IEEE Guide for the Design and Testing of Transmission Modular Restoration Structure Components

IEEE Power Engineering Society

Sponsored by the
Transmission and Distribution Committee

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Abstract: A generic specification, including design and testing, for transmission modular restoration structure components used by electric utilities is provided.
Keywords: box sections, column sections, end plates, foundations, gimbals, guy plates, transmission mutual aid

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Introduction

This introduction is not part of IEEE Std 1070-2006, IEEE Guide for the Design and Testing of Transmission Modular Restoration Structure Components.

In the past years, most of the utilities in North America have joined together through mutual aid programs to help one another in case of emergencies. As part of the mutual aid for transmission, a modular restoration structure was developed and is now being used by several utilities worldwide. The versatility of this structure and its contribution to the utility industry prompted the preparation of this guide.

This guide is generic in its design so that any utility desiring to use the modular concept as part of a mutual aid plan can do so. Structures built to this design would then be compatible with the structures of another company using the same concept. This feature affords many positive results in that savings are realized in crew training, crew readiness for emergencies, and total investment of emergency structures (i.e., fewer structures because structures could be loaned from mutual aid participants). Of course, this modular concept is not limited to any particular application.

Numerous requests for a generic design of a modular structure were received from throughout the industry. The Subcommittee on the Engineering in the Safety, Maintenance and Operation of Lines (ESMOL), part of the Transmission and Distribution (T&D) Committee of the IEEE Power Engineering Society, accepted this project. A working group from the ESMOL Subcommittee was formed to complete this task. The guide published in 1995 has now been updated and revised by this 2006 edition.

This guide represents a significant contribution to the utility industry that emphasized the spirit of cooperation between diverse groups in the presentation of such a document and is based on sound engineering principles and accepted operational practices. It is the intention of the ESMOL Working Group to continue to update this guide as future needs dictate.

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Contents

IEEE Guide for the Design and Testing of Transmission Modular Restoration Structure Components

1. Overview

1.1 Scope

This guide will provide the industry with a generic specification, including design and testing, for transmission modular restoration structure components.

1.2 Purpose

The purpose of this guide is to provide the industry with a generic specification that can be used by companies for acquisition of transmission modular restoration structure components. This particular design would then be compatible with the modular restoration structures presently in use within the utility industry and allow the highly successful plan of transmission mutual aid to be greatly enhanced.

The testing prescribed in this standard provides a high level of confidence between manufacturers and/or suppliers and is intended to promote competitive acquisition practices within the industry.

This guide is not intended to be an application guide for complete assembled emergency restoration structures. However, the application and capabilities of emergency restoration structures that utilize the components described in this guide have been well documented by Goodreid and Magwood [B6],[1] Rutty, et al. [B11], Aristizabal and Cortez [B2], Lopez Tagle, et al. [B8], Pohlman, et al. [B9] and [B10], Agrawal and Erickson [B1], and Schweiner, et al. [B11].

2. Normative references

The following referenced documents are indispensable for the application of this guide. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

AISI C1040 Metals Handbook, Vol. 1 – Properties and Selection: Irons, Steels, and High-Performance Alloys, ASM International, 10th ed., 1990.[2]

[1] The numbers in brackets correspond to the numbers in the bibliography in Annex A.
[2] AISI publications can be found at: http://www.asminternational.org.

Aluminum Design Manual, Aluminum Association, 2000.[3]

Aluminum Standards and Data, Aluminum Association, 2000.

Aluminum Structural Welding Code, American Welding Society, 1997.

ANSI/AWS D1.2, Structural Welding Code—Aluminum.[4]

ASTM A36/A36M, Standard Specification for Carbon Structural Steel.[5]

ASTM A123/A123M, Standard Specification for Zinc (Hot Galvanized) Coatings on Iron and Steel Products.

ASTM A153/A153M, Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware.

ASTM A240/A240M, Standard Specification for Heat-Resisting Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels.

ASTM A394, Standard Specification for Steel Transmission Tower Bolts, Zinc-Coated and Bare.

ASTM B209, Standard Specification for Aluminum and Aluminum-Alloy Sheet and Plate.

ASTM B308/B308M, Standard Specification for Aluminum Alloy 6061-T6 Standard Structural Profiles.

ASTM B633, Standard Specification for Electrodeposited Coatings of Zinc on Iron and Steel.

3. Technical requirements

3.1 Material

All structural shapes and plates used in fabrication of all sections, foundations, guy plates, and box sections should be of 6061-T6 and 6061-T651 aluminum alloy.

All filler alloy used to weld aluminum shapes and plates should be 4043 alloy.

All structural shapes and plates should be certified as having the alloy and temper as specified above. All filler alloy should also be certified as having the alloy as specified above. The manufacturer should keep certifications on file and make copies available to the purchaser.

[3] For more information please see http://www.aluminum.org/.
[4] ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (http://www.ansi.org/).
[5] ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA (http://www.astm.org/).

Any steel used in fabrication of the gimbal joints should conform to specifications given in ASTM A36/A36M.[6] After fabrication, all steel should be hot dip galvanized in accordance with ASTM A123/A123M.

All bolts should be made from AISI C1040 steel. The shape of the bolts and nuts should conform to the specifications of a 5/8-UNC regular semi finished hexagon bolt and nut. All bolts should be 88.9 mm long and have a minimum thread length of 63.5 mm. Bolts and nuts should be electroplated zinc coated in accordance with ASTM B633. If the components are to be kept in service longer than three years, appropriate aluminum bolts should be used.

Stainless steel washers, type 304 or equivalent, should be permanently affixed to the 2.134 m, 4.267 m, and 6.4 m tower sections' connection holes (16 places per tower section); see Figure 1 (A and B).

3.2 Design considerations[7]

The 610 mm × 610 mm lattice column was designed with aluminum diagonal angles to a compressive load of 334 kN at a column height of 25.6 m. The basic column section is 6.4 m with other column heights of 4.27 m and 2.13 m. These combinations allow considerable flexibility in building structures for most standard transmission voltages. These three lengths maintain the same diagonal spacing for ease of climbing. The entire column assembly is welded for consistency, strength and to eliminate the loss of bolted members.

The column end plates have guide pins and mating holes for ease in assembly. The assembly hole pattern on the end plates has the same spacing throughout, and it meshes with all other components. A 4 in channel is placed next to the end plates to create a stacking slot. A hole is centered in the column end plates and can be used for a load line through the center section of the columns.

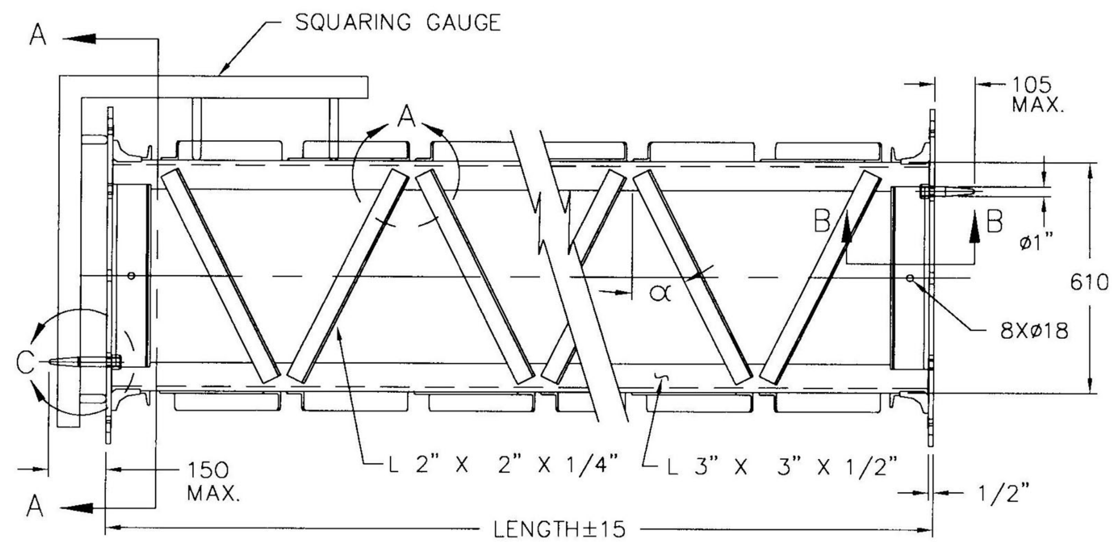
The foundation base has the same assembly hole pattern as the columns. Handholds (lifting rings) are provided, and large holes conveniently spaced are for stabilizing bars, which can be driven into the ground or bolted to a crib of crossarms or cross ties.

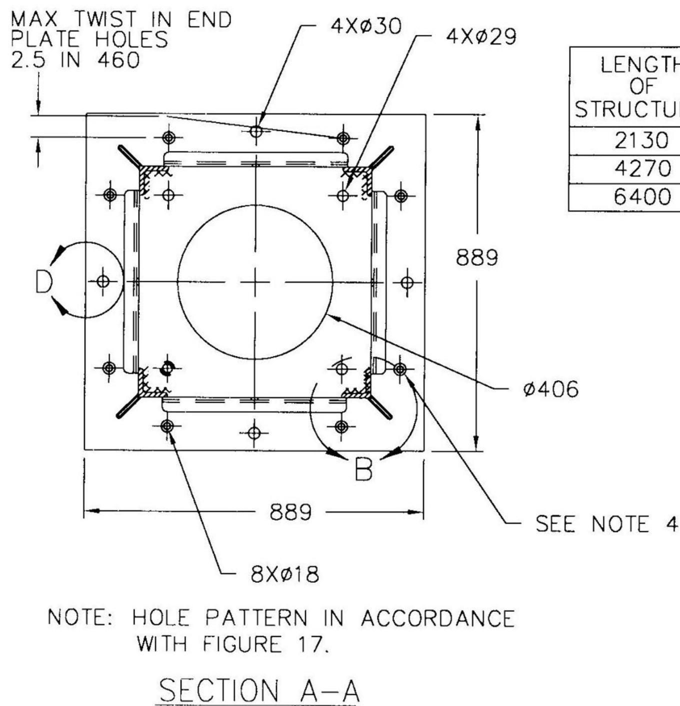
The guy plates fit between the column sections to serve as guy wire and insulator attachment points. The assembly bolts are long enough to connect two column end plates and three guy plates, as required. The three holes in the guy plates are to accommodate spread or straight guys. If a temporary guy is necessary, the permanent guys can be installed without affecting the temporary guy.

The box section is available to support horizontal post insulators, provide vertical spacing for bundle conductors and attachment points high strength guy plates, if required. The box section has the same assembly hole pattern and can be used between column sections and guy plates or above the foundation to help level a structure. The gimbal is 2.13 m high and meshes with the foundation and column end plates. According to its intended use, the gimbal can remain a pivot, or it can be connected in a rigid manner with stays.

Combinations of these parts can make a variety of structures, as shown in Goodreid and Magwood [B6], Grose [B7], and Van Name, et al. [B13].

[6] Information on references can be found in Clause 2.
[7] See Cole [B3].





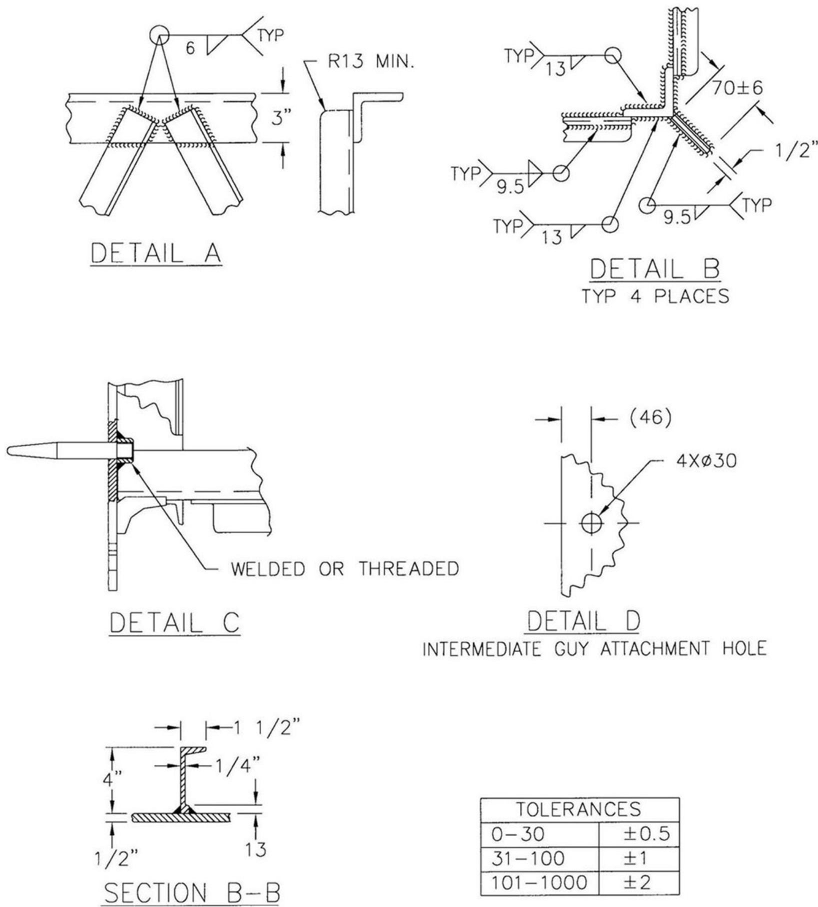
LENGTH OF STRUCTURE	TOTAL QTY. OF LATTICE MEMBERS	QTY. OF LATTICE MEMBERS ON EACH SIDE	ANGLE OF LATTICE α ±.1°
2130	24	6	24.2°
4270	48	12	26.5°
6400	72	18	26.7°

TOLERANCES	
0–30	±0.5
31–100	±1
101–1000	±2

NOTE 1—All dimensions are in millimeters unless otherwise noted.[8]
NOTE 2—Structure fabrication should conform to Clause 3.
NOTE 3—Each section to be supplied with ten bolts, nuts, and lock washers in accordance with 3.1.
NOTE 4—The ø25 guide pins should be on opposite corners
NOTE 5—Affix eight stainless steel washers to the eight ø18 holes on each tower end plate as shown.

Figure 1A—Column section design tolerance

[8] Notes in text, tables, and figures are given for information only, and do not contain requirements needed to implement the guide.



NOTE 1—Structure fabrication should conform to Clause 3.
NOTE 2—Each section to be supplied with ten bolts, nuts, and lock washers in accordance with 3.1.
NOTE 3—The ø25 guide pins should be on opposite corners.

Figure 1B—Column section design and tolerance

3.2.1 Column design and tolerance

For column sections, all manufacturing tolerances and basic design should be as specified in Figure 1. The number of diagonals required for each tower section should be as specified in Figure 1. The diagonals should be positioned on the tower with all flanges located in the same direction, as shown in Figure 1, to facilitate tower climbing.

3.2.2 End plate design and tolerance

For end plates, all manufacturing tolerances and basic design should be as specified in Figure 1. The perpendicularity tolerance should be a maximum deviation of 3.17 mm over a 610 mm distance.

3.2.3 Guy plate design and tolerance

For guy plates, basic design and all manufacturing tolerances should be as specified in Figure 2.

3.2.4 Gimbal design and tolerance

For gimbals, basic design and all manufacturing tolerances should be as specified in Figure 3.

3.2.5 Foundation base design and tolerance

For foundation bases, basic design and all manufacturing tolerances should be as specified in Figure 4.

3.2.6 Box section design and tolerance

For box sections, basic design and all manufacturing tolerances should be as specified in Figure 5.

3.2.7 Workmanship

All work should be performed using the best modern practices of the industry. Material should be as specified in 3.1 (new and free of defects or irregularities). All components of the same design and designation should be identical; like components should be interchangeable. All corners should be rounded and sharp edges should be broken.

3.3 Fabrication

Fabrication should not begin until the purchaser has approved drawings. The best modern practices should be used in the manufacture and fabrication of the types of materials covered in this guide.

3.3.1 Bending

All bending should maintain sufficient thickness of material in order to provide full strength without impairing the material.

3.3.2 Cutting

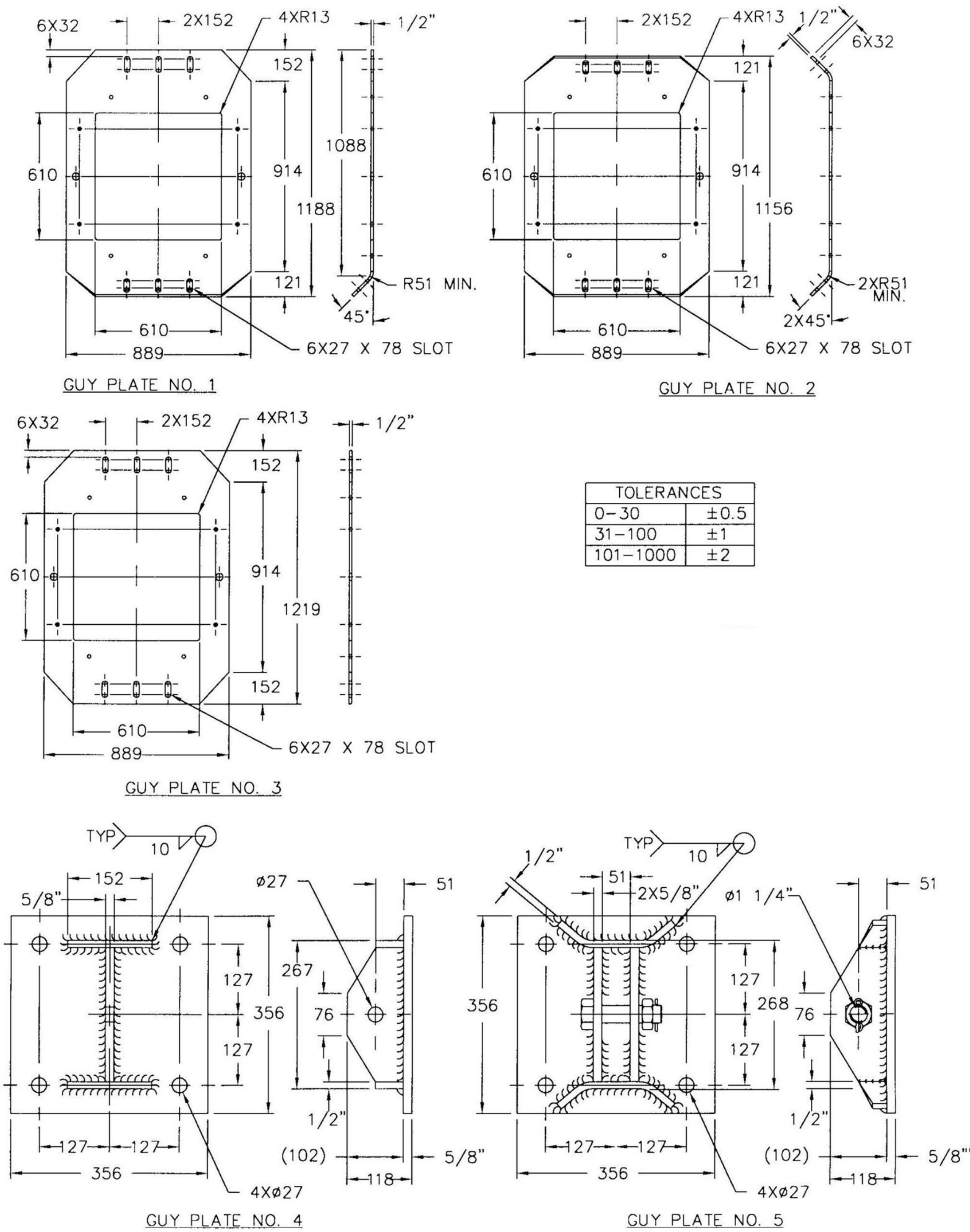
Cutting of plates and structural shapes should be guided by electrical or mechanical means to assure a neat, accurate cut. Cuts should be clean and free from sharp edges.

3.3.3 Drilling and milling

All load-bearing holes should be drilled, and all slots should be milled in all material thicknesses. Punching of holes or slots is not recommended.

3.3.4 Welding procedures

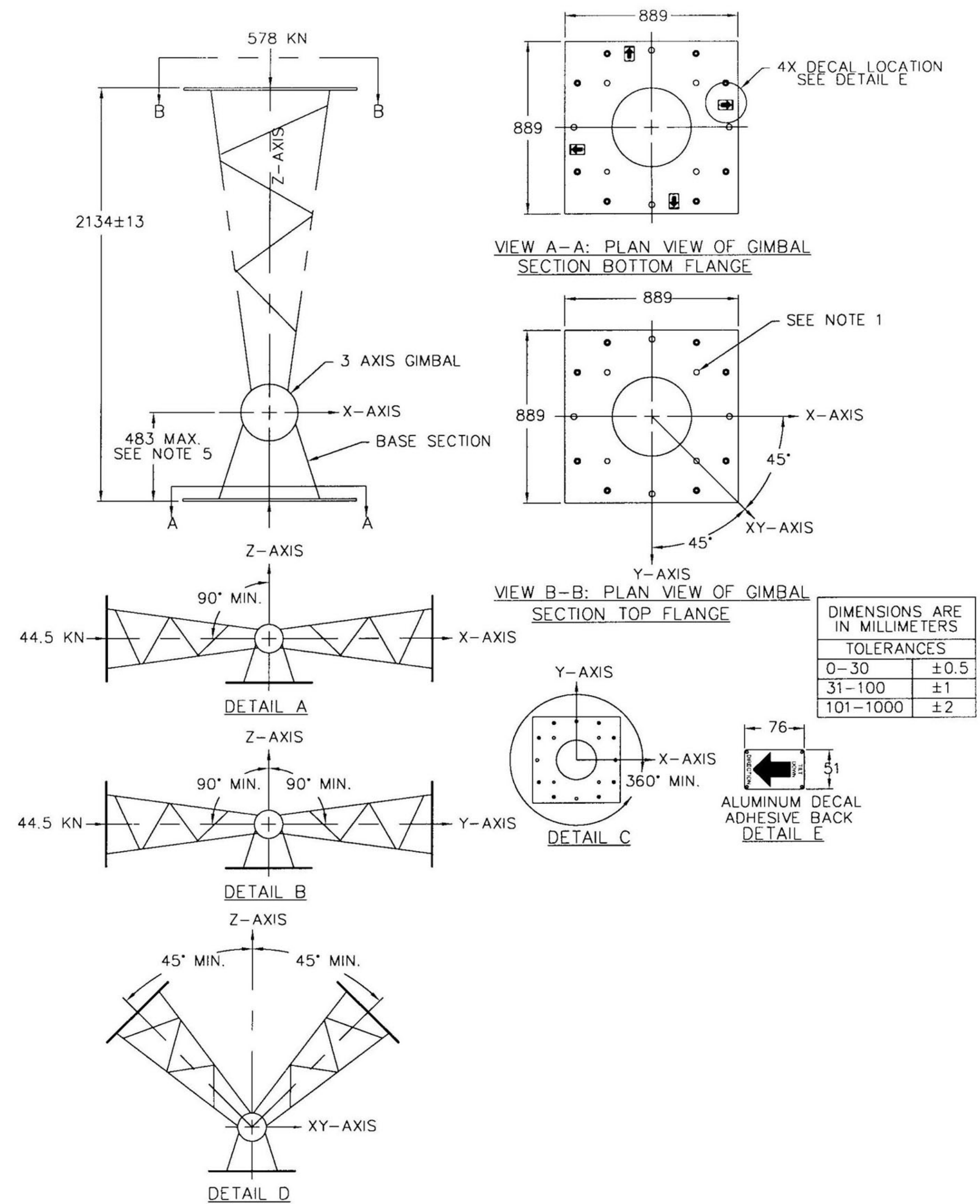
Welding procedures should be in accordance with American Welding Society’s *Aluminum Structural Welding Code*. All welds should completely seal. There should be no voids or seams between joining surfaces into which fluids may enter. Welders and welding operators should be qualified in accordance with ANSI/AWS D1.2.



TOLERANCES	
0–30	±0.5
31–100	±1
101–1000	±2

NOTE 1—All dimensions are in millimeters unless otherwise noted.
NOTE 2—Holes on plates 1, 2 and 3 should be interchangeable with holes on towers, foundation base, and box section as shown in Figure 1, Figure 4, and Figure 5.

Figure 2—Guy plate design and tolerance



NOTE 1—All dimensions are in millimeters unless otherwise noted.

NOTE 2—Holes on gimbal section top and bottom flange should be interchangeable with holes on towers, foundation base, and box section as shown in Figure 1, Figure 4, and Figure 5.

NOTE 3—The gimbal section should be designed to be locked rigidly parallel to the two axes for ease of storage and transportation. When unlocked, the top section of the gimbal should be able to rotate as follows:

a. ± 90° about the Y-axis (see detail A)
b. ± 90° about the X-axis (see detail B)
c. 360° about the Z-axis (see detail C)
d. ± 45° about the XY-axis (see detail D)

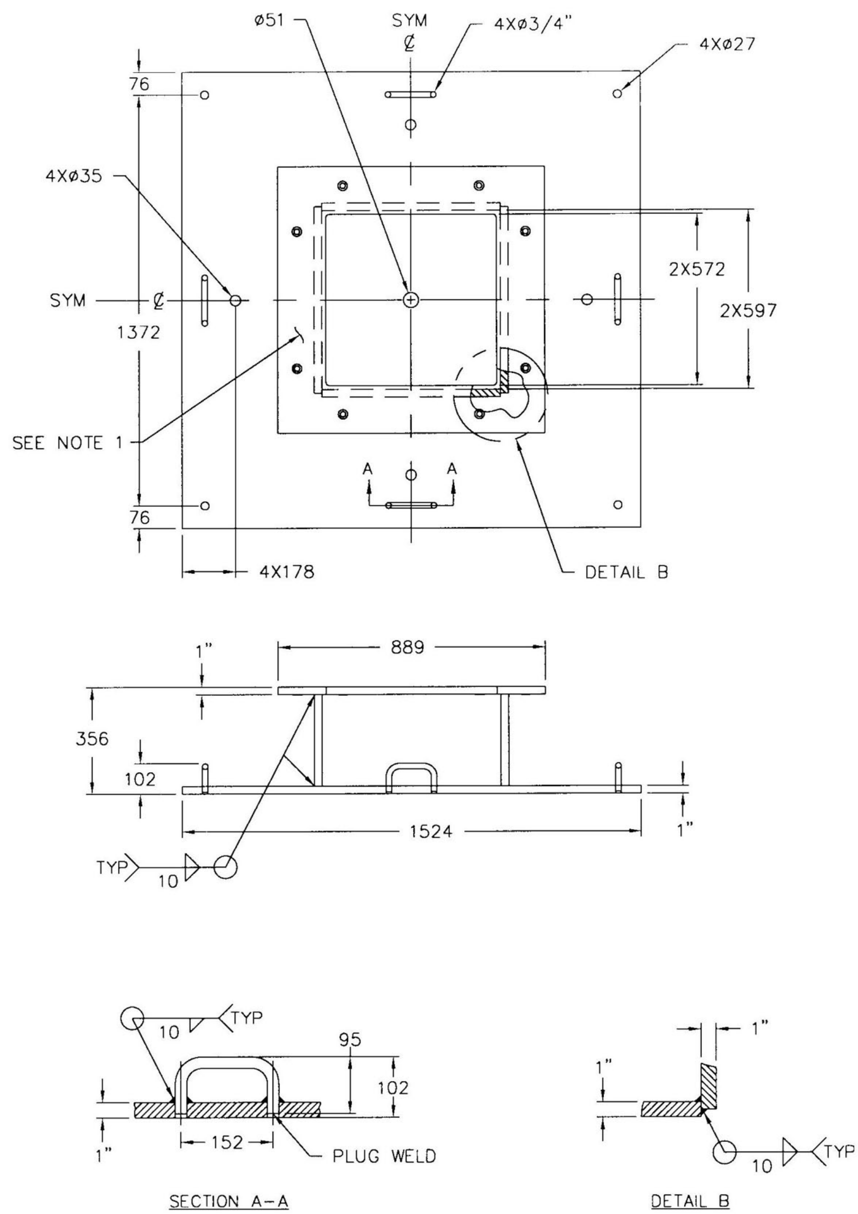
NOTE 4—When unlocked, all three axes of the gimbal should be mechanically held together so that any rotations, or combination of rotations as described in Note 2, should not cause the top and base sections to separate.

NOTE 5—When unlocked, the gimbal should be designed to allow disconnecting the top section from the bottom section.

NOTE 6—The X-axis and Y-axis should be a maximum of 483 mm above the flange of the base section and should be at least 127 mm above the flange of the base section.

NOTE 7—Each gimbal section to be supplied with ten bolts, nuts, and lock washers in accordance with 3.1.

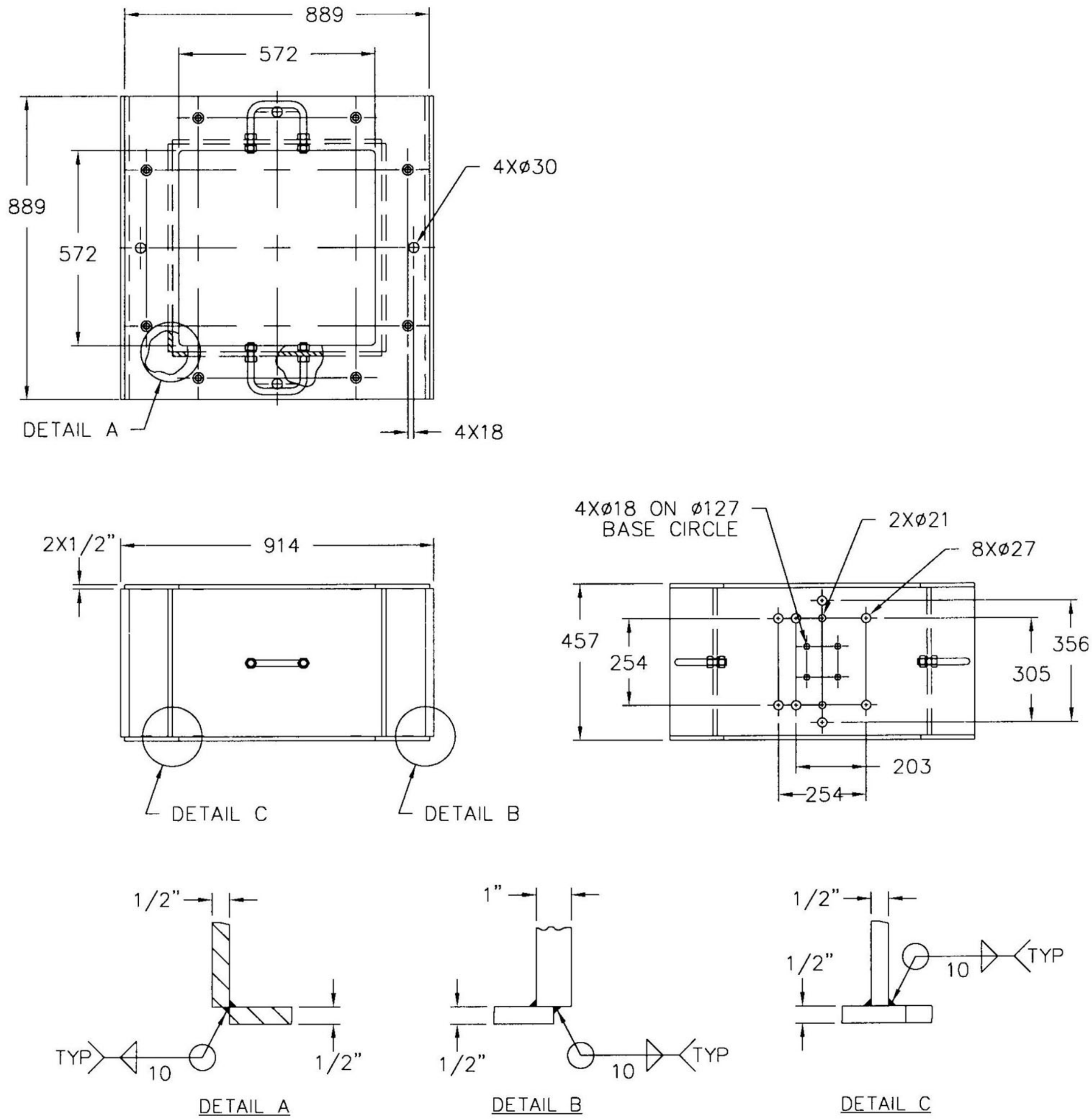
Figure 3—Gimbal design and tolerance



TOLERANCES	
0–30	±0.5
31–100	±1
101–1000	±2

NOTE—Holes on base flange should be interchangeable with holes on towers, gimbals, and box sections as shown on Figure 1, Figure 3, and Figure 5.

Figure 4—Foundation base design and tolerance



TOLERANCES	
0–30	±0.5
31–100	±1
101–1000	±2

NOTE—Holes on box section top and bottom flange should be interchangeable with holes on towers, gimbals, and foundation bases as shown on Figure 1, Figure 3, and Figure 4.

Figure 5—Box section design and tolerance

4. Test requirements

4.1 Strength test verification

The first production units of 6.4 m column sections, guy plates, and box sections should be tested by the manufacturer as specified in 4.1.1 through 4.2.3 and as illustrated in Figure 6 through Figure 16. A detailed test report should be submitted. Elastic and permanent deformation of each component should be measured to 0.025 mm, at load intervals of 50%, 75%, 90%, and 100% of the maximum test load and recorded in the test report. All test loads should be held for 5 min before measurements are taken.

If the manufacturer has previously tested the same design, in accordance with these or equivalent requirements, and manufactured the same assemblies listed below, the results of those tests may be submitted in lieu of performing new tests.

4.1.1 Compression of the columns

A 6.4 m column should be tested to 290 kN, with compression applied at the center axis (see Figure 6). Maximum permanent deformation should be less than 0.508 mm.

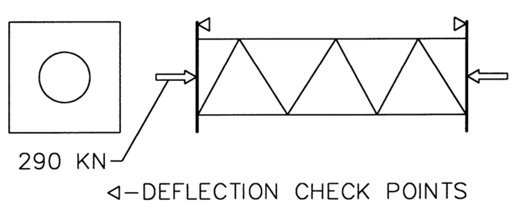


Figure 6—Compressive load test

4.1.2 Bending of columns

Using production bolts and nuts, a 6.4 m column section should be bolted to a suitable test structure on one end of the column. A cantilever load of 11.34 kN should then be applied at the center axis of the opposite end without failure (see Figure 7). Maximum permanent deformation should be less than 2.032 mm.

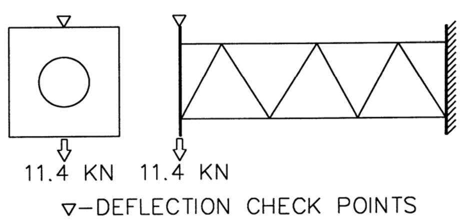


Figure 7—Cantilever load test

4.1.3 Torsion strength

A 6.4 m column section should be tested as in 4.1.2 except that an 8 kN load should be applied at the cantilevered end at a point 0.457 m from the center axis of the column without failure (see Figure 8). Maximum permanent rotational deformation of the column should be less than 0.5°.

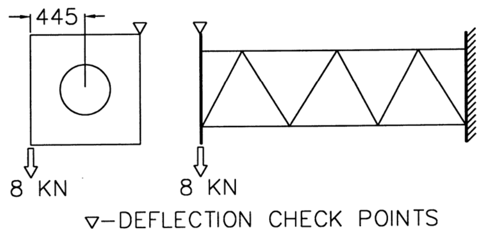


Figure 8—Torsional load test

4.1.4 Combined bending and compression test

A 6.4 m column section should be loaded to 445 kN compression and 22.2 kN cantilever load simultaneously. The loads, elastic and permanent deflections, should be measured and recorded (see Figure 9). Maximum permanent deformation should be less than 0.508 mm in compression and 2.54 mm in bending.

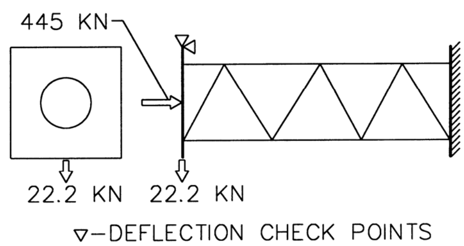


Figure 9—Compressive and cantilever load test

4.1.5 Ultimate strength bending—bolts

Using production bolts and nuts, a 6.4 m column section should be bolted to a suitable test structure on one end of the column (identical to Figure 7 except with the loads specified in the following sentences in this paragraph). A load should be applied at a rate not to exceed 8.9 kN/min. The combined assembly of column, bolts, and nuts should have an ultimate strength greater than an equivalent moment of 190 000 Nm. The first component to fail should be the bolt and nut assemblies. The welded column should not be the first to fail; however, secondary failure of the welds after a bolt failure is permissible.

4.1.6 Ultimate strength bending—welds

Using extra high strength bolts and nuts, a 6.4 m column section should be bolted to a suitable test structure on one end of the column (identical to Figure 7 except with the loads specified in the following sentences in this paragraph). Four tests should be performed by rotating the column. A load should be applied at a rate not to exceed 8.9 kN/min unless failure occurs. In no case should the column have an ultimate strength less than an equivalent moment of 190 000 Nm.

4.1.7 Box section load test

The box section should be pull tested (using test fixtures similar to guy plate No. 5) at the transverse hole locations to 267 kN across the box section without failure or excessive permanent deformation (see Figure 10).

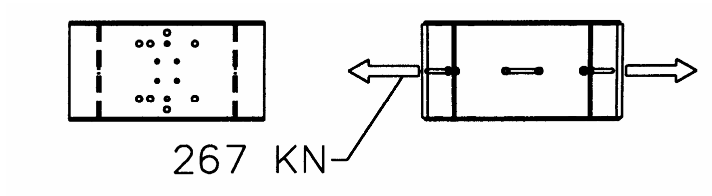


Figure 10—Box section load test

4.1.8 Guy plate load test

a) Guy plate No. 3 should be pull tested to 133.5 kN using a 19.05 mm diameter bolt from the center slots as shown in Figure 11, as a qualification test for plates No. 1, No. 2, and No. 3. No failure or excessive permanent deformation of the plate should occur.

b) Guy plate No. 4 should be pull tested to 133.5 kN perpendicular to the mounting base as shown in Figure 12. No failure or excessive permanent deformation of the plate should occur.

c) Guy plate No. 5 should be pull tested to 267 kN perpendicular to the mounting base as shown in Figure 13. No failure or excessive permanent deformation of the plate should occur.

NOTE—One-inch diameter bolts are to be used to anchor plates No. 4 and No. 5.

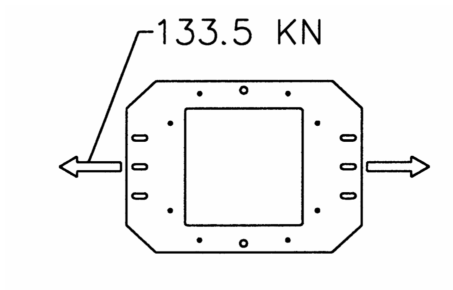


Figure 11—Tensile load test guy plate No. 1, No. 2, and No. 3

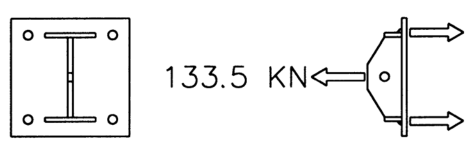


Figure 12—Tensile load test guy plate No. 4

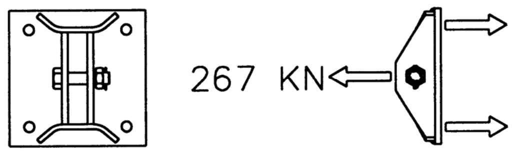


Figure 13—Tensile load test guy plate No. 5

4.1.9 Bolt and nut ultimate strength test

Three samples from the production run of 5/8-UNC tower connection bolts and nuts should be pull tested (see Figure 14). The average ultimate strength of three assemblies should be greater than 107 kN.

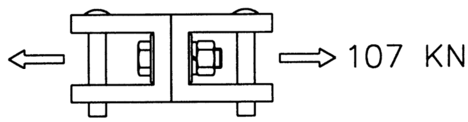


Figure 14—Tensile load test of tower connection bolts and nuts

4.1.10 Column buckling test

A quantity of six 6.4 m column sections should be bolted together with production bolts and nuts. The column should be tested horizontally, and a simultaneous 156 kN axial load should be applied to the column (see Figure 15). The load should be held for 5 min and then released. The maximum permanent deformation should be less than 3.2 mm.

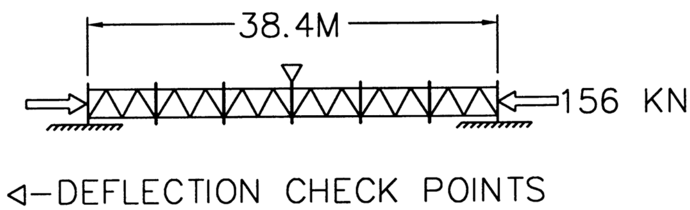


Figure 15—Column buckling test

4.1.11 Stainless steel washer freeze/thaw test

A stainless steel washer should be affixed to a production type sample of tower section end plate material. The test sample should then be heated to 90 °C for a period of 2 h. The test sample should then be cooled to room temperature for 2 h. Finally, the test sample should be cooled to 0 °C for 2 h. This 6 h cycle should be repeated five times. A production type bolt, nut, and lock washer should then be bolted to the test sample. Torque the bolt-nut assembly from 54 Nm to 163 Nm in 13.5 Nm increments. At no time during freeze-thaw cycle or torque test should the stainless steel washer break away from the aluminum test sample.

4.2 Gimbal tests

If the manufacturer has previously tested the same design, in accordance with these requirements or equivalent agreed to by the purchaser, and manufactured the same assembly, the results of those tests may be submitted in lieu of performing new tests.

4.2.1 Gimbal articulation tests

The first production units of a gimbal section should be tested by the manufacturer to verify the minimum rotation requirements as specified in Note 2 of Figure 3.

4.2.2 Gimbal compression tests

The first production unit of a gimbal section should be tested by the manufacturer. The gimbal should be tested in compression to 578 kN, with the load applied at the center axis of the gimbal as shown in Figure 3. No sign of excessive permanent deformation of the gimbal should be noted at 578 kN compression load.

4.2.3 Gimbal transverse test

The first production unit of a gimbal section should be tested by the manufacturer. The gimbal should be loaded to 44.5 kN as shown in details A and B of Figure 3. No sign of excessive permanent deformation should be noted after the test.

5. Production test requirements

5.1 Strength proof test

Before shipment, each column section should be subjected to a proof test of 290 kN compressive load applied on the center axis of the structure and held for 5 min (see Figure 16). No failure should occur.

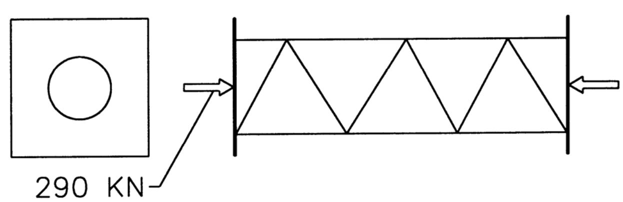


Figure 16—Production proof load test

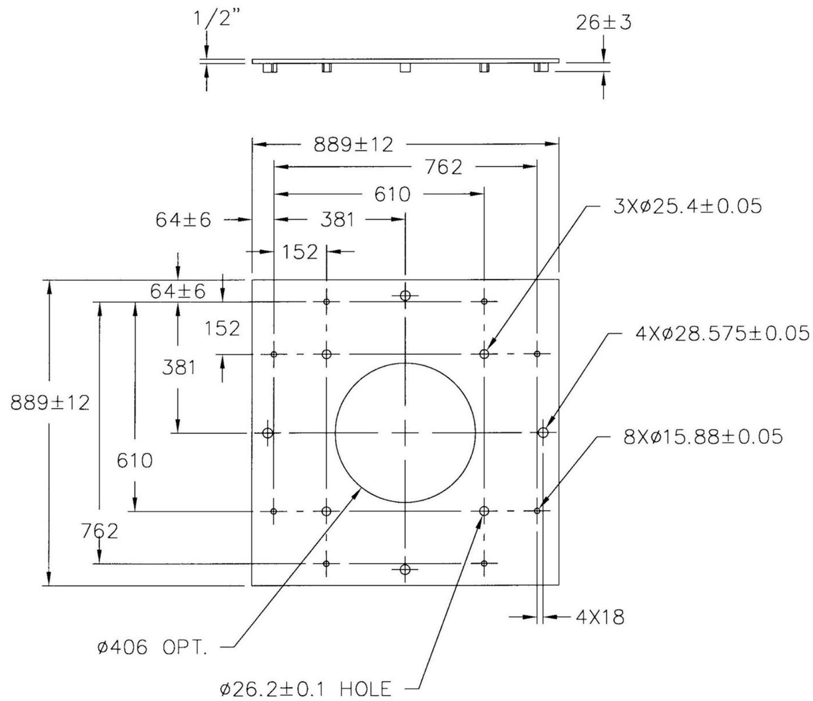
5.2 Dimensional test

5.2.1 End plate

Prior to shipment, each column section, box section, and gimbal should be checked with a jig or fixture to verify required tolerances for pin and bolt hole alignment, thus assuring interchangeability of tower sections. The fixture should be manufactured to the dimensions and tolerances shown in Figure 17.

5.2.2 Parallel end plate

The end plates of each column section should be measured with a squaring gauge to verify the perpendicularity of the end plate to the vertical leg of the column. The points of measurement should be at a point on the plate opposite and in line with the column legs, as shown in Figure 1. This check should be repeated on all four sides and at both ends of the column. The tolerance should be as specified in 3.2.2.



TOLERANCES	
0–30	±0.1
31–100	±0.1
101–1000	±0.1

Figure 17—End plate checking fixture

6. Other requirements

6.1 Identification

Every column section, base fixture, box section, and gimbal should be marked with the manufacturer's name, part number, tower type, serial number, and date of manufacture. Guy plates should be marked with part numbers. In addition, each column section should be marked with the applied proof test load. These markings should be permanently embossed on a nameplate in a protected location.

6.2 Modification

Design modifications should be tested in accordance with the specifications as set forth in Clause 4. Any design modification should not inhibit the basic interchangeability and integrity of the equipment. All design modifications should meet or exceed the technical and fabrication requirements set forth in 3.2 and 3.3. Complete test data and test certifications should be permanently documented and made available to the users of the components.

Annex A

(informative)

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