

# Evaluation of Effective Slab Width for Composite Cable-Stayed Bridge

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**ABSTRACT:** Bridge design has developed over the centuries in a fashion that continues to improve upon the types of materials being used, as well as to use existing materials in a more efficient manner. However, with new technology such as cable stayed-bridge, the rush to implement the new concept frequently does not permit the answering of all the important engineering questions prior to implementation. A composite section is made up of a concrete slab attached to a steel girder by means of shear connectors. Under positive bending moment, part of the slab will act as the flange of the girder and will resist the longitudinal compression. When the spacing between the girders becomes large, it is evident that the simple beam theory does not strictly apply because the longitudinal compressive stress in the flange will vary with distance from girder web, the flange being more highly stressed over the web than in the extremities. This phenomenon is termed as “shear-lag”. The effective width concept has been introduced, widely recognized, and implanted as a simplified practical method for design and evaluation of structural strength and stiffness while accounting for shear-lag effects indirectly. The present study aims in the evaluation of the effective slab width to be used in cable-stayed bridge longitudinal analysis, with a composite double girder steel-concrete deck, based on finite element model results. A cable-stayed bridge model is analysed in SAP software. The results of the study show that, the effective width of the section varies throughout the length of the bridge.

**KEYWORDS:** Composite deck; Effective width; Cable stayed bridges.

## I. INTRODUCTION

The continuous increase of the deck spans, together with the aesthetic concerns associated with bridges, has led to cross-sections slender and stronger. The great progress in materials that has been observed in the last decades, as well as the achieved experience itself, has shown that composite steel–concrete decks are a very efficient solution. The combination of the two materials allows taking advantage of their best features, allowing the deck to be light, strong and slender. Bridge design has developed through the centuries in a fashion that continues to improve upon the types of materials being used, and also to use existing materials in a more efficient manner. Thus with new materials, construction methods, analysis methods, and design concepts are developed; they are frequently employed in bridges because of society's need for more durable, longer spans that can be built within ever-tightening public budgets. However, with new technologies like the cable-stayed bridges, the rush for implementing the concept frequently does not permit the answers of all the important questions of engineering prior to implementation. The most common composite cable-stayed deck is composed by two steel main girders, continuously suspended by cables, and a concrete slab supported on a grid formed by this main girders and cross-beams. The main girders, spaced between stay-cables, support the longitudinal and transversal bending moments while the concrete slab resists to the local loads and also mainly supports the high axial compressions introduced on the deck by the stays anchorages. Composite girders were widely used in the early 1900s. Many researchers investigated the behaviour of the composite girders both analytically and experimentally starting in the late 1930s.

In bridge engineering, a deck-girder system acting compositely is usually reduced to the analysis of a T-beam section characterized by elementary beam theory, and is called as beam-line analysis. In this approach, and consistent with beam theory, the normal longitudinal stress on the deck section is assumed to be constant. However, due to in-plane shear flexibility of the deck, the longitudinal normal stress over a centre-to-centre bridge deck section is non-uniform

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along its transverse cross section. The maximum value of stress occurs at the mid-line junction with the girder; and gradually decreases towards the centre spacing line, as shown in figure 1.1. This non-uniform distribution of stress is known as shear lag.

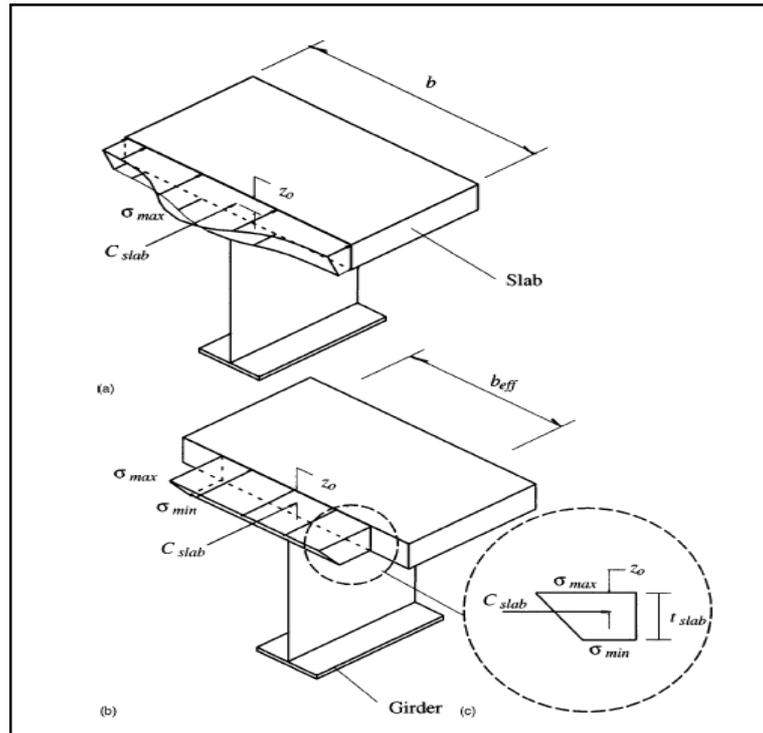


Figure 1 Effective width concepts  
[Stuart S. Chen et al. (2007)]

The stress distribution depends on several factors. These factors include cross sectional dimensions and stiffness of the deck (flange) and girder and loading conditions. This results in analytical solutions not easily applicable in practice. Therefore, to simplify the problem an effective flange width is used in design practice.

## II. LITERATURE REVIEW

**M. Chiewanichakornet. al. (2004)** in this paper, study has been carried out to evaluate and determine the actual effective slab width of steel-concrete composite bridge girders using three-dimensional non-linear finite element analysis. Based on this study a new definition for effective slab width has been proposed. Comparison with various national and international codes of practice has been carried out, to utilize a newly developed effective slab with definition from the research to verify its accuracy and conservatism. This codes include AASHTO-LRFD [AASHTO 1998], British [BSI 1979, BSI 1982], Canadian [CSA 2000, CSA 2001], Japanese [JRA 1996], and Eurocode [Eurocode 4 1992, Eurocode 4 1997] specifications.

**Jonathan P. Moses et. al. (2006)** this study uses results from various in situ load tests of three steel girder bridges with the same Glass Fibre-Reinforced Polymer (GFRP) deck system, to determine the degree of composite action that may be developed and the transverse distribution of wheel loads that may be assumed for these structures. The results of this study indicate that, the current design practice to treat GFRP deck systems in a manner similar to non-composite concrete decks may results in non-conservative bridge girder design. Specifically1. The effective width of the GFRP deck that may be engaged is lower than that of an equivalent concrete deck.2.The engaged effective width shows some evidence of degradation with time.3.Increased apparent moment distribution factors, indicating reduced

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transverse distribution of wheel loads, are observed due to the increased transverse flexibility of the GFRP deck system.

**Stuart S. Chen et al. (2007)** this paper proposes simpler and more versatile design criteria for computing the effective width (beff) in steel-concrete composite bridges. A parametric study was conducted based on finite-element analysis of bridges selected by a statistical method – namely design of experiment concepts. Both simple-span and multiple-span continuous bridges were considered in the parametric study. The finite element methodology was validated with companion experiments on  $\frac{1}{4}$  and  $\frac{1}{2}$  scale specimens. Effective width values at the critical sections were computed from stresses extracted from FEA models and used in developing candidate design equations. Use of full width- the most versatile, simplest and sufficiently accurate effective width design criteria, is proposed for both positive and negative moment regions.

**Zhibin Lin and Jian Zhao (2011)** in this paper, shear-lag effects in box girders were studied by using variation analysis method to evaluate the effective flange width provisions in the AASHTO specifications. To determine the most influential factors for shear lag behaviour in the girders, a parametric study was also conducted. The study indicated that beam-width-over-span ratio, flange thickness, the longitudinal flange stiffeners and the material properties need to be considered in determining effective flange width. Based on the study, recommendations for the effective flange width provisions of AASHTO specifications were suggested.

**F. Garaet. al. (2011)** this paper presents a simplified analysis method for the design of twin-girder and single box steel-concrete composite bridge decks. The main advantage of the study is its ability to determine the normal longitudinal stress distribution in the slab based on the results of a structural global analysis carried out using the real geometry of the deck, i.e. without considering the use of effective widths. New analytical expressions are presented in this paper to calculate the effective width. The approach presented in the paper is capable of handling different loading conditions, such as constant uniformly distributed loads, envelopes of transverse actions due to traffic loads, support settlements and concrete shrinkage. The first part of the paper describes about the results of an extensive parametric study carried out by means of finite element formulation, based on which various analytical expressions have been obtained. Finally, a realistic case study of a bridge with varying cross-section is considered to show the robustness of proposed methodology.

**Wenchao Song et. al. (2013)** in this paper the equivalent strip width for stiffness-driven design of FRP superstructures is been proposed. The paper demonstrates that using a Timoshenko beam approximation 2D special orthotropic plates idealized from FRP superstructures can be designed as 1D beam. To calculate the equivalent strip width to determine deflection at points of interest in practical design, a tractable and accurate analytical solution is first derived in accordance with classical laminate plate theory (CLPT). The paper then shows that the equivalent strip width obtained from the analytical solution together with Timoshenko beam theory is sufficient to calculate both flexural deflections and the deflections due to out of plane shear deformations. The equivalent strip width calculation is further simplified, for the FRP superstructures in current practice, by considering only two or three key parameters identified by this paper. Hence, the difficulty of making excessive assumptions about both material and section properties of an FRP superstructure at the beginning of its design can be overcome by the simplified equivalent strip width. Based on the results of the paper, a new design procedure is proposed.

### III. METHODOLOGY

In this study, a three-dimensional finite element analysis is employed to evaluate and determine the actual effective slab width of steel-concrete composite bridge girders. The three-dimensional models used beam finite linear elements for the steel structures of the deck, and of the towers and cables. Finite elements of the slab, plans and four-nodes, based on the theory of thin slabs to represent the concrete slab. The consideration of finite elements already mentioned, provide information about the transverse distributions of stresses in the slab, therefore allowing for the definition of an effective slab width to be used when the slab is modelled as a beam in the longitudinal bridge numerical models. The details of the bridge are shown in figure no. 1. In the current study effective width has been found for the dead load. Constitutes of dead load from structural elements and non-structural elements. Dead load refers to the gravity loads of structural members such as bridge decks, tower (i.e., pylon), piers, cables, etc. Also gravity load of non-structural elements placed on the bridge structure after concrete hardened, which include bridge railings, pavement.

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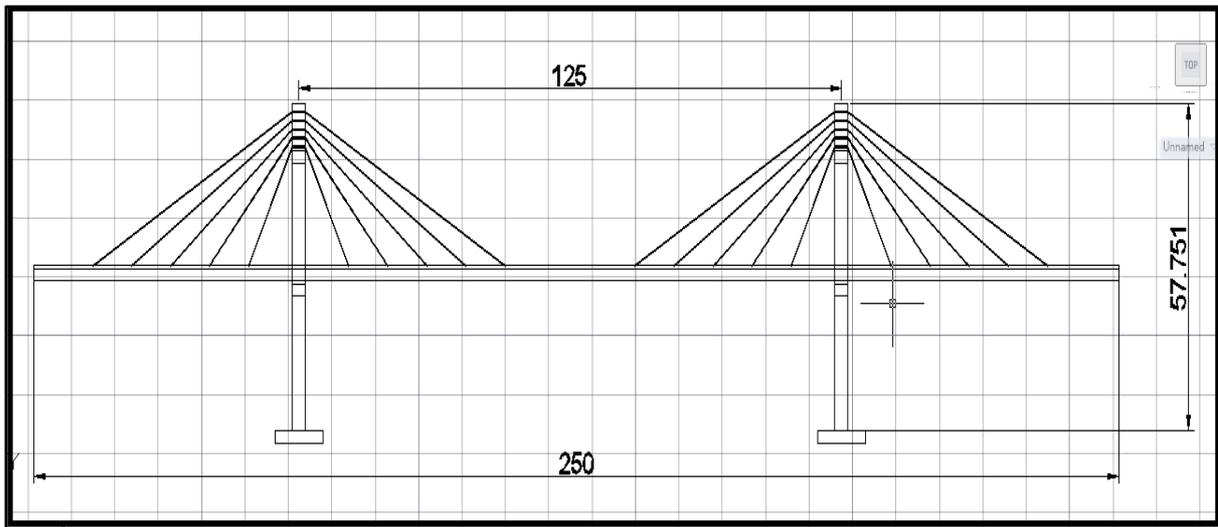


Figure No.2 Bridge details

For the above geometry a model was prepared in SAP 2000 software and analysed for the above mentioned loading. The FEM model is obtained using SAP2000. While modelling, large numbers of joints were defined. For the given cable stayed bridge there are 1012 joints. There are a total 40 numbers of cables provided to this bridge. Necessary restraints have been assigned to certain joints from the total joints as per the boundary conditions. The bridge structure has got various key elements namely; the main girder, cross girder, tie beam pylon and deck slab. The cross sectional properties of these will be enlisted in this section.

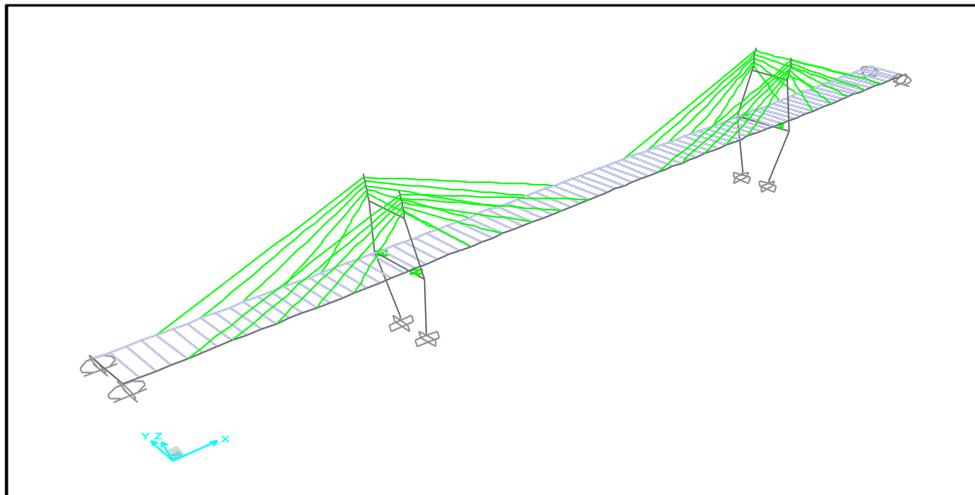


Figure No. 3 SAP Modell

## IV. ANALYTICAL RESULTS

A bridge model prepared in SAP software was analyzed for the dead load and cable forces. After analysis sections were drawn at a regular interval of 3m along the length of the bridge. These sections give the values of total axial force and,

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stress values at the section. By using the definition given in following equation, values of effective width and effective width factor at every section is calculated.  $b_{eff} = \frac{1}{\sigma_{max}} \int_{-b/2}^{b/2} \sigma dy$  (equation 1) Where  $b_{eff}$  is effective slab width and  $b$  is physical slab width. [Amjad J. Aref (2007)]. Table No. 1 shows the values of total axial force, stress, effective width and effective width factor for the.

**Table No. 1 Effective Width Variation**

Section	Force	Max stress	Min stress	Avg. stress	Beff	Beff factor
12	2065	2.4	1.2	1800	3.824074074	0.31867284
15	3018.3992	2.4	1.2	1800	5.589628148	0.465802346
18	4130	2.4	1.2	1800	7.648148148	0.637345679
21	3723.9512	2.4	1.2	1800	6.896205926	0.574683827
24	4692.7164	2.4	1.2	1800	8.690215556	0.72418463
27	6486	2.4	1.2	1800	12.01111111	1.000925926
30	6486	2.4	1.2	1800	12.01111111	1.000925926
33	8786	3.6	2.4	3000	9.762222222	0.813518519
36	8786	2.4	1.2	1800	16.27037037	1.355864198
39	8786	2.4	1.2	1800	16.27037037	1.355864198
42	10140	2.4	1.2	1800	18.77777778	1.564814815
45	10140	3.6	2.4	3000	11.26666667	0.938888889
48	10140	3.6	2.4	3000	11.26666667	0.938888889
51	11854	3.6	2.4	3000	13.17111111	1.097592593
54	11854	4.8	3.6	4200	9.407936508	0.783994709
57	11854	6	4.8	5400	7.317283951	0.609773663
60	11854	7.2	6	6600	5.986868687	0.498905724
63	6435.8693	10.8	9.6	10200	2.103225261	0.175268772
66	6435.8693	6	4.8	5400	3.972758827	0.331063236
69	6435.8693	6	4.8	5400	3.972758827	0.331063236
72	6435.8693	3.6	2.4	3000	7.150965889	0.595913824
75	6435.8693	3.6	2.4	3000	7.150965889	0.595913824
78	6435.8693	3.6	2.4	3000	7.150965889	0.595913824
81	3323.8073	1.2	0	600	18.46559611	1.538799676
84	3323.8073	1.2	0	600	18.46559611	1.538799676
87	3323.8693	2.4	1.2	1800	6.155313519	0.512942793
90	1987.8693	3.6	2.4	3000	2.208743667	0.184061972
93	1987.8693	3.6	2.4	3000	2.208743667	0.184061972
96	1987.8693	3.6	2.4	3000	2.208743667	0.184061972
99	1987.8693	3.6	2.4	3000	2.208743667	0.184061972
102	486.1307	6	4.8	5400	0.300080679	0.025006723

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105	486.1307	6	4.8	5400	0.300080679	0.025006723
108	1632.131	6	4.8	5400	1.007488272	0.083957356
111	1632.131	6	4.8	5400	1.007488272	0.083957356
114	8622.12	4.8	3.6	4200	6.842952381	0.570246032
117	8622.13	6	4.8	5400	5.322302469	0.443525206
120	8622.13	6	4.8	5400	5.322302469	0.443525206
123	8622.13	6	4.8	5400	5.322302469	0.443525206
126	8622.13	6	4.8	5400	5.322302469	0.443525206
129	8622.13	6	4.8	5400	5.322302469	0.443525206
132	8622.13	6	4.8	5400	5.322302469	0.443525206
135	8622.13	4.8	3.6	4200	6.842960317	0.570246693
138	8622.13	3.6	2.4	3000	9.580144444	0.79834537
141	1632.131	4.8	3.6	4200	1.295342063	0.107945172
144	1632.131	4.8	3.6	4200	1.295342063	0.107945172
147	488.1307	4.8	3.6	4200	0.387405317	0.032283776
150	488.1307	4.8	3.6	4200	0.387405317	0.032283776
153	488.1307	4.8	3.6	4200	0.387405317	0.032283776
156	488.1307	3.6	2.4	3000	0.542367444	0.045197287
159	1987.8693	3.6	2.4	3000	2.208743667	0.184061972
162	1987.8693	3.6	2.4	3000	2.208743667	0.184061972
165	1987.8693	2.4	1.2	1800	3.681239444	0.306769954
168	3325.8693	1.2	1.2	1200	9.238525833	0.769877153
171	3325.8693	1.2	1.2	1200	9.238525833	0.769877153
174	3325.8693	3.6	2.4	3000	3.695410333	0.307950861
177	5039.8693	3.6	2.4	3000	5.599854778	0.466654565
180	5039.8693	4.8	3.6	4200	3.99989627	0.333324689
183	5039.8693	6	4.8	5400	3.111030432	0.259252536
186	5039.8693	6	4.8	5400	3.111030432	0.259252536
189	11856	12	10.8	11400	3.466666667	0.288888889
192	11856	6	4.8	5400	7.318518519	0.609876543
195	11856	4.8	3.6	4200	9.40952381	0.784126984
198	11856	4.8	3.6	4200	9.40952381	0.784126984
201	11856	3.6	2.4	3000	13.17333333	1.097777778
204	11856	3.6	2.4	3000	13.17333333	1.097777778
207	10142	3.6	2.4	3000	11.26888889	0.939074074
210	10142	3.6	2.4	3000	11.26888889	0.939074074
213	10142	3.6	2.4	3000	11.26888889	0.939074074

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216	8788	3.6	2.4	3000	9.764444444	0.813703704
219	8788	2.4	1.2	1800	16.27407407	1.35617284
222	8788	2.4	1.2	1800	16.27407407	1.35617284
225	6488	2.4	1.2	1800	12.01481481	1.001234568
228	6488	2.4	1.2	1800	12.01481481	1.001234568
231	6488	2.4	1.2	1800	12.01481481	1.001234568
234	4130	2.4	1.2	1800	7.648148148	0.637345679
237	4130	2.4	1.2	1800	7.648148148	0.637345679
240	4130	2.4	1.2	1800	7.648148148	0.637345679

The variation effective width and *Beff* Parameter along the length of the deck is shown in the following graph.

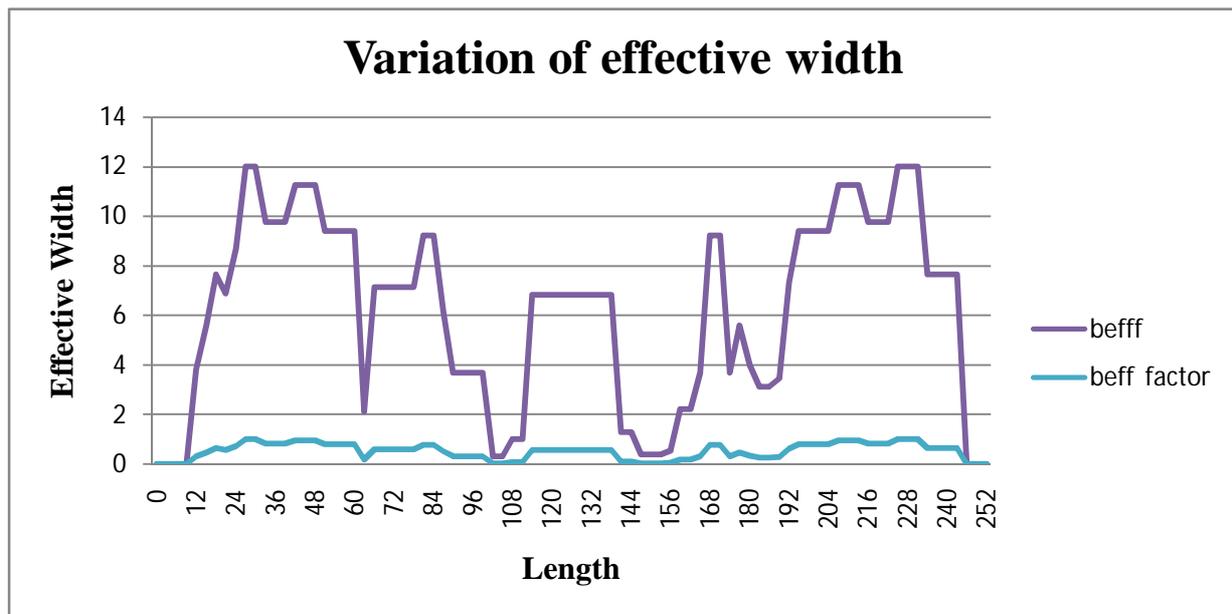


Figure No. 4 Variation of effective width

## V. CONCLUSION

We have implemented an automatic text detection technique from an image for Inpainting. Our algorithm successfully detects the text region. The analytical study was carried out to determine the effective slab width value for composite steel-concrete cable stayed bridge. The analysis results lead to the following conclusions. The effective width values change throughout the length of the bridge. The main reason behind the change in the effective width values is the variation of axial force. The variation in axial force is due to variation of cable forces in the deck. The effective slab width at the initial sections as well as sections towards is negligible due to the absence of axial force. The results obtained are compared with experimental evaluation done by Jonathan P. Moses et al. (2006). The value of effective width parameter obtained in this study varies from 0.4 to 1. The values of effective width parameter lower than 0.4 or 1 are also obtained. The absence of force in that particular section is the main reason behind the lower values of effective width parameter. The higher values indicate that, at that particular section entire slab width is

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effective. Table 1 shows the comparison of AASHTO and Observed effective width values studied by Jonathan P. Moses.

Table 2. Effective Width Values comparison of AASHTO and Observed

<b>Table 2. Comparison of AASHTO and Observed Effective Width Values</b>				
Bridge	Girder	Girder spacing ( <i>S</i> ) (mm)	Observed effective width (mm)	Observed <sup>b</sup> (AASHTO)
Fairground Test 1	Interior	2,847 <sup>a</sup>	2,492	0.88
	Exterior	2,034	1,775	0.87
Fairground Test 2	Interior	2,847 <sup>a</sup>	2,975	1.04
	Exterior	2,034	1,445	0.71
Boyer Test 1	Interior	1,754	1,223	0.70
	Exterior	1,260	1,350	1.07
Boyer Test 2	Interior	1,754	1,326	0.76
	Exterior	1,260	1,160	0.92
Boyer Test 3	Interior	1,754	1,378	0.78
	Exterior	1,260	916	0.73
Boyer Test 4	Interior	1,754	n.a.	n.a.
	Exterior	1,260	698	0.55
SC S655 Test 1	Interior	2,440	1,744	0.71
SC S655 Test 2	Interior	2,440	2,097	0.86
SC S655 Test 3	Interior	2,440	1,156	0.47

The values in the last column are ratios of observed effective width to the available width, i.e. effective width parameter. The range of this parameter is from 0.47 to 1. The same range of values is obtained in the present study. From the image which consists of mixed text-picture-graphic regions. We have applied our algorithm on many images and found that it successfully detect the text region.

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