Bolts and Set Screws – **Are they interchangeable?**

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Introduction:

This technical note discusses the definitions, standards and variations pertaining to bolts and screws. Also this highlights the applications where bolts and screws could be used after due consideration given on their suitability with respect to each application.

At conclusion, this technical note provides the key criteria for determining the suitability of product based on the application in tabulated form.

Definition of Bolt and Screw (+ Stud):

The words Bolt, Screw and Stud are used commonly in bolting technology. Therefore it is necessary to have a clear understanding of the differences in geometries of these three components. *Figure 1* shows a schematic of the bolt screw and stud.

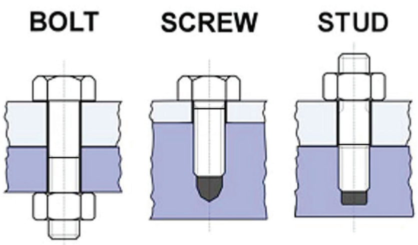

Figure 1: Schematic of Bolt, Screw and a Stud.

Bolt: Has a Head, longer unthreaded Shank Portion, Thread and a Drive Feature. Bolt is generally tightened with a nut or a threaded-through hole or a blind hole.

Screw: Similar to a bolt but has a much longer thread almost to the head. It can be tightened with a nut or a threaded-through hole or a blind hole. In some instances, a screw could cut or form its own thread (eg. timber screws, thread forming screws).

Stud: A stud does not have a Head. It may have a drive feature. It could be threaded at one end, at either end or all the way. It can be used with one or two nuts, as a Screw or as a Bolt.

Relevant Standards and basic characteristics

Bolts:

The general dimensions of bolts are given in standards such as AS1110.1/ISO4014 (Product grade A, B), AS1111.1/ISO4016 (Product grade C), AS/NZS1252.1 (high strength structural bolts), EN14399-3-HR (High strength bolt assemblies for pre-loading, System HR), EN15048.1 (Structural bolt assemblies for non pre-loading applications), ISO4015 (Product grade B, Reduced Shank), ISO8765 (Metric fine thread, Product Grade A, B), ISO 15071 (Hexagon Bolts with Flange, Small Series, Product grade A), DIN6921 Hex Flange bolts and Cap Screws (withdrawn), EN1665 8.8 Hexagon Bolts With Flange - Heavy Series (Replacement), etc.

Thread length is the basic characteristic that defines a bolt from a screw.

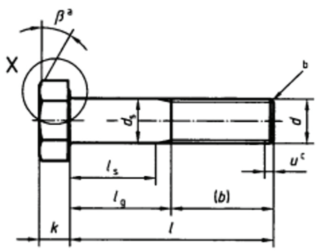

Image from AS1110.1

In above standards, the thread length of a bolt (b) is generally determined by the following formula;

When the bolt length (l) is up to and including 125mm
Thread length $b = 2D + 6$mm,

When the bolt length (l) is over 125mm and up to and including 200mm
Thread length $b = 2D + 12$mm,

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When the bolt length (l) is over 200mm

Thread length $b = 2D + 25$mm,

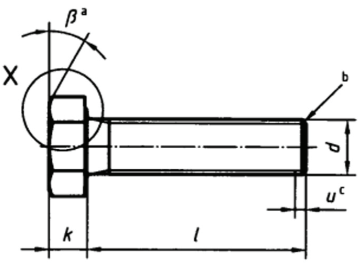
where D is the nominal diameter of the bolt.

Unthreaded shank portion (l_s) = Bolt length (l) - thread length (b)

Screws:

The general dimensions of screws that are used with nuts or in pre-threaded holes are given in standards such as AS1110.2/ISO4017 (Product grade A, B), AS1111.2/ISO4018 (Product grade C), ISO8676 (Metric fine thread, Product Grade A, B), etc.

Here the allowable shank length (unthreaded portion, a) is given as 1p (min) to 3p (max), where p is the thread pitch. The corresponding minimum thread length (b) = bolt length (l) - 3p.



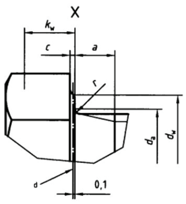


Image from AS1110.2

From this comparison it is now clear that a bolt would have a shorter thread length than a screw. In general, bolt would have an unthreaded shank portion while the unthreaded shank portion of a screw is almost non existing.

Applications and Limitations when using Bolts or Screws

Shear joints (S/TB):

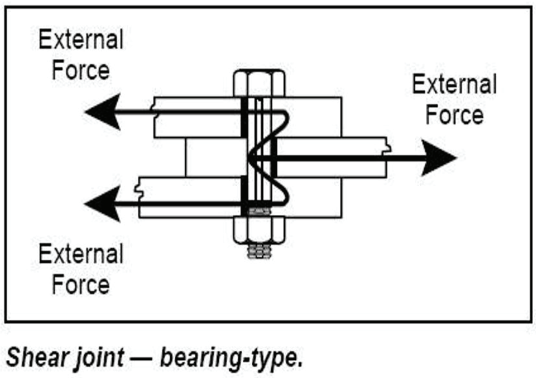


Figure 2: Load Transfer in Shear (S)-snug tight or (TB)-Tension Bearing Joint

The interface surfaces between plates are called the shear planes.

As shown in *Figure 2*, in shear joints, predominant load transfer is perpendicular to the bolt middle plate to two end plates via the bolt. In the above joint there are two shear planes. If only two plates were there, there would have been only one shear plane.

For most materials, Shear Capacity (the amount of force it can resist in shear) is proportional to the Shear Area. In a bolt, the shank section has a larger shear Area, A_s, than the threaded section core Area, A_c. Hence the **bolt shank has a larger shear capacity**.

The shear area across the shank of the bolt (A_s) and the shear area across the thread of the bolt (A_s) are given by the formula;

$$A_s = \frac{\pi D^2}{4}$$

$$A_c = \frac{\pi}{4}(D - 1.22687p)^2 \quad \text{ISO Metric - thread}$$

where p is the pitch of the thread and D is the nominal diameter of the bolt. As can be seen in the above formula, A_s is always greater than A_c. Hence when the bolted joint is designed as a shear joint, it is always better to have the **shank across the shear planes**. This way, maximum shear capacity for the joint could be realised.

The above discussion highlights the fact that for a shear joint, bolts are preferred. **Screws cannot replace these bolts, as with screws shear planes will almost always pass through the threaded area, thus reducing the shear capacity of the joint.**

Even with bolts, as they have a thread length in excess of twice the nominal diameter, in many cases it is not possible to avoid a shear plane crossing the thread area. In such situations, the shear capacity of those shear planes crossing the threaded area shall be calculated using A_c instead of A_s.

This simple reduction in shear capacity for the core area A_c is only applicable to bolts/screws of property class PC8.8 or less as all of them be ductile and no reason to have increased stress concentrations (ductile material would locally yield to prevent stress concentration).

However, if the threaded area of a PC10.9 or higher bolt/screw crosses the shear plane, there should be an additional reduction in shear capacity due to stress concentration associated with brittleness of such bolts. Hence, it is not possible to achieve the full benefit of PC10.9 when HR bolts are used in shear, as some of the threaded area most likely will cross a shear plane. This situation is further discussed in a latter section of this report.

Tensile Joints:

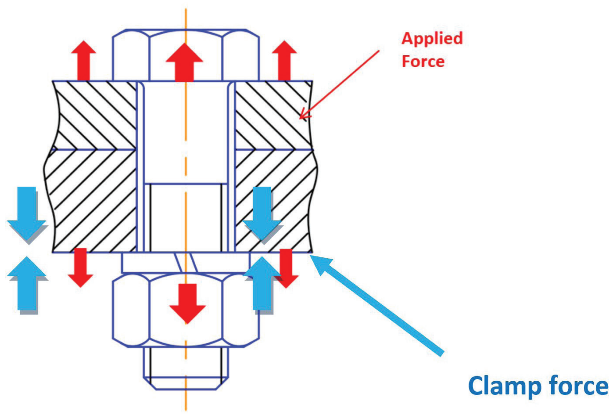


Figure 3: Load Transfer in a Pre-tensioned Tension Joint

Figure 3 shows a typical tensile joint. In this type of joint, the predominant load transfer is in the direction of the bolt axis. The bolt is pre-tensioned so that a clamp force is imparted between the two joining members. This clamp force has to be sufficiently large to prevent the joint from separating under applied loads. Generally, applied tensile loads are limited to less than 50% of the applied clamp force. This ensures joint separation would not occur under normal loading conditions.

In this case, the predominant force applied on the bolt is a tensile force (pre-tension force = clamp force). Applied tension force on the joint is going to partially relax the clamp force while slightly increasing the bolt force. In a properly designed joint, the increase in the bolt force is far less than the relaxation of clamp force. This ratio is dependent on the stiffness ratio between the bolt and the joint. Slender, less-stiff bolts (thin, long) with stiff joints (thick plates) provide the best performance.

The tensile load capacity of a bolt is determined by the stress area of the thread (A_t). The following formula provides the stress area for a metric bolt with nominal diameter D and pitch p;

$$A_t = \frac{\pi}{4}(D - 0.938194\, p)^2 \text{ - ISO Metric - thread}$$

When compared to the formula for A_c presented earlier, this shows that A_t is always greater than A_c.

A_t will be the same for a bolt or a screw as it is dominated by the thread instead of the shank. **Therefore, for a tensile joint, a screw can always replace a bolt.** However, replacing a screw with a bolt may not be advisable unless the joint is closely analysed by a qualified engineer. When the screw is used fulfil an additional ductility requirement of the joint, replacing a screw with a bolt would be detrimental as the stiffness of a bolt is always greater than that of a screw.

Combined Tension/shear joint:

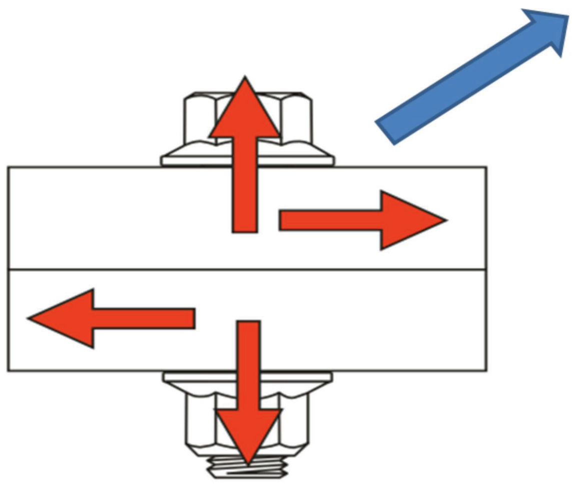
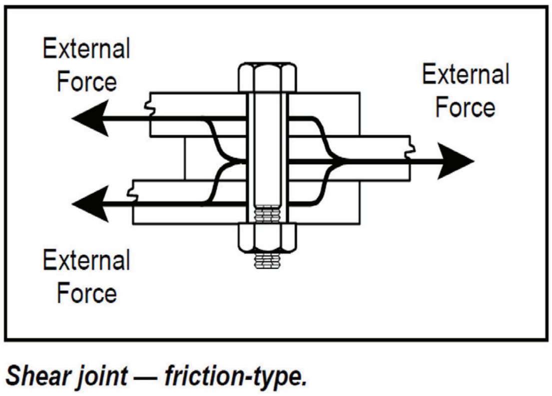


Figure 4: Combined Tension Shear Joint

In this type of joint, both tensile and shear forces acting on the joint are of the same order of magnitude (*Figure 4*). Such joints shall be designed as combined tension/shear joints. For these joints more shear planes crossing the shank area are beneficial. Therefore, similar to shear (S) or tension bearing (TB) joints, bolts are preferred. Replacing a bolt with a screw is not advisable for such joints unless recommended after analysis by a qualified engineer. For the design of these joints, the combined tension/shear formula as given in AS4100 should be used.

Friction Grip Joints (TF):

In friction grip joints, the predominant load transfer is a shear force in the direction perpendicular to the bolt axis similar to S/TB type joints discussed previously. However, the load transfer mechanism is different. *Figure 5* shows the load transfer of a Friction Grip (TF) joint.



Shear joint — friction-type.

Figure 5: Load Transfer in Friction Grip (TF) Joint

In this case, the bolt provides a large clamp force on the joining plates. The friction coefficient of the mating surfaces generates a friction force greater than or equal to the applied shear force. Hence, the load is transferred from one plate to the other plates via friction and not via the bolt. As in a tensile joint, the bolt only senses tensile loads when the applied force is less than the friction force. Based on this argument, it is possible to replace a bolt with a screw if the joint is always friction dominated (ie No Slip occurs).

However, this is not the case in many situations. While friction grip design considers serviceability design, in their ultimate capacity they behave as shear (S) or tension bearing (TB) type joints (once the load exceeds the limiting load). Therefore, these bolts shall not be replaced with screws.

Explanation on Ductility Requirements

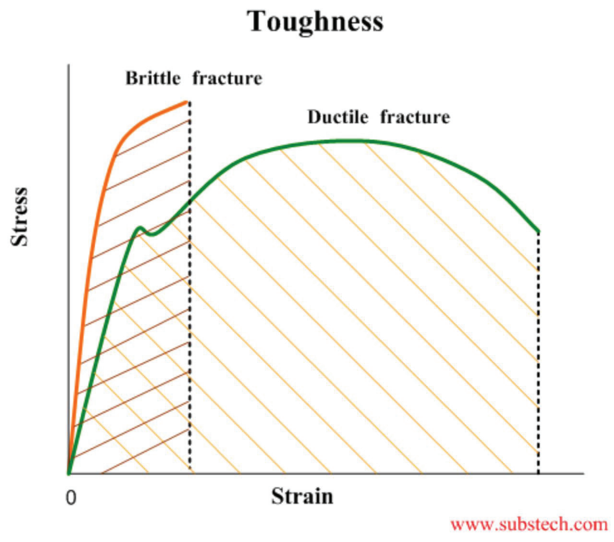


Figure 6: Stress Strain behaviour of Brittle and Ductile bolts

Figure 6 shows the typical stress strain curves for Brittle and Ductile bolts. Typically strength of property class PC10.9, PC12.9, PC15.9, etc. are considered brittle. Bolts of strength class PC8.8 or less are considered ductile.

Ductility is quantified by the length of the stress strain curve between the yield point and the ultimate failure point. A longer separation denotes a ductile bolt while a shorter separation denotes a brittle bolt, as shown in the above figure. In other words, ductility is a measure of elongation prior to ultimate failure or the amount of notice given prior to the final failure.

In general, in structures, ductile failure is far more preferred to brittle failure as brittle failure is typically sudden.

EN14399-3 HR/ EN14399-4 (HV) PC10.9 bolts for pre-loading applications

A special situation occurs when PC10.9 bolts are used for pre-tensioned shear applications (TF). As discussed, the EN14399-3 HR PC10.9 bolt also has a thread length in excess of twice the bolt nominal diameter, depending on the length of the bolt. As such, it is always possible that at least one shear plane will pass through the threaded area where the shear capacity has to be significantly reduced not only due to reduced cross section but also for increased brittleness.

Furthermore, these HR bolts should be used in a way that approximately two threads are protruding outside the nut. If longer thread length is outside the nut, desired ductility of the joint may not be achieved as the deformation of the remaining thread portion provides the necessary ductility in this arrangement.

Brittle bolts will act similar to glass and any notch will cause it to fail prematurely. This is due to the introduced stress concentration (increased local stress level at the notch) due to its brittleness. In fact, bolt threads are essentially notches. Hence, when the shear plane crosses the threaded area, the notch formed by a thread introduces a larger stress concentration at the thread root. When this effect is taken into consideration the additional reduction in shear capacity due to concentrated stress takes away the advantage gained by using a PC 10.9 HR bolt in shear arrangement.

To overcome this issue, a new family of PC10.9 bolts with reduced thread length is introduced in EN14399-4 HV PC10.9 category. These bolts have a thread length well less than 2D. Hence, it is possible to use these bolts in shear/tension applications (TF/Combined) in such a way that the shear plane does not cross the thread area. This way, greater shear and tensile capacities could be achieved by using PC10.9 HV bolts.

As this family of bolts (HV) does not have excess thread length, these bolts do not achieve ductility from thread as with PC 10.9 HR bolts. With HV bolts, ductility is achieved by letting the threads strip inside the nut. Through this technique HV bolts also achieves the same ductility as HR bolts in the ultimate condition, although if the joint is overloaded, thread stripping failure would occur instead of fracture of unused threaded portion as found with AS1252.1 bolts or EN14399-3 HR bolts.

Potential for fatigue failure under dynamic loading:

Up to now the entire discussion was mainly focussed on the bolts and screws that are used in structural steel applications. These are generally designed with the guidelines from AS4100 or AS3990.

There are certain other applications mostly in vehicle engineering that the bolts and screw are subject to vibration and other significant dynamic loads (eg: Truck/car chassis, railway carriages, locomotives, trucks etc). In most of these designs the predominant failure mode would be fatigue.

In fatigue, the load experienced by the bolt is dependent on the stiffness ratio between the bolt and the joint. Significantly ductile or slender fastener is always preferred in such applications. As discussed earlier, a screw would always have **more thread** length compared to a similar length bolt. As such, a screw is **more ductile** compared to a bolt.

Therefore for the joints which are fatigue critical (subject to dynamic loads) screws are preferred to bolts. In such joints, replacement of a screw with a bolt may be detrimental and should be done after consultation with a qualified machine design engineer.

A summary of critical parameters associated with bolts and screws

Table 1 summarises what is discussed and presented in this document. Summary of critical parameters associated with bolts and screws.

Parameter	Bolt	Screw
Shank length (l_s)	$= l - (2D + 6)$ when $l \leq 125mm$ $= l - (2D + 12)$ when $125 < l \leq 200mm$ $= l - (2D + 25)$ when $l > 200mm$	$l_s \leq 3p$ $l_s > p$
Thread length (b)	$= (2D + 6)$ when $l \leq 125mm$ $= (2D + 12)$ when $125 < l \leq 200mm$ $= (2D + 25)$ when $l > 200mm$	$l - 3p \leq b < l - p$
Shear Joints (S/TB)	Bolt is preferred.	Screw Not suitable
Friction Grip Joints (TF)	Bolt is preferred.	Screw Not suitable
Tensile joints	Bolt could be replaced with a screw.	Screw is preferred. Screw may be replaced with a bolt but advice from an engineer should be sought.
Combined Tension/Shear joint	Bolt is preferred.	Screw Not suitable
Tensile Joints Dynamic/fatigue	Bolt could be replaced with a screw.	Screw is preferred. Screw should not be replaced with a bolt.

EN14399.3 (HR)/EN14399.4 (HV) PC10.9 Bolts - Special Case

EN14399-3 (HR) PC10.9	Suitable for shear (S/TB) or friction grip (TF) or combined joints when shear plane does not cross the thread area (not suit many joint configurations). Suitable for tensile joints. Thread length is same as a bolt. Ductility is due to unused thread. Tensile failure will occur in the loaded unused thread area.	A screw should Not be replaced with a HR bolt unless on advice from a Qualified Engineer.
EN14399-4 (HV) PC10.9	Suitable for shear (S/TB) or friction grip (TF) or combined joints when shear plane does not cross the thread area (will suit more joint configurations). Suitable for tensile joints. Thread length is shorter than a bolt. Ductility is due to thread stripping. Tensile failure will occur mostly by thread stripping.	A screw should Not be replaced with a HV bolt unless on advice from a Qualified Engineer.

REFERENCES

Prof. Saman Fernando, *'Bolts and Set Screws - Are they interchangeable?'*.

Figure 6, www.substec.com.

Page 1, *image 2* from AS1110.1

Page 2, *image 1* from AS1110.2

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