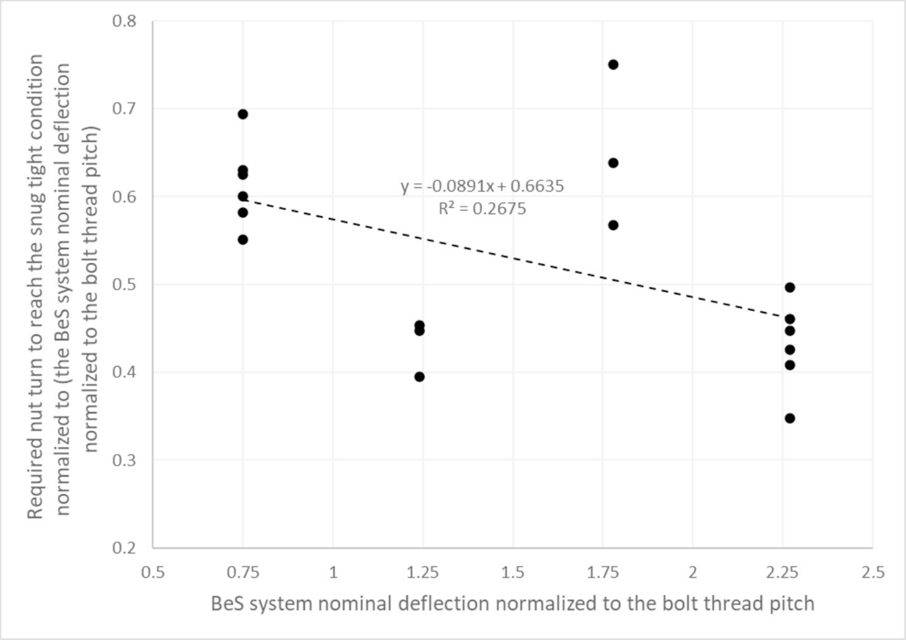

Fig. 29. The relationship between BeS system nominal deflection and Required nut turn to reach the snug tight condition for the tests T4.

b) Having two BeSs, one at each side, which is recommended for such connections [20,21]:

$$0.35 + \left(0.8 \times \frac{\text{BeS system nominal deflection}^{*}}{\text{Bolt thread pitch}}\right)$$

This is based on $R^2 = 98$ % related to the data points of the experiments with two BeSs, one at each side. (Fig. 36).

*BeS system nominal deflection for the case of having only one type of BeS = Number of BeSs used in the bolt assemblage × Nominal deflection of one BeS up to the target installed bolt tension. If there is more than one type of BeS in each bolt assembly, this parameter needs to be calculated accordingly.

The purpose of hand (finger)-tightening each nut in step iii, while the other bolts are in either a snug-tight or final target tension state, is: 1) to minimize the influence of the installer's physical strength on bolt preload (i.e., to eliminate the variations associated with snug-tight method, which were also observed in the experiments), and 2) to create conditions as close as possible to a bolt with minimal tension and plies with minimal gaps prior to applying the specified nut turn. It is also worth noting that including the bolt deformation's parameters (i.e., axial elongation during tightening) in the data analysis did not noticeably increase the accuracy of the predictive equations for determining the required turn of the nut to install the bolt with BeSs.

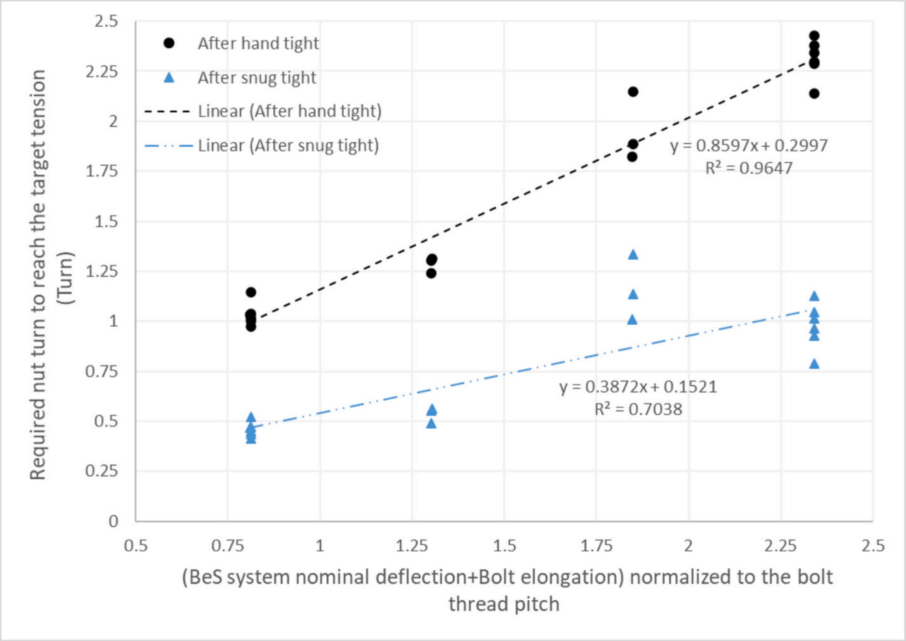

Fig. 30. The relationship between (BeS system nominal deflection + Bolt elongation) and Required nut turn to reach the target tension after snug turn for the tests T4.

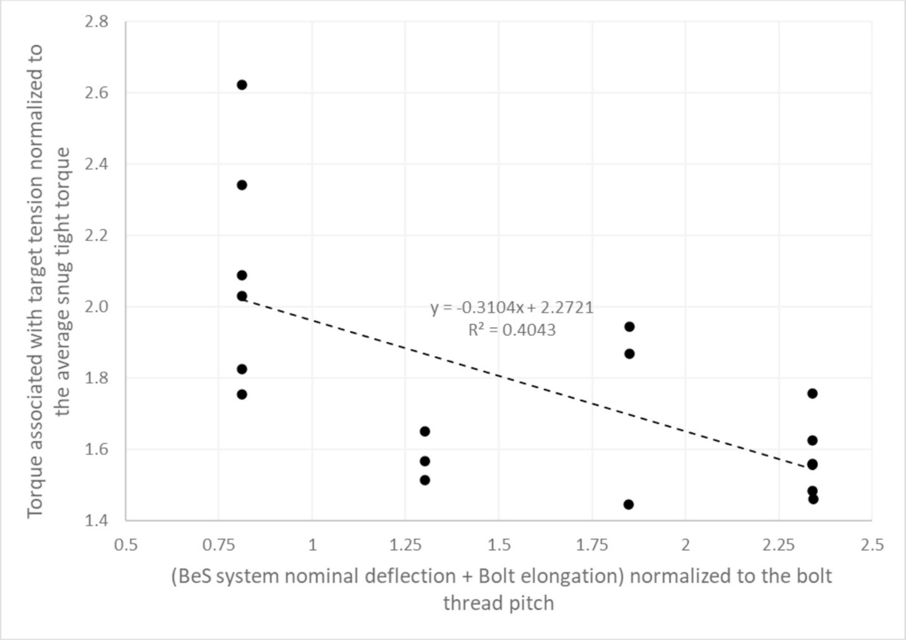

Fig. 31. The relationship between (BeS system nominal deflection + Bolt elongation) and Torque associated with target tension for the tests T4.

Following the proposed procedure, the achieved installed bolt tension is expected to be within around ±5 % of the target installed bolt tension. For example, based on the data from six experiments shown in Fig. 36, the maximum and minimum errors between the regression trend prediction and the actual data points are +7 % and − 6 %, respectively, for the case where the BeS system nominal deflection is 0.48 times the bolt pitch. In comparison, these errors reduce to +3 % and − 2 % when the BeS system deflection is 1.03 times the bolt pitch. The latter case aligns more closely with the BeS system deflection level recommended for seismic friction-sliding connections [20–22]. In the overall seismic-resisting system, as some bolts will be over and others under the target installed tension, the proposed approach is expected to be satisfactory for achieving the key targeted bolt tension required to partially deflect the BeSs as specified by the design and to maintain the bolts within the elastic range. It is worth noting that the design procedures for structural systems incorporating friction-sliding seismic-resisting connections should account for both strength reduction and overstrength factors to address variations and uncertainties in design parameters, such as clamping force (which may be affected by short-term and long-term bolt tension loss) and the coefficient of friction of the sliding surfaces. The smaller these variations and uncertainties, the more reliable and predictable the system behaviour becomes, and the closer these two factors may be.

It is important to note that the accuracy and precision of the

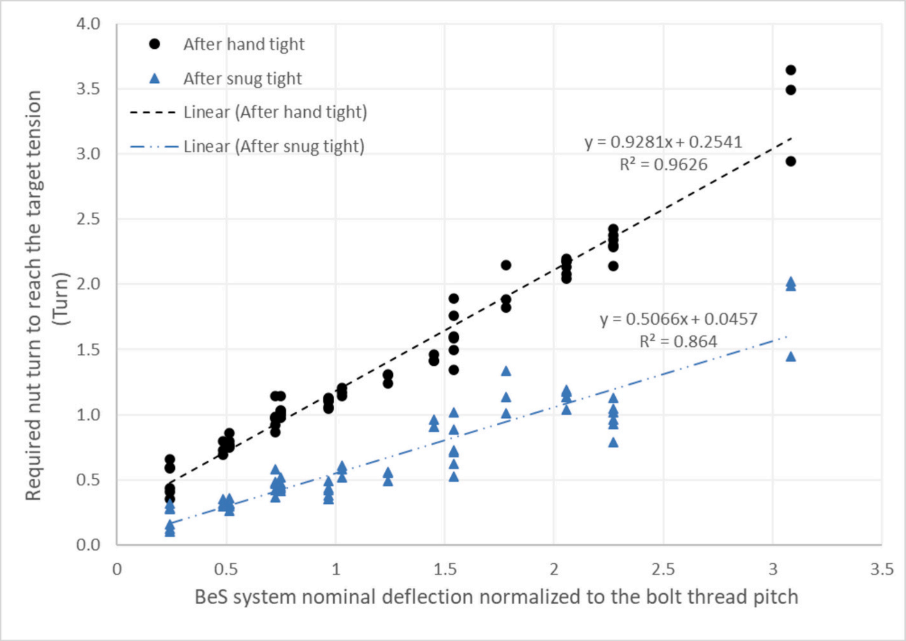

Fig. 32. The relationship between BeS system nominal deflection and Required nut turn to reach the target tension (All BeS types and configurations).

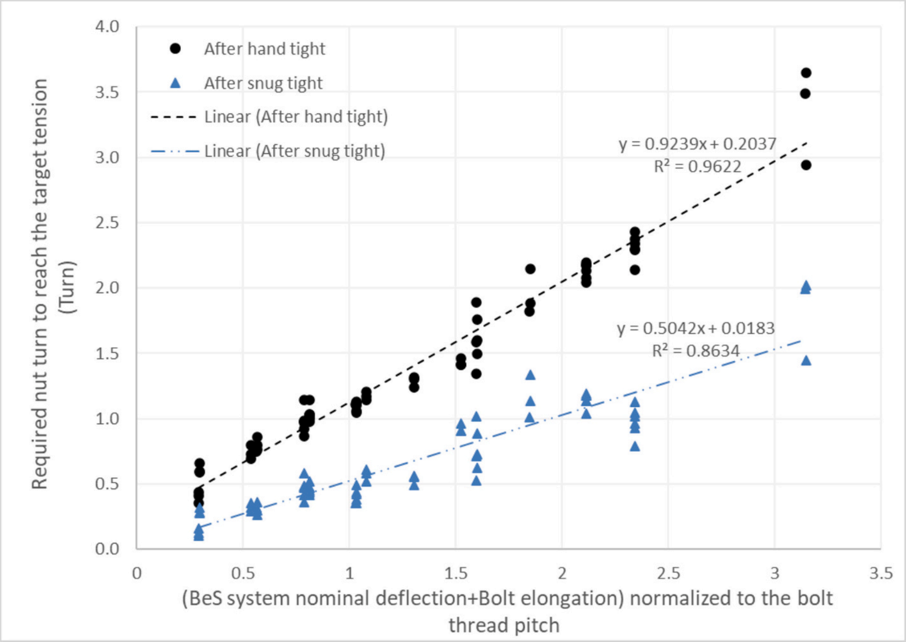

Fig. 33. The relationship between (BeS system nominal deflection + Bolt elongation) and Required nut turn to reach the target tension (All BeS types and configurations).

proposed method depend on several factors, including the accuracy, precision, and consistency of the BeS load-deflection data provided by the supplier, the accuracy, precision, and consistency of the bolt pitch, and the tolerances in the construction-specifically how closely the actual friction-sliding connection in practice matches the test setup used in this research. For instance, excessive tolerances and gaps between the connecting members may impact the accuracy of the tightening method by introducing prying force(s) and reducing the faying force(s) generated by the bolts. To ensure the reliability of the proposed method, the friction-sliding connection within the seismic resisting system should, in practice, consist of plies that are effectively in contact with minimal gaps between them. It is recommended that for specialized or unusual connection details (e.g. bolts and/or plies with unusually high or low axial stiffness or unusual stiffness ratios) and/or systems with excessive tolerances, a calibration exercise be performed on the proposed method before applying it to the entire structure. Such an exercise may involve installing donut load cells on a typical connection within the structure, or replicating the connection with adequate boundary conditions in a laboratory, and performing the tightening procedure while recording the resulting preloads. If necessary, the required nut rotation can then be adjusted to achieve the desired target installed tension.

It is also recommended that the nominal deflection values for BeS used in the calculations be taken from the manufacturer's specifications for each particular BeS. In practice, field personnel may measure a

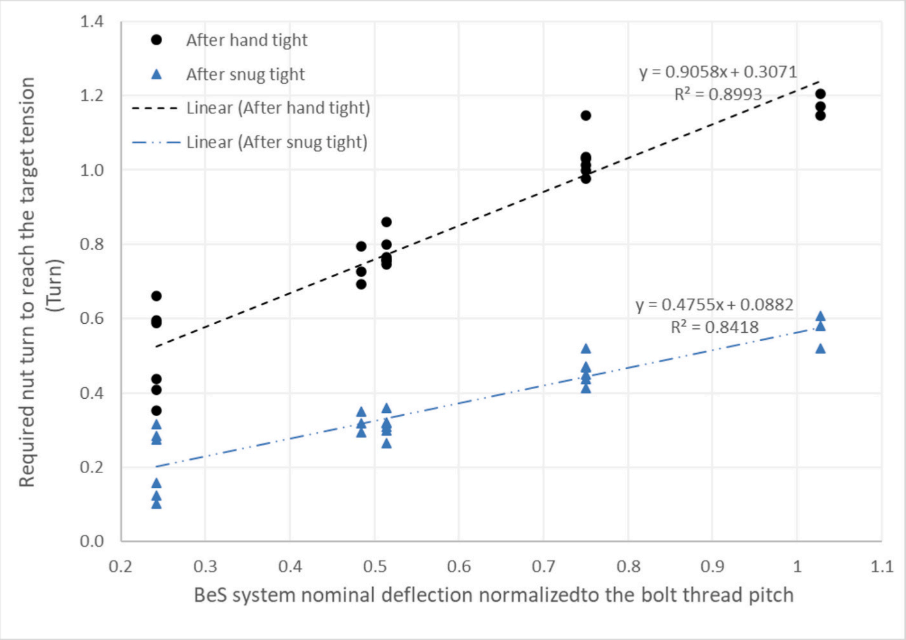

Fig. 34. The relationship between BeS system nominal deflection and Required nut turn to reach the target tension, for the cases of all BeS types and configurations (Not more than 2BeSs).

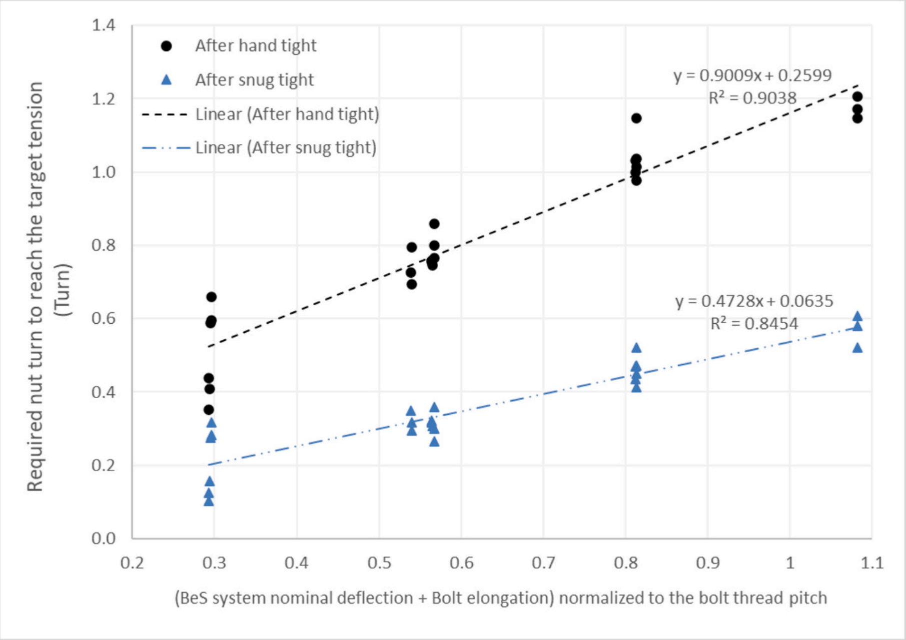

Fig. 35. The relationship between (BeS system nominal deflection + Bolt elongation) and Required nut turn to reach the target tension, for the cases of all BeS types and configurations (Not more than 2 BeSs).

higher deflection (and corresponding load) than the nominal value, which could affect the accuracy of the achieved preload. By using the nominal value from the specifications, the risk of such inaccuracy is minimized. Load-versus-deflection requirements for spring supply necessitate that the BeS supplier provide this data for each manufacturing batch. According to standards established by the Deutsches Institut für Normung (DIN), European Standard (EN), and International Organization for Standardization (ISO), the general allowable tolerance for load at a given deflection in this type of design is typically expected to be around +10 % / -5 % [30–33]. Results for any given batch are expected to fall within this range. Accordingly, the accuracy of the proposed method is proportional to this tolerance.

CRediT authorship contribution statement

Shahab Ramhormozian: Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **G. Charles Clifton:** Writing – review & editing, Validation, Supervision, Project administration, Funding acquisition. **George P. Davet:** Writing – review & editing, Methodology.

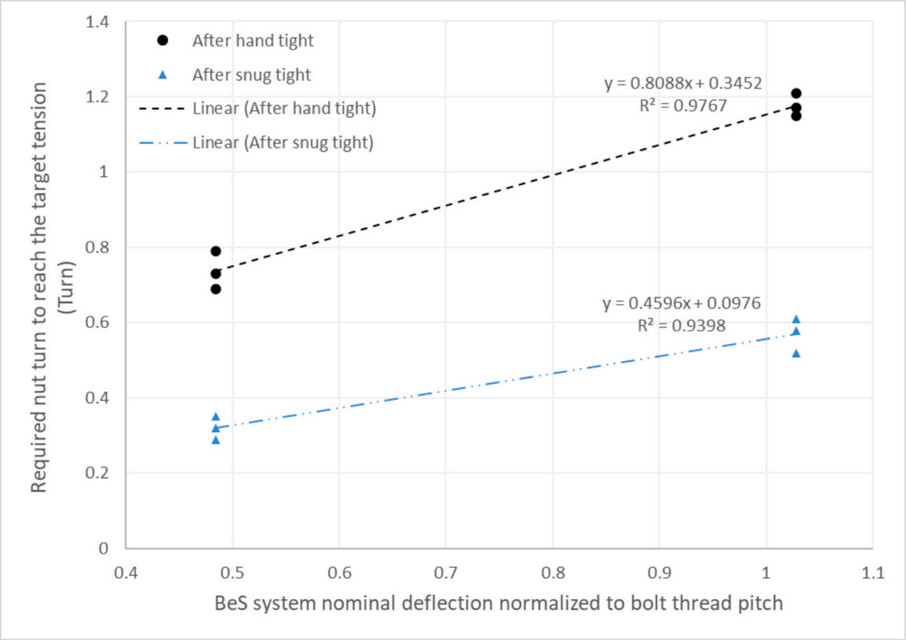

Fig. 36. The relationship between BeS system nominal deflection and Required nut turn, for the cases having two BeSs of the same type, one under the nut and one under the bolt head.

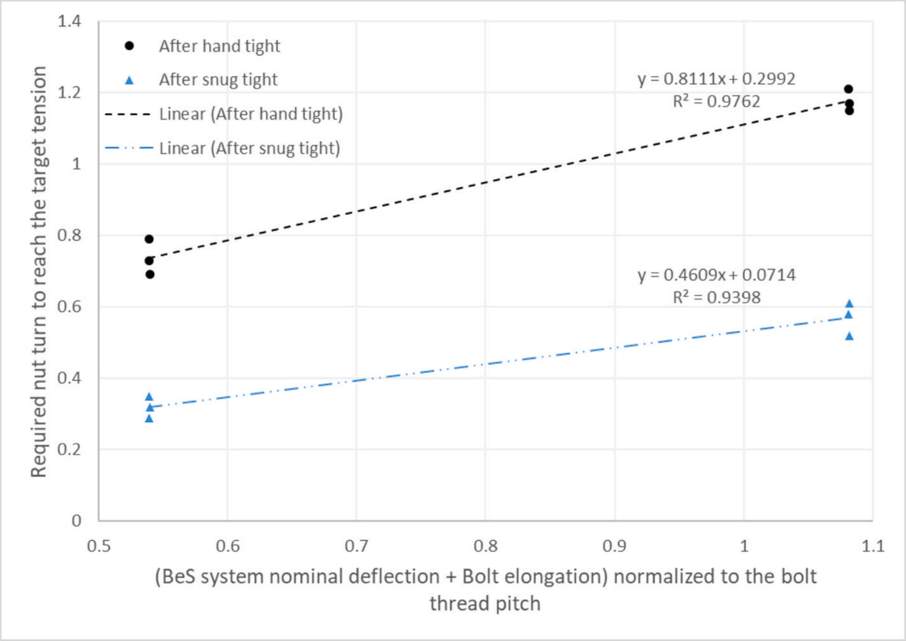

Fig. 37. The relationship between (BeS system nominal deflection + Bolt elongation) and Required nut turn, for the cases having two BeSs of the same type, one under the nut and one under the bolt head

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The support from New Zealand Ministry of Business, Innovation and Employment (MBIE) through an Endeavour Fund for the Research Programme (Sustainable Earthquake Resilient Buildings for a Better Future - PROP-83779-ENDRP-AUT) is greatly appreciated. The support from the New Zealand Natural Hazards Commission Toka Tū Ake (formerly known as the Earthquake Commission (EQC)) is appreciated. The assistance provided by the Postgraduate Student, Mr. Hai (Henry) Nguyen, in all stages of the experimental tests, data collection, and data analysis is sincerely appreciated. The assistance of the technical team at the laboratory is also acknowledged and greatly appreciated. A number of this paper’s figures are drawn by Dr. Zhenduo Yan. This help is appreciated.

Data availability

Data will be made available on request.

References

[1] NZS3404, Steel Structures Standard, Incorporating Amendments 1 and 2. 1997/2001/2007, Standards New Zealand, Wellington [N.Z.], 2007.
[2] BS EN 1092-2, Execution of Steel Structures and Aluminium Structures. Technical Requirements for Steel Structures, British Standards Institution and European Standardization Organisations, 2011.
[3] JIS B 1083, General Rules for Tightenning of Threaded Fasteners, Japanese Industrial Standard (JIS), 2008.
[4] AS/NZS1252, High-strength Steel Bolts with Associated Nuts and Washers for Structural Engineering, in Australia/New Zealand Standard, 1996.
[5] A.S. Pall, Limited Slip Bolted Joints - A Device to Control the Seismic Response of Large Panel Structures, in Centre for Building Studies, Concordia University, Montreal, Quebec, Canada, 1979.
[6] A.S. Pall, C. Marsh, Response of friction damped braced frames, J. Struct. Eng. 108 (9) (1982) 1313–1323.
[7] A. Filiatrault, S. Cherry, Performance evaluation of friction damped braced steel frames under simulated earthquake loads, Earthquake Spectra 3 (1) (1987) 57–78.
[8] T.F. FitzGerald, et al., Slotted bolted connections in aseismic design for concentrically braced connections, Earthquake Spectra 5 (2) (1989) 383–391.
[9] R. Tremblay, Seismic Behavior and Design of Friction Concentrically Braced Frames for Steel Buildings, The University of British Columbia, 1993.
[10] C.E. Grigorian, E.P. Popov, Energy Dissipation with Slotted Bolted Connections, Earthquake Engineering Research Centre, Berkeley, California, 1994.
[11] S. Jaisee, F. Yue, Y.H. Ooi, A state-of-the-art review on passive friction dampers and their applications, Eng. Struct. 235 (2021) 112022.
[12] J. Butterworth, C. Clifton, Performance of hierarchical friction dissipating joints in moment resisting steel frames, in: 12th World Conference on Earthquake Engineering (WCEE), 2000. Auckland, New Zealand.
[13] J. Butterworth, Seismic response of moment-resisting steel frames containing dual-level friction dissipating joints, in: NZ Society for Earthquake Engineering, 1999.
[14] J. Butterworth, Seismic damage limitation in steel frames using friction energy dissipators, in: 6th International Conference on Steel and Space Structures, 1999. Singapore.
[15] T.-S. Yang, E.P. Popov, Experimental and Analytical Studies of Steel Connections and Energy Dissipators, Earthquake Engineering Research Center, Berkeley, University of California, 1995.
[16] G.C. Clifton, Semi-rigid joints for moment-resisting steel framed seismic-resisting systems, in: Department of Civil and Environmental Engineering, University of Auckland, Auckland, New Zealand, 2005.
[17] M. Latour, V. Piluso, G. Rizzano, Free from damage beam-to-column joints: testing and design of DST connections with friction pads, Eng. Struct. 85 (2015) 219–233.
[18] H.H. Khoo, Development of the low damage self-centering Sliding Hinge Joint, in: Department of Civil and Environmental Engineering, University of Auckland, Auckland, New Zealand, 2013.
[19] G. Ferrante Cavallaro, et al., Experimental behaviour of innovative thermal spray coating materials for FREEDAM joints, Compos. Part B Eng. 115 (2017) 289–299.
[20] S. Ramhormozian, et al., Stiffness-based approach for Belleville springs use in friction sliding structural connections, J. Constr. Steel Res. 138 (Supplement C) (2017) 340–356.
[21] S. Ramhormozian, et al., Experimental studies on Belleville springs use in the sliding hinge joint connection, J. Constr. Steel Res. 159 (2019) 81–94.
[22] S. Ramhormozian, G.C. Clifton, Optimised Sliding Hinge Joint (OSHJ): Design and Installation Guide for a Low Damage Seismic Resisting System - R4-155, Heavy Engineering Research Association (HERA), Auckland, New Zealand, 2020.
[23] Ramhormozian Shahab, et al., The Optimised Sliding Hinge Joint (OSHJ): design, detail, and implementation in practice, in: 2021 New Zealand Society for Earthquake Engineering (NZSEE) Annual Technical Conference, 2021. Christchurch, New Zealand.
[24] M. D'Antimo, et al., Short- and long- term loss of preloading in slotted bolted connections, J. Constr. Steel Res. 167 (2020) 105956.
[25] S. Ramhormozian, et al., The high strength friction grip property class 8.8 bolts: variability of installed tension and potential resulting effects on the friction-type connections' behaviour, in: New Zealand Society for Earthquake Engineering (NZSEE) Annual Technical Conference, New Dimensions in Earthquake Resilience, 2015. Rotorua, New Zealand.
[26] S. Ramhormozian, et al., Determination of the required part-turn of the nut with respect to the number of free threads uunder the loaded face of the nut in fully tensioned high strength friction grip property Class 8.8 bolts, in: Steel Innovations, 2015. Auckland, New Zealand.
[27] S. Ramhormozian, G. Clifton, K. Cowie, Proposed changes on NZS 3404 specified part-turn method of tensioning High Strength Friction Grip (HSFG) Property Class 8.8 bolts, in: New Zealand Society for Earthquake Engineering (NZSEE) Annual Technical Conference, Reducing Risk Raising Resilience, 2016. Christchurch, New Zealand.
[28] AS/NZS 1252.2, High-Strength Steel Fastener Assemblies for Structural Engineering - Bolts, Nuts and Washers - Part 2: Verification Testing for Bolt Assemblies, AS/NZS, 2016.
[29] G. Ferrante Cavallaro, et al., Standardised friction damper bolt assemblies time-related relaxation and installed tension variability, J. Constr. Steel Res. 141 (2018) 145–155.
[30] DIN 2093:1992-01, Disc Springs; Dimensions and Quality Specifications, Deutsches Institut für Normung (DIN), 1992.
[31] DIN 2092:2006-03, Disc Springs - Calculation, Deutsches Institut für Normung (DIN), 2006.
[32] DIN EN 16983:2017-09, Disc Springs - Quality Specifications - Dimensions, Deutsches Institut für Normung (DIN) and European Standard (EN), 2017.
[33] ISO 19690-2:2018, Disc Springs; Part 2: Technical Specifications, International Organization for Standardization (ISO), 2018.