AASHTO DESIGN CRITERIA APPLIED TO MACHINERY BASCULE BRIDGES

by

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The code we are referencing is the Standard Specification for movable highway bridges published 1978, by the American Association of State Highway and Transportation Officials. It should be noted, as it is in the introduction to the specifications, that much of the material included in this specification was adopted from the American Railway Engineers Association Specifications that apply to movable bridges. Those specifications were prepared and apply to railway bridges. The AREA expresses no opinion as to their suitability for highway bridges and cannot be responsible for any highway applications thereof that may be adopted. It is also stated that the AASHTO Movable Bridge Specifications be used in the conjunction with the standard specifications for highway bridges.

As an interesting note, we have two volumes of a text entitled, "Movable Bridges" in our company library. Volume I deals with structure, Volume II deals with machinery. The author of these texts is Otis Ellis Hovey, BSCE, published by John Wiley & Sons, in the year 1927. Appendix A of Volumn II is entitled "Specifications for Movable Bridges" by O.E. Hovey, published in 1925. Much of that specification, as it applies to power requirements and machinery design, odd as it may seem, is identical to the 1978 AASHTO specification. It has apparently stood the test of time and is proven to be a more than suitable guide in the design of bascule bridges.

The basic intent of this paper is to discuss the specifications as they apply specifically to bascule bridges. The AASHTO specifications start out with Division I entitled, "General Provision" and is specifically written as a guide for contractors, but it would be well worth the time of any designer to be aware of its requirements.

With respect to machinery, Article 1.1.4 "Time of Opening" defines the meaning of normal time of operation. The actual time for bridge openings is not specifically spelled out in the specification. As a general practice, between 60 and 75 seconds is considered the normal time of opening and closing.

Article 1.1.6 Machinery Design spells out, among other things, various items to be considered as conditions of loading.

A) The effect of acceleration or retardation generally considered to be between 5 and 15 seconds. The obvious force here is overcoming inertia, or the effect of braking.

B) Frictional resistance accounting for the frictional resistance in the main trunnion bearing, frictional resistance in machinery bearings, the efficiency of meshing gears, shafts and gear reducers are basic items of consideration.

C) Any unbalanced condition of the bridge. It is generally accepted that some unbalance be required for bascule bridges. This unbalance is normally to make the bridge nose heavy, thus requiring somewhat less force for closing, and to provide a positive downward force at the live load shoe.

D) Wind loads for which three load conditions are generally considered. A 2 1/2 pound wind used for the selection of power and design of machinery to operate the bridge in the normal time frame, 60-75 seconds. A 10 pound wind used for selection of power and design of machinery to operate the bridge in twice the normal time, 120-150 seconds, and a 20 pound wind force used to establish machinery design and brake size for holding the bridge in any position.

Division II of this specification is entitled, "Design" and is divided into two groups, structural and machinery. Of interest in the structural section is Article 2.1.11 entitled, "Impact". All machinery is supported by some sort of structural element and will be affected by the operating machinery. This section requires that stresses in structural parts caused by the machinery or by forces applied by moving or stopping the span, shall be increased 100% as an allowance for impact.

Article 2.1.12, "Fatigue", refers the designer to the basic design criteria and allowable fatigue stresses as given by the current edition of AASHTO Standard Specifications for Highway Bridges. As an example of a structural system to be subjected to impact and fatigue requirements the commonly used arrangement of motors, gear reducers, gears, and structural elements is known a Hopkins Frame, or Hopkins Gear Train. This system requires a structural frame pin supported at the base, to the machinery platform to stand vertically upon which motors, brakes, gear reducers, shafts, bearings, pinnion gears and gears are attached. This requirement of Article 2.1.11 and 2.1.12 have a significant impact upon the details and member sizes selected. The designer is cautioned to exercise great care in their analysis of this and similar systems as they have given bridge owners signficant trouble and expense in their repair.

Continuing on into the Machinery Design section - the designers first series of steps is to determine the power requirements for the machinery system and the following steps would thus be necessary:

1) Establish normal time for opening - 60-75 seconds.

2) Establish the Maximum angle of opening generally 74 to 77 degrees.

3) Select the RPM's to be specified for the electric motors. Most commonly used is a 900 rpm motor producing an actual 860-870 rpm's at full load rated torque.

4) Select the radius for the rack gear. This is generally between 7 1/2 feet to 10 feet. Ones initial selection would most likely rely on his experience in design of bascule bridges. Select the size of rack and pinnion gear teeth, again experience would dictate ones initial selection.

5) Calculate rack travel, volocity, and number of pinnion gear revolutions for the full angle of opening. Number of pinnion gear revolutions is usually found to be between 2 and 3.

6) Determine the appropriate gear ratio or gear reduction required to open and close the bridge for the normal time of operation allowing 5-10 seconds for acceleration and deceleration. Gear reduction needed would be approximately 300-450.

7) Calculate or estimate the various individual load considerations as mentioned earlier, such as overcoming inertia, resistance in the trunnion bearing, resistance in the gear train, unbalanced moment due to unbalanced load conditions, and the loads created by the 2 1/2 pound wind, the 10 pound wind and the 20 pound wind.

Article 2.5.3, "Power Requirements and Machinery Design" established specific load conditions and combinations for which machinery shall be proportioned and power provided.

Condition A is the combination of loads for normal time of opening, the 60-75 second time frame. For bascule bridges the load combinations include the effects of frictional resistance, inertia, unbalanced load conditions and a wind load of 2 1/2 pounds per square foot acting normal to the floor with the bridge in any position, for open decked grid floor bridges that portion of the floor area may be reduced by 15%.

Condition B is the combination of loads for which an extended time of operation is allowed, specifically 1 1/2 times the normal time. This combination requires an additional 2 1/2 pounds per square foot for ice loading be applied. In addition to those loads specified under condition A above. Obviously, this load condition need only be explored where ice is likely to be encountered.

Condition C, again allowing for an extended time of operation, specifically twice the normal time, requires the following combination of loads: Frictional resistance, inertia, unbalanced load conditions, and a wind load of 10 pounds per square foot on any vertical projection of the open bridge and an ice load of 2 1/2 pounds per square foot. Again, the ice loading need only be applied in areas where ice is anticipated. When calculating the actual time of operation, at no time should the wind loads be less than 2 1/2 pounds acting normal to the bridge as compared to the 10 pounds per square foot acting on the vertical projection of the open bridge.

At this point it is important to discuss and consider the characteristics of electric motors. Selection of the type of electric motor and the type of speed controls used is an important factor in establishing whether or not the powers applied will be able to operate the bridge in the normal time, 1 1/2 the normal time, or twice the normal time.

Electric motors generally have the ability to develop higher torques for short periods of time when subjected to higher than normal loading and will operate at slower speeds. Many torque speed curves would clearly indicate the ability of a motor to develop 150%, 200%, 250%, and even 300% full load rated torque at a slower speed. It has generally been our interpretation of the code that the provision for extended time, in effect, implied an understanding of these characteristics and that they be considered when selecting motor size. Speed controls also have a bearing on this selection and provide for some additional torque when needed. It is our understanding of today's speed control equipment, that they are designed to disrupt service when loads exceed 150% of normal full load rate torque. It is therefore been our practice in selecting motor size to allow or to limit overtorque conditions to 150%. It is therefore our interpretation of the code that the power requirement would be as follows:

For Condition A normal time of operation 100% of full load rated torque of the electric motor selected.

For Condition B up to 150% or the maximum torque developed at a reduced speed such that the time of operation is 1 1/2 times normal time of operation.

For Condition C allow 150% of full load rated torque for the motor selected. It is not likely that any reduction would be necessary since the 10 pound load per square foot wind would not create higher loads than the 2 1/2 pound wind force until the bridge were opened between and 40° and 50° and then only increase gradually as the bridge reaches the fully opened position.

With the above understanding of electrical motors and the load combinations, one now has the ability to select or determine his initial power requirements. It has been out experience in the past that load condition C generally dictates the power requirements. It is still important to know the power requirements for load condition A since many bridges are supplied with two motors. In most two motor operations one would find that the horsepower supplied from a single motor could operate the bridge under normal conditions and therefore during a motor malfunction the bridge could remain operational with some care and diligence on the part of the bridge tender not to subject the bridge to unusual loading conditions.

Article 2.5.4 "Machinery Design" specifically states that the machinery components, gears, bearings, shafts shall be designed for 150% of the full load rated torque developed by the prime mover and that the normal allowable unit stress shall be used in their design.

The specifications require that brakes be supplied and be sized to stop the bridge motion when necessary or to provide the holding force necessary to accommodate the 20 pound per square foot provision for wind loading. Since brakes are normally mounted on the extension of motor shafts when two motors are provided and motor shaft and the input shaft of the gear reducers when a single motor is provided, It is obvious this results in the breaking or holding force being transmitted through the entire gear chain and is thus an alternate design consideration when sizing machinery components. When stopping the bridge with brakes, brakes should be applied gradually, allowing for a proper deceleration of the leaf so as not to incur forces due to inertia that have not been provided for. It is our suggestion that brakes be used only to hold the bridge in position and that speed controls provide the necessary force to slow the bridge down and stop it with the electric motors. When sizing the machinery for the holding force allowable stresses may be increased by 150%.

At this point the designers next step is to make his initial determination as to machinery components and their size. Obviously we have a rack gear and pinnion gear to design and generally the pinnion gear is supported by two bearings placed upon a support stand. Most gear trains today include at least one fully enclosed gear reduction box. These gear boxes are produced by a number of manufacturers who have prepared tables and charts indicating gear box dimensions, rated horsepower and torque capabilities. It is our suggestion that if at all possible a single large gear box with a gear reduction in the neighborhood of 300-450 to 1 be used. If the loading for a specific bridge is such that a gear box with the necessary capability is not readily available or if the gear box is of such dimensions that it would not fit in the space allowed, the designer could go to a second set of gear boxes or one or two sets of external gears. External gears are not recommended if possible, due to the fact that they require a great deal of maintenance to insure their longevity. Obviously the designers efforts would be greatly simplified if a single gear box can be selected. If external gears are necessary, it is recommended that they be mounted on a common support stand with the pinnion gear. This would allow for factor fabrication and alignment of gears. Obviously proper alignment will ensure wearability of the gear train and any field alignment that can be eliminated will greatly simplify and reduce the cost of the gear train. It is the responsibility of the designer to arrange the gears geometrically and provide sufficient space for their placement on the machinery platform. The designer should provide at least one operational system, gear reducer, shafts, bearings, pinnion gears, gears and rack and support stands, in the construction plan. Generally specifications allow for alternate design by the contractor. It may be necessary once the final selection of gear reducer and gears has been established that the designer repeat the process of power selection and gear train design to insure that the final gear ratio and speed of operation is in compliance with the code and capable of withstanding the loads applied.

This paper was not intended to provide the reader with a detailed analysis and example calculations that would be necessary to produce a complete design. It is rather a overview and the author's interpretation of some of the items in the current code. It is hoped that the reader has a better insight into the design criteria and considerations necessary in which to produce a reliable operating system for bascule bridges. It is also hoped by the time of the next bridge symposium that this paper can be expanded and indeed provide the user with a more detailed analysis of a sample gear train.