LRFD

23-1 BURIED REINFORCED CONCRETE BOX STRUCTURES

Introduction

Buried reinforced concrete box (RCB) structures are closed rectangular conduits for conveyance of water, vehicles, utilities and pedestrians. A buried RCB can be comprised of a single-cell box or multi-cell boxes. The Standard Plans provide details for a range of single-cell RCB and multi-cell RCB.

Buried RCB structures can be constructed either by the cast-in-place (CIP) method or by the precast (PC) method. An RCB usually includes headwalls and wingwalls at each end. Refer to Caltrans Standard Plans for standard designs of the RCB, wingwalls and headwalls. For buried RCB not covered by Standard plans, a special structural design is required.

This memorandum provides Caltrans supplemental requirements and direction for designing and installing new buried RCB structures. It also provides direction for determining the load capacity of an existing RCB and considerations for extensions.

Design Considerations

The structural design criteria of the buried RCB structures on the State Highway System is based on the latest *AASHTO LRFD Bridge Design Specifications* with California Amendments (AASHTO LRFD-BDS-CA) as well as Caltrans supplemental requirements. If used for drainage purposes, the hydraulic design must be conducted by the District hydraulic engineers or by Structure Hydraulic and Hydrology engineers. See *Highway Design Manual* (HDM) 800-890 for drainage requirements.

Buried RCB structures are designed for strength and service limit states such as Strength I, Strength II and Service I as defined in AASHTO LRFD-BDS-CA. For the design of the RCB, the following live loads must be considered: HL-93, a combination of design truck or tandem, and design lane load (Strength I and Service I limit states only). The Permit design load used by Caltrans for Strength II limit state usually does not control design for the RCB with span less than 15 feet but should be taken into account when the span is greater than 15 feet. The design should consider life cycle costs and sustainability since repair or replacement of buried RCB is very difficult and costly.

Buried RCB structures are usually classified as a rigid box structures due to their higher structural stiffness compared to the stiffness of the surrounding soil envelope. For projects without a geotechnical report, the following two design loading cases are shown based on Caltrans research in 1977 and requirements, which results in the following two design conditions for earth pressures:

Case 1: Max. Vertical + Min. Horizontal, $140H_1 : 36H_2$ ($\text{lb/ft}^2 : \text{lb/ft}^2$)

Case 2: Max. Vertical + Max. Horizontal, $140H_1 : 120H_2$ ($\text{lb/ft}^2 : \text{lb/ft}^2$)

In the above, H_1 (in feet) is the earth cover from top of slab to road surface and H_2 (in feet) varies representing the height from any locations of the wall to the road surface. The vertical earth pressure on top of slab is derived from the weight of the prism of soil above the top slab and the amplification by the soil-structure interaction factor. The lateral soil pressures on walls reflect a large range of variation due to uncertainties in soil profiles around RCB. The uncertainties can come from many reasons such as soils are compacted around walls during structural backfill and RCB may be buried in saturated soils because of no drainage measures outside of the buried RCB.

For projects with a geotechnical report, the maximum horizontal pressure in Case 2 can be reduced but must have a minimum value of $100H_2$. Other soil pressures in Case 1 and Case 2 must remain the same.

The design earth cover for a buried RCB is a range of cover, instead of a specific design cover, to consider the variations of the ground surface in the future. See Standard Plans D80, D81, D82, D83A, and D83B for buried RCB with standard sizes for details. For non-standard sized RCB or for RCB with design earth cover over 20 feet, special design must be conducted with an earth cover range from two feet less than to two feet greater than the design cover to consider future variations of the ground surface levels.

It is assumed that the loading applied to the top slab is uniformly distributed over the entire bottom slab in the transverse direction. The width of the top slab strip used for load distribution shall also be used for structural design of the walls and bottom slab. This assumption applies to all loads acting on the top slab including the dead load, earth load and live load.

Live load surcharge for lateral soil pressure on walls can be evaluated as an equivalent height of soil as in the case for vehicular loading on abutments perpendicular to traffic as in AASHTO LRFD-BDS-CA using at-rest pressure coefficient.

For a buried RCB with a span over 20 feet or for a buried RCB that crosses a fault, earthquake load effect should be considered. Contact Office of Earthquake Engineering Analysis and Research for project specific requirements. Buried rectangular structures such as RCB undergo racking deformations from ground shaking. Seismic shear waves can cause side-sway movement (racking effect) which might increase the moments around RCB corners and increase the shear forces in the structural members.

Buried RCB designed for drainage purposes must use Class 2 exposure condition for control of cracking. RCB for other purposes may consider control of cracking based on project need. The minimum thickness of the top slab must be eight inches for exposed RCB.

For buried RCB with a skew angle less than 15 degrees, the skew effect may be neglected. Otherwise the skew effect must be considered. One method to address skew effect is to design parapets at the ends of the RCB as edge beams as shown in standard plans.

Buried RCB might not be an efficient structural type when earth cover is over 25 feet. One alternative is reinforced concrete structures with an arch shaped top. Special design must be conducted in this case, which should be approved by Underground Structure Specialist.

Installations

Cut-and-cover RCB installations must comply with Standard Plans A62E, A62G and D88 as well as Standard Specifications Sections 19, 51, 52 and 90. Buried CIP RCB can be built with tops exposed at grade or buried underground. Buried PC RCB is built with cover not less than one foot. Refer to *AASHTO LRFD Bridge Construction Specifications*, Section 27, for additional information. Water proof measures at joints are needed when a PC buried RCB is used for drainage purpose. PC RCB must be built monolithically for each segment in the direction of the RCB alignment.

Geotechnical investigations are needed to see if the required bearing capacity of the buried RCB foundation can be reached. If the required bearing capacity of the RCB foundation cannot be reached or loose soil is found, replace the loose soil with compacted structural backfill or make soil improvement as recommended by geotechnical engineers. Pile foundations are not recommended to avoid unexpected additional load effects and distress. Buried RCB is allowed to slightly but uniformly settle along the length of the RCB.

Capacity Evaluation of Existing RCB

When the clear span of a single-cell RCB or the total span of a multi-cell RCB, measured between inside faces of the external walls along the centerline of the roadway, is 20 feet or less, the RCB is considered to be a culvert based on the definition in HDM 806.2. For single-cell RCB with a span over 20 feet or for multi-cell RCB with a total span greater than 20 feet, a bridge number must be assigned by Structure Maintenance & Investigations (SM&I). See HDM 62.2 for additional information.

Prior to conducting the as-built capacity analysis, consult with SM&I for RCB with bridge numbers or consult with Culvert Inspection Program personnel for RCB without bridge numbers to determine if capacity analysis is needed.

An as-built analysis for capacity evaluation of an existing RCB must be conducted in any one of the following cases:

1. It is found that the current physical condition of the RCB has reached a level that raises a concern for the safety of the structure based on inspections or recommendations by SM&I or the Culvert Inspection Program.
2. Buried RCB has additional loading effects to the original design due to an increase of earth cover, new loading, or significant load pattern changes, etc.

The designer may conduct an as-built analysis based on the engineering judgement for structural safety in addition to the above reasons. The capacity evaluation may result in no action, strengthening or replacement.

The Load and Resistance Factor Rating (LRFR) methodology in *AASHTO The Manual for Bridge Evaluation* (MBE) can be used for buried RCB capacity evaluation. When LRFR is used for the RCB capacity evaluation the formula to obtain a Rating Factor (RF) in MBE must be modified to be applicable when the RCB is buried at any depth, especially when buried deep. For example, the earth cover is more than 8 feet for the RCB with a span less than 8 feet, or earth cover is more than the span of the RCB when the span of the RCB is more than 8 feet. The formula of Rating Factor in MBE is only applicable when the earth cover is shallow.

The analysis conducted should be based on Section 12, "Buried Structures and Tunnel Liners" in AASHTO LRFD-BDS-CA. The ratio of capacity-demand, R_{dc} is recommended for capacity evaluation of the RCB using LRFR methodology, which can be expressed as:

$$R_{dc} = \frac{\phi_c \phi_s \phi R_n}{\gamma_{EV} EV + \gamma_{EH} EH + \gamma_{DC} DC + \gamma_{LL} LL(1.0 + IM)} \qquad (23\text{-}1\text{-}1)$$

Where system factor ϕ_s can be taken as 0.95, representing structural redundancy factor, ϕ_c is a condition factor as defined in MBE. Using National Bridge Inventory (NBI) rating system,

R_n = nominal resistance calculated according to LRFD

ϕ_c = 0.85 for NBI Rating of 4 (Poor)

ϕ_c = 0.95 for NBI Rating of 5 (Fair)

ϕ_c = 1.00 for NBI Rating of 6 or higher (Good)

All other factors in the equation are specified in AASHTO LRFD-BDS-CA.

If an accurate method is not needed, the load case represented by the ratio of the vertical earth pressure to horizontal earth pressure can be simplified as:

Vertical and Lateral Earth Pressures: $136H_1 : 66H_2$ ($lb/ft^2 : lb/ft^2$)

In the above, H_1 and H_2 are defined in the Design Considerations section.

It can be seen that the earth pressure model in capacity evaluation for existing buried RCB is different from Caltrans design earth load model as shown in the Design Considerations section.

Geotechnical investigations can provide refined earth pressure evaluations by considering soil-structure interaction when needed.

The capacity evaluation of the buried RCB is based on existing structural conditions, material properties, loads, and traffic conditions at the RCB site. The age, strength, and physical conditions of the existing structure should be considered. As-built plans and standard plans are important resources. If as-builts are unavailable, core samples for lab testing and field scanning for reinforcement size and spacing. MBE also has recommendations for material properties such as concrete strength and reinforcement yielding stress at different design and construction periods. To calculate the demand, use HL-93 for structures designed by LRFD. Use HS-20 for structures designed by LFD as long as the safety level matches the LRFD methodology.

Prior to 1977, designs only considered a single soil loading condition using a soil density of 120 pcf specified as:

Vertical and Lateral Earth Pressures: $120H_1 : 36H_2$ ($lb/ft^2 : lb/ft^2$)

R_{dc} in Eq. (23-1-1) is the most critical capacity-demand ratio, which is the minimum value among capacity-demand ratios at all critical sections. When $R_{dc} \geq 1.0$, the existing RCB meets the current LRFD design specifications. When $1.0 > R_{dc} \geq 0.70$, the existing structure does not meet current design specifications and there are capacity deficiencies in structure members but it does not pose an imminent structural safety concern. When $R_{dc} < 0.70$, the existing structure has such capacity deficiencies that the structure is continually damaged under current design load. It should be strengthened or replaced in this case. Decisions should be made based on the capacity evaluation as well as other influencing factors such as project budget, schedule, traffic control, and so on.

Buried RCB Extensions

Whenever possible, effort should be made to widen an existing RCB with the same type of structure and foundation.

A design review should be made by the Division of Engineering Services when the proposed extension will considerably increase the load on the existing buried RCB.

The existing buried RCB should be checked for the hydraulic adequacy by District hydraulic engineers or Structure Hydraulics and Hydrology engineers. Geotechnical investigations should be conducted to provide foundation information for buried RCB extensions to make sure bearing capacities are sufficient.

The existing buried RCB considered for extension should be inspected for structural material conditions and hydraulic conditions such as scour and erosion. The inspection shall include assessment of the existing conditions and recommendations for repair or replacement if needed. If the RCB being extended has no additional load and is in good condition, evaluation may not be needed. Refer to the Capacity Evaluation section for guidelines.

Procedures to extend an existing buried RCB can be summarized as:

1. Consult with SM&I and Culvert Inspection Program or conduct inspection on the existing buried RCB to check the physical conditions and make recommendations for repair, replacement or capacity evaluation.
2. Check if there is additional loading to the original design applied to the existing RCB due to increasing ground surface or other reasons.
3. Decide if capacity evaluation is needed, referring to the Capacity Evaluation section.
4. Develop a work plan for the existing buried RCB for no-action, repair, strengthening or replacement based on load capacity evaluation. If retrofitted, the RCB must meet the present design criteria as shown in Design Considerations section.
5. Design the extension referring to the Design Considerations section. Standard Plan D82 also provides details for connection to the existing RCB.

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