

الأستخدام و الأجهاد و التصميم للمسامير ذات رتبة ٨.٨
كمسامير عادية عالية المقاومة

دكتور على عبد الحكم على عبدة
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ملخص البحث

عادة ما تستخدم المسامير عالية المقاومة ذات رتبة ٨.٨ لتعمل كمسامير عادية. تظهر مشكلتين فى هذه الحالة. أولاً لا يوجد أرشادات للتصميم فى المواصفات المصرية للمنشاءات المعدنية عند ربط هذه المسامير بمفتاح اليد. ثانياً لا توجد مواصفات مصرية للخواص الميكانيكية لمادة المسامير ذات رتبة ٨.٨. هذا البحث يقيم المقاومة القصوى لهذه المسامير. تم عمل تجارب معملية و تعريض المسامير لقوى شد و قص حتى الأتھیار. المسامير المختبرة تم أختيارها من السوق المحلية و مصنوعة فى خمس بلاد مختلفة. النتائج المستخرجة فى الشد توضح أستيفاء المسامير لمتطلبات الشد فى المواصفات العالمية و البريطانية. قيم أجهادات القص المستخرجة من التجارب غير متقاربة. هذا يوضح أهمية تحديد القيمة الدنيا المطلوبة لأقصى أجهاد فى القص. تم مراجعة قواعد التصميم المتاحة فى المواصفات المصرية و البريطانية. تم مناقشة تأثير ربط المسامير ذات رتبة ٨.٨ بمفتاح اليد على سلوك و تصميم الوصلات و كذلك مدى التقارب بين هذه المسامير و المسامير العادية الأخرى.

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USE, STRENGTH AND DESIGN OF GRADE 8.8 BOLTS AS HIGH STRENGTH ORDINARY BOLTS

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Abstract

High strength bolts of grade 8.8 are commonly used to function as ordinary bolts. Two problems arise. Firstly, no design guidance is given in the Egyptian code of practice for the use of grade 8.8 bolts when tightened by hand spanner. Secondly, there is no Egyptian standard that specifies the properties of grade 8.8 bolts' material. This paper assesses the strength values of grade 8.8 bolts available in the local market and manufactured at different countries. An experimental programme was carried out. The bolts were subjected to direct tension and shear until failure. All the bolts satisfied the tensile strength requirements of the ISO 898 - 1 and the BS 3692. The bolts exhibited inconsistent shear strength values. The safety factor against failure in shear is found less than that in tension and less than that of other structural members. This highlights the need of defining the shear strength in the codes of practice. The results obtained are compared to other experimental data presented in the literature. The design guidance in the Egyptian codes and BS 449 is reviewed. The use of grade 8.8 bolts when tightened by hand spanner is discussed. The compatibility of grade 8.8 bolts with other ordinary bolts allowed in the Egyptian code is studied.

Key words:

grade 8.8 - bolts, strength - bolts, ordinary - bolts - design

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Introduction

Bolts of grade 8.8 are commonly used in practice to function as ordinary bolts. They are used in clearance holes and tightened by hand spanner. Two problems arise in this case. Firstly, no design guidance is given in the Egyptian code of practice (1) for the use of grade 8.8 bolts when tightened by hand spanner. High strength bolts are required to be pretensioned using torque wrench, clauses' 6.3.2 and 6.3.6 (1). This is accepted in friction type connections. The induced forces between the gripped plies are designed to transmit the applied forces. In bearing type connections, bolts' are expected to function as ordinary bolts. Pre tensioning the bolts in this case can not be justified. This is because of the difficulties of tightening the bolts and hence the increase in the cost of erection. An impact wrench or 2.0 meter break back spanner is more difficult to use than normal spanner. At heights, it is often necessary to provide staging from which tightening can be carried out. Adding to this, the tightening equipment must be calibrated at least once per shift and if there is a change of bolt diameter.

Secondly, there is no Egyptian standard that specifies the properties of grade 8.8 bolts' material. Only the yield and ultimate tensile strengths' values are defined (1). On contrast, the Egyptian Standard No. 2135 (2) provides all the required information about grades' 3.6, 6.8 and 10.9 bolts. Grade 8.8 bolts and their nuts are not produced in Egypt. By reviewing the available data at the Public Association for Checking Exportation and Importation, the authors found the following. Bolts of grade 8.8 have been imported from more than 10 different countries. Bolts imported from the same country are not usually produced by the same manufacturer. Nuts are imported from different countries to those of the bolts. The Public Association for Checking Exportation and Importation requires certificate from the manufacturer contains the specification of the imported 8.8 bolts. The results of the tested bolts should meet these specifications.

This paper assesses the strength values of grade 8.8 bolts available in the local market and manufactured at different countries. An experimental programme was carried out to measure the tensile and shear strengths of the bolts. The obtained results are compared to the ISO 898 - 1 (3) and the BS 3692 (4) and to the other experimental data presented in the literature (5). The design guidance in the Egyptian codes of practice (1) and BS 449 (6) is reviewed. The use and design of grade 8.8 bolts when tightened by hand spanner are discussed.

Test Programme

A total number of 30 bolts of grade 8.8 and size M 20 was subjected to direct tension and shear until failure. They were divided into five groups. The bolts of each group were imported from the same country and produced by the same manufacturer. Two of the groups were imported from two different countries in Western Europe. The other three groups were imported from Eastern Europe, the far east of Asia and a neighboring Arab country. Each group was named by a letter just for designation. All the bolts were black except those of group B, table 1. Most of the nuts used were of grade 10. Failure is expected to be in the bolts as they are the scope of this study. A universal testing machine of 500 KN loading capacity was used throughout the test programme.

Tension Tests

Four bolts of each group were subjected to tension until failure, table 1. The first bolt of each group and its' nut were installed between the jaws of the test rig as shown in figure 1. Tension load was applied until failure. The other bolts were tested using the test rig shown in figure 2. It is designed to simulate the interaction behavior between the bolt and the gripped material when subjected to tension. The bolts were tightened using hand spanner. The rig was positioned in the testing machine and compression load was applied, figure 3. This would induce tension force in the bolt and its' nut. This process was continued until failure.

Shear Tests

Two bolts of each group were tested in single shear, table 3. The failure plane was made in the threaded portion for one bolt and in the shank for the other. Figure 4 shows a bolt installed in the test rig. Compression load was applied until shear failure.

Results of Tension Tests

The two methods of tension tests gave nearly the same results, table 1. The experimental ultimate tensile loads T_u of the tested bolts exceed the minimum ultimate tensile load values T_{uISO} and T_{uBS} specified in the ISO 898 - 1 (3) and the BS 3692 (4) respectively. This applies to all the bolts except bolt no. 6 of group B. The difference in this particular case is 0.5%. The bolts of groups D and E show superior results in comparison to those of groups A, B and C. Nut grade affected the ultimate tensile loads' values but not to a significant degree. All the

bolts tightened with grade 8 nuts, except no.18, failed by threads stripping in the bolt itself and/or its' nut. This result confirms the finding of Godley (5). " Grade 8.8 bolts with grade 8 nuts have higher likelihood of threads stripping." Most of the bolts tightened with grade 10 nuts failed in the threaded portion. The failure plane is at 45° to bolts' axis in group B and perpendicular to bolt axis in group C, figure 5. Table 2 compares between the average ultimate tensile load of the bolts in each group and the results presented by Godley (5). These are the only available experimental published data found in the literature for grade 8.8 bolts. They tested bolts of size M 20, manufactured in the United Kingdom and tightened by hand spanner. The results of groups C, D and E exceed those of reference (5).

Results of Shear Tests

Table 3 presents the ultimate shear loads S_u of the tested bolts. The bolts of groups D and E show superior results in comparison to those of groups A and B. Group C exhibits poor results. It worth mention that the ratio between the ultimate loads of the first and second bolts in each group is found nearly equal to 0.71, except in group D. This value is less than the ratio of the cross sectional area at the threaded portion to that at the bolt shank. It is equal to 0.78 for the bolts of size M20. The ultimate shear strength USS presented in table 3 was calculated using the actual stressed area at which failure occurred. Shear strength values are found ranging between 0.75 to 0.99 of those presented in reference (5). Figure 6 shows the failure modes in shear tests.

Assessment of Bolts' Shear Strength

The ultimate shear strength of grade 8.8 bolts are not specified in either BS 3692 (3) and the ISO 898 - 1 (4). The ratio of the ultimate shear strength USS to the average ultimate tensile strength UTS_{ex} of the bolts of the same group is calculated and presented in table 3. Godely (5) reported a value of 0.69 for this ratio. Fisher (7) reported a value of 0.62, but for different grade of bolts. Most of the tested bolts in this study failed to exceed any of these values. Non of the bolts achieved a value for this ratio equal to or more than 0.66. This value is equal to the ratio of the allowable shear to tension stresses specified in BS 449 (6) for grades' 4.6 and 8.8 bolts. This means that the bolts exhibit values for the safety factor against failure in tension higher than that in shear.

Table 3 also includes the ratio of the ultimate shear strength to the minimum ultimate tensile strength UTS_{BS} specified in BS 3692 (3). The values of this ratio are less than 0.66 for 50% of the bolts. This would produce values for the safety factor against failure in shear less than 2.85. The latter value is the minimum requirement in BS 449 (6) for the safety factor against failure in tension. This implies that bolts subjected to shear would fail before those subjected to tension and even before other structural members. This applies to the bolts of groups A, B and C. However, the bolts of groups D and E are expected to behave in a relatively consistent manner in tension and shear. This highlights the need of specifying a minimum value for the ultimate shear strength. Other solution is to specify the shear strength as a ratio of the minimum ultimate tensile strength. Unfortunately, this piece of information is not available in the Egyptian code (1), BS 3692 (3) and ISO 898 - 1 (4).

Design Guidance in Codes of Practice

(i) Egyptian Code of Practice

The Egyptian code (1) does not allow the use of grade 8.8 bolts when tightened by hand spanner. Connections of high strength bolts are classified into friction type and bearing type. Bolts are required to be pretensioned to 70% of their yield loads in these two types using torque wrench. Table 4 presents the specified allowable stresses of grade 8.8 bolts as ratios of the bolts' material yield stress f_y . The ratio of the minimum ultimate tensile strength to the allowable tension stress is equal to 2.98. The ratio of the experimental ultimate tensile load T_u to the allowable load T_{aE} for all the bolts exceeds this value, table 1.

The allowable shear stress in friction type connections τ_f is calculated by dividing bolt friction capacity to its' shank area, table 4. The value of τ_f depends on the friction coefficient μ and a safety factor with regard to slip γ . The values of γ are ranging between 1.1 to 1.6. This would not allow slip at working loads. At ultimate conditions, all the joints will have slipped into bearing. It worth mention that when excluding the value of γ and using value for $\mu = .5$, the allowable stress would equal to $0.26 f_y$. This is nearly equal to the allowable stress in bearing type connections.

(ii) British Standards BS 449

The BS 449 (6) allows the use of grade 8.8 bolts with nuts of grade 8 when tightened by hand spanner. The values of the allowable tension and shear stresses are higher than their

counterparts specified in the Egyptian code (1) for bearing type connections, table 4. The safety factor against failure in tension should exceed 2.85. All the tested bolts satisfied this value, table 1. In shear, the bolts of groups A, B and C gave inconsistent values for the safety factor.

The Use of Grade 8.8 Bolts as Ordinary Bolts

The adoption of grade 8.8 bolts as high strength ordinary bolts is evaluated in terms of its structural performance. They are tightened by hand spanner. This does not affect the bolts' ultimate strength. At ultimate loading conditions, bolts become into bearing. Connections with ordinary bolts and those with pretensioned bolts are expected to exhibit nearly the same behavior and strength. At working load conditions, the bolts' tightening degree influences the joint's behavior significantly. The designer needs to decide whether joint slip is critical or not. For high redundant structures and those subjected to dynamic loads, joints slip are likely to have major effect on forces' distributions and/or the initiation of fatigue failure (5). Joint slip becomes the failure criterion. The uses of pretension bolts are essential. However, in most of steel structures, specially those subjected to static loads, joints slip have only second order effect. Joint slip can not lead to a significant deformation of the structure and does not affect the forces in the members to a significant degree. High strength bolts of grade 8.8 bolts can be tightened by hand spanner and designed to function as ordinary bolts.

Compatibility of Grade 8.8 Bolts with Other Ordinary Bolts

In developing design guidance for grade 8.8 bolts as ordinary bolts, it is necessary to satisfy the design requirements in the codes. The allowable stresses should be compatible with those of other ordinary bolts and those of other structural members. In Egypt, ordinary bolts have been made from steels of grades 37, 44 and 52. Rolled members and plates are produced locally from steel 37. Most of steel structures are fabricated from steel 37. Table 5 presents the values of the safety factor against yielding FOS_y and the safety factor against failure FOS_f . These values are obtained from the Egyptian code (1) as follows:

$$FOS_y = \text{allowable tension stress} / \text{yielding stress}$$

$$FOS_f = \text{allowable tension stress} / \text{minimum ultimate tensile strength}$$

The use of $FOS_y = 2.1$ for grade 8.8 bolts would produce a value of 2.6 for the safety factor against failure. This value is less than that of the other ordinary bolts. The induce of any prying forces would reduce this value further. Failure in this circumstance is expected to occur in grade 8.8 bolts before other bolts and structural members. On the other side, the uses of $FOS_f = 3.3$ would produce a value for FOS_y equal to 2.64. This value is higher than that of FOS_f of steel 37. Members of steel 37 would fail while 8.8 bolts are still elastic.

The allowable stresses specified for bearing type connections in the Egyptian code, clause 6.3.6 (1), can be used. However, the bolts would be tightened by hand spanner. They provide balanced values between the two extreme cases considered above. In tension, the values of FOS_y and FOS_f are equal to 2.38 and 2.96 respectively. These values are nearly equal to those of other ordinary bolts and higher than those of steel 37. This difference would compensate for any prying forces not taken in design considerations. Further, it provides an acceptable margin between the yielding and the failure of the bolts and the other structural members. In shear, the ratio of the allowable shear to tension stresses is equal to 0.64. Most of the tested bolts, in this case, would be exhibiting safety factor against failure in shear exceeding 3.0. Bolt shear capacity should be related to the area at which failure plane occurs and not to the shank area. This condition is included in BS 5950 (8). This would produce the same values for the safety factor when fully threaded bolts are used, (9). In bearing, the ratio of the allowable bearing stress to the yield stress is found equal to the value of this ratio but for other ordinary bolts, clause 3.6.8 (1).

Proposed Notes

The use of grade 10 nuts with grade 8.8 bolts would produce relatively higher strength and reduce the probability of threads stripping failure mode. Recent developments in codes (10) allow the use of different methods for tightening high strength bolts in friction type connections. The turn of nut method and the load indicating washers are methods that do not require calibration of the tightening tools. Washer thickness is limited to 4.0 mm in the code (1) for the bolts of size up to M24. No guidance is given for the bolts of larger sizes. Thick washers give superior behavior and reduce long term relaxation's, (11).

CONCLUSION

Grade 8.8 bolts are not produced locally in Egypt. They have been imported from more than 10 different countries. A total number of 30 bolts of grade 8.8 and size M 20 was subjected to direct tension and shear until failure. They were tightened by hand spanner. All the bolts satisfied the ultimate tensile strength values specified in BS 3692 (3) and ISO 898 - 1 (4) and the safety factor required in the Egyptian code (1) and BS 449 (6). Nut grade affected the ultimate tensile loads' values but not to a significant degree. All the bolts tightened with grade 8 nuts, except no.18, failed by threads stripping. The bolts exhibited inconsistent shear strength values. The values of the safety factor against failure in shear for 50% of the bolts are found less than that in tension and even less than that of other structural members. To avoid this inconsistency, a minimum value for the ultimate shear strength should be specified in the codes. Pre tensioning high strength bolts should depend on the structure redundancy and the type of the applied loads. The use of grade 8.8 bolts as ordinary bolts should be allowed . The allowable stresses specified for bearing type connections in the Egyptian code, clause 6.3.6 (1), are found compatible with those of other ordinary bolts.

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APPENDIX II - Notations

f_y	yield stress.
FOS_f	factor of safety against failure.
FOS_y	factor of safety against yielding.
S_{aBS}	allowable shear load according to the British Standard BS 449 (6).
S_u	experimental ultimate shear load.
T_{aBS}	allowable tension load according to the British Standard BS 449 (6).
T_{aE}	allowable tension load according to the Egyptian code (1).
T_u	experimental ultimate tensile load.
T_{uISO}	minimum ultimate tensile load value specified in the ISO 898-1 (4).
T_{uBS}	minimum ultimate tensile load value specified in the BS 3692 (3).
USS	ultimate shear strength.
UTS_{BS}	minimum ultimate tensile strength specified in BS 3692 (3).
UTS_{ex}	experimental ultimate tensile strength.
τ_f	allowable shear stress in friction connections (1).
μ	friction coefficient.
γ	safety factor against slip.

Figure 1 Arrangements of direct tension tests.

Figure 2 Test rig for tension tests.

Figure 3 The rig in the universal testing machine.

Figure 4 Bolt in single shear.

Figure 5 Failure modes due to direct tension test.

Figure 6 Failure modes due to single shear test.

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