# AASHTO DESIGN CRITERIA APPLIED TO HYDRAULIC 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 current edition of AASHTO contains very little reference to hydraulics but certain sections can be utilized even if the reference is to machinery. 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 hydraulics, 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/Hydraulics 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.

B) The effect of frictional resistance which generally consists of the frictional resistance in the main trunnion bearing, the efficiency of the hydraulic system which should account for pressure losses in lines, fittings, and components.

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. For hydraulic cylinder this may also help even-out operating pessure when coming down since the rod end of the piston yields a smaller area upon which to develop the total operational force.

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 hydraulic system to operate the bridge in the normal time frame, 60-75 seconds. A 10 pound wind used for selection of power and design of hydraulic system to operate the bridge in twice the normal time, 120-150 seconds, and a 20 pound wind force used to establish maximum hydraulic pressure 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". Hydraulic cylinders are supported by some part of the structure and will be affected by the operating forces. This section requires that stresses in structural parts caused by the machinery/hydraulic 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.

Article 2.1.14 "Hydraulic Cylinder Connection". The stresses on the structural connection to the cyliners shall be based on a cylinder pressure of 150 percent of the setting of the pressure-relief valve controlling the maximum pressure available at the cylinder.

Continuing on into the Machinery Design section - the designers first series of steps is to determine the location and size of hydraulic cylinders 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) Positioning of hyraulic cylinders. Obviously the first choice would be to locate hydraulic cylinders under main girders. This would not be the only location available and in the case of bridge renovation where a hydraulic system were to replace a machinery system, other locations may prove to be more suitable. The connection of the rod eye at the end of the piston rod via pillow blocks (bearings) to the main girder or structure should be located well below the trunnion and as far forward of the trunnion as is possible. The bottom surface of the bottom flange of the main girder provides the designer with both these features. The basic object is to create a situation where the moment arm, being the distance between the piston rod and the center of rotation (trunnion), is maintained at a maximum throughout the opening and closing process. This, in effect, will produce the minimal amount of operating force needed during the entire opening process. Cylinders can be supported on the machinery platform at the end with a clevis type device or at intermediate points between the bottom and the top of the cylinder. In effect, one consideration in determining the ultimate length of the cylinder would be the stability of the cylinder and piston rod when fully extended. The shorter the distance between the rod eye and the point of support of the cylinder which would result in an overall shorter cylinder. In essence, the cylinder is made longer in order to leave the piston deeper within the cylinder when the piston rod is fully extended. The term for this is "stop-tube distance", a distance added to the length of stroke required to fully actuate the bridge. It has been our finding that a center mounted trunnion cylinder provides the best features for design. Supporting the cylinder too close to the top also results in the need for a very accurate alignment between the vertical axis of the main girder and the horizontal positioning of the cylinders.

4) At this point one should calculate or estimate the various individual load considerations as mentioned earlier, such as overcoming inertia, resistance in the trunnion bearing, efficiency loss in the hydraulic system, unbalanced moments 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 (Hydraulic) Design" established specific load conditions and combinations for which the hydraulic system 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 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.

A brief discussion and consideration of electric motors and pumps is important at this point. In most hydraulic applications a somewhat higher speed motor is generally provided than that used for the machinery design systems. It has been our practice to select an 1800 rpm motor. The hydraulic pump that we intend to use will require horsepower control. With this pump the monitoring of horsepower in terms of flow (gallons per minute) and pressure will be provided. With this type of pump we will obtain automatic stroking or ramping of the pump to insure that the combination of flow and pressure generated by the system will provide a uniform horsepower output. Thus the motor is generally brought up to speed prior to energizing or stroking the pumps. With this motor pump combination the system has the ability to operate under a variety of load combinations and the effect would be to regulate flow thus extending the time of operation. This feature is a perfect match for the AASHTO loading combinations in which, as the loads are increased, the times for operation are extended. The following series of steps are suggested in sizing cylinders and selecting power:

5) Would first require the calculation of the forces generated by each of the three load conditions, A, B, and C. Generally each lift consists of two main girders and it is therefore implied that a minium of 1 cylinder be required under each main girder. It has been our practice on the somewhat larger bridges, that two cylinders be located under each main girder, or a total of 4 cylinders per leaf. This provides the designer and the owner with the ability, during repair and servicing of cylinders, to remove one or even two cylinders and still have the capability of bridge operation under normal loading conditions. We have generally found that load condition C will dictate the number of cylinders or size of cylinders that must be provided and by reviewing the operating pressures developed for load condition A when two cylinders have been removed from the system will find that operating pressures are within safe limits.

6) Determine the total operating force generated by condition A based on normal time of operation. This should be done for both the opening procedure and for the closing procedure by calculating the surface area of the piston for all cylinders and dividing that into the opening force generated one can determine the operating pressure required, and similarly calculating the surface area on the rod side of the cylinder and dividing that into the force required to close the leaf will generate the operating pressure that results. Generally operating pressures for normal time of operation should be around 500-600 psi.

7) Determine operating force, and the pressures for condition B with an extended time of 1 1/2 the normal time in a similar fashion to 6 above, a pressure of approximately 1000 psi would be appropriate.

8) Determine operating force, and the pressures for condition C with an extended time of twice the normal time in a simlar fashion to 6 above, a pressure in the range of 1500 to 2000 psi.

9) The next condition of consideration is the ability of the cylinders to hold the bridge in the fully open position for the 20 pound wind force. Under this condition the maximum pressure of between 2500 and 3000 psi would be appropriate.

10) Having calculated the various combinations of loads and cylinder pressures and thus determined the appropriate number and size of cylinders, and having positioned them, our next step would be to determine stroke length and verify the time of operation for the various load conditions. Since loads and moment arms vary as the bridge

is opened and closed, the designer must calculate these factors based on small increments of opening. We have found the use of a computer to be very beneficial in making the calculation since the computer can perform such calculations for each degree of opening in a very short time. This would allow the designer to make the most optimum selection of cylinder size and horsepower required. With the proper program the designer could input leaf dimensions, geometric locations of trunnion, connection points of the cylinders, number of cylinders, size of cylinders, size of the piston rod, angle of opening under various loading conditions, his estimate of horsepower required, the efficiency of the system and time for acceleration. Because of the rotation of the leaf the moment arm between the center of rotation and the piston rod vary with each degree of opening and since the 10 pound wind load is applied to the vertical projection of the leaf, the forces applied to the cylinder vary with each moment of opening. With the computer program the designer would analyze in one degree increments, all conditions of loading, calculate the length of stroke, moment arm, forces required to push the leaf up and pull the leaf down, pressures encountered, and time required to move the leaf through each degree of opening.

Once the hydraulic cylinders, motor, pumps have been established, various other components must be selected. In order to utilize the hydraulic cylinders as an effective brake in which the leaf can be held in any position, check valves are necessary and should be located as close to cylinder ports as is practical. In our case, pilot actuated check valves are necessary so that when pressure is applied to the cylinder at one port, the check valve at the other end is automatically opened. Thus whenever the power or pumps are shut-off the check valves automatically close locking fluid in cylinders and therefore results in holding the bridge in its current position. Relief valves are so necessary that operating pressures do not exceed design limitations. As we discussed, the maximum operating pressure for load condition C would be in the range of 1500 to 2000 psi and we should therefore have at an appropriate location, a relief valve which is set to the maximum operating pressure expected, and since the cylinders are to be utilized as brakes with the capability of withstanding the 20 pound holding force, a second set of relief valves would be necessary which would have a pressure setting of somewhere between 2500 and 3000 psi. The selection of other components such as counter balance valves and four-way directional valves, would be selected based on the volume of flow. Hydraulic tanks should be sufficiently large enough to hold between 4 and 5 times the required volume of fluid to operate the bridge during one cycle. This large volume of fluid is primarily used to dissipate heat, but certainly insures ample supply of fluid. Where hydraulic systems are anticipated to be used a numerous number of times in quick succession and it is likely that an excessive heat build-up can be anticipated the need for a heat exchange should be provided. On the other hand, it may be necessary to provide a heating element to bring oil temperatures up to operating levels. This is generally necessary when hyraulic systems are first used on cold mornings or even continue to be used on cold days. Proper filtration of hydraulic fluid is probably the most important item to be considered. The size of filtration and the location of filters is important. Fluid should be filtered just prior to returning to the tank. Fluid should be filtered prior to entering pumps to eliminate contaminates that might damage the pumps unless pump designs are capable of handling contaminants without damaging the pumps, otherwise filters should be used just after pumps so as to prevent contamination of hydraulic components and cylinders.