Science Arena Publications
Specialty Journal of Architecture and Construction
Available online at www.sciarena.com
2016, Vol, 2(4): 39-53

Investigating Instruction Manuals' Compatibility with the Laboratory Estimations in Computing the Maximum Tensile Strength

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Abstract: *In order to obtain a strong and integrated steel structure, it is necessary to connect the main parts, namely the beams and columns in an appropriate manner so as to be able to guarantee the intended productivity. The integrity and cohesion between the main parts can be made feasible via the connections implemented in two forms of welded and bolted but it is worth mentioning that the bolted connections are more widely applied because of the high assembly speed and low costs. The simplest loading type in bolted connections is the state where the connected sheet is subjected to direct tension. Force transferring method in bolted connections is in two forms of bearing and frictional and the present study tries to deal more with the bearing connections. After designing and constructing a small frame, sixteen connection sheets with a fixed thickness of 6 mm and a shield in the present study, clearance from the hole center was taken into consideration and each of the specimens was tested under strain in laboratory environment in such a manner that firstly each specimen was installed and the bolts were placed and tightened by making use of jacks, then the strain force was measured at certain times and recorded by the use of a data logger. The process continued from tension to failure. The result was that the maximum amounts of strength obtained in laboratory tests showed an error range of 15% to 62% in comparison to the theoretical calculation of maximum strength according to the Instruction Manual. Therefore, it can be concluded that the Instruction Manual has followed a very conservative trend so as to main a higher margin of assurance and it is not cost-effective because such an error percentage and the increase in the specimen strength rate acquired during laboratory tests in comparison to what is posited theoretically suffer a 25% reduction, for each of the specimens, in case that the coefficients are not applied in calculation relations. Comparing the specimens' characteristics, it is concluded that with the increase in the specimens' widths (W), both the maximum force obtained during the laboratory tests and the Td obtained through solving the relations mentioned in the Instruction Manual undergo an increase; in addition, with a comparison of the specifications regarding the specimens where the holes lie concentrically and with similar specimens where the holes do not exhibit clearance from the center, it was concluded that the hole's clearance of the center brings about a reduction in the maximum force obtained in laboratory and the amount of Td obtained through solving the relations proposed in the Instruction Manual.*
Keywords: *bolted connections, connection sheets, strain members, strained bolted connections, bearing connections, Instruction Manual compatibility*

INTRODUCTION

Nowadays, the use of bolted (nuts and bolts) constructs is experiencing a considerable increase in such a manner that, in the past, such constructs were exclusively unique to industrial factories and petrochemical compounds and the constructs in gas industries. Now, these constructs are frequently being used in residential, administrative and business buildings made in the context of the cities. One of the most important reasons behind the considerable use of bolted constructs in industrialized countries is the lack of the requirement to perform welding operations when mounting the constructs; furthermore, they can be more easily installed when difficult situations arise as well as the quicker pace of installation in contrast to welded constructs. Also, the skeletons which are manufactured in the vicinity of the building projects are not only lacking the expected quality because of the limitations in sufficient power supply and the application of the modern welding devices (with a high standard and penetration rate), the absence of heavy industrial tools, experienced painting teams and improper anti-rusting but they are also completely awkward and time-consuming and these, altogether, lead to the congestion of traffic in the intercity streets and interference in the routine life of the neighbors. Figure (1) illustrates a sample of bolted connection. The traditional method of constructing skeletons in the proximity of the project site, besides the aforementioned pitfalls, incurs high costs in terms of hiring a crane. Another point is the generally lower and economical costs of manufacturing bolted connections in comparison to the common traditional procedures and this accounts for a substantial percentage of costs when the iron beams (girders) supplies fall short of satisfying the needs as well as when the prices are increased.

Figure (1): a specimen of the bolted connections

Nowadays, the steel-made construct components are connected by means of welding or bolting or a combination of the two. Up to several decades ago, welded or rivet connections were the prevalent method of connections. The American committee of bolted and rivet connections was first founded in 1970. The committee published its first instruction manual in 1951. The instruction manual contained the criteria for replacing the highly strong bolts for rivets. Since then, the use of bolts, particularly the highly resistant bolts, found prevalence and became the common method of connections in such a manner that rivets are no longer applied in steel structures [5]. The present study aims at the survey of the laboratory specimens' resistance and, subsequently, acquiring more precise information regarding the maximum tensile strength in bolted connections.

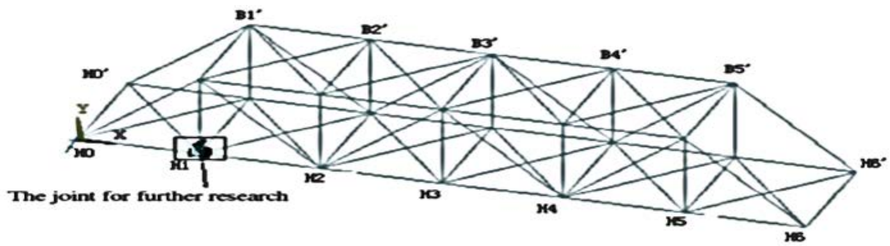
Here, we deal with the survey and review of a number of similar studies and articles carried out concerning the theme presented in the present study:

In 2006, Loveh et al. examined the bottom-sheet connections by means of composite two-head cross-shaped screws tightened to CFT columns under resisting moment. Based on their report, the use of CFT prevents the pipe from developing local fractures. In contrast, hollow steel usually fractures as a result of extreme transformations along the pipe surface and it is pulled out of the Hollbolt [24].

Wang et al. (2010), in a study, investigated the hardness and the primary strength of a blind-bolt connection on a t-stub model behavior when being applied in resisting moment connections. This was carried out through conducting a study on the effects of strength hardness and cleavage of a t-stub connection. It was found out that the beam wing thickness exerts a predominant effect on the strength and the hardness of the blind-bolt connection in comparison with the flaring sleeve and body diameter [20].

Jin Hwa Tang (2011), in an article entitled “the survey of the elastoplastic parameters in the vicinity of the screw notch for the steel used in bridge truss” writes: “the precise model of failure mechanics has been simulated by taking advantage of some software in the proximity of a screw notch for a simple truss metal bridge” and the elastic and plastic parameters have been examined in the vicinity of the crack tip. The results indicate that the elastic and plastic hardness indices were clearly calculated in parallel and perpendicular to the crack line and the hardness index in the close distance to the crack tip and the screw notch grew in a more brittle manner [22] (Figure 2).

Figure (2): a bridge featuring a steel truss [22]



Tizan and Ridley-Alice (2013) performed a survey using a modified hollbolt which is called threaded hollbolt (EHB). In EHB, the bolt and the threaded cone thereof are unified and a threaded bolt’s shank along with an additional nut (called curbing nut) is used (corresponding to figure 3). The threaded bolt’s shank is soaked into the filled concrete by way of which a higher rate of hardness and tensile strength is obtained in two-head closed bolts. Since the EHB’s tensile failure state acts in a similar way as in the standard bolted connections, the usefulness of the technique is confirmed; in other words, the tensile strength of the bolt shank is compensated by the bolt shank failure. The integrity of the threaded shank of the bolt causes the dismissal of the unwanted similar failures quite similar to what occurs along the welded elongations [24].

Figure (3): Elongated Hollbolt (EHB) [24]

No.	Components
A	Bolt head
B	Collar
C	Rubber washer
D	Sleeve
E	Threaded cone
F	Bolt shank
G	Anchor nut

Anis Abid et al. (2014) researched on the effect of bolt resisting moment rigidity on t-stub bolted steel connections’ behavior as it is described below: t-stubs are predominantly used for indicating the strain area of the fortified concrete against the torque power of the bolt. They concluded that because of the flexibility of t-stubs flanks, the resisting moment in the bolts subjects the t-stub’s robustness to changes [25].

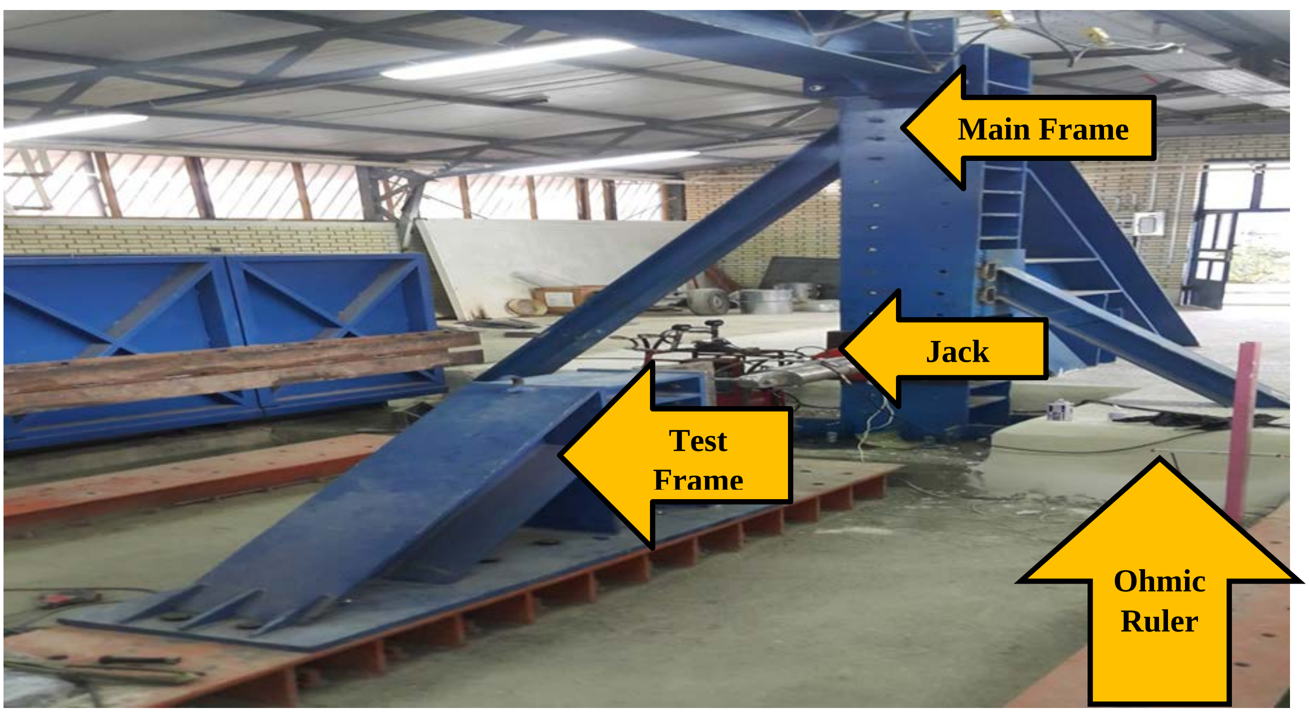
After designing and constructing a small frame, sixteen connection sheets with a fixed thickness of 6 mm and a shield in the present study, clearance from the hole center was taken into consideration and each of the specimens was tested under strain in laboratory environment in such a manner that firstly each specimen was installed and the bolts were placed and tightened by making use of jacks, then the strain force was measured at certain times and recorded by the use of a data logger. The process continued from strain to failure.

The result was that the maximum amounts of strength obtained in laboratory tests showed an error range of 15% to 62% in comparison to the theoretical calculation of maximum strength according to the Instruction Manual. Therefore, it can be concluded that the Instruction Manual has followed a very conservative trend so as to main a higher margin of assurance and it is not cost-effective because such an error percentage and the increase in the specimen strength rate acquired during laboratory tests in comparison to what is posited theoretically suffer a 25% reduction, for each of the specimens, in case that the coefficients are not applied in calculations.

Laboratory Equipment:

According to the subject of the experiments which included the bolted connections and their behaviors, thus we were in need of tools and equipment by way of which such an examination could be accomplished. Therefore, according to the ideas and notions acquired from the respectable professors and based on the extant facilities present in Civil Engineering Laboratory of Islamic Azad University, Kermanshah Branch, the experiment process was commenced. The laboratory is located in an industrial building with an area of approximately 400 m2 which is considered as appropriate for performing specialized tests within various fields of civil engineering especially earthquake engineering and constructions. The laboratory is equipped with tools and instruments including a data-logger (or recorder)'s jack main frame, different types of crane load cell for moving parts and the entire array of the equipment and devices deemed useful in the process of experiments.

Figure (4): Laboratory equipment



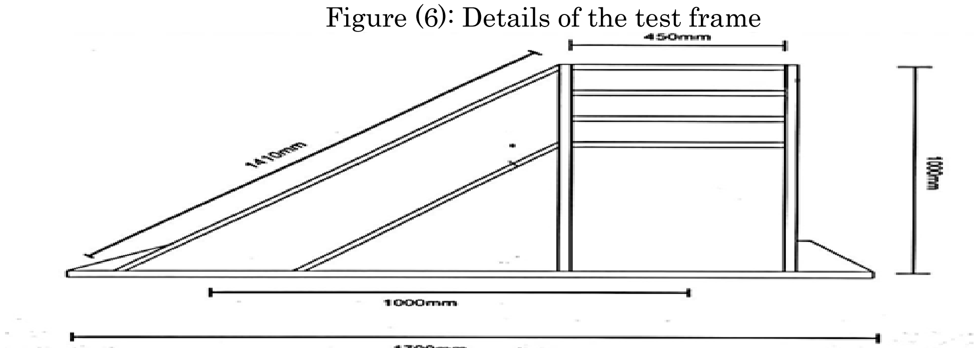
- **Jack:**
  The jack of concern to the current research paper has been shown in Figure (4). It is capable of generating nearly 100-ton strain and pressure but in the present experiment, we make use of the jack's strain capacity. In the beginning part of the jack's shaft, there is a 40-mm hole in order to be able to connect the experimental parts and specimens by the use of special bolts to it.

- **Data-logger:**
  It is an electronic device which collects and processes the data transferred by load cell. As it is observed in figure (5), the instrument has a display and a touch keyboard and it can be used as an independent device as well.

Figure (5): Data-logger

- **Ohmic Ruler:**
  It is a sensor that can precisely measure the linear displacement. Generally, the sensor is a coil. The linear displacement is read via entering an iron rod inside the coil by means of which magnetic field variations are caused. The difference between the ohmic ruler and LVDT is in that the ohmic ruler is not capable of recording the displacements featuring high speeds; but, LVDT possesses this ability. Since low-speed displacement takes place in this experiment, therefore, there is made use of ohmic ruler as presented in Figure (4).
- **Test Frame:**
  According to the beam holes built on the foundation, the main base part was designed, constructed and installed for the purpose of undergoing tension test. The aforesaid part was built in such a manner that it could have the sufficient resistance against the exertion of tensile force. The part of concern for the present study tension test has been illustrated in figures (6) and (7), and it had the following characteristics:

Figure (6): Details of the test frame



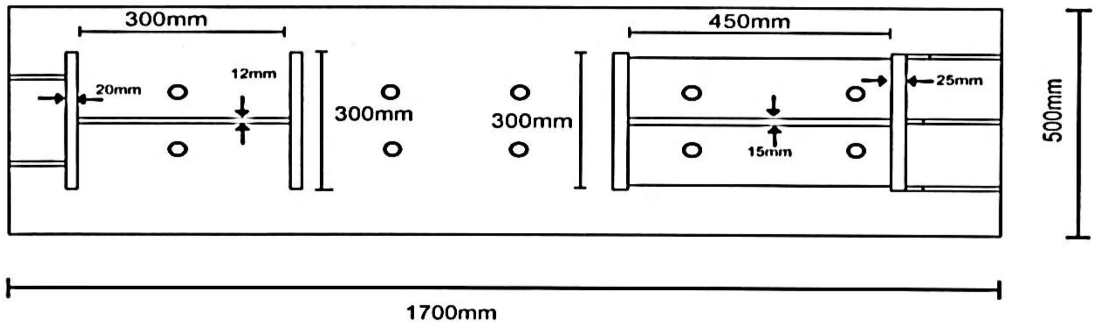


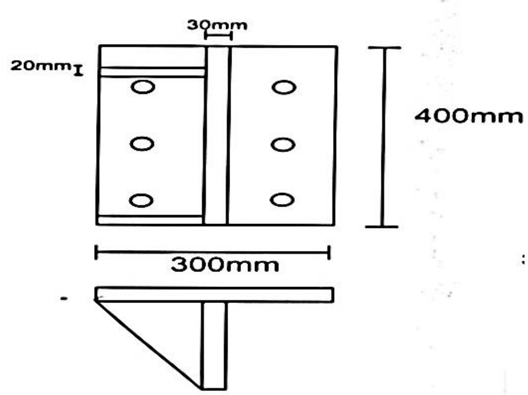
Figure (7): Details of the test frame

As it is observed in Figures (6) and (7), there are hardeners devised in the breech section of the perpendicular member, these hardeners have been manually welded but the remaining welds on the part are factory-welded and a submerged welding has been carried out and it has a very good quality. Figure (8), illustrates a view of the test frame.

Figure (8): Test frame and shield

- **Shield:**
  To perform tests between the connection part and the main part an intermediary part was designed which is installed on the perpendicular member by mean of six bolts. The dimensions and the characteristics of the intermediary part have been demonstrated in Figure (9).

Figure (9): Shield Details

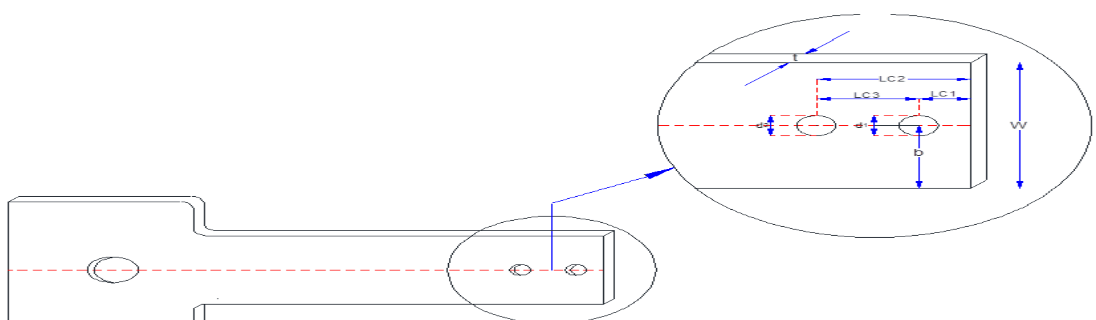


In order for the intermediary part to be exactly aligned with the holes' existent on the jack shaft, the holes devised on the intermediary part were selected of a bean-shape type.

Test Specimens for Tension Test:

Test specimens included 16 T-shaped temsheets made of 6mm-thick ST37 sheets. All of the parts were made of one type of sheet and the temsheets were cut based on CNC cutting method so as to avoid residual tension and have a greater rate of precision. The parameters are depicted in Figure (10) and the dimensional characteristics are given in Table (1).

Figure(10): a) Tension test sheet drawn by Autocad



b) Tension test sheet drawn by Autocad considering the clearance from center

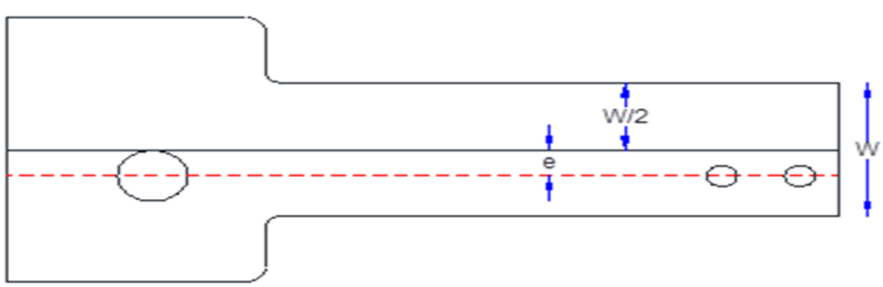


Table 1: Specimens' general characteristics

T (mm)	e (mm)	D2)mm(	D1 (mm)	b (mm)	Lc3)mm(	Lc2)mm(	Lc1 (mm)	W (mm)	Sample No.
6	0	16.4	15.9	20.05	55.85	76.8	20.95	39.9	193
6	0	16.5	15.9	29.95	56	76.85	20.85	59.8	194

6	0	16.5	15.9	39.85	55.9	76.85	20.95	80.1	195
6	20	16.4	15.9	20.15	55.65	76.8	21.15	80.3	196
6	0	16.5	15.9	49.95	55.7	76.75	21.05	99.8	197
6	20	16.4	15.8	29.9	56	76.9	20.9	99.8	198
6	0	16.4	15.6	59.9	56	76.7	20.7	120.4	199
6	30.1	16.4	15.8	29.9	56	76.9	20.9	120	200
6	0	16.5	15.9	19.95	56	83.85	27.85	39.9	201
6	0	16.4	15.8	21.8	55.8	83.7	27.9	59.9	202
6	0	16.1	15.6	39.7	55.25	83.55	28.3	79.9	203
6	20	16.2	15.9	19.95	55.75	83.5	27.75	79.9	204
6	0	16.3	15.8	49.9	55.75	83.65	27.9	99.8	205
6	19.85	16.4	15.8	30	55.8	83.7	27.9	99.7	206
6	0	16.4	15.8	59.8	55.9	83.8	27.9	120	207
6	34.92	16.3	15.9	25.18	55.9	83.75	27.85	120.2	208

- **Sheet and Bolt Characteristics:**
  In this experiment, all of the specimens have been cut and prepared from a single type of sheet with identical characteristics. Three holes were made in each of the specimens, one, 38 mm in diameter, for connecting to the jack shaft. A bolt, 36mm in diameter was used. Another two bolts were also applied for connecting the specimen to the small frame by means of an intermediary part, mentioned previously characterize by a hole diameter of 16 mm and an 8.8mm highly-resistant bolt with a diameter of 14 m. In order to make sure of the perfect compatibility of the sheet characteristics with what was intended, a sample of each of the specimens was sent to an authentic laboratory (soil mechanics laboratory) and the results are given in tables (2) and (3).
- **Tension Test Results for Bolts and Nuts:**
  ASTM: A370

Table 2: Bolts and nuts tension test results

Sample characteristics	Effective cross-section A(mm)^2	Load on flowing point (kgf)	Load on detachment point (kgf)	Flowing limit in offset state (0.2 Re) effective MPa	Tensile strength (Rm) MPa	Relative length increase (%)
Bolt no.M14-8.8	115.4	10593	12109	947	1049	15

- **Tension Test Results for Steel Sheets:**
  ASTM: A370

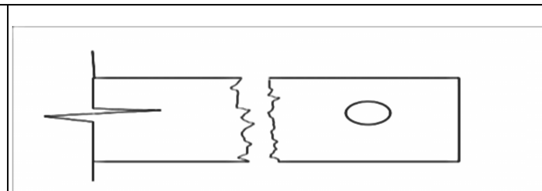
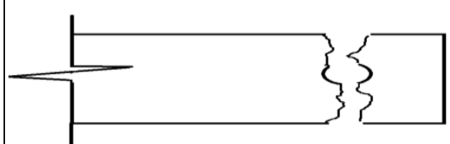
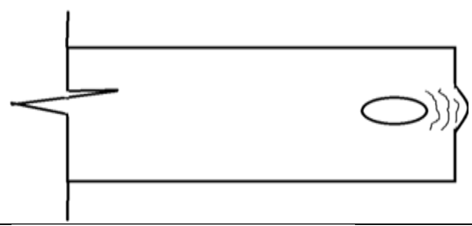
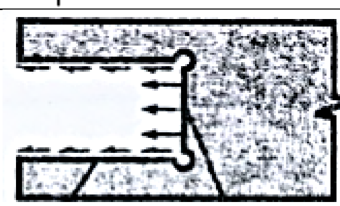
Table 3: Steel sheets tension test results

Sample characteristics	Sheet dimensions		Steel sheet cross-section cm2	Load on flowing point kgf	Load on detachment point kgf	Flowing limit Mpa	Final top of tension Mpa	Relative length increase (%)	Detachment point
	Width Mm	Thickness Mm							
Steel sheet no.37 with a thickness of 6 mm	39.2	5.7	2.23	4489	7048	201	316	32	In the standard area

As it is observed in Table (3), the amount of final strain is equal to 316 Mega Pascal. After that, the sheet is disjoined. Also, it is seen that the detachment point lies within the standard area. The tested specimen is a 5.7 mm-thick sheet with a width of 39.2 millimeters.

Test Procedure:

After the main part was installed on chassis and then mounting the intermediary part on the main part, jack was placed on the perpendicular member of the main frame and finally the holes in the intermediary part were aligned with the holes on the jack shaft. Ohmic ruler was also moved along and parallel to the jack direction to record the displacements caused as a result of tension. The data obtained by ohmic ruler were transferred to a data-logger via a cable and the displacements were recorded as processed at different times.
The test stages for each of the specimens were as follows: firstly, the specimens were installed and tightened with the bolts. Jack exerted tensile force at certain intervals on the specimens. The amount of the exerted force as well as the displacement value was recorded and process by a data-logger. The process continued from tension to failure. The likely failures resulting from the generation of tensile force on the sample took one of the types stated below.

1. tensile yield in general cross-section (Failure A):	
2. Sheet detachment in net cross-section (Failure B)	
3. Bolt breaking (Failure C)	
4. Bearing strength in the hole wall (Failure D)	
5. Frame detachment (Failure E)	

In the following section, the results pertaining to one of the temsheets has been provided (specimen 195):

- **The results obtained from tension test of the Specimen 195:**

- The results of the specimen 195's test are given in Table (4) and illustrated in Figures (11) and (12).

Table 4: the results obtained from tension test of the specimen 165

Maximum strength (Kg)	Maximum displacement (mm)	Failure type code	D2 (mm)	D1 (mm)	e (mm)	Lc3 (mm)	Lc2 (mm)	Lc1 (mm)	W (mm)
12273.9	20.62	1&4	16.5	15.9	0	55.9	76.85	20.95	80.1

Resistance (kg)	Displacement (mm)
Load	Delta
0	-0.01
0	-0.03
327.7	1.37
1012.9	2.88
1340.6	4.15
1757.7	5.24
2353.5	6.49
3455.8	7.78
5749.7	9.7
6941.3	10.78
7835.1	11.94
8490.5	13.46
8907.5	14.73
9354.4	15.97
10575.8	17.81
10188.6	19.49
12273.9	20.62
10665.2	21.87
10546	23.22
11141.9	24.64
5034.7	26.82
4975.1	28.39
3187.6	30.6

Figure (11): load-displacement diagram of the specimen

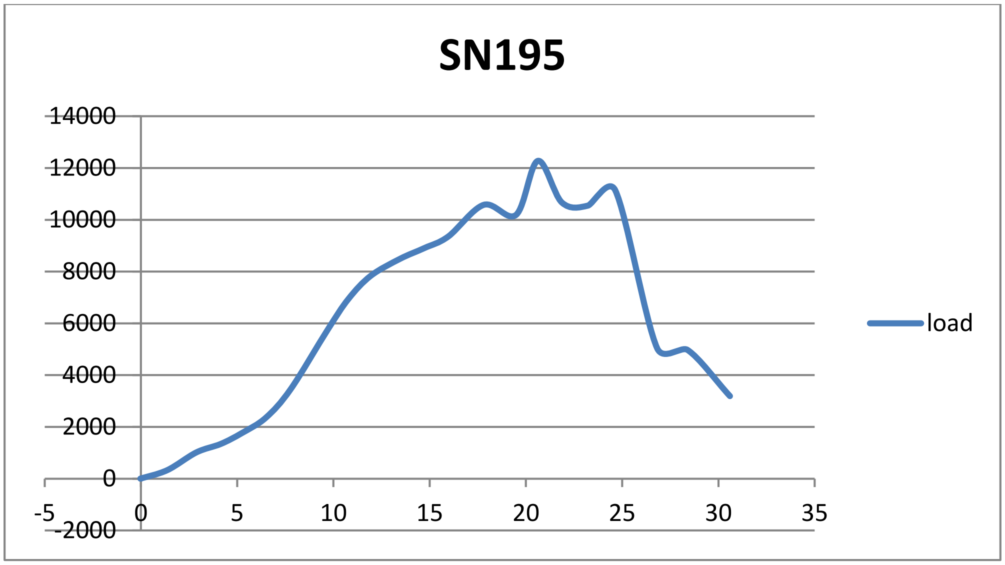


Figure (12): the failure stages of the specimen 165

The results for the rest of the specimens were similarly computed.

Figures (13-16) show the images for the specimens' post-failure.

Figure (13): failure in specimens 193-196

Figure (14): failure in specimens 197-200

Figure (15): failure in specimens 200-204

Figure (16): failure in specimens 205-208

The Instructional Manual Calculation Method Results:

The calculations and tests were conducted in five stages on the specimens as outlined below. The minimum obtained T from these four stages along with the final strength in terms of the instructional manual calculations and the governing Td were also taken into consideration.

1. **Tensile Yield in the General Cross-Section (Failure A):**
   T1=0.9 Fy Ag
2. **Sheet Detachment in Net Cross-Section (Failure B)**
   T1=0.75 Fu An
   Where, in above relation An=Ag-D.t. D is the calculated diameter of the hole and equal to 18 mm.
3. **Bolt Breakage (Failure C)**
   In this stage, we have, based on the table considering the bolt characteristics:
   Bolt area: $\frac{\pi}{4}\text{Ab} \times 14^2$
   Therefore, we have: T3=O.75(0.45Fu) Ab.
   In the above relation, Fu is the final tension of the bolt.
4. **Bearing Strength in the Hole Wall (Failure D)**
   T4=0.75 min (R1, R2)
   R1=1.2 Lc1 t Fu≤2.4 d t FU
   R2=1.2 Lc3 t Fu≤ 2.4 dt FU
5. **Frame Detachment (Failure E):**
   T5= 0.75 min (R3, R4)
   R3= 0.6 Fy Agv+Ubs Fu Ant
   R4=0.6 Fu Anv+ Ubs Fu Ant

For each of the temsheets, T1, T2, T3, T4 and T5 values are calculated and the governing Td (design) becomes equal to:

Td =min (T1, T2. T3. T4, T5)

The results obtained from the calculations for the specimen 195 have been offered in Table (5).

Table 5: Calculating Sample 195's Td

Specimen 195				
T1 (Kg)	T2(Kg)	T3 (Kg)	T4 (Kg)	T5 (Kg)
10368	10323	9312	5194	11416
	Governing Td=5194			

The calculations pertaining to the rest of the specimens followed a similar procedure.

Data Analysis:

After the calculations were carried out based on the Instructional Manual, Chapter 10, the data are compared and evaluated in Table (6).

Table 6: Laboratory and instructional manual data analysis and comparison

Failure type			Capacity			
Failure Conformity	Laboratory	Instructional manual	Error percentage	Laboratory	Instructional Manual	Sample no.
o.k.	B	B	25%	4945	3663	193
n.o.	B	D	45%	9562	5194	194
o.k.	D	D	57%	12273.9	5194	195
o.k.	B	B	58%	8430	3516	196
o.k.	D	D	57%	12125	5194	197
n.o.	B	D	54%	11350	5194	198
o.k.	D	D	55%	11678	5194	199
n.o.	B	D	54%	11529	5194	200

o.k.	B	B	21%	4647	3663	201
o.k.	B	B	15%	8281	6993	202
n.o.	B	D	33%	12095	7992	203
o.k.	B	B	62%	9443	3516	204
error	error	D	38%	12988	7992	205
o.k.	B	B	51%	11499	5542	206
n.o.	C	D	38%	13018	7992	207
error	error	B	51%	12631	6142	208

According to the idea that the instructional manual does not present any special relations for the temsheets that showed clearance from the center, so some other relations were applied in which the clearance from the hole center, e, has been taken into consideration so as to obtain optimum results that could be compared to the laboratory tests results.

The maximum tensile strength obtained in the laboratory showed an error percentage ranging in value from 15& to 62% in comparison to the maximum tensile strength presented predominantly theoretically in the instructional manual. Therefore, it can be concluded that the instructional manual has acted conservatively to save itself a margin of confidence and this indicates that the values presented therein are not economically appropriate.

Conclusion:

The present study dealt with the survey of the bolted connections designing criteria in under tension members. In this way, the connection temsheets, characterized by identical thickness, 6 mm, and of similar dimensions but different LCs and also considering the holes' concentricity and the lack of it were tested and observed.

According to the fact that the instructional manual does not provide relations regarding the temsheets that exhibit clearance from the hole center, so it has been in line with obtaining optimized results comparable to laboratory results that the clearance from the center of the hole, e, has been taken into consideration. The maximum amount of strength obtained in the laboratory is indicative of an error value ranging from 15% to 62% in comparison to the maximum amount of tensile strength presented theoretically by the instructional manual. Thus, it can be concluded that the instructional manual has acted more conservative in order to save itself a margin of confidence and it is not economically cost-effective; this error percentage as well as the sample's increase of the strength in laboratory tests in comparison to the theory is reduced by 25% for each specimen in case that the constants are not applied in the calculation relations. Moreover, comparing the specimens' characteristics with one another, we came to a conclusion that with the increase in the temsheets' width (W), both the maximum amount of the force obtained in the laboratory tests and the Td obtained from the relations presented in the Instructional Manual show an increase. Also, comparing the characteristics of the specimens in which the holes do not lie in the center with similar specimens lacking such a feature, we concluded that the clearance of the center by the holes causes a reduction in the maximum amount of the force obtained in laboratory and the Td value obtained from the relations presented in the instructional manual. The specimen nos. 205 and 208 showed a faulty failure. Additionally, it was observed that the failures occurred in the other fourteen temsheets were exactly the same as the instructional manual in nine of them and in the remaining five temsheets where the failure type was contradictory to the optimum failure as presented in the instructional manual it can be stated that the reason resides in the type and the material of the bolts.

Acknowledgement:

The authors of the present article, hereby, express their gratitude to Construct Research Laboratory associated with Islamic Azad University, Kermanshah Branch.

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