CHAPTER 5—MECHANICAL DESIGN LOADS AND POWER REQUIREMENTS

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5.1—SCOPE

The following shall supplement *A5.1*.

This chapter contains information and criteria related to the design of movable bridge machinery. It sets forth the basic Louisiana Department of Transportation and Development (LADOTD) design criteria that are exceptions and/or additions to those specified in the latest edition of the *AASHTO LRFD Movable Highway Bridge Design Specifications*, including all interim revisions.

Construction specifications shall be the latest edition of *Louisiana Standard Specifications for Roads and Bridges (Standard Specifications)*. *Standard Specifications* are subject to amendment whenever necessary by supplemental specifications and special provisions to specific contracts. In the absence of specific information in *Standard Specifications*, follow the latest edition of *AASHTO LRFD Bridge Construction Specifications*.

5.2—DEFINITIONS

The following shall supplement *A5.2*.

Hydraulic Bascule Bridge—Bascule bridge utilizing machinery comprised of electric motors, hydraulic pumps, hydraulic cylinders, hydraulic motors, piping, manifolds, solenoid-operated valves, reservoirs, any other hydraulic machinery suitable for use on movable bridges, electrically-released disk brakes or shoe brakes to be used as machinery, and/or motor brakes to operate a movable span.

Hydraulic Swing Span Bridge—Swing span bridge utilizing machinery comprised of electric motors, hydraulic pumps, hydraulic cylinders, hydraulic motors, piping, manifolds, solenoid-operated valves, reservoirs, any other hydraulic machinery suitable for use on movable bridges, electrically-released disk brakes or shoe brakes to be used as machinery, and/or motor brakes to operate a movable span.

Machinery Brake—An electrically-released brake that, acting in conjunction with the motor brake, applies enough static torque to the span drive system to hold the span in the open position against the loads/conditions specified in *A5.5* and *D5.5*. This brake should have a time delay of 5 to 6 seconds, so that it does not set while the motor brake is bringing the span to a controlled stop during normal operation of the span.

Mechanical Bascule Bridge—Bascule bridge utilizing machinery comprised of electric motors, enclosed gear boxes, electrically-released shoe brakes, disk brakes, and open gears to operate a movable span.

Mechanical Swing Span Bridge—Swing span bridge utilizing machinery comprised of electric motors, enclosed gear boxes, electrically-released shoe brakes, disk brakes, and open gears to operate a movable span.

Mechanical Vertical Lift Bridge—Vertical lift bridge utilizing machinery comprised of electric motors, enclosed gear boxes, electrically-released shoe brakes, disk brakes, and open gears to operate a movable span.

Motor Brake—A brake that, acting alone, applies enough dynamic torque to the span drive system to stop the span in 3 to 4 seconds under the normal operating loads/conditions specified in *A5.4.2 – A5.4.4* and *D5.4.2 – D5.4.4*. This brake should have no time delay, and should apply the braking force immediately when called for by the span control system.

5.4—SIZING PRIME MOVER FOR SPAN OPERATION

5.4.1—General

The following shall supplement *A5.4.1*.

Inertia shall be accounted for when sizing the prime mover for acceleration.

The contract documents shall specify that electric motors, nameplates, and data sheets shall be supplied in English units.

Clearly indicate on the plans the following required torques:

T_A - The maximum torque required to accelerate the span to meet the required time of operation.

T_S - The maximum torque required for starting the span.

T_{CV} - The maximum torque required for constant velocity.

Electric motors for span drive hydraulic systems shall be sized to satisfy the provisions of *A7.5.2* and *D7.5.2.*

C5.4.1

The following shall replace the 5th paragraph in *AC5.4.1*.

Past editions of AASHTO specifications for movable Highway bridges did not include inertia forces in T_S**.** For LADOTD, the inertia forces shall be included in the applicable provisions.

The following shall replace the 8th and 9th paragraphs in *AC5.4.1*.

Equipment shall be manufactured per NEMA Standard MG 1. No metric electric motors will be allowed on LADOTD projects.

5.4.2—Bascule Spans

The following shall replace the 1st paragraph in *A5.4.2*.

Maximum Starting Torque (T_S) **–** Shall be determined for span operation against static frictional resistances, unbalanced conditions specified in *A1.5* and *D1.5*, a wind load of 10 psf on any vertical projection, and shall include inertial resistance due to acceleration.

In Louisiana, ice loading shall be neglected.

The following shall supplement *A5.4.2*.

Specify a drive capable of developing the torques stated in *A5.4.1* and *D5.4.1*, and opening or closing the leaf within a 90 second time limit.

5.4.3—Swing Spans

The following shall replace the 1st paragraph in *A5.4.3*.

Maximum Starting Torque (T_S) **–** Shall be determined for span operation against static frictional resistances, a wind load of 10 psf on any vertical projection of the open bridge, and shall include inertial resistance due to acceleration. A 10 second acceleration time shall be used when calculating the acceleration time for the maximum starting torque.

In Louisiana, ice loading shall be neglected.

5.4.4—Vertical Lift Spans

The following shall replace the 1st paragraph in *A5.4.4*.

Maximum Starting Torque (T_S) **–** Shall be determined for span operation against static frictional resistances, rope bending, unbalanced conditions specified in *A1.5* and *D1.5*, a wind load of 2.5 psf on the area specified in *A2.4.1.3.1* and *D2.4.1.3.1*, and shall include inertial resistance due to acceleration.

In Louisiana, ice loading shall be neglected.

C5.4.4

T_S will be at a maximum when opening the span from the fully closed position, due to the imbalance required for positive seating.

5.5—HOLDING REQUIREMENTS

The following shall replace the 2nd paragraph in *A5.5*.

The machinery shall be designed assuming the span is to be held in the open position against wind loads specified in *A2.4.1.3.1* and *D2.4.1.3.1*, even if separate holding devices are to be used.

C5.5

Any span type that is not normally left in the open position will not normally require any extra device to lock the span in the open position. Special circumstances might dictate otherwise.

Any span type that is normally left in the open position shall have an extra locking device capable of holding the span on its own, but the machinery should still be designed to hold by itself against the “holding load.”

5.5.2—Swing Spans

The following shall supplement *A5.5.2*.

When a swing span is to be normally left in the open-to-marine-traffic position, provisions shall be made to lock the span in this position either at the center pier or at the end lifts by the use of a locking pin or other suitable method. The movable span shall be designed to hold against the wind loads specified in *A2.4.1.3.3* and *D2.4.1.3.3*. Also, the open position shall be investigated for the full wind pressures specified in *AASHTO LRFD Bridge Design Specifications, A3.8,* and *LADOTD BDEM, Part II, Volume 1, A3.8*. Locking the span open shall be part of the normal operation of the bridge.

The Designer may use an alternate means for locking the swing span open by incorporating two additional end piers (one for each end of the span), oriented such that the span, when swung open to marine traffic, can have its end lifts driven to pin the span open against the end piers, similar to what is done when pinning the span in the closed-to-marine traffic condition. This will reduce the wind load requirements to that specified for a "normally closed span," specified in *A5.5.2* and *D5.5.2*. When designing these end piers, live load and live-load impact may be neglected.

C5.5.2

For normally open swing spans pinned at the center pier or other suitable method which do not have provisions to drive the end lifts, the span and balance wheels, including all supporting members tied into the bridge cross bracing, must satisfy the full wind pressures specified in *AASHTO LRFD Bridge Design Specifications, A3.8,* and *LADOTD BDEM, Part II, Volume 1, A3.8*.

When providing the additional rest piers oriented to allow the end lifts to drive and pin the span while in the open position, the design wind loads used shall be that of a normally closed span.

5.5.3—Vertical Lift Spans

The following shall replace the 1st paragraph in *A5.5.3*.

Where a vertical lift span is normally left in the open position, resistance to satisfy wind loads specified in *A2.4.1.3* and *D2.4.1.3* shall be provided by separate holding or locking devices. The machinery shall also be designed without separate holding or locking devices to satisfy the wind loads specified in *A2.4.1.3* and *D2.4.1.3.*

5.6—Sizing Brakes

The following shall supplement *A5.6.*

System inertia shall be incorporated into the brake sizing for deceleration. The brake system shall be designed to hold against loads/conditions specified in *A2.4.1.3* and *D2.4.1.3*, both in the span-open and span-closed positions.

5.6.2—Bascule Spans

The following shall replace the 1st paragraph in *A5.6.2*.

The motor brakes shall have sufficient capacity to stop the span in a maximum of 10 seconds when the span is moving at a speed conforming to the normal time for opening under the influence of the greatest unbalanced loads specified in *A5.4.2* and *D5.4.2* for T_{CV}.

In Louisiana, ice loads shall be neglected.

For the mechanical bascule type bridges, one thruster-operated shoe brake located between the drive motor and the main gear box shall be used on each bascule leaf as a motor brake. This brake shall stop the span in a smooth and controlled manner. The motor brake in this case does not need to comply with the requirements specified in *A2.4.1.3* and *D2.4.1.3.*

The following shall supplement the 2nd paragraph in *A5.6.2*.

For mechanical bascule-type bridges, machinery brakes shall be located as near each output rack as practical and shall engage approximately 4 seconds after the motor brake sets.

5.6.3—Swing Spans

The following shall supplement the 1st paragraph in *A5.6.3*.

For rack and pinion types of swing span bridges a thruster-operated shoe brake shall be used as the motor brake and shall be capable of stopping the span in a smooth controlled manner without exceeding 10 seconds. If two pinions are used then each of the pinions respective motor shall have a motor brake.

Machinery brakes (thruster operated shoe brakes) shall be used in addition to the motor brakes. The machinery brake shall be sized to hold under the requirements specified in *A2.4.1.3* and *D2.4.1.3.*

For swing spans operated by hydraulic cylinders, braking shall be accomplished by slowing down the flow of hydraulic fluid being pumped to and from the cylinders. The “machinery braking” shall be accomplished by activating solenoid-operated stop valves upon arrest of the span.

The following shall supplement the 2nd paragraph in *A5.6.3*.

Hydraulically-operated bridges shall not be left in the unattended “open” position without some form of mechanical lock installation. Blocked-in or closed-valve hydraulic lines shall not be used as a holding brake in this case.

C5.6.3

The recommended method for controlling the flow rate is by using a swash plate hydraulic pump. A gear motor and linkage shall be used to stroke the pump from full flow to creep flow to no flow.

5.6.4—Vertical Lift Spans

The following shall replace the 1st paragraph in *A5.6.4*.

The motor brake(s) shall have the capacity to stop the span in a maximum of 10 seconds when the span is moving at a speed conforming to the normal time for opening or closing–under the influence of the greatest imbalance loads specified in *A5.4.4* and *D5.4.4* for T_{cv}.

In Louisiana, ice loads shall be neglected.

For the mechanical vertical lift type bridge, one thruster-operated shoe brake located between the drive motor and the main gear box shall be used on each tower. This brake shall stop the span in a smooth and controlled manner. The motor brake in this case does not need to hold under the requirements specified in *A2.4.1.3* and *D2.4.1.3*.

The following shall supplement the 2nd paragraph in *A5.6.4*.

For the mechanical vertical lift type bridge, the machinery brake shall engage approximately 4 seconds after the motor brake sets.

C5.6.4

The maximum braking torque occurs when the span is at the nearly seated position while moving downward and span heavy. Under these circumstances, the differential and leveling clutch, located on the main reducer, takes approximately 6 seconds to actuate. The span motor brake(s) shall set after a 1 second delay, allowing the drive motors to plug for 1 second.

In the event that a strong wind load prevents the span from stopping in the desired 4 seconds, the machinery brake(s) shall be applied. This is done by the use of a mechanical time delay integral with the shoe brake, set at a 4 second delay after power is removed from the electric motors.

The goal here is to stop the span before the differential and leveling clutch actuator has completed its operation, allowing the span to stop before the main gearbox is in full differential mode.

When the clutch has finished engaging, the brakes are released, and the span is allowed to float down under its own imbalance and then seats into place.

5.7—MACHINERY DESIGN CRITERIA

5.7.1—General

The following shall replace the 1st paragraph in *A5.7.1*.

Where machinery of the commercial manufactured type is specified, the contract documents shall specify testing requirements to document that such machinery satisfies the project requirements as determined by the Designer.

The following shall supplement *A5.7.1*.

If wound rotor motors are used, all drive machinery shall be designed to handle 200 percent full load motor torque.

All design factors shall be included in plans.

Prime mover sizing criteria may not necessarily establish the maximum load rating of the drive train, because the brake or holding requirements of a particular bridge may be greater than its operational load requirement. Final criteria shall be shown in the design calculations and drawings.

For bascule bridges, compute the acceleration torque for the inertia component and the loading specified for the maximum constant velocity torque. In addition, the drive must be capable of meeting the maximum starting torque requirements and the machinery must be capable of holding the leaf against a 20 psf wind load in the full open leaf position.

The following shall replace *Table 5.7.1-1.*

For A.C.-controlled wound rotor motors, the overload limit state stress can be as high as 300 percent FLT. See Figure A5-1: Wound-rotor Motor Speed Torque Curves in the appendix of this chapter.

Table 5.7.1-1 – Machinery Design Prime Mover Loads

Prime Mover	Service Limit State	Overload Limit State Stress
A.C. (Uncontrolled)	1.5 FLT	Greater of 1.5 ST or 1.5 BDT
A.C. (Controlled)	1.5 FLT	Greater of 1.0 ST or 1.5 AT
A.C. (Wound Rotor Controlled)	2.0 FLT	3.0 FLT
D.C. (Controlled)	1.5 FLT	3.0 FLT
Hydraulic	Refer to Hydraulic Section- Article 7.4	Refer to Hydraulic Section- Article 7.4
I.C. Engines	1.5 FLT	1.0 PT at Full Throttle
Manual Operation	See provisions of Article 5.7.2.1	

5.7.2.1—Auxiliary Drives

The following shall supplement *A5.7.2.1.*

For vertical lift bridges using the drive motor/selsyn arrangement (two drive motors and two selsyns), a separate auxiliary drive is not needed. In the event a motor fails, the bridge can still operate using a single motor in conjunction with two selsyn motors.

For hydraulic swing spans and hydraulic bascule bridges, the hydraulic power unit shall be designed to have redundancy by using dual motors, pumps, valves, etc., that normally act together, but can operate the span in twice the time if operated independently.

C5.7.2.1

The tower drive vertical lift bridge has redundancy built into the drive system, giving it the capability of operating the entire span using one electric motor and two selsyns. The faulty motor can be refurbished while the bridge operates in this mode.

5.7.3—Braking

The following shall supplement *A5.7.3*.

For hydraulic motor brakes, the total mechanical brake system used must be capable of surviving a power failure occurring during maximum operating speed. Elements employed to delay automatic activation of hard-set devices must be reliably demonstrated if the mechanical brake system cannot withstand a full-force impact.

Motor brakes and separate machinery brakes are most applicable for open-gearing installations where multiple shafts are used. As the number of drive shafts is reduced (by integral driver & reducer installations), the ability to incorporate a separate brake directly on the final low-speed drive shaft becomes unfeasible. Designs that incorporate an integral outboard high-speed motor brake shall only be incorporated with an up-sized associated gear reducer capable of the brake-developed torque loadings, regardless of the motor torque curves developed. Brakes installed on a reducer high-speed shaft shall be up-sized to account for dynamic impact of decelerating loads.

C5.7.3

This case arose from the use of a hydraulic motor driving a rack and pinion for the St. Ann swing span, located in Terrebonne Parish.

REFERENCES

AASHTO LRFD Movable Highway Bridge Design Specification, Latest Edition, American Association of State Highway and Transportation Officials, Washington D.C.

AASHTO Standard Specifications for Movable Highway Bridges, 5th Edition, MHB 5, American Association of State Highway and Transportation Officials, Washington D.C., 1988.

AASHTO LRFD Bridge Construction Specifications, Latest Edition, American Association of State Highway and Transportation Officials, Washington D.C.

Borden, L. V. Torque Characteristics of Wound Rotor Motors, Revisited. *Heavy Movable Structures Symposium*. 1996.

Louisiana Standard Specifications for Roads and Bridges, Latest Edition, State of Louisiana Department of Transportation and Development, Baton Rouge, LA

Applicable Codes and Standards:

NEMA—National Electrical Manufacturers Association

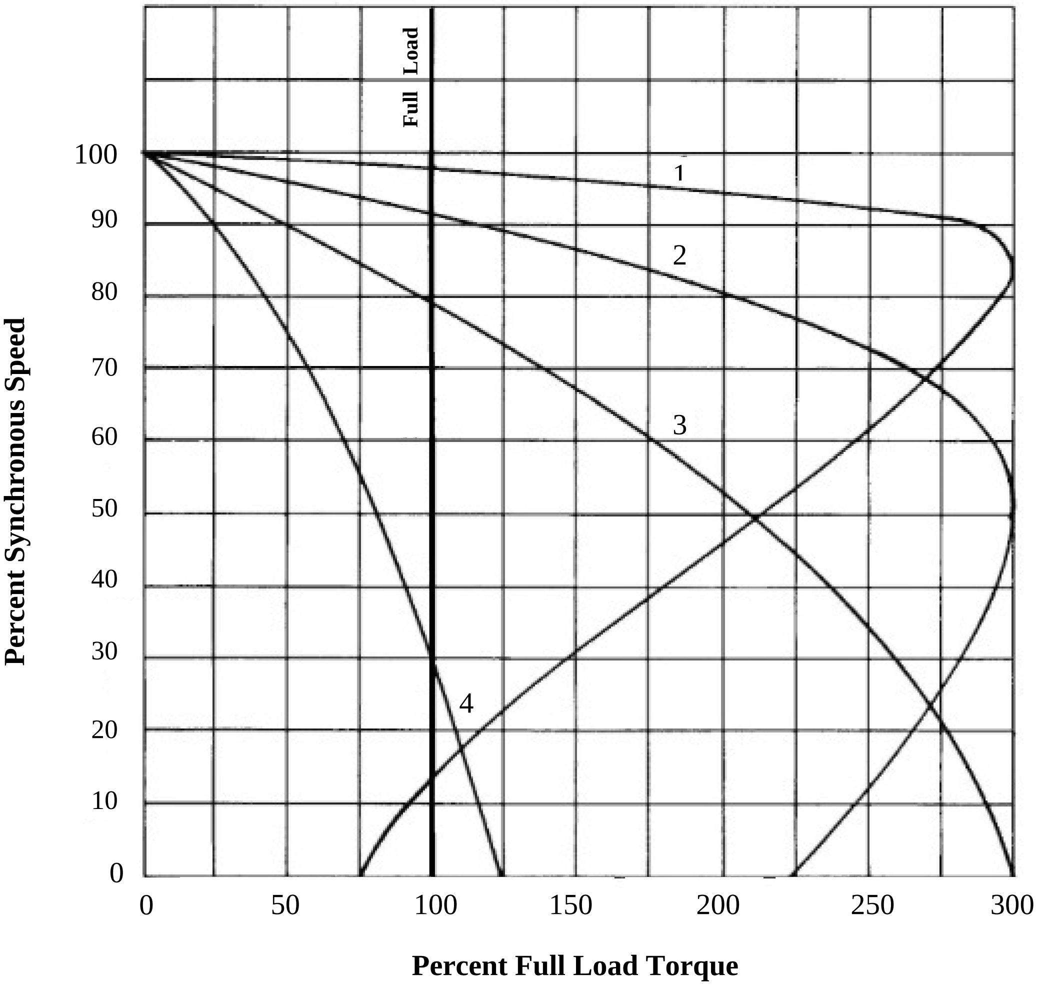
APPENDIX—MOTOR TORQUE CURVES

The following figure below shows the typical wound-rotor motor speed torque curves.

Wound-rotor motor speed-torque curves

1: rotor short-circuited;

2-4: increasing values of external resistance.



Wound-rotor Motor Speed Torque Curves