Comportamiento estructural y criterios de diseño de los puentes extradosados: visión general y estado del arte

Structural behavior and design criteria of extradosed bridges: general insight and state of the art

José Benjumea*[1], Gustavo Chio*, Esperanza Maldonado*

* Universidad Industrial de Santander, Bucaramanga. COLOMBIA

Fecha de recepción: 01/ 08/ 2010
Fecha de aceptación: 01/ 10/ 2010
PAG. 383 - 398

Resumen

Durante los últimos 10 años, los puentes extradosados se han convertido en una solución estructural atractiva alrededor del mundo, gracias a los buenos resultados obtenidos con las primeras realizaciones en Japón. Esta nueva tipología, reconocida generalmente como una solución intermedia entre los puentes atirantados y los de pretensado de viga cajón construidos por voladizos sucesivos, se ha convertido en una opción interesante. Por consiguiente, dado el interés que hoy en día existe alrededor de este tipo de puente, en este trabajo se presenta el contexto histórico que describe su origen, y se exponen la influencia de los principales elementos estructurales en el comportamiento del puente, y los criterios de diseño que han sido propuestos por investigadores en el tema. De esta manera, se espera ofrecer una visión general de la concepción y el comportamiento estructural de los puentes extradosados para que sea considerada una alternativa más de tipología estructural de puentes en nuestro medio.

Palabras Clave: Puentes, puentes no convencionales, puentes extradosados, comportamiento estructural de puentes, criterios de diseño de puentes.

Abstract

Over the past 10 years, Extradosed bridges have become an attractive structural type around the world, due to the good results obtained with the first bridges constructed in Japan. This new typology, generally recognized as an intermediate solution between cable stayed bridges and cantilever constructed prestressed box-girder bridges, because these take advantages of design and constructions methods of the other two typologies, has become an interesting option. Therefore, given the interest that exist about this type of bridge, in this paper the historical context that describes its origin, the influence of the principal structural elements and the design criteria proposed by researchers are presented. In this way it is expected to offer a general insight into the design conception and structural behavior of Extradosed Bridges, so that they may be considered as an alternative structure for bridges in the Americas.

Keywords: Bridges, non-conventional bridges, extradosed bridges, extradosed bridges, structural behavior of bridges, design criteria.

1. Introduction

During X IX century, one of the most relevant contributions to bridges engineering has been the introduction of prestressed technique, which is a solution to the need of controlling stress on elements in bridges. Initially this technique was employed by means of internal and external prestressed tendons, until 1925 when modern cable-stayed bridges appeared – the Tempul Aqueduct, which was developed and built by Eduardo Torroja (Torroja, 1927). In 1988 Jacques Mathivat proposes the concept of extradosed cables that are external prestressed tendons allocated in the deck´s outer and upper side, which are diverted by low size masts (Mathivat, 1988).

[1] Autor de correspondencia / Corresponding author:
E-mail: josemiguelbenjumea@gmail.com

Six years later the first prestressed extradosed bridge is built in Japan: Odawara Blueway (Ogawa et al., 1998a). Ever since the use of such typology has steadily increased, especially in Asian countries where, high seismic activity has not been a compound to the construction of these kinds of bridges. However, in some other countries such typology seems to be unknown, thus discarding the advantages offered by this structural system. This study introduces the typology, by highlighting basic features that define its structural behavior and the project criteria stated by literature.

2. Hystorical background

Currently there are two trends awarding the origin of prestressed extradosed bridges to different engineers. The first trend awards the creation of the concept to Cristhian Menn, who in 1980, propose the Ganter Bridge in Switzerland (Figure 1) in order to span a valley with a 140 meters high bridge, by means of a superstructure composed of a prestressed box-girder by concrete wall- embedded cables and stiff piers, which are well able to stand strong winds in the zone of Ganter Bridge in Switzerland (Figure 1), (Virlogeux, 2002 and Mermigas, 2008). At that time cables´ adapted arrangement involved technical innovation however; the structure has been mostly admired by the engineering community by its esthetics and harmony with the landscape (Virlogeux, 1999).

For the second trend, other authors (Ogawa et al., 1998a; Chio, 2000; Hino, 2005; Kasuga, 2006; Ishii, 2006) award the concept and denomination of such typology to Mathivat, who suggested a solution for the tendered Arrêt Darré viaduct in France, by means of a bridge replacing the internal tendons of the upper beam fin by external cables arranged in a small size mast over the bearing pile sections and on the deck upper side (Figure 2). The solution by Mathivat, which was rejected, proposed a 30% material saving regarding the box-girder solution and furthermore it would enable the effective use of cables by stressing them at the same level than conventional prestressed tendons (Mermigas, 2008).

In Virlogeux's opinion (1999) part of the concept proposed by Mathivat was based on the "distortion of specification codes" for future efficient use of tendons, since restrictions for strain variations due to traffic load are more rigorous for cable in cable-stayed bridges than for prestressed tendons.

However the dispute regarding the origin of extradosed bridges has been solved. According to Mermigas (2008), it was not relevant that Menn knew Mathivat's ideas on extradosed bridges, because both engineers reflected the trends and approaches of their original countries in their own proposals.

Figura 1. Puente de Ganter en Suiza, 1980 (Janberg, 2009)
Figure 1. Ganter Bridge in Switzerland, 1980 (Janberg, 2009)

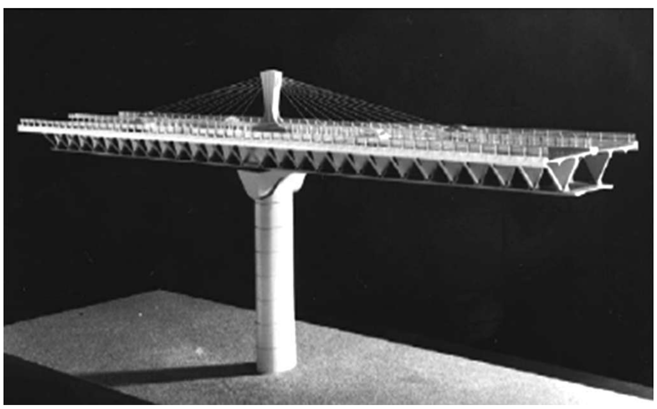

Figura 2. Propuesta para el viaducto Arrêt Darré (Virlogeux, 1999)
Figure 2. Proposed Viaduct for Arrêt Darré (Virlogeux, 1999)

Ganter Bridge served as inspiration for the construction of other similar bridges, such as Barton Creek Bridge (United States, 1987 (Gee, 1991) and Papagayo Bridge (Mexico, 1991 (Fernandez, 1999), considered as a Fin Back Bridge and the Socorridos Bridge (Portugal, 1993 (Reis & Pereira, 1994), identified as a Cable Panel Bridge. Some disadvantages such as the impossibility of replacing strainer wires and the additional costs for concrete walls uplifting, have not allowed a spread use of such typologies. On the other hand, Mathivat's proposal inspired Japanese engineers, who constructed the Odawara Blueway Bridge (Figure 4) in 1994, which is considered by some authors (Chio, 2000; Kasuga, 2002; Ishii, 2006; Dos Santos, 2006) as the first extradosed bridge in the world. We recommend the review of further references by Ogawa et al., 1998a, Kasuga, 2002 and Kasuga, 2006 to readers interested on such type of bridge.

Figura 3. Puente de Socorridos en Portugal, 1993 (GRID Ltda, n.d.)
Figure 3. Socorridos Bridge in Portugal, 1993 (GRID Ltda., n.d)

Figura 4. Puente Odawara Blueway en Japón, 1994 (Kasuga, 2006)
Figure 4. Odawara Bridge in Japan, 1994 (Kasuga, 2006)

3. The concept of extradosed bridge

Concrete bridges made with prestressed extradosed technique have arisen as a new typology for half span bridges. By means of the utilization of concrete and prestressed technology (together with the use of steel strainer wires) a new solution strongly favorable towards such structures is intended. In extradosed bridges prestressed tendons are externally arranged on the cross section edge and on deck´s upper side by anchoring them to low size masts, or deviated from masts by means of anchorage seats placed on the pylons upper side (Chio and Aparicio, 2002). From morphological point of view, extradosed bridges are well known as intermediate bridges between cable-stayed bridges and prestressed box-girder bridges, ref. Figure 5. Such statement is also supported by the amount of required material involved, as shown in Figure 6, where Mermigas (2008) compared concrete average thickness (concrete volume of deck´s beam/cantilever) and, on the other hand Kasuga (2002) compared the amount of tendons required for extradosed cable-stayed bridges and prestressed box-girder bridges built by consecutive cantilevers; both graphs indicating that main materials consumption in extradosed bridges, falls into an intermediate zone between the other two typologies.

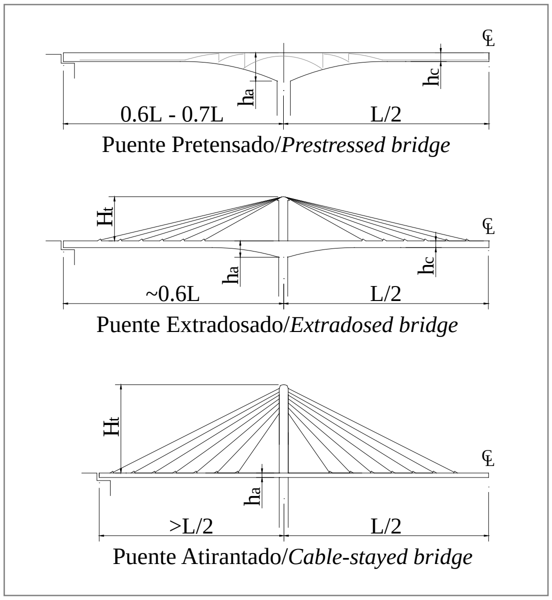

Figura 5. Comparación entre puentes pretensados, extradosados y atirantados
Figure 5. Comparison among prestressed bridges, extradosed bridges and cable-stayed bridges

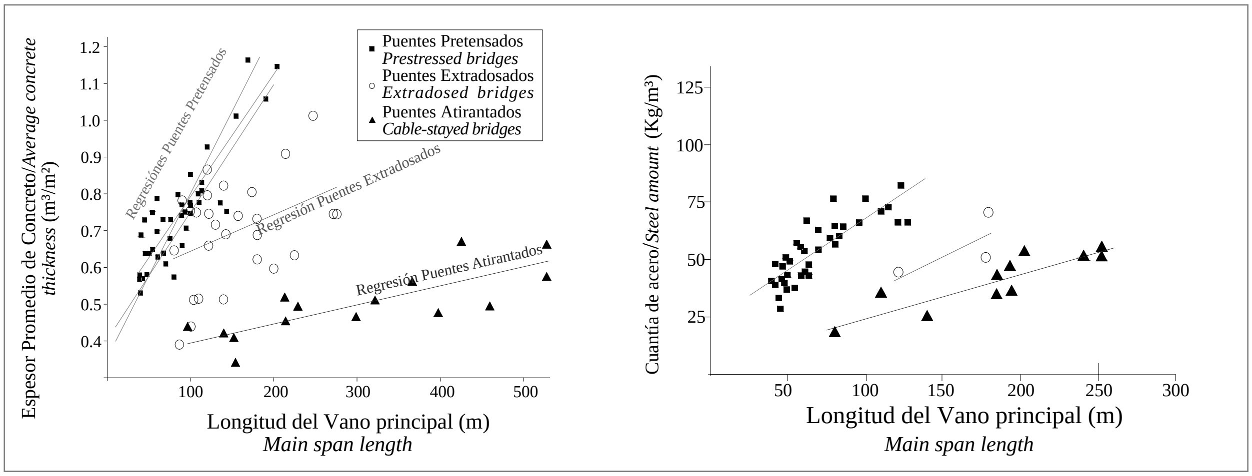

Figura 6. Comparación del consumo de materiales para puentes pretensados construidos por voladizos sucesivos, extradosados y atirantados: Izquierda) Espesor promedio de concreto (Modificado de Mermigas, 2008) . Derecha) Cuantía volumétrica de acero (Modificado de Kasuga, 2002)

Figure 6. Comparison of consumption material for prestressed consecutive cantilever, extradosed and cable-stayed bridges. Left: average concrete thickness (Modified from Mermigas, 2008). Right: Volumetric steel amount (MModified from Kasuga, 2002)

4. Structural behavior

Since extradosed bridges take part in an intermediate zone between prestressed bridges and cable-stayed bridges, their structural behavior may be similar to these kinds of typologies, depending on design criteria adopted during the project stage. Generally a rigid deck extradosed bridge shall have a similar behavior to the prestressed bridge´s, thus avoiding high stress oscillations of stay cables and, consequently, avoiding fatigue conditions associated with anchorages and tendons present in a slender deck extradosed bridge, which behavior is quite close to the cable-stayed bridge. Its construction demands the acquaintance of technologies currently applied on straight course-prestressed concrete bridges and cable-stayed bridges, which is generally developed by means of the consecutive cantilever method but counting with the assistance of tension rods that are not placed on temporary, but on permanent basis.

Prestressing is a mixed technique in prestressed extradosed bridges, on one hand it is internal (inside the edge) and on the other hand is extradosed. Both of them shall have their own features that make them different regarding their arrangement and behavior inside the bridge.

For extradosed bridges which behavior is similar to a prestressed beam bridge, constant loads are transported towards foundation by means of the combined action of a shear – flexure mechanism performed by deck and tensile stress performed by the stay cables. On the other case, the load is transported by means of axial forces between tension roads an deck, similar to cable-stayed bridges.

4.1 Influence of deck depth and mast's height

According to Chio (2000), for a constant depth deck its strain strength shall be most sensitive to live load as long as it becomes slender and, strain oscillations on tension rods due to live load ($\Delta\sigma_L$), as well as the longitudinal strain strengths, shall increase in the upper and lower deck´s fibers. If the mast height decreases, the effort performed by the deck increases, which produces a strain strength increase due to over load. As far as tension rods ´strain oscillation is concerned, it increases as mast´s height goes up, being its impact even greater than the one provoked by depth deck adjustment.

Deck - mast interaction for tension rod stayed bridges may be explained by extrapolating results obtained by Ruiz-Terán (2005) and Ruiz-Terán & Aparicio (2007) from lower stressed bridges, bridges as the tension rods extradosed bridges, which stressing system effectiveness depends on relative deck´s slenderness in regards to the stressing system. As far as slenderness ratio decreases, due to a decrease of deck depth or to the increase of mast´s height, the stressing system effectiveness increases and, therefore, the contribution from tension rods in load distribution also increases, thus making them most sensitive to over loads.

4.2 Influence of deck-pier joint

When deck is supported by piers, see Figure 7, the over load action on the main span produces deflection downwards and upwards in side spans. However, if deck is fixed to the pier, see Figure 8, the bridge changes into a portal frame scheme where stiffness provided by the pier partially limits elements rotation, which effect is reflected by deflections decrease and side and central spans decrease, which in turn show a tensile variation reduction for stay cables.

Due to higher deck slenderness, the live load effect on flexural moment for an extradosed bridge is higher, in comparison to a prestressed box-girder bridge therefore, it is quite clear that reduction of elements actions by means of adjustments to deck and pier connecting system, provides benefits to structural elements. However, in the case of seismic loads, deck fixation onto the pier may yield an increase of strengths on them, thus significantly affecting design and substructure´s costs involved. In accordance with Otsuka et al. (2002), piers strengths on a cable-stayed bridge, which main span length is the same as in an extradosed bridge, are lower than (20%-30% shear and 50%-60% flexural moment) because of damping effect on the supported structure, phenomenon not taking place in extradosed and box-girder bridges with stiff connection between deck and piers. In Shin-Karato Bridge, Kobe - Japan, piers separated from the superstructure were employed by using rubber supports to reduce dynamic loads (Tomita et al., 1999).

Figura 7. Puente Shin-Karato, Japón, 1998 (Tomita et al., 1999)
Figure 7. Shin-Karato Bridge, Japan, 1998 (Tomita et al., 1999)

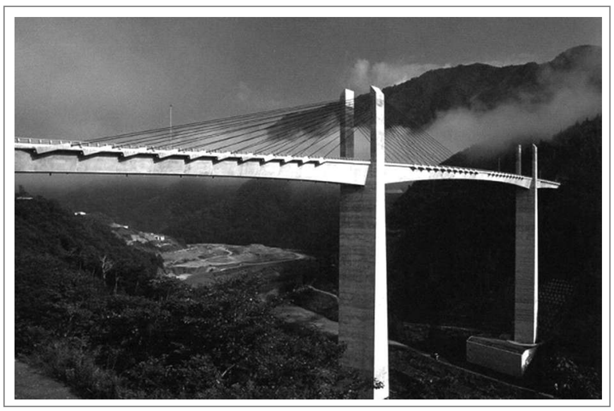

Figura 8. Puente Tokunoyama en Japón, 2006 (JSCE, n.d.)
Figure 8. Tokunoyama bridge, Japan, 2006 (JSCE, n.d.)

4.3 Influence of haunching of the deck

In cable-stayed bridges unlike in extradosed bridges, stay cables located close to masts are not effective regarding permanent loads compensation. Therefore, since construction of such bridges is generally conducted by using consecutive cantilever method, the employment of variable depth deck becomes convenient for the entrance zone.

According to Chio (2000), for an extradosed bridge with main span (L) and parabolic haunchig type, see Figure 9, by increasing the relation between deck height in the pier support section (h_a) and deck height in the central span (h_c), the first tension rod may be placed farer away from the mast (L_b) and tension variations in such rods are reduced. The adjustment of corner plate length (L_a) is not quite relevant on rods tension variation. However, the increase of deck ratios $\frac{h_a}{h_c}$ and $\frac{L_a}{L}$, generates lower deflections and, although there is a slight increase of strain strengths in the pier support section, at a tension level, a decrease is produced in deck.

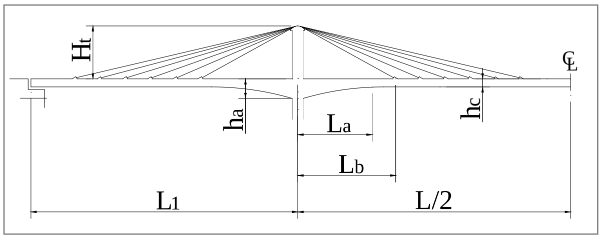

Figura 9. Nomenclatura de las dimensiones del acartelamiento del tablero
Figure 9. Dimension nomenclature for deck corbelling

4.4 Influence of side span length

Kasuga (2006) stated that due to the similar structural behaviour of extradosed bridges with prestressed box-girder bridges, side spans length should be determined proportionally to them, generally between 0.6 and 0.8 from main span length. However, Chio (2000) indicated that for an extradosed bridge with constant depth deck, the use of ratios $\frac{L_1}{L}$ higher than 0.60, produces high deflexions, strainer strengths and tension increases on deck in comparison to closer side spans. According to Chio (2000), side span length variation (L_1) has relevant effects on deck flexural moments in the side span, which decrease as long as ratio $\frac{L_1}{L}$ goes down. In central span and tension rods, the length decrease of side span, produces fewer deflections and flexural moments and higher tension oscillations, respectively, although not relevant for both cases. However, the use of shorter side spans ($\frac{L_1}{L}$ lower than 0.4) and, therefore, the use of cables acting as retention stay cables similar to those in cable-stayed bridges, provoke side support uplifting, which shall later require technological solutions to solve such problem.

5. Design

An extradosed bridge may be designed under two approaches. There is wide freedom to choose stiffness arrangement for cables and deck to bear live load. The first approach considers an adequate stiffness arrangement among deck, cables and substructure, in such a way tension variation on cables due to live load does not supersede standard limits on specifications (ref. numeral 5.1.4) and, might be stressed at maximum possible. Generally, the first approach corresponds to a stiff deck with fixed connection among mast, deck and piers as originally used for the first extradosed bridges.

The second design approach consists of stiff masts and a deck bridge, which is attributed to a. Menn, who in 1987 introduced some ideas about advantages involved in the use of stiff masts in cable-stayed bridges (Menn, 1987, quoted by Mermigas , 2008, p.8). Menn transferred his ideas to extradosed bridges when building Sunniberg bridges (Switzerland 1998; Drinkwater, 2007) and by proposing a design for Poya Bridge (Switzerland, 1989) which was not accepted by the jury (Menn, 1991). In accordance with this approach, deck is designed as much slender as possible, so that live load may be transmitted into piers, as a couple of axial strengths in cables and box-girder, similar to those in cable-stayed bridges (Mermigas, 2008). This design produces high tension oscillation values in stay cables, due to live load and therefore, such elements must be stressed at a lower level than the first approach, thus providing a less effective use of such elements.

According to Mermigas (2008), generally the approach for extradosed stiff deck bridge does not provide any significant advantage over the stiff mast approach, which capacity to stand multiple piers on simple supports is higher.

Few researches have been developed to define project criterion on extradosed bridges, which structural behavior is quite similar to cable-stayed bridges, hence there is a need to deepen into this subject. However, main conclusions obtained from some researchers are presented below. It is made quite clear that projects criteria introduced by researchers are based on particular load conditions and allowable tension limits for each study or, in case of well-known engineers from experience obtained from completed projects. Therefore such criterion should not be regarded as a straight jacket when considering an extradosed bridge design, which would limit the engineer possibility to explore different configurations and materials.

5.1 Design criteria

5.1.1 Deck depth and mast height

In an article published in 1988, Mathivat proposed a constant depth deck, slender $L/_{h}$ from 30 and 35, a mast height so that $L/_{Ht}$ is equal to 15. Komiya (1999 quoted by Mermigas, 2008, p. 54) suggested for pier embedded bridges: edge with 35 slenderness in the pier support section and 55 in the main center span and, mast heights ranging from L/12 and L/8. Chio (2000) proposes project criterion using an edge for the pier support edge of L/30 and central span L/45, i.e. $^{ha}/_{hc}$ equal to 1.5. He also recommends a mast height equal to L/10, so that rods tension oscillations due to live load would be delimited by 80 MPa value. Dos Santos (2006) proposed a steady deck height L/33 and mast height L/10, however, since he did not considered concrete deformation and steel relaxation effects, his proposal has a limited applicability.

5.1.2 Length supported by cables

Since tension rods close to the mast are powerless in a fan tension rod arrangement, Chio (2000) recommended that the first tension rod should be fixed between 0.18 and 0.25 from center span. Such value differs from Mathivat, who suggested that the first tension rod should be fixed at 0.1 from central span.

According to Komiya (1999 quoted by Mermigas, 2008, p.59) the combined cost for extradosed cables and internal tension roads fixed at 0.14, 0.20 and 0.24 from central span, has a variation of approximately 2% among them and, the most cost effective arrangement is the one corresponding to the first fixed stay cable at 0.20 from main span.

5.1.3 Side span length

For stiff-deck extradosed bridges, Chio (2000) recommended side span lengths lower than 60% from main span, but higher than 40%. Dos Santos (2006) suggested lengths between 60% and 65% from main span. Supported in the similarity held between extradosed bridges and cantilever constructed prestressed box-girder bridges, Kasuga suggests side span length between 60% and 80% from main span. Previous recommendations are not of great application in extradosed bridges which are similar to cable-stayed bridges: Mermigas (2008) found that in stiff deck extradosed bridges with 140 m main span, it is not possible to use side spans which length is 50% higher than main span length, because moments are quite significant and exceed deck capacity.

5.1.4 Cables´ allowable allowable stress in serviceability limit state (SLS)

In his proposal, Mathivat (1998) employed an allowable stress in tension rods of 0.6 f_{pu}, which is a criterion adopted by the first constructed extradosed bridges (Kasuga, 2002; Ogawa et al., 1998b; Tomita et al, 1999), since rigid connection between deck and piers, together with main spans between 90 and 180 meters produced lower tension values in rods due to live load. However, the arrival of higher spans bridges beaten by slender decks produced significant tension variations due to live load. Therefore rods´ allowable stress was decreased by employing - in some cases - values lower than the limit 0.45f_{pu} normally used in cable-stayed bridges, such as Kanisawa Bridge (Japan, 1998 (Kikuchi & Tabata, 1998).

Such inconveniency lead to the conclusion that there was not clear distinction between allowable stress to be adopted by cable-stayed bridges and extradosed bridges, which could be quite unsafe for extradosed bridges if value was fixed at 0.6 f_{pu}.

Ogawa and Kasuga (1998, quoted by Kasuga, 2002, p.10) defined β index, which expresses load distribution between tendons and deck, due to vertical standard load applied in the main span. For some extradosed and cable-stayed bridges built in Japan, Kasuga (2006) depicted rods strain strength variation due to live load ($\Delta\sigma_L$) versus β index, demonstrating that máximum allowable stress in cables should not be determined from the kind of structure, otherwise it depended on the cables fatigue due to live load variation of tensions, ($\Delta\sigma_L$), see Figure 10.

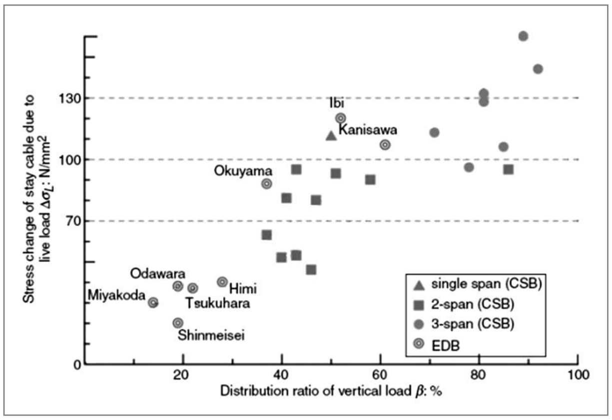

Figura 10. Parámetro $\Delta\sigma_L$ contra β para puentes extradosados (EDB) y atirantados (CSB). (Modificado de Kasuga, 2006)
Figure 10. ($\Delta\sigma_L$) Parameter against β index for extradosed bridges (EDB) and cable-stayed bridges (CSB). (Modified from Kasuga, 2006)

Different specifications have been proposed, which are to be considered for live load tension variation effect, see Figure 11. In Japan the Japanese Prestressed Concrete Engineering Association's Specifications proposed allowable strain strength varying from 0.40 f_{pu} to 0.6 f_{pu}, for tension variation due to live load, between 70 and 100 MPa when the rods system is composed by threads and; between 100 and 130 MPa when prefabricated wires are used (Kasuga, 2006). Recommendation by Service d'études sur les transports les rutes es leurs aménagements (SETRA, 2001) allowable stress (f_a) for tension rods is calculated in function of:

$$f_a = \begin{cases} 0.6 f_{pu} & \text{, si } \Delta\sigma_L < 50 \text{ MPa} \\ 0.46\left(\frac{\Delta\sigma_L}{140}\right)^{-0.25} & \text{, si } 50 \leq \Delta\sigma_L \leq 140 \text{ MPa} \\ 0.46\, f_{pu} & \text{, si } \Delta\sigma_L > 140 \text{ MPa} \end{cases} \qquad (1)$$

According to Dos Santos (2006) it is quite favorable to adopt 50 MPa maximum tension variations for rods in extradosed bridges, since vibration and flexure effects on cables anchorage zone in deck´s upper surface may be ignored by the implicit safety factor.

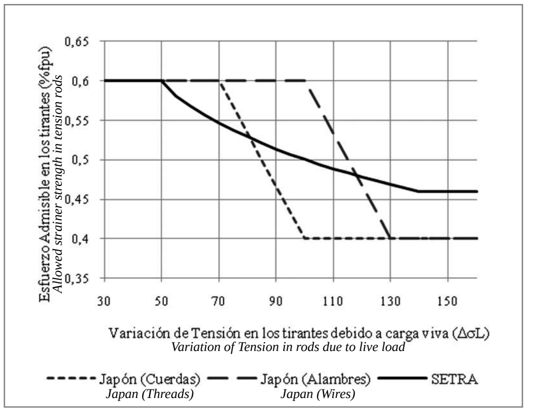

Figura 11. Esfuerzo admisible máximo en los tendones extradosados como función de $\Delta\sigma_L$
Figure 11. Maximun allowable stress in extradosed tension rods in function of $\Delta\sigma_L$

6. Conclusion

The concept of extradosed bridges goes back to 1988 with the proposal by the French Engineer Jacques Mathivat. However, the idea was not totally accepted in its origin continent. It was only adopted six years later when the first extradosed bridge was built in Japan. Ever since and because different worldwide well-known bridge engineers, among them Akio Kasuga and the prestigious Professor Christian Menn, chose this typology obtaining positive results, then extradosed bridges have become a competitive structural solution as well as prestressed box-girder bridges, for main spans between 100 and 200 m.

Structural behavior in such bridges depend on the interaction among each structural element involved, therefore, provided that they share some morphological and constructive similarities with cable-stayed and prestressed box-girder bridges, similar behaviors to these two typologies may be achieved by modifying structural elements. Consequently two approaches have been developed for designing extradosed bridges.

The first approach intends to reach a low cable tension variation due to live load, by means of an adequate stiffness distribution alongside deck, cables and substructure. The second approach developed by Menn, intends to reach a behavior similar to cable-stayed bridges, by employing slender decks and stiff masts which increase stressing efficiency faced to over load, at the expense of high cables tension variations due to live loads.

Few researches have been conducted to define project criteria on extradosed bridges, so that benefits provided by this typology may rise and become well-known, thus letting project engineers to include it in their range of possibilities. However, design proposals for this kind of bridges are available on literature and may be used as a preliminary design method on extradosed bridge project.

7. Acknowledgements

This study is part of results from a research project named Application of concrete bridges with prestressed extradosed method in Colombia, which is financed by the Industrial University of Santander, UIS, and by the Colombian Institute for Science and Technology Development Francisco Jose de Caldas, COLCIENCIAS.

8. Referencias / References

Chio G. (2000), Comportamiento Estructural y Criterios de Diseño de los Puentes con Pretensado Extradosado. Tesis Doctoral. Barcelona: Universidad Politécnica de Cataluña.

Chio G. y Aparicio A. (2002), El puente con pretensado extradosado, un nuevo tipo estructural. UIS Ingenierías, 1(1), 67-73.

Dos Santos D. (2006), Comportamento Estrutural de Pontes com Pretensão no Extradorso. Tesis de Mestrado. São Paulo: Escola Politécnica da Universidade de São Paulo.

Drinkwater L. (2007), Analysis of the Sunniberg Bridge. [internet] Department of Architecture, University of Bath. Available at: http://www.bath.ac.uk/ace/uploads/StudentProjects/Bridgeconference2007/conference/mainpage/Drinkwater_Sunniberg.pdf. [Fecha de Acceso: 15 de Octubre de 2009].

Fernández L. (1999), Tierra sobre el agua, visión histórica universal de los puentes. 1a Ed. Madrid: Colegio de Ingenieros de Caminos, Canales y Puertos.

Gee A. (1991), Concrete Fin-back Bridge in USA. Proceedings of the Institution of Civil Engineers, 90(1), 91-122.

Grid (2010), Grid Ltda. (n.d.), Socorridos Bridge. [Photograph] Available at: http://en.structurae.de/photos/index.cfm?JS=15736. [Fecha de Acceso: 14 de Abril de 2010].

Hino S. (2005), The Great Himiyume Bridge, Highway entrance to Nagasaki: The world first extradosed bridge using corrugated steel plate webs. Civil Engineering, JSCE, 42.

Ishii, M. (2006), Sistemas Estruturais de Pontes Extradorso. Tesis de Mestrado. São Paulo: Escola Politécnica da Universidade de São Paulo.

Janberg N. (2009), Ganter Bridge. [Photograph] Available at: http://en.structurae.de/photos/index.cfm?JS=153412. [Fecha de Acceso: 14 de Abril de 2010].

JSCE (2009), Japanese Society of Civil Engineers. (n.d.), Tokunoyamahattoku Bridge. [Photograph] Available at: http://www.highestbridges.com/wiki/index.php?title=Tokunoyamahattoku_Bridge. [Fecha de Acceso: 20 Febrero de 2009].

Kasuga A. (2002), Construction of Extradosed Bridges in Japan, In: Japan International Cooperation Agency & The Road Engineering of Malaysia, Seminar on Design and Construction of Prestressed Concrete Cable-Stayed Bridges. Kuala Lumpur, Malaysia.

Kasuga A. (2006), Extradosed Bridges in Japan. Structural Concrete, 7(3), 91-103.

Kikuchi M. & Tabata T. (1998), Extradosed Prestressed Concrete Bridge – Kanizawa Bridge. In: FIP (Fédération Internationale de la Précontrainte), Prestressed Concrete in Japan, Proceedings of XIII FIP Congress - National Report . Amsterdam, Holland, 147-150.

Mathivat J. (1988), Recent developments in prestressed concrete bridges. FIP Notes, 2, 15-2.

Menn C. (1991), An approach to bridge design. Engineering Structures, 13(2), 106-112.

Mermigas K. (2008), Behaviour and Design of Extradsed Bridges. MSc Thesis. Toronto: University of Toronto.

Ogawa A., Kasuga A. & Okamoto H. (1998a), Prestressed Concrete Extradosed Bridge – Odawara Blueway Bridge. In: FIP (Fédération Internationale de la Précontrainte), Prestressed Concrete in Japan, Proceedings of XIII FIP Congress - National Report . Amsterdam, Holland, 47-50.

Ogawa A., Matsuda T. & Kasuga A. (1998b), The Tsukuhara Extradosed Bridge near Kobe, Structural Engineering International, 8(3), 172-173.

Otsuka H., Wakasa T., Ogata J., Yabuki W. & Takemura D. (2002), Comparison of structural characteristics for different types of cable-supported prestressed concrete bridges. Structural Concrete, 3(1), 3-21.

Reis A. y Pereira A. (1994), Soccoridos Bridge: A Cable-Panel Stayed Concept. In: International Conference A.I.P.C.-F.I.P.: Ponts suspendus et à haubans: cable-stayed and suspension bridges. Deauville, France, 343-350.

Ruiz-Terán A. (2005), Puentes Atirantados no Convencionales, Comportamiento estructural y Criterios de Diseño. Tesis Doctoral. Santander: Universidad de Cantabria.

Ruiz-Terán A. y Aparicio A. (2007), Parameters governing the response of under-deck cable-stayed bridges. Canadian Journal of Civil Engineering, 34(8), 1016-1024.

SETRA. (2001), Haubans - Recommendations de la commission interministérielle de la précontrainte. Service d'études techniques des routes et autoroutes. 2001.

Tomita M., Tei K. y Takashi S. (1999), Shin-Karato Bridge in Kobe. Structural Engineering International, 9(2), 109-110.

Torroja E. (1927), Acueducto-sifón sobre el río Guadalete. Revista de Obras Públicas, 2477, 193-195.

Virlogeux M. (1999), Recent evolution of cable-stayed bridges. Engineering Structures, 21(8), 737–755.

Virlogeux M. (2002), New Trends in Prestressed Concrete Bridges. Structural Concrete, 3(2), 67-97.