January 31, 2019

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Subject: Moonlight Towers Replacement Parts Vendor Research Summary

Enertech Resources, LLC Project Number: 18-20-0229

Project Name: **Inspection, Repair, and Restoration of Moonlight Towers**

Mr. Pittman,

Enertech Resources, LLC is pleased to submit this **"Moonlight Towers Replacement Parts Vendor Research Summary"** containing a log of our efforts to identify suitable replacement star-post members for the Moonlight Towers restoration project.

In our efforts to repair and restore the Moonlight Towers, existing tower leg "Star Post" members have been taken from storage or other towers to be used as replacements for members that do not meet specifications. We have reached a point in the process at which no further towers can be restored without either casting / fabricating replacement parts or decommissioning additional towers in order to borrow acceptable parts. In an effort to aid in the identification of suitable replacement parts, we have reviewed historical documentation, material tests, and reached out to various foundries. The findings of our efforts are contained within this report.

Historical documentation identifies the Star Post material as "wrought iron", with similar properties to that of steel (Exhibit A). Enertech has commissioned additional testing of the Star Post materials (Exhibit B), with results indicating that the material is a low-carbon steel, likely cast, similar in physical properties to what was identified in the historical testing.

In order to identify suitable replacement parts for the failing Star Posts, we considered the results of the previous restoration project as well as modern production methods. The original method of casting, as well as modern methods of production such as rolling, extrusion, machining (milling), and the use of substitute shapes such as standard square tube were considered for their similarity to the original star posts, strength of materials, production availability, and cost to produce. A request for the use of substitute shapes was reviewed by the Texas Historical Commission, which has currently declined to amend the permit based on the information submitted and requested that Austin Energy and Enertech continue to pursue alternative options (Exhibit E).

The criteria for production of the Star Posts were determined from both the previous restoration's evaluation requirements and from modern materials testing results. The previous restoration project includes standards for straightness and identification of defects. The material testing commissioned by Enertech Resources in 2016 identifies modern equivalents to the type of steel found in the Star Posts, which guided recommendations for fabrication of new members. These specifications as provided to potential fabricators are included in Exhibit C.

Because the original Star Post members are believed to be cast, this method was given preference in searching for foundries to produce replacement parts. We were not able to find a foundry which felt they would be capable of producing the Star Posts, either due to the overall size of the members, or because of the challenges associated with maintaining straightness of members which are as long and narrow as required. A summary of contact with these 21 vendors is provided in Exhibit D.

In summary, the optimal replacement Star Post material was identified to be steel, based on historical testing and similarity to the existing material properties. In order to shape the material into the unique cross section of the Star Posts, it would either need to be cast, extruded, or milled. Extrusion methods are unable to maintain the straightness specifications as required. Casting was found to be unavailable in the sizes required or unable to maintain the specifications provided. For this reason, we would like to request on behalf of Austin Energy to mill the star post replacements in order to maintain the Star post shape, strength of materials, and production availability. This request and our findings are in agreement with the results of the APT Bulletin report (Exhibit A).

Respectfully submitted by:

Dale B. Shumaker, PE January 31, 2019
Vice President

Attachments:
Exhibit A – Preservation Study of the Moonlight Towers, Austin, Texas – APT Bulletin
Exhibit B – Material Property Testing of Moonlight Tower Star Member Section
Exhibit C – Moonlight Towers Star Post Detail and Evaluation Criteria
Exhibit D – Fabricator Contact Log
Exhibit E – Re: Proposed Amendment to Historic Buildings and Structures Permit #784, Austin “Moonlight Towers,” Restoration of 17 Towers, Travis County, Texas

Preservation Study of the Moonlight Towers, Austin, Texas

MARK MOORE, PE, and KARL STRAND

Restoration of the Moonlight Towers was undertaken by the Electric Utility Department of Austin, Texas, in order to preserve an unusual and significant form of street lighting. The approach used by the architects and engineers permitted careful evaluation of the existing towers, development of a phased program for restoration, and identified the elements which required replacement.

The Moonlight Towers, built in Austin, Texas, in 1895, have been well maintained throughout their life. However, the wrought iron lighting towers had been exhibiting deterioration from corrosion, vehicular impacts, and overstressed components. Of the thirty-one original towers, sixteen remain standing. Owned and operated by the Electric Utility Department, City of Austin, Texas, the towers are registered with the Austin Historic Landmark Commission and are listed in the National Register of Historic Places and the Historic American Building Survey. All of the remaining towers are located within an approximately three-mile radius of downtown Austin with the exception of one tower, which was relocated to Austin Municipal Park, approximately fifteen miles northwest of the city.

In 1985, the City of Austin commissioned a detailed study of the Moonlight Towers, with the primary purposes being to evaluate the condition of the towers and to identify repairs that would be necessary to restore the towers as close as possible to their original condition. The goal of the restoration effort was to achieve approximately one hundred additional years of service.

As part of the restoration effort, comprehensive research relating to the history of the towers was conducted by Geier, Brown, Renfrow, Architects, Washington, D.C. (GBR). The historical background of the towers is fully described in a report entitled "Moonlight Towers – Structural Evaluation, Phase I," prepared by GBR and Wiss, Janney, Elstner Associates, Inc. The historical information presented in this paper was condensed from the work done by GBR.

History

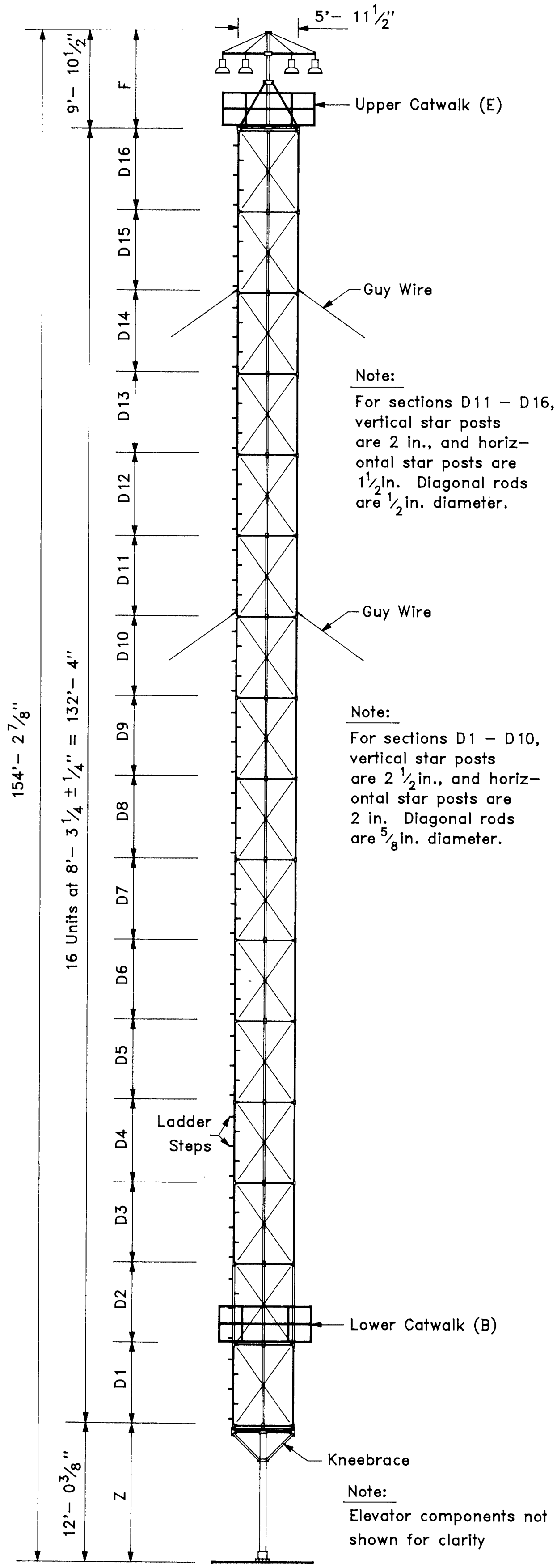
By the early 1890's, Austin had emerged from its frontier status to that of a progressive city. Founded in 1839, Austin became the state capital and by the 1880's had acquired a number of civic monuments befitting a major city. The Texas State Capitol, a massive granite building styled after the United States Capitol, and the ambitious plans for the University of Texas were key symbols of the city's physical and cultural transformation. In other ways, too, Austin had attained the qualities of urbanity, and these changes were particularly evident in the city's public works. While gas lighting came to Austin in 1871, two decades after it gained popularity in Eastern cities, telephone and electric service arrived in 1881 and 1883, dates contemporary with installations in leading American cities. Therefore, it is not surprising that in 1893 when the city considered plans for street illumination, a state-of-the-art system of large towers was selected.

The Moonlight Towers, designed and manufactured by the Star Iron Tower Company, provided a form of broadcast lighting that was a dramatic break from the more traditional system of street lighting. Instead of hundreds of closely-spaced individual street lamps, Austin was illuminated by thirty-one colossal iron towers topped with clusters of high-intensity, carbon arc lamps. The tower system of carbon arc lights was considered desirable because a large area could be lit by a single cluster of lamps. Austin is a city of hills, and in the 1890's most of the residential streets were unpaved and unsafe at night. Concentrating expenses and upkeep to a limited number of towers, each lighting a large area, was considered much more desirable than a complex system of poles and wires throughout the city. The designers guaranteed that the light from each tower would be sufficient to read the time of day on an ordinary watch, on the darkest night, anywhere within 150 feet of the base of the tower. The quality of light was similar to that of a full moon, hence the popular nickname, Moonlight Towers.

This novel system of lighting had been developed in the early 1880's by the Jenney Electric Company, the parent firm of the Star Iron Tower Company. The firm had supplied similar lighting for the New Orleans World Fair of 1884 and the Statue of Liberty in 1885 and in the next decade provided permanent installations in the cities of Detroit, Grand Rapids, Little Rock, Philadelphia, and Albany, New York. The Jenney Electric Company was subsequently sold and reorganized as the Fort Wayne Electric Corporation prior to construction of the Austin towers.

The design of the Moonlight Towers resulted from the successful combination of individual technological developments, each protected under separate patents. Foremost of these developments was that of the carbon arc lamp, which was first installed by the Brush Electric Company in a Cleveland train station in 1879. The Jenney Electric Light Company later refined the carbon arc lamp to produce the brightest of all artificial lighting sources at the time and patented their design in 1881.

Patents for iron light towers and light suspension systems, initially developed by brothers Edward J. and



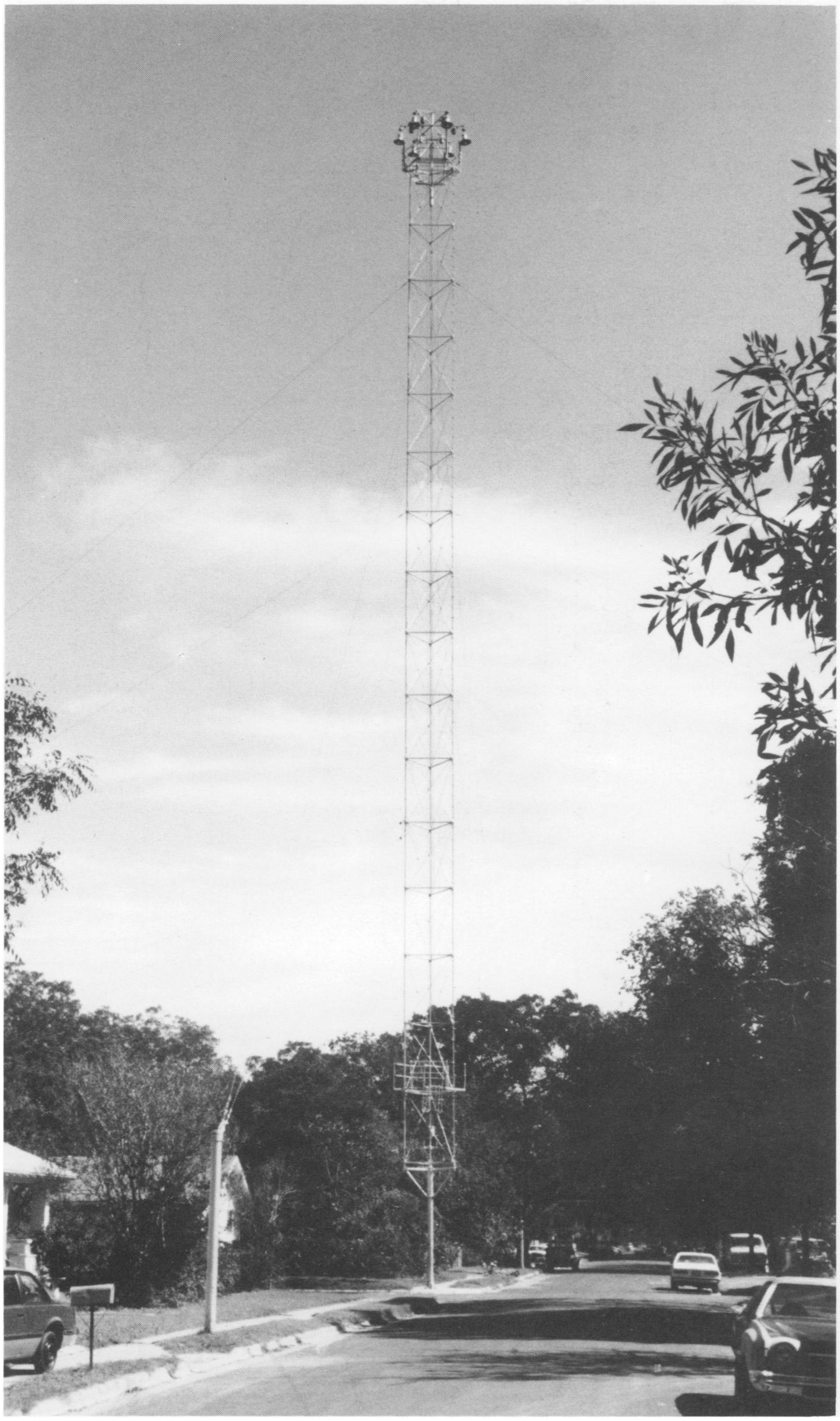


Fig. 1 (left) and Fig. 2 (above). Many of the sixteen remaining Moonlight Towers are located in residential neighborhoods and remain a coveted feature in many parts of Austin, Texas. The open lattice frame of the tower is supported by a single round column at the base and is topped with a candelabra containing six light units.

William H. O'Beirne in 1883 and 1885, were purchased by the Jenney Company. This purchase, together with the hiring of the O'Beirnes, allowed the Jenney Company to develop a lighting tower with carbon arc lamps, such as those later installed in Austin. The Moonlight Tower design was also influenced by two other inventors, John S. Adams and David Maxwell. Adams's patents of 1884 and 1886 and Maxwell's patent of 1890 offered improvements over the O'Beirnes' structural support and light suspension systems.

The work of erecting the electric light poles and towers and stretching the wires was begun in Austin in the latter part of June, 1894, and continued with little interruption until completion. Mayor A. P. Wooldridge ceremoniously turned on the new city lighting system on May 6, 1895.

Technology

The Moonlight Towers are a series of nearly identical iron towers, about 160 feet in height and weighing approximately 5,000 pounds each. Spaced at varying intervals throughout the hilly terrain of Austin, the towers are typically located at street intersections, with the pipe column bases and guy wire anchor posts often set quite close to the street curb. Each tower consists of a pipe column base approximately 10 feet in height, above which is a tower structure composed of sixteen nearly identical stacked sections, triangular in plan and each slightly more than 8 feet in height. Crowning the tower is a hexagonal cluster of six lamps. The principal materials include patented, wrought-iron "star posts" for horizontal and vertical tower members and diagonal rods also made of wrought iron. Connection sockets, which join the diagonal braces and star posts of adjoining units, are of malleable cast iron. At each side of the triangular unit, the diagonals converge at the center within a tension ring assembly. Catwalks are located at the top and bottom of each tower structure, along with a counter-balanced, hand-operated elevator that provides vertical access. The elevator was necessary because the original carbon arc lamps required replacement each day. Attached to one of the three vertical star posts were ladder steps, providing an additional means for ascending the tower. The upper six sections have slightly thinner members than the lower sections. At the top of the tenth and fourteenth sections, guy wires extend in four directions to anchor posts spaced between 100 and 200 feet from the pipe column tower base.

Each tower was originally fitted with six carbon arc lamps that provided a total of 12,000 candlepower of brilliant white light. Between 1894 and 1923, this type of lamp was replaced with "magnetite" carbon arc lights, which lasted up to three weeks rather than one day. In 1923, incandescent lamps were installed for a total of 9,000 candlepower per tower. Mercury vapor lamps were first installed in 1936 and have been replaced several times with other types of lamps. The present lighting consists of six, 400-watt mercury vapor lamps which provide approximately 12,600 to 13,200 candlepower per tower.

Investigation

The investigative portion of the project was completed in two phases. The first was a preliminary assessment to determine typical tower conditions, dimensions, and material properties. The second phase included detailed field inspection of all towers, structural analysis of a typical tower, and metallurgical testing of representative samples.

Preliminary assessment. Architectural and structural evaluations were performed to assess the present conditions at each tower. The architectural assessment viewed each tower as a whole and took into account site considerations including the relative location of roadways, off-street parking, manholes, fire hydrants, and overhead utilities. The structural assessment concentrated on the safety and stability of the towers and included evaluations of tower member conditions, guy wire conditions, and vertical alignment of the towers.

The scope of the architectural work involved gaining a firm understanding of the materials and methods of original construction and determining current tower conditions. In recent years three towers were removed, partially dismantled, and stored at a common location. The towers in storage provided an opportunity to study thoroughly and measure all tower parts. Measurement and documentation of the parts provided the opportunity to make an organized, part-by-part assessment of a typical tower.

Comparison of the tower assessment documentation with historical information provided a reasonably clear understanding of the original tower assembly techniques. Patent documents for a forerunner to this tower yielded the following sequence of assembly for towers very similar to the Moonlight Towers.

According to the O'Beirnes, a 20-foot-tall gantry was placed at the site of the tower to be erected. The gantry was four-sided and large enough that the tower section could be assembled on the ground within the four sides. Assembly began with the assembly of the uppermost tower unit, the lighting assembly and upper catwalk. Once assembled, it was raised up approximately 9 feet within the center of the gantry, using a block and tackle mechanism, and the next tower unit assembled beneath it. Once completed, the two units were raised again, and the third unit assembled below them. This continued until all units were complete. As the tower become taller and taller, temporary guy wires were used for support. Once complete, the pipe column was placed under the assembled section, and bolted to the prepared concrete foundation. Lastly, the permanent guy wires were attached and tensioned.

Measurements were taken to prepare scaled tower drawings with details of the major components. The parts and dimensions of the three towers in storage were found to be completely uniform. It was determined that all parts of the triangular tower units, such as star posts, connection sockets and diagonal rods, were interchangeable between sections having the same size parts. This uniformity of parts would later eliminate the need for the marking of identical individual parts during the restoration phase of the project. A cursory comparison of this information with the standing towers confirmed the uniformity of the elements. Documentation of the stored towers, including sketches and photographs, was used to develop an inventory of parts for a typical tower.

Preliminary inspection of the standing towers required the establishment of a nomenclature for identification of all units and structural members. The tower base unit, consisting primarily of the pipe column and kneebraces, was identified as unit Z. The lower catwalk was identified as unit B, and the elevator assembly as unit C. The sixteen units stacked atop one another forming the main body of the tower were identified as units D1 through D16, starting at the lowest unit. These typical tower units were further broken down and each component given a designation. Combinations of these designations were used to identify connection sockets at member joints.

The upper catwalk was identified as unit E, and the lighting assembly, or candelabra, as unit F.

The preliminary study included seventeen towers, designated as Tower Nos. 1 through 17. During the investigation, Tower No. 8 was severely damaged by a vehicle. It was disassembled, and the components were moved to the storage yard. Each tower was inspected visually for obvious previous repairs, reinforcements, damage, and deformations. An overall photograph was taken of each tower, and additional detailed photographs were taken to document observed conditions.

Interviews were conducted with the Electric Utility Department of the City of Austin personnel most closely involved with maintenance of the towers, to gather information about previous repair, repainting, and relocation of towers. Repairs had consisted primarily of efforts to brace damaged or deflected star post and kneebrace members. It was learned that Electric Utility Department crews had moved at least four of the towers over the last twenty years. One tower was moved approximately 30 feet while in a standing position, reportedly using more than thirty men. At least twenty-four men held the guy wires while the remainder moved the base of the tower using a backhoe.

The scope of the field work for the structural assessment involved visual inspections of all standing towers with the aid of binoculars to verify and supplement information from the architectural survey regarding previous repairs, reinforcements, damage, and deformations. Team members climbed several towers to view in-situ components and joints. A detailed elevation and distance survey was performed to provide detailed geometry information relative to tower position and vertical alignment at each site and determine the location of guy anchor posts

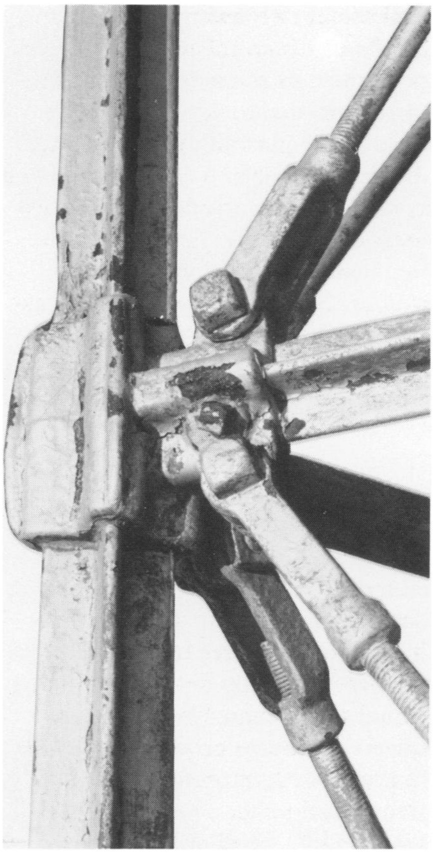


Fig. 7. The key component to the towers is the cast-iron socket, which provides the connection between the horizontal, vertical, and diagonal members.

relative to the tower base.

These visual inspections were performed to locate structural deficiencies as well as conditions that could affect the structural performance of a tower member or of the tower as a unit. Several kneebrace members were found to be bent, apparently as the result of vehicular impact. Some star post members at higher elevations, including both horizontal and vertical members, exhibited varying degrees of distortion, varying from slight deflection to partial buckling. The most severely distorted members were braced temporarily by the attachment of additional members by others prior to this investigation.

The guy wires were found to be in generally good condition and free of corrosion. However, many of the guy wires exhibited excessive sag, indicating that guy wire tensions may be too low to adequately restrain the towers in high winds. The guy wires are attached to the anchor posts by means of eyebolts threaded into turnbuckles, which are in turn bolted to a collar around the post. The eyebolts and turnbuckles were observed in many cases to be bent and/or corroded, thus hampering adjustment of guy wire tension.

The guy anchor posts themselves were found to be in good condition, although some leaned excessively toward the tower, and many were found close to streets and driveways and quite susceptible to impact by vehicles. In many places, tree branches and trunks interfered with the operation of the guy wires and guy anchor posts.

An elevation and distance survey was performed to obtain a more precise location of the tower with respect to curbs, sidewalks, and the guy anchor posts. The elevations of the guy anchor posts were used in conjunction with their distances from the tower base to determine guy wire lengths and angles for use in the structural analysis of a typical tower.

A verification of the vertical alignment of each tower was also completed during the survey. To accomplish this, the vertical crosshair of the survey instrument was sighted on the edge of a star post at the bottom of the tower. The instrument was then plumbed in a vertical plane to sight the same star post at the top of the tower. The misalignment at the top of each tower was noted as a percentage of the horizontal stadia line. By sighting each tower from approximately the same distance, a relative value of misalignment was assigned to each tower. The four towers with the most significant misalignment were scaled by a crew member and a rule placed horizontally at the top of the tower. The vertical alignment of the tower was then measured using a theodolite setup at a distance of approximately 300 feet from the base of the tower. Vertical misalignments at these towers ranged from 4 inches to 13 inches.

Structural analyses. A series of structural analyses was conducted utilizing a general-purpose finite-element computer program to evaluate the structural capacity and wind load response of a typical tower. Tower geometries and material properties collected during the preliminary tower assessment were used in developing the computer models.

The analytical model used for the analysis of a typical tower consisted of a three-dimensional space frame, with the tower members represented by beam elements. The characteristics of the entire system could be derived from the known characteristics of the elements, including cross-sectional geometries and material properties. Using the detailed geometries of the tower and properties of the individual components, stresses and strains throughout the tower could be computed. Elastic spring elements were used to model the guy wire assemblies.

The sockets where the horizontal and vertical star posts are engaged were typically modeled as moment-resisting joints. For portions of the lateral load analysis, the joints were also modeled as pinned connections to provide comparisons for the effects of joint fixity. Connections of the diagonal rods to the socket assemblies and the center tension ring were modeled as pinned joints. However, because of the center tension ring assembly, the diagonal rods are not capable of resisting compressive forces. Therefore, during the lateral load analysis, diagonal members identified as compression elements were assigned a modulus of elasticity near zero to simulate no compression force capacity.

Gravity loads applied to the structure were modeled in two parts. Actual self weights of members included in the model were computed by internal routines within the program based on the cross-sectional area, length of each member and the unit weight of the material. Additional dead loads were applied to the model at selected node points to simulate the weight of components in the actual structure which were not included in the model. These non-structural components included the light fixtures, the elevator components, and the upper and lower catwalks.

In addition, the Electronics Industries Association (EIA) Standard 222-C, *Structural Standards for Steel Antenna Towers and Antenna Supporting Structures,* March, 1976, was used to develop an alternate set of wind loads. From the 1985 version of the Uniform Building Code (UBC), a design wind speed of 70 mph was chosen. The worst-case loading was achieved by the UBC-derived wind loads.

The typical tower was assumed to have guy wires at the joint between sections D10 and D11 and sections D14 and D15. The stiffness of the elastic spring used to model the guy wire restraint was computed based on the length and cross-sectional area of the guy wire and the guy wire material properties. The guy wire on the leeward side was assumed to go slack as the tower deflects laterally and was given zero stiffness. The guy wires perpendicular to the direction of the applied wind were assumed to provide lateral restraint to the tower but not contribute to resisting the applied wind.

Additional analyses of the guy wire systems were conducted to evaluate the effects of addition or relocation of guy wires. The initial analysis indicated that under design wind loads, displacements in the upper tower sections adversely affected the capacity of vertical star post members. Relocation of the existing guy wires or addition of new guy wires was studied to determine the effect each of these alterations would have on tower behavior. It was determined that the addition of a third level of guy wires would significantly reduce displacements and stresses in the vertical tower members. The best locations for the three levels were determined to be joint numbers D9/D10, D12/D13, and D15/D16.

In general, the structural analyses indicated that the maximum stresses in tower members were approximately 10 percent of the wrought iron's tensile strength of 40 ksi (kips per square inch), for most loading combinations. Under static dead load conditions, stresses in the vertical star post members were less than 1 ksi, with the maximum occurring at the bottom of the tower. For the lateral wind loading analysis using the UBC design wind load of 70 mph, maximum compressive stresses of approximately 3.8 ksi were induced in the vertical star post members of Section D5. Likewise, the maximum tensile stresses of approximately 5.1 ksi occurred in the vertical star post members of Section D5. Typically, the maximum axial

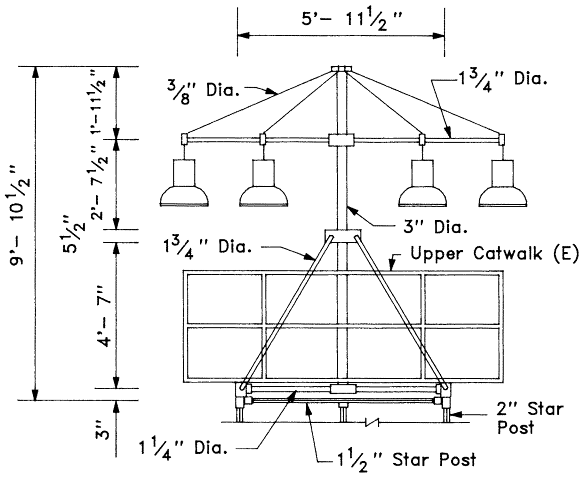


Fig. 4. The upper tower units E and F include a walkway platform and the light candelabra.

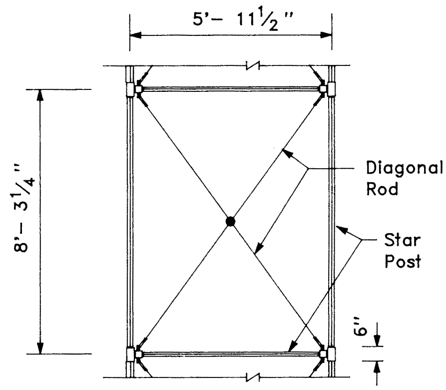


Fig. 5. This typical tower unit consists of 3 vertical star posts, 3 horizontal star posts, and 6 diagonal rods. The diagonal rods are not continuous through the clam shell connectors at the center of the tower units.

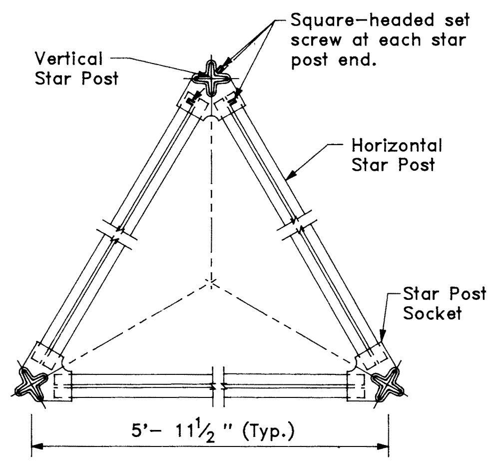


Fig. 6, above. In plan, the towers are triangular, and open in the center to permit passage of the elevator platform.

Fig. 8, below. The star post members in the towers are three sizes, 2½ inches, 2 inches, and 1½ inches wide.

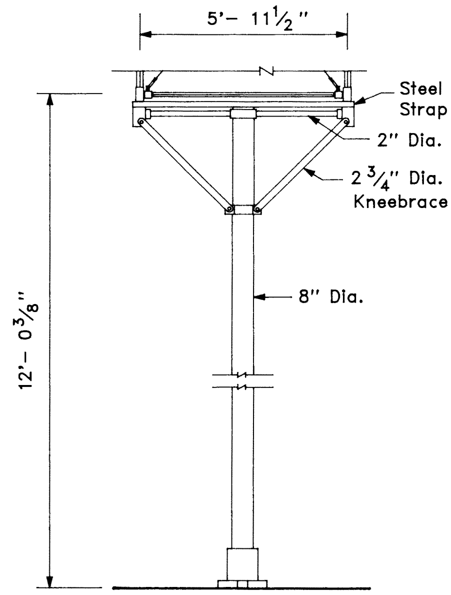
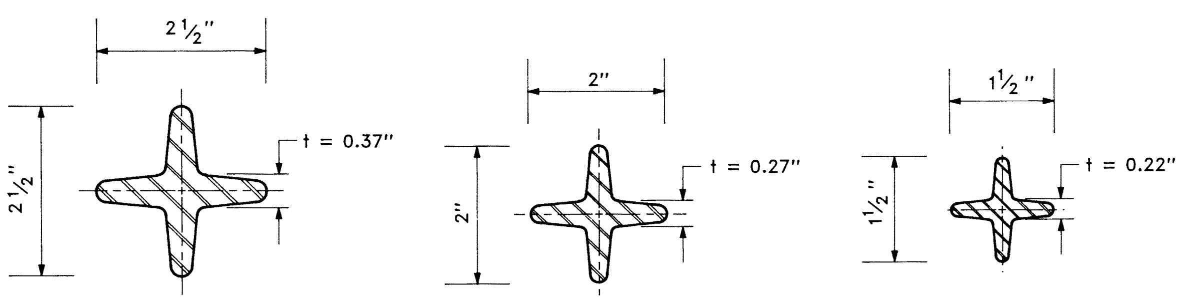


Fig. 7. This base section, column 2, includes a round post that supports the tower through a series of diagonal struts. These diagonals are susceptible to vehicular impact.



compressive loads occur in vertical members on the windward side of the tower at an elevation approximately halfway from the base to the lower guy wire attachment. Members with maximum axial tensile loads occur in this same region on the leeward side of the tower.

The bolts connecting the diagonal rod and clevis to the socket joint were found to be highly stressed. Typical axial forces of approximately 3,500 pounds were computed for diagonal members in the lower sections. The computed allowable load for these bolts was approximately 4,100 pounds.

The yield strength of wrought iron from tests on actual tower members was found to be approximately 25 ksi. From review of historic documents, it is believed that a safety factor of 4 was used for wrought iron at the time of original design and construction of the Moonlight Towers. Therefore, the safe working stress for the wrought-iron members of the towers would be approximately 6 ksi. With this in mind, then, the maximum stresses in the tower members under design wind load conditions were found to meet this criterion.

From the field measurements, distances from the tower to the guy posts varied from approximately 100 feet to almost 200 feet. The computed horizontal stiffness of the guy system varied approximately 27 percent for the lower guy system and approximately 9 percent for the upper guy. The resulting lateral tower deflections under the UBC wind loading, however, varied only 13 percent due to these changes in stiffness. In the analytical model, the degree of resistance to rotation, or fixity, assigned to the tower base had a more significant influence on the deflected shape. Base fixity was observed to significantly affect the lateral deflections, but had only a small influence on member forces away from the base section.

The vertical star post members were analyzed for susceptibility to lateral buckling. It was determined that significant compressive loads on the vertical star post members could result in buckling of these long, slender members. The level of loading necessary to cause buckling would be even less if the member was not straight originally. The predicted possibility for lateral buckling coincides with the observed distortions of vertical star post members at some towers.

Metallurgical evaluation. The purposes of the combined program of mechanical and metallurgical testing of the tower components included determination of present strengths of the components, as well as location of internal flaws, known as indications, particularly at the malleable cast-iron connection sockets. The ultimate goal of the program was to develop a procedure for nondestructive inspection of the components during restoration activities and to establish a criteria for acceptance/rejection of components.

Material properties of tower members were determined by physical testing in accordance with ASTM E8, *Test Methods for Tension Testing of Metallic Materials*. Cylindrical test specimens were cut from two different sizes of star post sections and from the 58 inch diameter diagonal rods. Rectangular specimens were cut from the base column. All specimens were oriented parallel with the longitudinal axis of the member. The specimens were determined to be wrought iron, with a nominal yield strength of 25 ksi and a nominal ultimate tensile strength of 40 ksi. The clevis bolt was found to be wrought iron with a nominal yield strength of 37 ksi and a nominal ultimate tensile strength of 55 ksi.

Metallurgical examination of the diagonal rod tension ring and the diagonal clevis indicated that they are malleable cast iron with estimated nominal yield and ultimate tensile strengths of 30 ksi and 50 ksi, respectively.

Due to the complex geometry of the sockets, it was necessary to develop a specialized procedure for magnetic particle inspection of the sockets to locate indications. The procedure used was an adaptation of ASTM A275, *Method for Magnetic Particle Examination of Steel Forgings*, and ASTM E709, *Practice for Magnetic Particle Examination*. In this procedure, a magnetic field is induced around the sample, with the magnetic lines of force at right angles to the suspected indication. A solution of fluorescent magnetic particles is sprayed on the sample just as the magnetizing current is disconnected. When viewed under a black light, indications of surface or near surface discontinuities appear as bright features.

Eight cast-iron sockets were evaluated using the method described above. The specimens were etched chemically to further reveal the grain structure. Each specimen was examined metallographically, with photomicrographs taken to document the observations.

One indication was evaluated further by causing complete fracture of the segment containing the indication by cooling in liquid nitrogen followed by a sharp impact. This technique causes crack extension from the tip of the indication. One half of the fracture was then cleaned to remove scale and corrosion product prior to examination of the surface in a scanning electron microscope. Pertinent surface features were documented photographically.

Every socket examined using the magnetic particle technique contained some type of indication. The observed indications consisted primarily of groups of small round or linear inclusions, considered typical of surface-related casting porosity. More serious indications were judged to be casting defects. There was no clear evidence of any in-service cracking or crack propagation.

Evaluation of options for member replacement. The results of the architectural and structural analyses and findings of the metallurgical studies indicated that repair or replacement of selected star post members would be required. The options available included the reconditioning and straightening of existing deformed members, the use of salvaged parts from previously disassembled and incomplete towers not scheduled for re-assembly, the fabrication of new members using wrought iron, and the fabrication of new members using a substitute material. In the end, replacements were secured from the salvaged towers, but only after substitutes were investigated.

Investigation of possible substitute materials for the structural wrought iron included evaluation of mild steel, stainless steel, galvanized steel, aluminum, and fiberglass. The criteria for evaluation of the substitute materials included physical properties, such as tensile strength, yield strength, and modulus of elasticity, and physical characteristics of the material including corrosion resistance, compatibility with the existing mechanical fastening systems in the towers, and compatibility with the proposed paint system.

It was anticipated that the replacement material would be used in conjunction with existing wrought-iron star posts and that cross-sectional dimensions of the replacement members would be required to match the existing wrought-iron sections. In addition, the replacement members would have to be geometrically compatible with the existing sockets. Because of these requirements, it was essential that any replacement material have physical properties similar to the existing wrought iron. Paramount to this compatibility was matching the modulus of elasticity of the replacement material to that of the wrought iron. Based on this criterion alone, the aluminum and fiberglass replacement options were eliminated from further consideration.

Fig. 9. The elevator platform provided access to the light candelabra when daily changes of the carbon arc lamps were required. The elevator platform is counterbalanced to assist the user in the ascent. Stopping the platform is accomplished by using a crude pinch-brake, which is foot-activated and clamps the platform to the guide cables.

Analysis of the original metals used on the towers, particularly the wrought iron, revealed an inherent resistance of the material to corrosion. The relatively good present condition of the towers was largely attributed to the corrosion resistance. Lacking this property, the towers would likely have corroded and deteriorated at a much faster rate. While the stainless steel corrosion rate of 0.2 mdd (milligrams per square decimeter per day) is acceptable, the corrosion rate of 50 mdd for mild steel was judged unacceptable. The corrosion rate of the substitute materials was evaluated, and the stainless steel alternative considered to be the preferred material if new replacement parts would be required.

The cost of producing the star post sections using the substitute materials was also evaluated. Cost estimates were developed based on the costs of the raw materials, the tooling, and the production of 250 members. It was determined that a few rolling mills in the Austin/San Antonio/San Angelo area could produce the star posts economically. While the aluminum and fiberglass are economical to produce, they did not satisfy the other criteria needed for good performance. Cost estimates for production of new wrought iron star post members could not be obtained.

It became clear from the analysis of replacement materials that stainless steel was the preferred substitute material, although the cost of producing replacement star post sections was quite high. Fortunately, the number of members that are severely damaged was low, and the supply of replacement members from towers in storage was adequate to complete the restoration work using the much

Material	Modulus of Elasticity (ksi)	Yield Strength (ksi)	Approximate Corrosion Rate (mdd)	Relative Cost ($)
Wrought Iron	28,000	25	Negligible	—
Stainless Steel	28,000	42	0.2	127,000
Mild Steel	29,000	36	50.0	92,000
Aluminum 2024	10,600	2	5.2	8,000
Aluminum 6061	10,600	35	2.7	4,000
Fiberglass	2.500	—	None	20,000

Fig. 10. Comparison of physical properties and costs of substitute material options.

preferred replacement material—historic wrought-iron star posts from salvaged towers.

Phased Restoration

The final portion of the project involved the development of a phased program for the repair and restoration of the Moonlight Towers. Because of the anticipated cost for restoration of each tower, the City of Austin stipulated that it would be necessary to allow five years for completion of the program. Because deteriorated conditions presently exist at many of the towers, it was also necessary to develop specific guidelines for the stabilization of each tower to ensure the structural stability of the towers over the specified five years.

The stabilization program, which was completed in December, 1990, consisted of plans and specifications for structural repairs to each tower, including such items as bracing of deflected star post members, replacement of bent kneebrace members, and replacement of inoperable guy wire turnbuckles. In addition, each tower was plumbed to within specified tolerances, and guy wires adjusted to specified tensions.

The restoration program includes disassembly of each tower, refurbishment of the individual parts, and reassembly of the towers. While the primary objective of the restoration program is to refurbish and re-use original tower components, some components require replacement because they are severely deteriorated, including all bolts, nuts, set screws, guy wire adjustment components, and all diagonal components. The two-piece diagonals with the center tension ring are being replaced with one-piece diagonals. Components of the tower which required replacement due to deterioration or inadequate strength were replaced with Type A304 stainless steel. The original tension rings will be re-attached at their original location for preservation purposes.

A procedure for tower disassembly was developed utilizing an assembly of steel blocks and wedges that gripped each of the three vertical star posts; a series of hydraulic rams force the star posts vertically out of the connection sockets. The rams react against another set of steel blocks bearing on the socket shoulders. When one tower was relocated as part of the construction of a new convention center in Austin, the project team had the opportunity to test the disassembly procedure prior to finalization of the restoration plans and specifications.

Selection criteria and methods for assessment have also been developed for evaluation of the iron star posts and connection sockets. The evaluation program is based on the results of the metallographic examination and magnetic particle testing of the connection sockets. Requirements for the star posts also include specific tolerances for straightness of the members and methods for mechanical straightening where required.

Prior to reassembly of the towers, individual parts will receive a silver-colored protective coating consisting of an epoxy primer, an epoxy-polyamide intermediate coat, and an acrylic polyurethane enamel top coat. Tests of this type of coating have indicated that a service life of twenty years can be expected for this type of application.

Finally, the reassembly of the towers was designed to be simply a reversal of the disassembly process. This procedure requires shop assembly of two-unit segments, field erection of the units, and final adjustment of the guy wires to achieve the specified tower plumbness and guy wire tensions.

MARK MOORE, P.E. is a consultant and project manager for Wiss, Janney, Elstner Associates, Inc., in Irving, Texas (WJE). Mr. Moore served as the project engineer during the investigation and structural analysis phases of the project and as project manager for WJE on the restoration phases of the work.

KARL STRAND is a project engineer in the WJE Irving office and has served as the project engineer for the restoration portion of the project.

The authors wish to thank the Electric Utility Department at the City of Austin, Texas; Baird Smith of Geier, Brown, Renfrow; and John Slater of Invetech, Inc., the metallurgical consultants, for their help throughout this project. The authors wish to acknowledge Mr. Smith also for his efforts in developing the alternate material evaluation portion of this paper. David Hoffman & Co. was the affiliated architect for the project.

Structural Integrity Associates, Inc.®

November 10, 2016

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Gregory J. Casey, PE
Enertech Resources, LLC
5920 W. William Cannon, Bldg 1, Ste 102
Austin, Texas 78749

Via email:

Subject: Material Property Testing of Moonlight Tower Star Member Section
SI Report: 1601245.401.R0
Enertech Resources, LLC PO No: 20-74 A 398

Dear Mr. Casey:

On October 28, 2016, Structural Integrity Associates, Inc. (SI) received a section of a star member from a Moonlight Tower (Figure 1). The material was suspected to be a ductile or malleable cast iron. SI was asked to perform materials testing on the sample to determine its chemical composition, measure its tensile strength, and evaluate the microstructure to determine the material type.

A portion of the star member was submitted for tensile testing and quantitative chemical analysis, and the results are provided in Tables 1 and 2. Based on the compositional analysis, and particularly the carbon content, the star member is a low carbon steel and not a cast iron. The composition is consistent with UNS G10050 or ASTM A29 Grade 1005. The material was found to have a tensile strength of about 50 ksi and a yield strength of about 30 ksi.

A cross-sectional sample from the star member was prepared for evaluation using standard laboratory techniques. The prepared sample was examined using a metallurgical microscope for evaluation of the microstructure, which is shown in Figure 2. The microstructure consisted of perlite, nonmetallic inclusions, and casting voids/flaws in a ferrite matrix. The microstructure is consistent with a low carbon steel and is not indicative of a ductile or malleable cast iron. The microstructure also showed significant deformation, presumably from forming the star shape. It is not clear if the casting voids/flaws present in the material indicate the material was originally cast and then formed, or if they are just indicative of the quality of the material at the time of manufacture (i.e., the component is not a casting).

Hardness measurements were made on a cross-sectional sample using a Brinell tester with a tungsten carbide ball and a 1000 kg load. The measured hardness values ranged from 96.1 to 107 Brinell (HB) with an average of 101.4 HB. The hardness results were consistent with the tensile properties and the observed microstructure.

Sincerely,

Wendy Weiss
Associate

Reviewed by:

Clark McDonald
Associate

Table 1. Tensile Test Results

Sample	Tensile Strength (ksi)	0.2% Offset Yield Strength (ksi)	% Elongation in 4D	% Reduction of Area	Fracture Location
1	51.0	31.6	24	33	Outside Middle 50% of Gage Length
2	47.0	29.2	19	25	Middle 50% of Gage Length

Table 2. Compositional Analysis Results (wt.%)

Element	UNS G10050	Star Member
Carbon	0.06 max	0.04
Manganese	0.35 max	0.15
Phosphorus	0.030 max	0.016
Sulfur	0.050 max	0.032
Silicon	Not Specified	0.228

Figure 1. An approximately six-foot section of a Moonlight Tower Star Member was received for materials property testing and microstructural evaluation. These images show a portion of the received section.

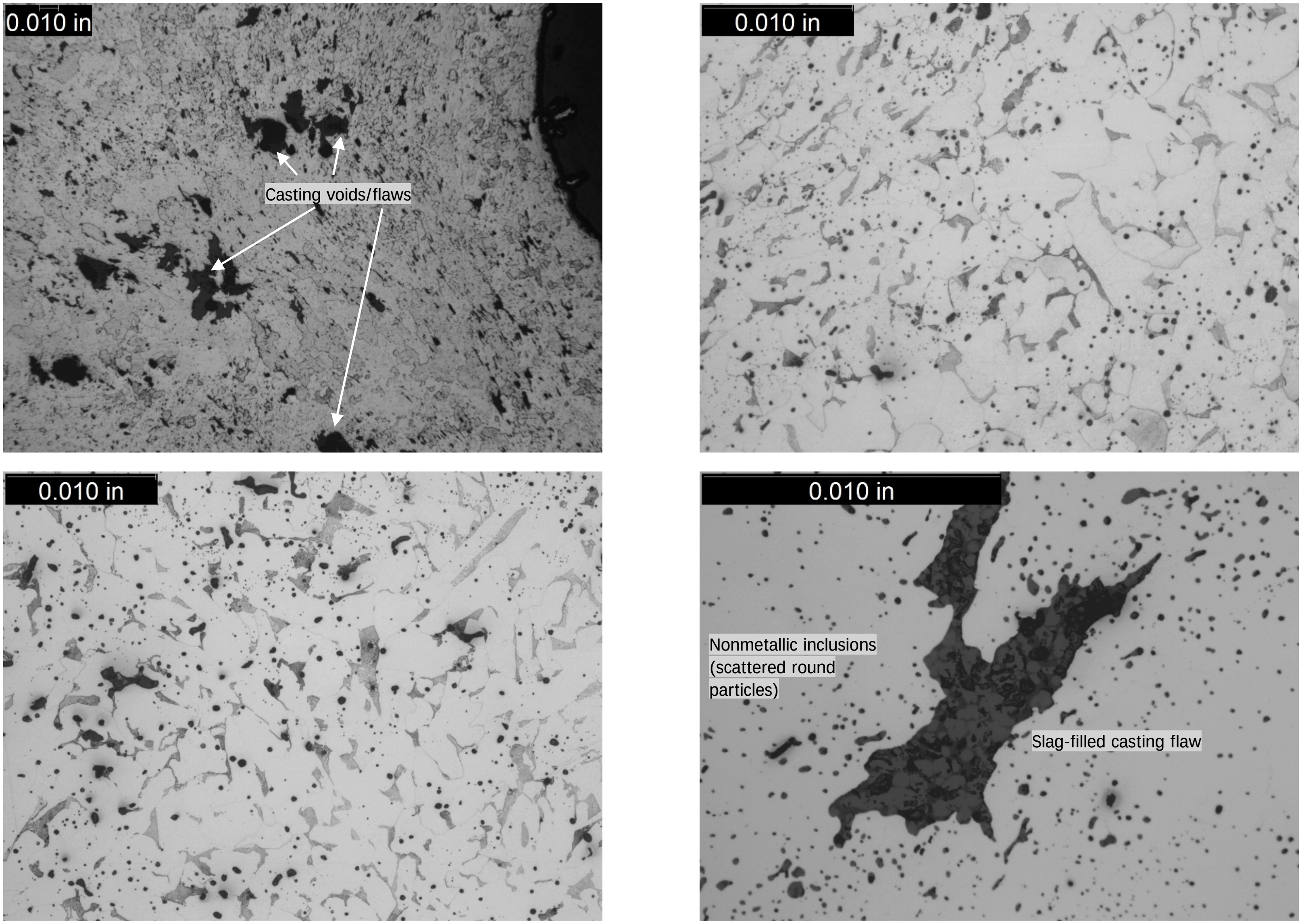
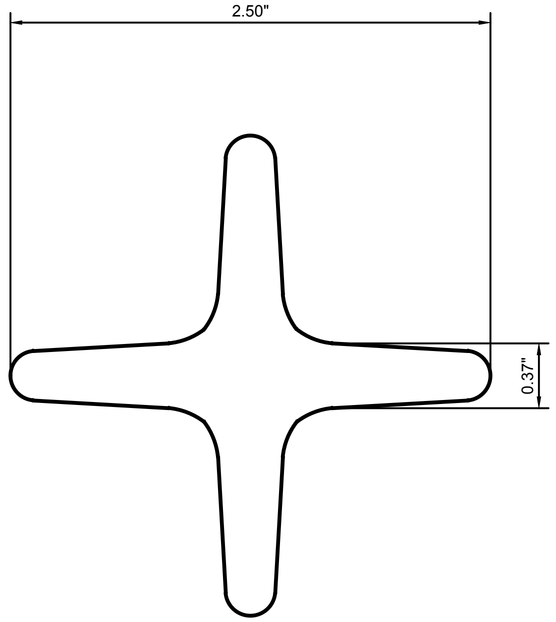
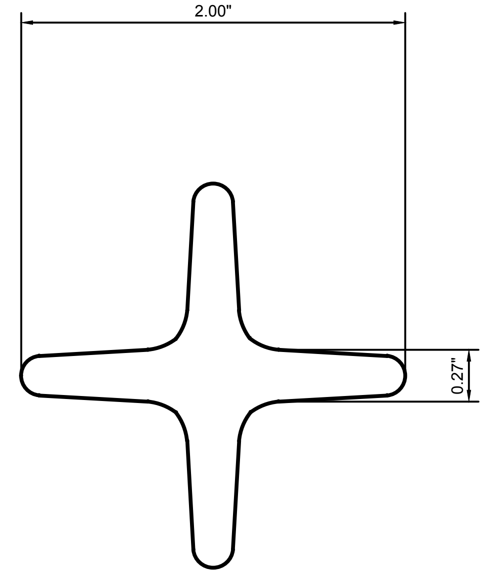


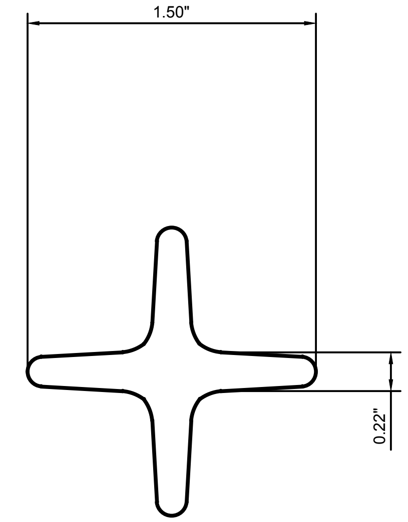
Figure 2. These images show the microstructure of the star member, which consists of pearlite, nonmetallic inclusions, and casting voids/flaws in a ferrite matrix. (Etchant: Nital, except for the lower right image, which is unetched)



2-1/2" STAR POST SECTION



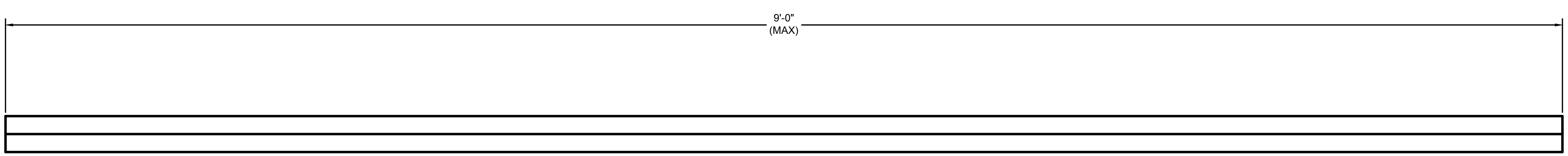
2" STAR POST SECTION



1-1/2" STAR POST SECTION

NOTES:

1. PREFERRED METHOD OF PRODUCTION IS GREEN SAND CASTING. ALTERNATIVE METHODS SUCH AS EXTRUSION OR MILLING MAY BE CONSIDERED.
2. LOW CARBON STEEL MATERIAL SHALL BE ASTM A29 GRADE 1005 / UNS G10050, MINIMUM YIELD STRENGTH OF 30 KSI AND TENSILE STRENGTHS OF 50 KSI. MILLED OR EXTRUDED MATERIALS SHALL BE A572-50 STEEL.
3. REFERENCE ATTACHED SPECIFICATIONS FOR REQUIREMENTS ON STRAIGHTNESS, DEFECTS, ETC. (REF. SECTION 05542 PARTS 3.02, 3.04, 3.05, 3.06)



STAR POST LENGTH

FOR INFORMATION ONLY

MOONLIGHT TOWERS

STAR POST DETAIL

1

SECTION 05542

EVALUATION, TESTING AND STRAIGHTENING OF STAR POST MEMBERS AND OTHER STRUCTURAL COMPONENTS

PART 1 - GENERAL

1.01 DESCRIPTION

A. Work Included: The work under this Section consists of cleaning of the star post sections and other structural members, evaluation and testing of the star post members to locate significant flaws, and methods for mechanical straightening of the members.

B. Related requirements specified elsewhere:

1. Summary of Work Section 01010

1.02 REFERENCE STANDARDS

A. American Institute for Steel Construction, AISC 9th Edition.

1.03 QUALITY ASSURANCE

A. Acceptable Laboratories: The Contractor shall employ and pay for an acceptable testing laboratory for the purpose of member evaluation work. The laboratory shall have a minimum five year experience in inspection of structural steel fabrication and erection.

1.04 SUBMITTALS

A. The Contractor shall prepare and submit to the Owner a detailed procedure for evaluation of the star post members. The detailed plan shall be in conformance with the provisions of this Section of the Specifications.

B. The Contractor shall develop and maintain a log which records the status of star post members which have been evaluated. The log shall summarize the disposition of the members following evaluation.

C. The Contractor shall prepare and submit to the Owner a detailed procedure for mechanical straightening of the star post members.

PART 2 - PRODUCTS

NONE USED

PART 3 - EXECUTION

3.01 CLEANING OF STAR POST MEMBERS

A. All star post members shall be cleaned by power tool methods (SSPC - SP3) in accordance with Steel Structures Painting Manual, Steel Structures Painting Council. As a minimum the cleaning process shall include removal of loose rust and loose paint. Refer to Section 09900 for cleaning required for painting.

3.02 VISUAL EXAMINATION OF STAR POST MEMBERS

A. Following cleaning of the star post members, each member shall be visually inspected for defects. Defects to be identified include cracks, dents, distortions of the outstanding legs and excessive corrosion at the member ends. The following criteria shall be used:

1. Any member with a crack shall be tagged as "DEFECTIVE".

2. Any member with cross-sectional dimensional losses due to corrosion greater than 10 percent at the member ends shall be tagged as "DEFECTIVE".

3. Any member that has been damaged, cut or otherwise altered from the original condition shall be tagged as "DEFECTIVE".

3.03 VISUAL EXAMINATION OF MISCELLANEOUS STRUCTURAL MEMBERS

A. Miscellaneous structural members to be inspected shall include inventory items Z1 through Z12 and Q1 through Q17."

B. Each miscellaneous structural member shall be cleaned in accordance with Section 3.01.

C. Each miscellaneous structural member shall be visually inspected for defects. Defects to be identified include cracks, dents, distortions and excessive corrosion. The following criteria shall be used:

1. Any member with crack shall be tagged as "DEFECTIVE".

2. Any member with cross-sectional dimensional losses due to corrosion greater than 10 percent at any point shall be tagged as "DEFECTIVE".

3. Any member that has been damaged, cut or otherwise altered shall be tagged as "DEFECTIVE".

3.04 TESTING OF STAR POST MEMBERS

A. Each star post member found not defective according to Section 3.02A shall be evaluated for straightness.

B. Member straightness shall be evaluated by one of the two methods described below:

1. A string line, pulled taught between the ends of the member at the point of maximum extremity of the star post, can be used as a reference line. The member straightness shall be evaluated by measuring the distance between the reference line and the member at the one-quarter points along the members length.

2. A straight bar or flat surface of sufficient length to fully support the member along the full length can be used as a reference line. The member straightness shall be evaluated by measuring the distance between the reference line and the member at the one-quarter points along the members length.

3.05 EVALUATION OF TEST RESULTS

A. Acceptance of star post members shall be based on the following criteria:

1. For members less than or equal to 6 ft in total length, members shall be considered acceptable if the maximum measured deviation is less than $\frac{1}{8}$ in.

2. For member greater than 6 ft in length, members shall be considered acceptable if the maximum measured deviation is less than $\frac{1}{4}$ in.

3.06 MEMBER STRAIGHTENING

A. Star post members that do not conform to the straightness criteria of 3.05A may be straightened.

B. Straightening of star post members may be completed by mechanical means with loads applied perpendicular to the axis of the distortion and the load applied at the point of maximum deviation.

C. Straightening shall not be completed by heating the members.

END OF SECTION 05542

Fabricator Contact Log

MPM0401 Inspection, Repair, & Restoration of Moonlight Towers
Star Post Fabrication

ENERTECH

No.	Contact	Website	Date of Contact	Notes
1	Reliance Foundry	https://www.reliance-foundry.com/castings/sand-casting	1/3/2019	Vendor opted to no-bid this project, stating the RFQ was for products outside their specialty.
2	Samco Sales	samcosales.com	1/3/2019	Spoke with vendor over the phone and emailed the specifications. No response received.
3	Waupaca Foundry	https://www.waupacafoundry.com/en/iron-castings/quality	1/3/2019	Vendor replied that they were not a good fit for the scope of this project.
4	Sawbrook Steel Casting Co	http://www.sawbrooksteel.com/green-sand-casting	1/3/2019	Spoke with Al Kinnard; parts are too big for green sand, but emailed specs to look into alternative casting options. Project was no bid, can't keep straightness specifications.
5	A and B Foundry	http://www.aandbfoundry.com/	1/3/2019	Vendor does not work with steel.
6	Leitelt Bros Inc	https://www.lbfoundry.com/green-sand-molding-casting.html	1/3/2019	Vendors does not work with steel.
7	Patriot Foundry and Castings	https://www.patriotfoundry.com/services/sand-casting/	1/3/2019	Vendor does not work with steel.
8	Century Foundry	https://centuryfoundry.com/capabilities/green-sand/	1/3/2019	Vendor does not work with steel or castings of this size.
9	Plymouth Foundry	http://www.plymouthfoundry.com/contact.html	1/3/2019	Vendor indicated 20" max for castings.
10	Bremer Manufacturing	https://www.bremermfg.com/custom-aluminum-casting/green-sand-molding/	1/3/2019	Vendor does not work with steel.
11	Willman Industries	https://willmanind.com/green-sand-foundry/	1/3/2019	Vendor does not work with steel.
12	5 Star Fabricators		8/6/2014	Vendor does not do any casting.
13	O K Foundry	https://www.okfoundry.com	1/3/2019	Emailed spec sheet reference and production run estimates. No response received.
14	Pacific Steel Casting	No Longer In Business	1/3/2019	Followup from original solicitation - Vendor filed for bankruptcy; closed foundry 2018
15	Clarksville Foundry	https://www.clarksvillefoundry.com	1/3/2019	Vendor is no-bidding based on size and materials (no steel, only iron). Vendor commented that materials size is difficult to keep straight.
16	General Foundry Service	https://www.genfoundry.com	1/3/2019	Vendor indicated max dimensions of 64" x 64"
17	Fisher Cast Steel	fishercaststeel.com	1/11/2019	Vendor no-bid the project stating that they were not a good fit.
18	AeroMetals	Aerometals.com	1/11/2019	Requested quote via website 1/11. No Response received.
19	Pure Castings Co	purecastingsco.com	1/11/2019	Vendor indicated that this project was not a good fit for their facilities.
20	Stainless Foundry & Engineering	stainlessfoundry.com	1/11/2019	Vendor no-bid this project stating that it was not their typical size or scope.
21	Southwest Steel Casting Company	swscc.com	1/11/2019	Vendor no-bid the project stating that they could not maintain straightness; parts are too narrow for their length.

November 16, 2018

Michael Pittman, PE
Austin Energy
4411-B Meinardus Drive
Austin, TX 78744

Re: *Proposed Amendment to Historic Buildings and Structures Permit #784, Austin "Moonlight Towers," Restoration of 17 Towers, Travis County, Texas*

Dear Mr. Pittman,

Thank you for your correspondence requesting an amendment to Historic Buildings and Structures Permit #784 for restoration of seventeen Moonlight Towers. The amendment would address a proposed fabrication method to replace star posts, the main structural members of the towers. This letter represents the comments of the Executive Director of the Texas Historical Commission, the state agency responsible for compliance with the Antiquities Code of Texas.

Understood to be the only examples of this type of late-nineteenth century tower lighting system remaining nationwide, the Austin "Moonlight Towers" received an official Texas historical marker in 1970, were listed in the National Register of Historic Places in 1976, and were designated as State Antiquities Landmarks in 1981. The towers also became City of Austin Historic Landmarks in 1975. The number of extant towers has dwindled, from thirty-one when originally erected in 1895 to fifteen standing with two in storage at the outset of the project in 2015.

The last comprehensive restoration of the towers undertaken in the early 1990s is described in an article published in the Association for Preservation Technology's journal (Mark Moore and Karl Strand, "Preservation Study of the Moonlight Towers, Austin, Texas," *APT Bulletin* 23, no. 1 (1991): 29–38). Metallurgical analysis was performed and the possibility of replicating members explored but not pursued. The article indicated that, "Fortunately, the number of members that are severely damaged was low, and the supply of replacement members from towers in storage was adequate to complete the restoration work using the much preferred replacement material—historic wrought-iron star posts from salvaged towers."

The approach of using salvaged star posts continued with the present project despite a relatively high failure rate, to the order of consuming parts from three towers to repair and reinstall five towers to date. It should be noted that this approach was neither explicitly discussed in the permit application nor addressed in the scope of work as issued for Permit #784. At this juncture, it is critical to determine a viable method to replicate the star posts before proceeding further, and the permit was placed on hold on July 25, 2018 to allow a permit amendment to be developed.

The Texas Historical Commission currently declines to amend the permit based on the information submitted, and it will continue to remain on hold. We appreciate Austin Energy and Enertech's efforts to determine a viable method to replace the star posts and thank you for hosting multiple meetings to discuss this issue and the question of relocation of some of the towers. However, we request that Austin Energy continue to explore accurate replication of the star posts and develop a more comprehensive approach to tower restoration.

In terms of options for replicating the star post members, Enertech has determined that green sand casting and extrusion are not viable due to limitations of current production methods and inability to locate a foundry willing to perform the work. An accurate replica of the star post shape can be achieved by milling solid stock, but this produces significant material waste and comes with a relatively high associated cost. As an alternative, Enertech has proposed use of square tube steel with milled ends to fit into the existing knuckles. Thank you for the opportunity to view a mockup of this proposal on April 9, 2018. With diffuse light on this cloudy day, staff considered the square tube steel promising; however, with subsequent observation of a standing tower on a sunny day, the shadow line at the inside corner of the star posts is visible over the full tower height. Given that the Moonlight Towers are relatively simple structures with engineering significance, the shape of the members is important to retain. While we understand the cost of milling the star posts is estimated at three times that of the square tube option, Austin Energy should address whether it is financially viable to proceed with the higher-cost alternative. We respectfully request that Austin Energy explore funding opportunities for an accurate replication.

Additionally, the permit amendment request should include a more detailed strategy for incorporation of replacement parts. We understand that each tower has been inspected but full, individual assessment of the members cannot be performed prior to disassembly for repairs. Nevertheless, an overall approach or decision matrix could be developed based on the types and rates of failure experienced thus far. We appreciate the indication that the replacement star posts will be placed as high on the towers as possible, but this does not address the three component sizes and relative failure rate of each. Use of accurate replica star posts may also eliminate the need to place replacement members high on the towers, and in-place replacement should be considered. Relative to the three towers to be reconstituted, as staff has previously indicated, ideally these will have a mixture of original and replacement star posts, and the permit amendment request should address salvaging a percentage of original members from the remaining towers to be restored.

Finally, we suggest that the amendment request include any proposed tower relocations. If not specifically addressed at this time, consultation should not wait until a tower is nearing or has been taken down for repair. In general, our position is that towers in original locations should remain there whenever viable, and conditions leading to a recommendation for relocation will require careful consideration by our office. Any proposed new locations should be within the area of the city where Moonlight Towers were original erected and provide a compatible setting. Preliminary discussions with the University of Texas and Austin Parks and Recreation Department have shown promise for potential sites near historic locations, and we look forward to continuing those dialogues.

Of particular interest to our office is the disposition of Towers 3 and 16, which were taken down to facilitate development projects. Tower 3 was removed from the corner of W. 4th and Nueces streets under SAL Permit #354, issued in 2006 in association with construction of the 360 Condominiums tower. Re-erection of the tower was delayed due to construction of the Austin Federal Courthouse and subsequent City of Austin-sponsored street improvements. As a result, the permit was cancelled in 2013 with an indication that a new permit application should be submitted. Tower 16 was removed from Trinity and Cesar Chavez streets under SAL Permit #375, issued in 2006. The tower had been moved to that location in 1992 and was proposed to be moved again to the corner of E. 3rd and Red River streets under the permit. When complications arose at that location, the THC closed the permit in 2011 with an indication that a new permit application would be required once a site was selected. No action was taken to determine appropriate locations and reinstall these towers, and as part of the present project they were two of the towers consumed for parts.

Thank you for your cooperation in this review process, and for your efforts to preserve the irreplaceable heritage of Texas. We look forward to further consultation with your office and hope to maintain a partnership that will foster effective historic preservation. **If you have any questions concerning our review or if we can be of further assistance, please contact Elizabeth Brummett at 512/463-6167.**

Sincerely,

Mark Wolfe

Mark Wolfe, State Historic Preservation Officer

MW/aeb

Cc: Gregory J. Casey, Enertech Resources
Steve Sadowsky, Historic Preservation Officer, City of Austin
Kate Singleton, Executive Director, Preservation Austin
Bob Ward, Chair, Travis County Historical Commission