Compression member response of steel angle on truss structure with variation of single and double sections

Arief Panjaitan, Purwandy Hasibuan
Civil Engineering Department, Faculty of Engineering, Syiah Kuala University,
Jalan Tengku Syech Abdurrauf No. 7, Darussalam, Banda Aceh, Indonesia
E-mail: purwandy.hsb@unsyiah.ac.id

Abstract. Implementation of an axial compression load on the steel angle can be found at the various structure such as truss system on telecommunication tower. For telecommunication tower, steel angle section can be suggested as an alternative solution due to its assembling easiness as well as its strength. But, antennas and microwaves installation that keep increases every time on this structure demand reinforcement on each leg of the tower structure. One solution suggested is reinforcement with increasing areas section capacity, where tower leg consisted of single angle section will be reinforced to be double angle section. Regarding this case, this research discussed the behavior of two types of steel angle section: single angle of L.30.30.3 and double angles of 2L.30.30.3. These two sections were designed identically in length (103 cm) and tested by axial compression load. At the first step, compression member together with tension member was formed to be a truss system, where compression and tension member were met at a joint plate. Schematic loading was implemented by giving tension loading on the joint plate until failure of specimens. Experimental work findings showed that implementing double angle sections (103 cm) significantly increased compression capacity of steel angle section up to 118 %.

1. Introduction
Steel angles are members that commonly used in various structures especially truss systems such as truss system on bridge structures and telecommunication tower. For telecommunication tower, the needs of highness of the structure are needed to ensure telephone, radio, and television signal can be distributed well. Implementation of steel angle on telecommunication tower can be suggested as an alternative solution because of its assembling easiness as well as its strength. The quantity of antennas and microwave that keep increases during the time causes loading accommodated by tower feet (legs) also grows up. The common reinforcement method is by increasing area section capacity where tower feet consisted of single angle section will be reinforced to be double angle sections.

This research emphasized to discuss the behavior of two types of steel angle section: single angle section of L.30.30.3 and double angle sections of 2L.30.30.3. These two sections were designed identically in length (103 cm) and tested by axial compression load. Based on the experimental work, it can be observed member responses started from elastic condition until their failure.

Assembling process of truss system was started with forming tensile component on diagonal member and compression component on horizontal member. Both of these members were joined at the gusset plate as a plate that was implemented as loading location. Loading step was started by giving tensile load gradually through loading plate until horizontal member (compression component) achieved its failure. Observation record was carried out due to tensile force on loading plate and buckling deformation on horizontal member.
They were automatically collected and notified through experimental equipment such as tension load cell, data logger, and transducers. Based on these data, the response of two specimens can be specifically described and discussed in detail.

2. Specimen Preparation

2.1 Experimental Work Setting Up
This research implemented two types of steel member (diagonal and horizontal member), and they were formed to be a truss system. Both of these members were fastened with bolts on their supporting plates where these supporting plates were connected with end plates through the welded connection. End plates then were fastened to loading frame with the bolted connection. The tensile force that was worked on the gravitational direction and applied on the joint plate (joint plate of the horizontal and diagonal member) caused the diagonal member to be tensile component and horizontal member to be compression component. This experimental work was emphasized on horizontal member that accommodated compression force.

Load recording was carried out through tension load cell and data logger. Meanwhile, deformation recording was conducted through transducers placed on flange and web of steel angle either for single angle and double angle

2.2 Material Characteristics Determination
Determination of material characteristics is essential to be carried out because it will give information due to the compression member. For obtaining steel characteristics, coupon test was conducted in steel angle and give the result as yield stress ($F_y$) by 224 Mpa and ultimate stress ($F_u$) by 324 Mpa.

2.3 Transducers Placement Position
There were 4 transducers placed on different position. Transducer 1 was placed on the end plate of horizontal member and transducer 2 was placed on the end plate of the diagonal member. Placement of these transducers was aimed to observe possibility of buckling on end plate due to tensile load implementation on the joint plate. Transducer 3 was located on steel angle web. Meanwhile, transducer 4 was located on steel angle flange. Both of these transducers were located to measure compression member deformation. Regarding the slenderness of web and flange of steel angle, the failure modes predicted are local buckling and lateral-torsional-buckling.

2.4 Experimental Work Activities
Experimental work was carried out with giving tensile force at gusset plate (joint plate of the horizontal and diagonal member). This loading schematic was carried out by fastening iron ring on the threaded cylindrical bar so it will produce a tensile force on tension load cell that was continued to sling rope. This sling rope was clamped so it can distribute tensile force to the gusset plate. This mechanism caused tensile force worked on the diagonal member, and compression force worked on horizontal member.

The observation was emphasized on compression component (horizontal member). Tensile member had to be in elastic condition so it can ensure the failure would occur at compression member at first.

Data recording was carried out through data logger. These data were tensile force and deformation and they have collected automatically during the fastening of iron ring. This recording gave specimens responses started from elastic, yield, until failure condition.

2.5 Observation Planning
Observation planning during experimental work was emphasized on:

a. Increasing pattern of compression load due to deformation for double steel angles for both of single angle and double angles

b. Increasing mode of deformation in web and flange of steel angle for both of single angle and double angles.
c. Failure mode (buckling) for both of specimens.

3. Literature Study

One research with experimental work approach that discussed eccentricity effects on the equal-leg single angle was carried out by Liu (2007). Experimental work was conducted to single angle of L51.51.6,4 with variation of length members (900, 1200, and 1500 mm) and eccentricity distance in x and y-direction (e_x dan e_y). Experimental work was conducted by Hydraulic Universal Testing Machine to each specimen with giving compression force gradually (with increment of 0,5 kN). The test results showed that the greater eccentricity implemented on the specimen, it would give significant degradation in the compression strength of specimen.

![Figure 1. Setting Up of Experiment: (a) Double Section; (b) Single Section](image)

Both of SNI 03-1729-2002 & SNI-03-1729-2015 asserted that a structural component subjected to ultimate
concentric compression force has to fulfil \( P_0 \leq \phi P_n \) and Slenderness ratio of compression member must be less than 200 (\( \lambda < 200 \)).

Compression strength of structural member (\( N_n \)) calculated based on SNI-03-1729-2002 for double steel sections in major and minor axis can be stated as:

\[
\phi N_{nx} = \phi \frac{A_g F_{crx}}{\omega_x}, \quad \phi N_{ny} = \phi \frac{A_g F_{crx}}{\omega_y}
\]

Nominal strength of compression, \( P_n \), calculated with code of SNI-03-1729-2015 for both single and double sections are:

\[
\phi P_{nx} = \phi A_g F_{cx}, \quad \phi P_{ny} = \phi A_g F_{cy}
\]

Where: \( \phi \) = reduction factor of compression member (\( \phi = 0.85 \)); \( P_n \) = Nominal strength of compression (N); \( A_g \) = Area section (mm\(^2\)); \( F_{crx} \) = Critical stress in major axis (MPa); \( F_{cry} \) = Critical stress in minor axis (MPa).

4. Test Results and Discussion

4.1 Tensile Force – Deformation Curve Of Transducer

Observation of this relationship curve aimed to gain information due to buckling on angle web of the compression member.

Deformation that occurred on web angle can be obtained through transducer 3. Experimental work showed that ultimate web deformation (buckling) of single angle (\( \delta_{u1} = 41,155 \) mm) was higher than ultimate web deformation of double angles (\( \delta_{u2} = 15,437 \) mm). This finding gave information that increasing section capacity to be double angles was effective to decline lateral buckling due to the slenderness of area section. Deformation of the flange can be measured through transducer 4 that was located on angle flange. Meanwhile, tensile force can be gained through tension load cell, and it would be transferred to the data logger.

![Figure 2](image)

**Figure 2.** Tensile force – deformation curve, (a) transducer 3, (b) transducer 4

Experimental work showed that higher ultimate deformation on flange was achieved by double angles (\( \delta_{u2} = 45,49 \) mm) if it was compared to flange deformation of single angle (\( \delta_{u2} = 25,465 \) mm). This was possible because double angles that were increased its section capacity would decrease its buckling possibility. So it performed optimally, and it would have higher buckling value on loading axis.
4.2 Comparison of Ultimate Member Forces and Ultimate Tensile Forces Due To Experimental Work Results, SNI 03-1729-2002, and SNI 03-1729-2015

Comparison of ultimate member forces and ultimate tensile force for single compression members and double compression members showed that double compression member performed ultimate member force \( (S_{u2} = 50172.83 \text{ N}) \) and ultimate tensile force \( (P_{u2} = 42100 \text{ N}) \). Both of these values were higher than single compression member values with ultimate member force \( (S_{u1} = 23060.43 \text{ N}) \) and ultimate tensile force \( (P_{u1} = 19350 \text{ N}) \). There were about 118% in difference for ultimate member force and ultimate tensile force between double compression members and single compression member.

Besides, the analysis was also conducted with the assumption that compression member will only accommodate concentric force. Both of these analysis methods were done by code of SNI 03-1729-2002 and SNI 03-1729-2015.

4.3 Failure Modes of Compression Member

There were differences of failure modes of single angle and double angles. The failure mode of single angle was lateral-torsional-buckling on the mid-span of the member. It is possible because single steel angle has slender web and flange, so they did not have a good capacity to accommodate high compression load. The failure mode of double angles was local buckling to loading direction on the flange that occurred on the mid-span. This failure mode showed that improving section capacity to be double sections was effective to prevent lateral-torsional-buckling failure.
5. Conclusion and Suggestion

5.1 Conclusions
Based on the observation, it can be concluded that higher compression strength ($P_{u \max} = 42100$ N) and higher deformation on the flange ($\delta_{flange} = 45.49$ mm) were achieved by double angles due to its area section capacity and its capability in accommodating compression load. Ultimate member force and ultimate tensile force obtained from experimental work results were higher than SNI analysis results due to SNI criteria refer to the elastic condition. Failure modes of each specimen showed that increasing area section capacity to be double sections was effective to prevent lateral-torsional-buckling failure.

5.2 Suggestions
For better understanding due to the behavior of compression member, it is suggested to conduct continued experimental work of single and double section in the form of the single element. Necessary to carry out experimental work of double sections with implementing diagonal plate (lacing) as substitution of batten plate.

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