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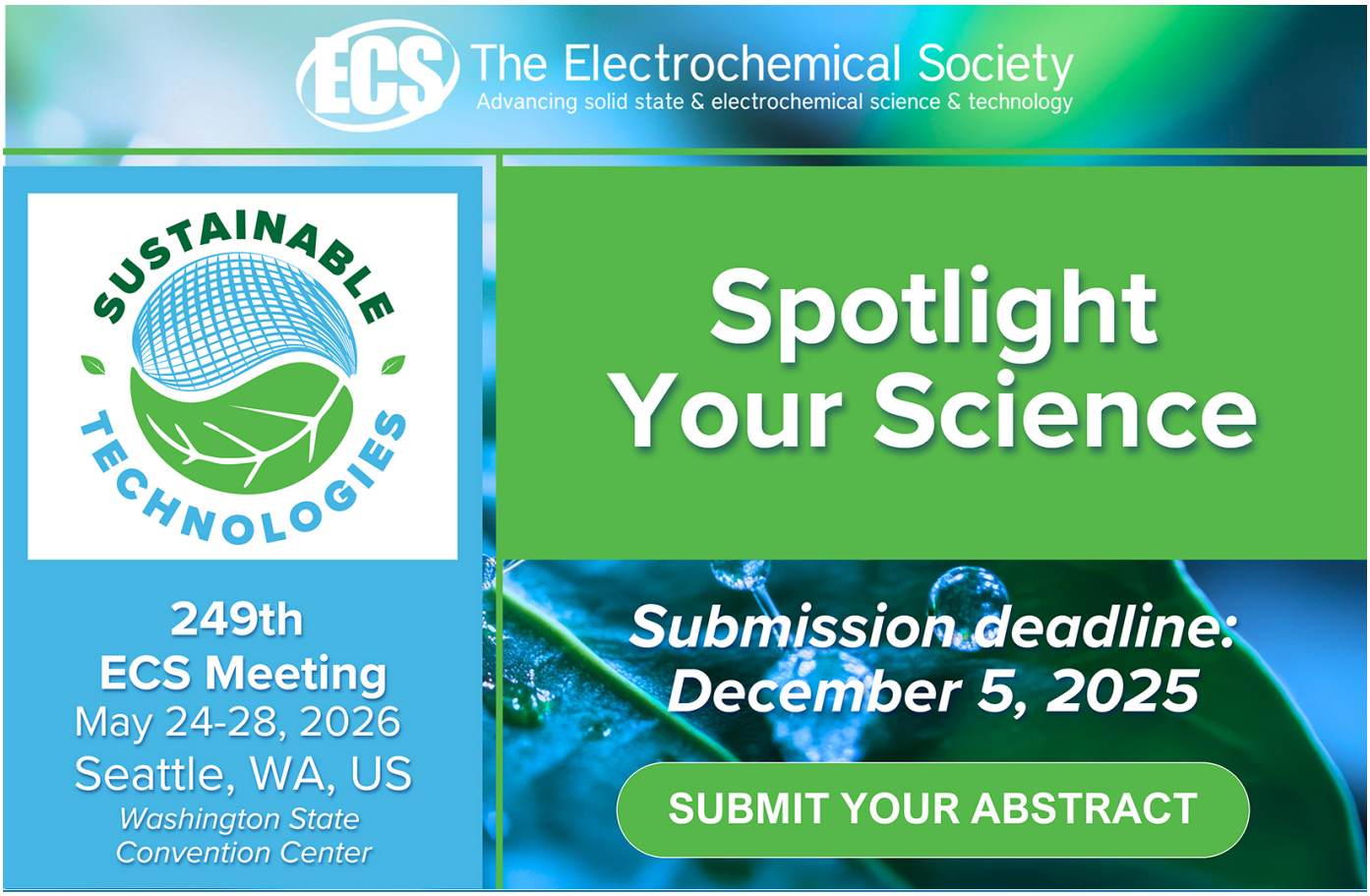
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Proposal to evaluate the load capacity of bridges subjected to bending and shear due to living load traffic

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Abstract. This research work reflects the procedure to evaluate the classification factors associated with the load capacity of existing reinforced concrete bridges in Colombia, taking as a case study a bridge simply supported by reinforced concrete with a span of 12 m, determined the physical relationship between the nominal flexion of the element and the flexion due to live load for the bridge under study, for which the established criteria were accepted is the philosophy based on load and resistance factor rating recorded in the manual for evaluation of bridges of the American Association of State Highway and Transportation Officials, concluding that the procedure implemented is consistent with the criteria established in the bridge design manual in Colombia based on the reliable use of statistical factors and the theory of probabilities for the development of bridge designs such structures.

1. Introduction

The study of load capacity for existing bridges allows to establish if a bridge is able to withstand the benefits generated by live load safely [1]; This information is the basis for prioritizing the execution of maintenance and/or rehabilitation works [2,3], and it is possible to determine the maximum allowed weight that the evaluated bridge can support [4]; determined the maximum weight allowed and the condition of deterioration of the structure due to lack of maintenance determines the carrying capacity of the elements that make it up [5].

In countries like the United States to assess the load capacity of existing bridges, the American Association of State Highway and Transportation Officials, in English, the American Association of State Highway and Transportation Officials (AASHTO), adopted in 2005 the manual of bridge evaluation (MBE) [6]. To determine the load capacity of an existing bridge, you must calculate the rating factor (RF), this factor defines the relationship between the remaining capacity of a structural element and the effect of the analyzed live load [6]. The load must be evaluated for three live load conditions as follows: design, legal and permission, to determine the remaining capacity of the element, information contained in the construction plans is used such as concrete compressive strength [7], detailed longitudinal and transverse reinforcement of reinforcing steel, likewise, the results of the last field inspection carried out on the bridge, in case of not having these data the MBE has a procedure for the calculation [8].

Colombia does not have regulations that allow the evaluation of the load capacity of existing bridges, in the presence of live loads [9]. The Colombian bridge design standard (CCP14) established in section

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3.1 that to evaluate existing bridges the live load defined in CCP14 can be used, also in section 4.2.8 the possibility of instrumentation or study under load is indicated Special purpose vehicle to determine the load capacity [10].

The objective of this research work is to implement a procedure for the evaluation of existing bridges in Colombia of reinforced concrete, adopting the guidelines defined in the MBE, for the design and legal qualification levels, knowing the structure design information, thus providing a guide to national engineering for the evaluation of existing structures based on normative standards of international recognition.

2. Design philosophies

The MBE has a philosophy-based load rating factors and resistance (LRFR), this methodology is based on calculating RF, the mathematical expression to determine this value is defined by Equation (1):

$$RF = \frac{C - \gamma_{DC}Dc + \gamma_{Dw}Dw \pm \gamma_{P}P}{\gamma_{ll}(LL+IM)}, \quad (1)$$

where C is the nominal capacity of an element to resist stress, compression, flexion, and shear stresses until the fault mechanism is activated, and the element ceases to fulfill the function for which it was designed. For the calculation of C, CCP14 provides procedures for its calculation, this value must be affected by reduction factors called: condition factor φc (Table 1), accounts for increased uncertainty in the resistance of deteriorated members at the time of rating and between future inspections system factor φs (Table 2), accounts for redundancy of the structural system the capability to carry loads after damage or failure of one or more of its members, and the RF φ depends on the failure zone of the element. Meanwhile, Dc is the effect caused by structural components and attachments; Dw is the effect caused by the tread layer and P refers to dead loads that are not permanent, such as public service networks, LL is an effect produced by live loads amplified by an IM factor, while γ_{DC}, γ_{DW}, γ_{P} and γ_{LL} they are factors of dead load by the structural elements, asphalt load, non-permanent dead load, and live load respectively [6]. The following are the condition factors established by the AASHTO.

Table 1. Condition factor AASHTO LRFR MBE, φc [6].

Structural condition of the member	φc
Good or satisfactory	1.00
Fair	0.95
Poor	0.85

The system factors φs implemented by the AASHTO [6] for flexural and axial load effects are presented in Table 2.

Table 2. AASHTO LRFR MBE system factor, φs, for bending and axial effects [6].

Type of superstructure	φs
Welded members in two-girder/truss/arch bridges	0.85
Riveted members in two-girder/truss/arch bridges	0.90
Multiple eyebar members in truss bridges	0.90
Three-girder bridges with girder spacing of 6 ft	0.85
Four-beam bridges with beam spacing ≤ 4 ft	0.95
All other beam bridges and slab bridges	1.00
Floor beams with spacing > 12 ft and non-continuous stringers	0.85
Redundant beam subsystems between floor beams	1.00

To assess the effect produced by (LL + IM), the LRFR method provides three levels of live load called: (i) design loads, (ii) legal charges and (iii) permit charges; (i) the design load is based on the new bridge design truck and is evaluated for two levels of classification: inventory and operation; (ii) the legal charges are based, in the case of Colombia, on all those approved by Resolution 4100 of 2004 issued by the Ministry of Transportation, Colombia [11]; and (iii) the permit charges are those that in order to travel through the nation's roads , need approval through a permit since they exceed the gross vehicle weights allowed.

For bridges evaluated with design load at the inventory level that obtain an RF ≥ 1, they will have the adequate capacity to support the passage of all legal loads. For RF <1 the evaluation is required for the second level of design called operation, in this case for RF ≥ 1 the bridge is able to withstand AASHTO legal charges, but not those allowed in Colombia, in the event that legal charges were incurred and separation between axes greater than those defined by AASHTO, if the result is <1, the bridge for legal charges must be evaluated [6]. The second level of evaluation to determine the load capacity of a bridge is evaluated for legal loads, establishing the safe passage for AASHTO loads and state loads that do not exceed the weights per axis and dimensions of AASHTO [6]. The legal loads evaluated allow us to establish the weight limits that can be transited by a bridge. The third level of classification, related to permitting charges, is determined considering the loads that exceed the weights and dimensions set for legal charges, should only be evaluated for bridges that have been classified in the level of legal charges RF ≥ 1. This analysis allows studying the permit applications for the passage of oversized and/or extra-heavy loads by the bridges, in this work, this level of classification was not considered.

The procedure described is presented schematically to evaluate the load capacity of existing bridges for a superstructure, as show the Figure 1.

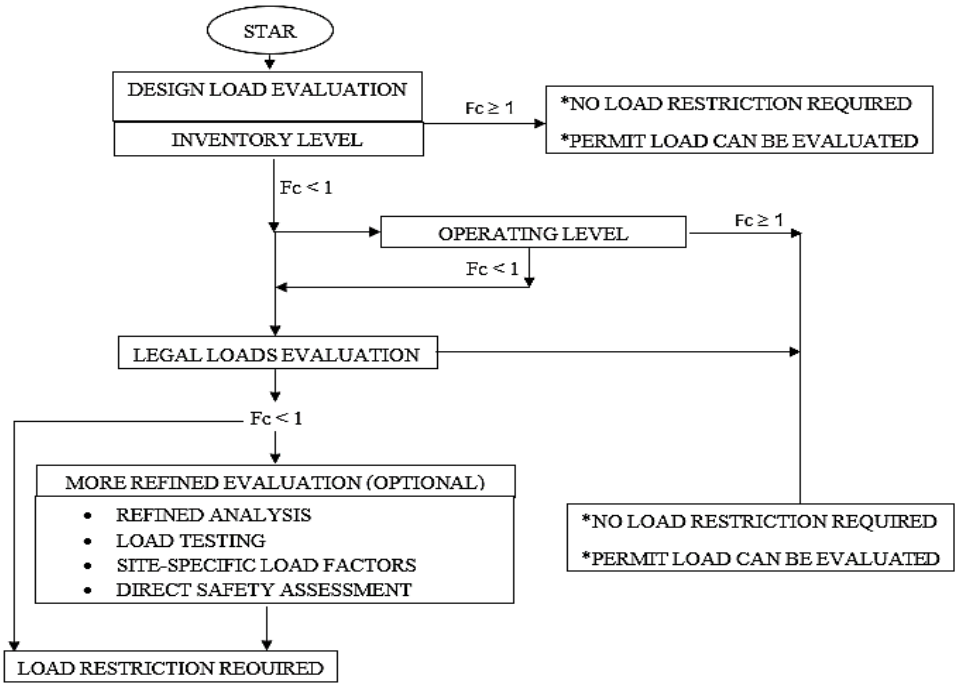
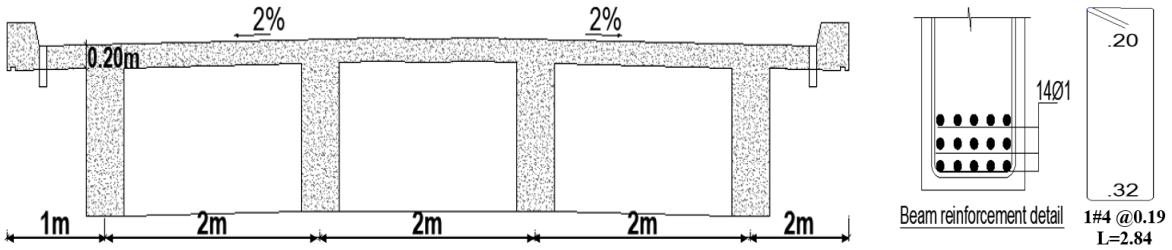


Figure 1. Load capacity analysis.

3. Superstructure evaluated

The RF was evaluated for the interior and exterior beams of a slab beam superstructure, of 14.00 m light reinforced concrete, and of the design drawings Figure 2(a) and Figure 2(b), it is known:

- Resistance to the understanding of concrete 28 MPa.
- Creep stress of reinforcing steel 420 MPa.



(a) (b)

Figure 2. Geometry and detailing of reinforcing steel (a) cross-section and (b) cutting and bending steel.

4. Design and evaluation loads for Colombia

New bridge design and evaluation loads in Colombia are defined as a freight train according to article 3.1 of CCP14 [10]. In Figure 3 the truck is presented to classify the bridge in the inventory and operation review levels.

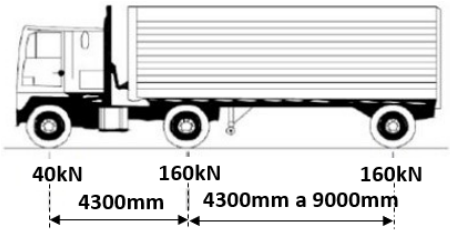


Figure 3. Design load.

4.1. Legal charges

Legal charges in Colombia are regulated by resolution 4100 of 2004 issued by the Ministry of Transportation, Colombia [11], as show the Figure 4.

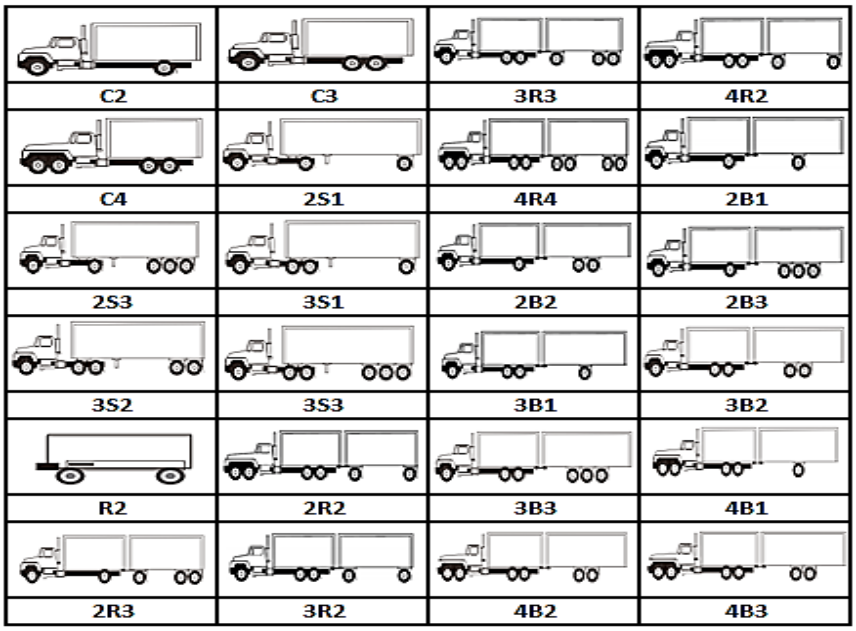


Figure 4. Legal charges.

5. Results

The results of the calculations performed to obtain the classification factor for the inventory level of the evaluated bridge are given below. Tables 3 and Table 4 record the moment results of the interior and exterior beams, indicating that the bridge has flexural capacity, Tables 5 and Table 6 establish the shear RF of the interior and exterior beams, indicating that the bridge has shear capacity. A bridge in good condition and with a redundant beam system was considered, so the condition factor φc is 1.00 and the system factor is 1.00. The values of ØMn and Vn were calculated with the following expressions: Nominal capacity of the flexural element is defined by Equation (2) [12].

$$\emptyset M_n = \emptyset Fy\left(d - \frac{a}{2}\right) As, \tag{2}$$

where fy and Creep effort; d is the distance of the fiber superior to the cancroid of the bending steel; Ace reinforcing steel. Nominal capacity of the cutting element is defined by Equation (3) [13].

$$V_n = v_c + v_s + v_p, \tag{3}$$

where Vc nominal shear strength of concrete; Vs nominal shear strength of steel; VP element in the direction of the applied shear force of the effective prestressing force.

Classification factor for inventory level moment, is presented in Table 3 and Table 4, both for exterior and interior beams.

Table 3. Classification of inner beams for bending.

Rating level inventory	
Mn (kN•m)	RF
2344	1.10

Table 4. Classification of exterior beams for bending.

Rating level inventory	
Mn (kN•m)	RF
2664.99	1.04

The classification factor for the sharp level of inventory is presented in Table 5 and Table 6, both for exterior and interior beams.

Table 5. Classification of inner beams for cutting.

Vc (kN)	Vs (kN)	Vn (kN)	RF
183.00	586.00	769.00	1.13

Table 6. Classification of external beams for cutting.

Vc (kN)	Vs (kN)	Vn (kN)	RF
168.00	586.00	754.00	1.02

6. Conclusions

The uncertainty that is generated by not having a technical document that allows the evaluation of existing bridges in Colombia has been the central theme of this research, so the AASHTO methodology contained in the MBE is adopted to perform the evaluation of interior beams and The exterior of a reinforced concrete superstructure simply supported 14 m in length, in addition to the above, the intention of making a document as a proposal for the classification of existing bridges, is to provide a better understanding of the application of the MBE evaluation philosophy and the use of PCC14 in the review of existing structures, for which the main conclusions are presented below.

The procedure implemented to determine the physical relationship between the nominal bending of the element and the bending due to live load for the bridge under study, by means of which the classification factors for the inventory level with design load of the bridges evaluated in The present investigation is consistent with the criteria established in the bridge design manual in Colombia based on the reliable use of statistical factors and the theory of probabilities for the development of the designs of said structures, allowing the identification of the acceptable condition or not of a structure before the passage of live loads, determined in the same way if a structure requires a reinforcement or on the contrary presents structural capacity.

Colombia does not have a document for the evaluation of bridges; however, the bridge design code allows the evaluation of bridges using the design truck. The live load factors used in CCP14 are the same as those contained in the MBE.

The factors of reduction of the nominal capacity of cut and flexion, a denominated factor of condition and factor of classification are subjective of the evaluator since they depend on the experience of the specialist in the valuation of bridges realized using inspection reports. From Table 3 and Table 4 the RFs of the interior and exterior beams obtained a classification factor for a moment greater than 1, indicating that they have sufficient capacity to withstand the design loads of the CC14 design truck, as well as the Table 5 and Table 6 the inner and outer beams obtained a rating factor for shear greater than 1, indicating that it has sufficient capacity to withstand the design loads of the CC14 design truck.

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