TALL TELEVISION TOWERS

By J. Roger Hayden*

(Presented at a meeting of the Structural Section, B.S.C.E., held on October 9, 1957.)

Tall television towers, in heights of 1000 feet or over, were almost non-existent just a few years ago. As television began to come of age the need for broader coverage patterns in some of the larger markets became apparent and the trend toward taller towers began. Video signals travel in a line-of-sight path hence the higher the antenna, the farther the signal goes. The first tall television tower was 1057 feet in height and was constructed for TV Station WSB in Atlanta, Georgia. Today about 10 per cent of the country's TV stations are equipped with towers in the 1000 foot to 1600 foot range.

Boston's new WBZ-TV tower which has been recently completed and the new WHDH-TV tower are typical television towers of this type.

The new television tower recently completed for WBZ in Needham near Boston, Massachusetts, has a number of future uses which are not apparent to the casual eye. These future uses added a number of different loading conditions to the design of the tower.

The present height of the structure is 1,199 feet above ground with the ground elevation being 150 feet above mean sea level. This places the overall height of the structure at 1,349 feet above mean sea level. At the present time, this height is the maximum permitted by existing air traffic considerations.

Air traffic will change from time to time and future considerations might permit an increase in height. Due to this possibility the design of the structure will permit the height being extended to 1,499 feet above ground or a height of 1,649 feet above sea level.

The present limitation on the height of the structure is 1,300 feet above mean sea level to a tolerance of plus 50 feet. This explains the rather odd dimension of 1,349 feet above mean sea level which is one foot short of the allowable limit of 1,350 feet.

*Dresser-Ideco Co., Columbus, Ohio.

Considerations of the future indicate that an overall height of 1,649 feet above mean sea level would be a reasonable top height, hence the reason for settling on an extension of 300 feet for the future.

The main tower body is triangular with each side of the triangle being 12′-0″ center to center of the corner members. The top 230 foot portion of the structure is restricted to a dimension of 5′-3″ center to center of the corner members. This portion of the tower is designed to permit installing two different television transmitting antennas mounted around the structure. Electrical considerations limit the size of this portion of the tower to a maximum dimension of a triangle 5′-3″ on a side.

The main tower body size is determined by the structural design and is the most economical size for this height tower. The lower 40 foot portion tapers to a flexure point or a pivot. This pivot assembly is made of circular plates welded to form an inverted "Wedding Cake" appearance. The diameter of the bearing plate is 8 inches and the entire weight of the structure rests upon this pivot point. The weight is then distributed to a concrete foundation through a similar "Wedding Cake" assembly which tapers from 8″ in diameter to a base plate which is 60 inches in diameter and is 4 inches thick. The pivot point base was used to eliminate any bending from the base foundation and to eliminate any need for considering secondary loads due to bending in the lower part of the tower.

Many television towers today have rigid foundation bases where the tower structure does not pivot and any loads existing at the base are handled in bending. This type structure is extremely desirable to permit simple connections to the various electrical lines feeding the television antennas. However, the ground at the WBZ tower is extremely hilly and the transmitter building is placed in a location that requires all electrical connections leaving the tower 50 feet above the base. This feature permits the use of the pivoted base with the simpler design work attached to it.

The structure is supported by a number of sets of guys with each set consisting of six guys. The six guys extend in three equally spaced directions and are arranged in pairs of parallel guys which are attached to concrete anchorages. The present tower uses 4 sets of guys with two sets extending to three anchors 400 feet from the base of the tower. The two upper sets extend to anchors 890 feet from the tower. If the tower is extended in the future a fifth set of guys will be used which will attach to the outer ring of anchors.

The guys are bridge strand and vary in size from 1 7/16 inches in diameter to 2 1/16 inches in diameter. The guys are pre-stressed to give an elasticity modulus of 28,000,000. The attachment of the guys to the tower and to the foundations is made by using bridge sockets with zinced-in connections. All connections are tested to a loading fifty per cent greater than the maximum expected design load.

The equipment supported on the tower at present is to be used entirely by WBZ on Channel 4. The top 82′-9″ of the structure is a transmitting antenna consisting of 6 sets of radiating elements named "Bat-Wings," a name coined from their shape. The main structural support is a steel pole 99′-2″ long which extends into the main tower structure. The dead weight of the antenna is 18,250 pounds. This antenna is fed by four transmission lines, 3⅛″ in diameter each, which extend from the antenna down through the tower and into the building to the transmitter.

A reflector, 8′ x 12′, is mounted on the side of the tower at a height of 540 feet. Signals are sent by micro-wave through the air from the studios of WBZ and are reflected to the ground at Needham where a receiving metal parabola picks them up and sends them into the transmitter building where they are used to send a signal into the transmitter.

The structure is constructed so that two additional television channels may be served by equipment mounted on the tower. Channel 5 may use a 14 bay antenna mounted around the tower near the top of the tower. This antenna may also be fed by two lines with each line being 6⅛″ in diameter. Channel 4 may also use an antenna consisting of a number of elements attached to the corners of the tower near the top. This antenna would be fed by two lines which would be 6⅛″ in diameter each. Another future use of the tower is space for 3 FM antennas which may be mounted below the television antennas and which would be fed by 3⅛″ diameter transmission lines.

The combination of a future height increase plus the addition of two future antennas required that the tower design be checked for any combination of one antenna, two antennas, three antennas on a tower of either of two heights. This combination required six different analyses of the structure.

The horizontal loads which must be carried by the stuctures and its supporting guys may be stated as follows:

Antenna Load	— 231,000#
Transmission Live Load	— 212,000#
Tower Structure Load	— 253,000#

The loads to be carried are divided almost equally between the antennas, lines and towers.

The design wind load adopted for the WBZ tower was graduated from a loading at the base of 60 pounds per square foot to a top loading of 80 pounds per square foot. These figures are the loads applied to a flat rectangular surface using the formula $P = .0042\ V$. Appropriate corrections are made for the use of cylindrical surfaces. No other corrections are made for different shaped surfaces or flat surfaces inclined to the wind.

The only shielding effect considered in calculating the loading on the tower is the bracing on the back sides of the structure. These faces are considered to be equivalent to ½ that of the front exposed face. The full projected area of all other parts of the structure is used as a basis for calculating the area exposed to the wind.

The graduated loading is divided into three parts consisting of a basic 60 pound loading on the lower third, 70 pounds on the middle third and 80 pounds on the upper third.

Since the air loading characteristics of a shape vary so extremely with different size material, shapes and relation of shapes to each other, good engineering judgment dictates that the loading be kept in terms of pounds per square foot rather than being translated into miles per hour velocity. The cost of making innumerable wind tunnel tests on various tower sections plus the rather dubious value of using a perfectly controlled smooth flow of air as a basis for rating a structure in miles per hour makes a rating in pounds per square foot with a definitely stated method of design a far more sensible way of stating the structure. However, the lay mind does not understand a design loading in pounds per square foot and does understand miles per hour. Hence we could say that the load used on this tower varies between 120 miles per hour to a load of 140 miles per hour, approximately, and we emphasize these are approximate. These are working loads and do not represent the ultimate strength of the tower.

The design of the tower follows the general practice used in all structural work today where working loads are selected, stresses in members are calculated and sizes are selected with the final unit stresses being within code limitations. These final unit stresses allow a safety factor based upon the yield point of the material. The working load multiplied by the safety factor would come close to representing the true ultimate strength of the structure. I would like to see structural design practice changed so that the strength of any structure could be stated in true terms.

A number of different types of steel was selected for various applications in the tower. The use of these materials may be of interest to the structural engineer. The leg members are made of U. S. Carilloy Steel having a guaranteed yield point of 90,000 pounds per square inch. This material is a rather complex alloy which is heat treated and has the very desirable characteristic of permitting welding operations without losing any of the physical properties of the material. Special welding rods and techniques must be used with this material. These leg members are round, solid and are machine straightened at the mill. This material is somewhat expensive but the cost is justified by using rather high unit stresses which in turn permits keeping the size to a minimum and keeps the area exposed to the wind to a minimum. This in turn imposes less load on the tower.

The bracing in the tower is made of standard hot-rolled structural steel to an A7-ASTM specification with a yield point of 33,000 pounds per square inch. Connections of the bracing to the leg members is made by the use of structural rib-bolts with a self-locking nut. These rib bolts are heat treated and are a high-strength bolt with ribs that require power equipment to drive into place. The bolts fill the holes completely and the entire structure tends to become a single piece with no possibility of slippage at any connection.

The guy cables are made of wire strands spun into bridge cable and are a typical high-strength steel wire assembly which has been galvanized prior to the final spinning.

The elevator rails are solid rods which are made of cold rolled steel. The reason for selecting round members is to keep the wind load to an absolute minimum.

As you can see this structure represents the use of steel in many different forms and compositions. The present style construction has been a gradual development through constructing a number of tall towers. For example: The leg members used at WSB in Atlanta on the first 1000′ tower were made of 14 inch diameter pipe. This proved to be too big and too costly. The next use was that of solid round members of Hot-Rolled steel to a 33,000 pound per square inch yield point. This proved to be a good solution until towers began to require bigger sizes than were rolled. A 1,572 foot tower, an even 100 feet taller than the Empire State Building in New York City, at Oklahoma City for KWTV was built using 14 inch wide flange beams for legs. Once again this was too big and too costly.

The next step was a 1,521 foot tower for Dallas, Texas, operated by KRLD-TV and WRAA-TV. We used forgings, 10½ inches in diameter, solid, and with a yield point of 45,000 pounds per square inch. Here the sizes are big and the wind load high.

The latest step is the use of 90,000 pound per square inch material for WBZ. This material permitted using 7½″ diameter solid rounds instead of 10½″ diameter forgings.

One other item of interest in the tower is the maintenance elevator which will be used to keep the various pieces of broadcasting equipment operating properly. This elevator consists of a small but extremely heavy cab running on round rails with plastic rollers to hold the cab in place in the tower. The cab has dual cables and all the safety devices necessary to insure the safety of the maintenance men working on the equipment. Since the transmission lines extend the full height of the tower, work may be necessary at any point throughout the height of the tower. Therefore, a ladder is mounted in front of the elevator cab and a workman may step from the cab to the ladder at any point. In effect we might say that the elevator has landings every 15 inches which is the ladder rung spacing. The elevator engine is powered by a standard electric motor and drives the cab up or down.

The tower for WHDH in Boston is now under construction and is quite similar in style with the exception that this tower does not have provision for extra antennas for other TV stations. The height of the WHDH structure will be 1,240 feet above ground and 1,649 feet above mean sea-level. This tower will have an elevator and will be equipped with all of the necessary ladders and work platforms.