Compression member response of double steel angles on truss structure with member length variation

Purwandy Hasibuan\textsuperscript{1}, Arief Panjaitan\textsuperscript{1}, Muhammad Haiqal\textsuperscript{2}
\textsuperscript{1}Civil Engineering Department, Faculty of Engineering, Syiah Kuala University, Jalan Tengku Syech Abdurrauf No. 7, Darussalam, Banda Aceh, Indonesia
\textsuperscript{2}Architecture 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: One type of structures that implements steel angles as its members is truss system of telecommunication tower. For this structure, reinforcements on tower legs are also needed when antennas and microwaves installation placed on the peak of tower increases in quantity. One type of reinforcement methods commonly used is by increasing areas section capacity, where tower leg consisted of single angle section will be reinforced to be double angle sections. Regarding this case, this research discussed behavior two types of double angle steel section 2L 30.30.3 that were designed identically in area section but vary in length: 103 cm and 83 cm. 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 the joint plate. Schematic loading was implemented by giving tension loading on the joint plate, and this loading was terminated when each specimen reached its failure. Research findings showed that implementing shorter double angle (83 cm) sections, increased compression strength of steel angle section up to 13 %. Significant deformation occurring only on the flange for both of specimens indicated that implementing double angle is effective to prevent lateral-torsional buckling.

1. Introduction
Implementation of steel angles as members of truss system has been acknowledged until recent years. One type of structures built up with steel angles as its main components is telecommunication tower.

On telecommunications tower, some members form its structural systems such as tower feet (legs), diagonal members (braces), redundants, and horizontal members. The leg is tower element that has a function as the last receiver of load distribution from other members. Furthermore, the leg is a place where antennas and microwave as a spreader of radio waves will be placed. The leg has similar characteristics with a column where the leg is a compression member like column and legs placed on the bottom will accommodate the largest compression load.

During the time goes away, antennas and microwaves installation placed on the peak of the tower will increase in quantity, so reinforcement solution is absolutely needed on legs. One type of reinforcement methods commonly used is by increasing area section capacity, where tower leg consisted of single angle section will be reinforced to be double angle sections. In addition, redundant members installed to divide the effective length of tower legs demands optimal effective length of tower legs so it can ensure strength and economic value of telecommunication tower structure.

Regarding this case, this research discussed behavior two types of double angle steel sections 2L 30.30.3
that were designed identically in area section but vary in length: 103 cm and 83 cm. Based on the experimental work, it can be observed member responses started from elastic condition until their failure due to a compression load.

### Table 1. Specimen Variations

| Numb | Specimen   | Member length (cm) |
|------|------------|--------------------|
| 1    | 2L 30.30.3 | 103                |
| 2    | 2L 30.30.3 | 83                 |

Truss system was formed with a 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 placement. 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 and based on these data, the response of two specimens can be specifically described and discussed.

2. Specimens Preparation

2.1 Experimental Work Setting Up
In determining response description of the compression member of double steel angle in truss system, this experimental work implemented two types of steel member (diagonal and horizontal member), and they were formed to be a truss system. When forming 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 a tensile component and horizontal member to be compression component. This experimental work was focused on a horizontal member that accommodated compression force.

For achieving the comparative result, both of specimens were planned similar on their batten plate distances: 206 mm for 2L 30.30.3 (103 cm) and 207.5 mm for 2L 30.30.3 (83 cm). Load recording was carried out through tension load cell and data logger. Meanwhile, deformation recording was done through transducers placed on flange and web of double steel angles.

2.2 Material Characteristics Determination
In obtaining steel angle characteristics that will be observed, coupon test was conducted in steel angle. Through this test, steel characteristics (yield stress and ultimate stress) were obtained, and they can be used as a description of steel angle mechanical properties.

### Table 2. Steel angle material characteristics

| Component | Stress (MPa) |
|-----------|--------------|
|           | Yield | Ultimate |
| Steel Angle | 224    | 324      |

2.3 Experimental Work Activities
Experimental work was started 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 would 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 an elastic condition so it can ensure the failure would occur at compression member at the first and the experimental work data can be optimally obtained.
3. Test Results and Discussion

3.1 Tensile Force – Deformation Curve Of Transducer 3 and Transducer 4

Deformation occurring on web and flange of angle can be obtained through transducer 3 and 4.

**Figure 1.** (a) Placement of transducers in truss system ; (b) Detail A : Upper gusset plate ; (c) Detail B : Bottom gusset plate ; (d) Detail C : Joint gusset plate ; (e) Detail D : Loading schematic of compression member ; (f) Specimen detail of 2L 30.30.3 (103 cm) and 2L 30.30.3 (83 cm)

![Tensile Force vs Deformation](image)

**Figure 2.** Tensile force – deformation curve of transducer 3

**Figure 3.** Tensile force – deformation curve of transducer 4

Experimental work showed that ultimate web deformation (buckling) of double angles (83 cm) was higher than ultimate web deformation of double angles (103 cm) with ultimate web deformation of double angles for
83 cm ($\delta_u$) was 18.61 mm and ultimate web deformation of double angles for 103 cm ($\delta_u$) was 15.437 mm. This was possible due to the failure mode of double angles (83 cm) that showed lateral buckling on a joint plate, so when buckling occurred on joint plate, member geometry will tend to follow the direction of plate buckling. Meanwhile, observation on angle flange showed that ultimate flange deformation (buckling) of double angles for 103 cm ($\delta_u$) was 45,49 mm. This value was higher than ultimate flange deformation (buckling) of double angles for 83 cm ($\delta_u$). It was 13,535 mm. This was possible due to the performance of double angles (103 cm) that was more optimal than double angles (83 cm), so it tended to give higher deformation (buckling) in compression member. It was different from double angles (83 cm). When premature buckling happened on joint plate, compression member was unable to increase its strength due to a compression force.

3.2 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 double compression members (103 cm) and double compression members (83 cm) showed that compression members (83 cm) performed ultimate member force ($S_{u2} = 57144,58$ N) and ultimate tensile force ($P_{u2} = 47950$ N). Both of these values were higher than double compression member (103 cm) values with ultimate member force ($S_{u1} = 50172,83$N) and ultimate tensile force ($P_{u1} = 42100$ N). There were about 14 % in difference for ultimate member force and ultimate tensile force between double compression members (103 cm) and double compression members (83 cm).

Furthermore, 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. Comparisons of ultimate member forces and ultimate tensile force for double compression members (103 cm) and double compression members (83 cm) based on experimental work results, SNI 03-1729-2002, and SNI 03-1729-2015 were:

![Figure 4. Comparation among ultimate tensile forces](image1)

![Figure 5. Comparation among ultimate member forces](image2)

Based on two bar charts above, it can be shown that either for ultimate member forces or ultimate tensile forces, experimental work results were higher than ultimate member force and ultimate tensile force of SNI analysis results. This is possible because SNI analysis commonly used for design needs referred to critical stress ($F_{cr}$) and based on coupon test on this research, critical stress value is smaller than yield stress. So it can be understood that SNI conducted analysis on the elastic range. Experimental work that was carried out over yield condition can be ensured to give higher compression load than SNI analysis. Comparison between analysis results of SNI 03-1729-2002 and SNI 03-1729-2015 showed that there was improving strength in compression from double angles (103 cm) to double angles (83 cm). Based on SNI 03-1729-2002, this improvement was 27 %. Meanwhile, based on 03-1729-2015, this improvement was 89 %. These facts showed that an aspect of reinforcement in double angles with shortening the effective length of the member, SNI 03-1729-2002 tended to show more conservative (safer) results than SNI 03-1729-2015 results.
3.3 Failure Modes of Compression Member

Failure modes for both of specimens were different each other. The failure mode of double angles (103 cm) 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 where this failure commonly occurs on steel section due to the slenderness of area section. The failure mode of double angles (83 cm) was lateral buckling on the joint plate due to lack of capacity of the joint plate in accommodating tensile force. This failure caused double angles (83 cm) was unable to perform optimally. It can be shown through its deformation either in flange or web that did not significantly occur when the failure happened on the joint plate.

![Figure 6](image_url)

**Figure 6.** Comparison of Failure Modes : (a) Failure mode of double angles (103 cm) ; (b) Failure mode of double angles (83 cm)

4. Conclusion

Based on the observation, it can be concluded that higher compression strength ($P_{u \ max} = 47950$ N) was achieved by double angles (83 cm) due to the smaller slenderness of double angles (83 cm), meanwhile higher deformation on flange ($\delta_u$ flange = 45.49 mm) was reached by double angles (103 cm) due to better performance in accommodating compression force. Besides, it can be found that ultimate member force and ultimate tensile force obtained from experimental work results were higher than SNI analysis results due to SNI criteria refers to the elastic condition. According to the analysis, it was found that comparison between analysis results of SNI 03-1729-2002 and SNI 03-1729-2015 showed that SNI 03-1729-2002 was more conservative (safer) in the aspect of reinforcing double angles with shortening the effective length of member than SNI 03-1729-2015.

References

[1] AISC 360-05 2005 Specification for Structural Steel Building (AISC Chicago-USA)
[2] Hasibuan P 2013 Identifikasi Gaya Batang Tekan Baja Profil Siku for Berbagai Macam Tumpuan melalui Metode Vibrasi Laporan Penelitian Tesis Universitas Gadjah Mada Yogyakarta (in Indonesian)
[3] Liu Y and Hui L 2008 Experimental study of beam-column behaviour of steel single angle Journal of Constructional Steel Research. 64 505-514
[4] Sakla S S S 2001 Tables for the design strength of eccentrically-loaded single angle struts Engineering Journal (Tanta University Egypt)
[5] SNI 03-1729.1-2015 Spesifikasi for Gedung Baja Struktural Badan Standarisasi Nasional (in Indonesian)
[6] SNI 03-1729.1-2002 Spesifikasi for Gedung Baja Struktural Badan Standarisasi Nasional (in Indonesian)