AERODYNAMIC PERFORMANCE OF LONG SPAN STEEL TRUSS BRIDGES IN INDONESIA

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Background

1) Many long span bridges have been constructed or are in the planning stage in Indonesia, which include suspension bridge, cable stayed bridge, steel truss arch bridge and concrete balance cantilever bridge.
2) Considering the span of the bridges and its aesthetic point of view, application of Long Span Steel Truss Bridges in Indonesia is very popular among others. Its span varies from 70 to 270 meters in length.
3) Long span bridges are flexible structures in which wind effects play a dominant role in the design process. Wind effects on long bridges can lead to instability of the whole bridge structure.
4) Consideration of wind effects on the whole structure starting from its preliminary design is important in order to get the appropriate design configuration

Background

5) This paper presents dynamic wind consideration during the design stage, as well as the parameters and characteristics of several Long Span Steel Truss Bridges in Indonesia. The performance of the bridges is assessed against BD 49/01, the British Standard for Design rules for aerodynamic effects on Bridges. The respective parameters and the assessment results are compared with the results obtained from wind tunnel tests

List of Long Span Truss Steel Bridges

No	Bridge Name	Location	Completion Year	Main Span length
1	Rumbai Jaya	Indragiri Hilir	2003	150 m
2	Kahayan Kota	Palangkaraya	2005	150 m
3	Martadipura	Kukar - Kota Bangun	2006	200 m
4	Kahayan Hulu	Gunung Mas	2006	160 m
5	Musi II Tebing Tinggi	Empat Lawang	2007	100 m
6	Bojonegoro / Malo	Bojonegoro	2007	128 m
7	Merdeka	Murung Raya	2008	100 m
8	Rumpiang	Barito Kuala	2008	200 m
9	Mahakam Ulu	Samarinda	2008	200 m
10	Batanghari 2	Jambi	2010	150 m

List of Long Span Truss Steel Bridges

No	Bridge Name	Location	Completion Year	Main Span length
11	Kalahien	Barito Selatan	2010	200 m
12	Teluk Mesjid	Kabupaten Siak	2012	250 m
13	Muara Sabak	Tanjung Jabung Timur	2012	150 m
14	Ogan I Pelengkung	Palembang	2013	160 m
15	Gugus	Tanjung Pinang	2013	120 m
16	Kali Mujur / Selowangi	Lumajang	2013	120 m
17	New Kutai Kartanegara	Kukar - Tenggarong	2015	270 m
18	Tayan Kapuas	Tayan	2016	200 m
19	Musi VI	Palembang	2018	200 m
20	Mahakam I Duplikasi	Samarinda	under construction	220 m

Bridges Considered

Tayan Kapuas Bridge

Musi VI Bridge

Teluk Mesjid Bridge

New Kutai Kartanegara Bridge

Wind Consideration During Design

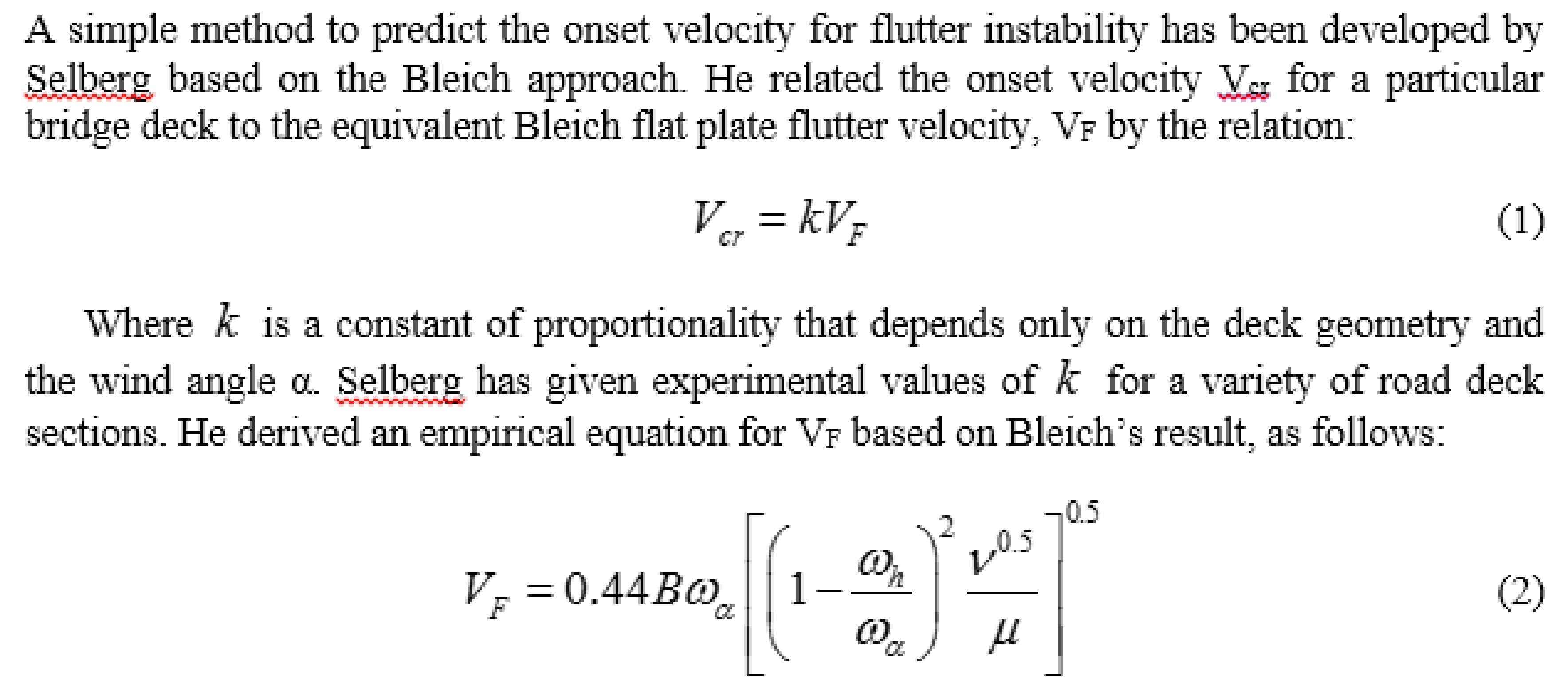
Effect of time-average wind pressure, wind force			
Static	Static instability	Divergence	
		Lateral Buckling	
Dynamic	Dynamic Instability	Galloping	Divergent Amplitude Response
		Torsional flutter	
		Coupled Flutter	
		Vortex excitation / low speed flutter	Limited amplitude Response
	Turbulence response (gust, buffeting)		

At the present time, the best procedure to predict the response of bridge structures to wind is a full model experiment in the wind tunnel in which the site conditions are simulated as close as possible.

Parameter Used to Predict Bridge Instability

1) Width ratio of the bridge deck,
2) Depth ratio of the bridge deck and
3) Stiffness of the bridge in term of frequencies
4) Frequency Ratio (first vertical / first torsional)

Selberg's Equation

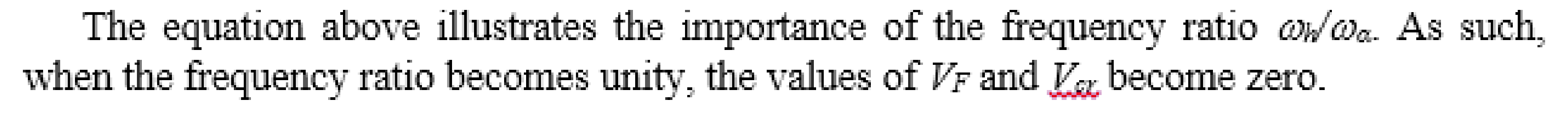


A simple method to predict the onset velocity for flutter instability has been developed by Selberg based on the Bleich approach. He related the onset velocity V_{cr} for a particular bridge deck to the equivalent Bleich flat plate flutter velocity, V_F by the relation:

$$V_{cr} = kV_F \qquad (1)$$

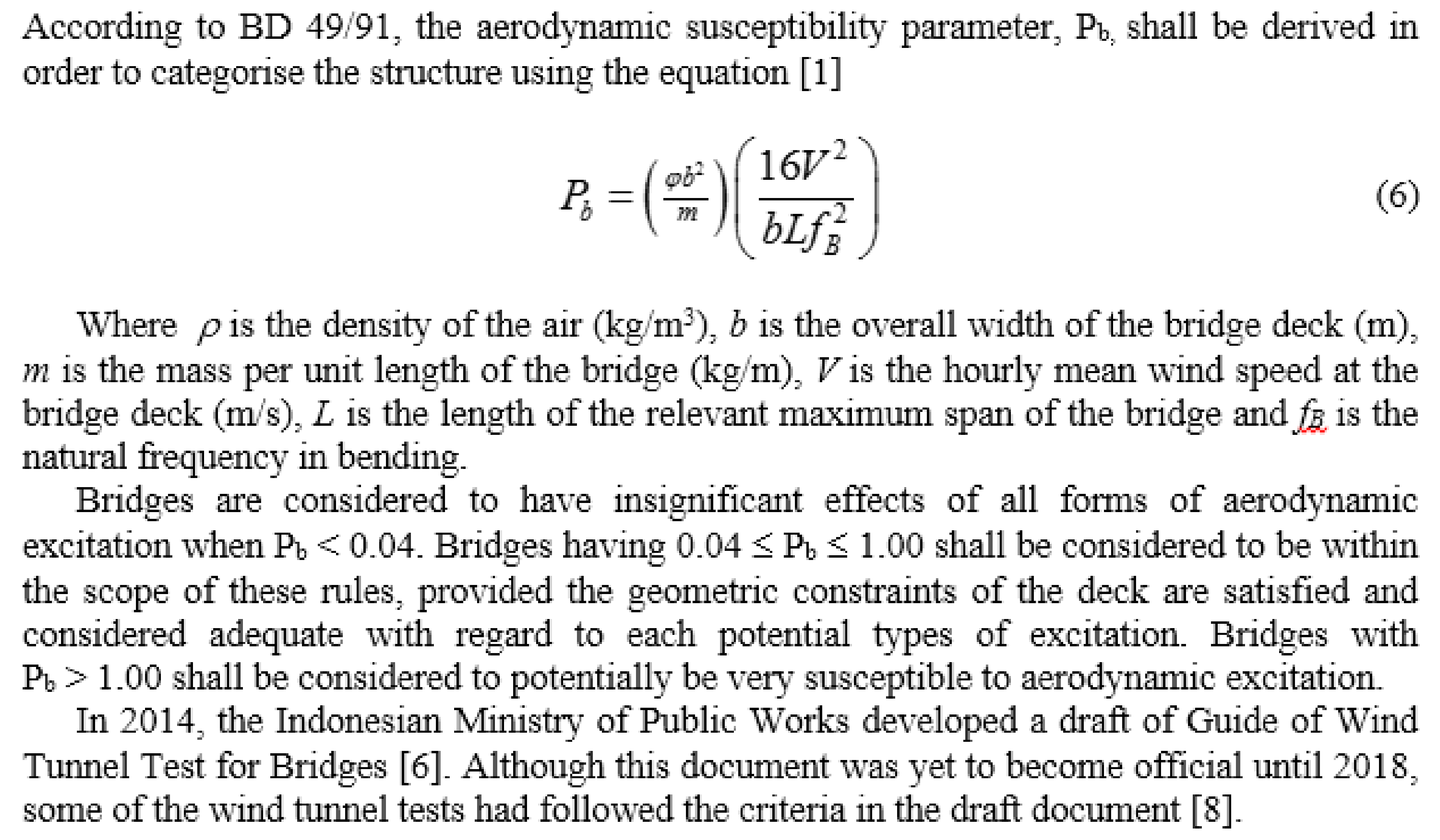
Where k is a constant of proportionality that depends only on the deck geometry and the wind angle α. Selberg has given experimental values of k for a variety of road deck sections. He derived an empirical equation for V_F based on Bleich's result, as follows:

$$V_F = 0.44B\omega_\alpha \left[\left(1-\frac{\omega_h}{\omega_\alpha}\right)^2 \frac{\nu^{0.5}}{\mu}\right]^{0.5} \qquad (2)$$



The equation above illustrates the importance of the frequency ratio ω_h/ω_α. As such, when the frequency ratio becomes unity, the values of V_F and V_{cr} become zero.

Aerodynamic susceptibility based on BD 49/01



According to BD 49/91, the aerodynamic susceptibility parameter, P_b, shall be derived in order to categorise the structure using the equation [1]

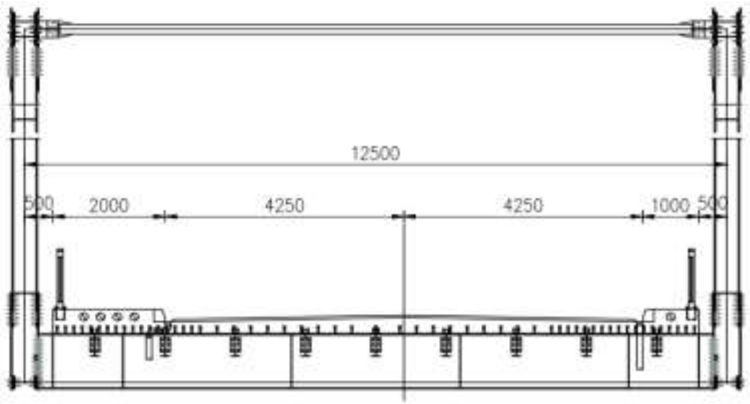
$$P_b = \left(\frac{\varphi b^2}{m}\right)\left(\frac{16V^2}{bLf_B^2}\right) \qquad (6)$$

Where ρ is the density of the air (kg/m^3), b is the overall width of the bridge deck (m), m is the mass per unit length of the bridge (kg/m), V is the hourly mean wind speed at the bridge deck (m/s), L is the length of the relevant maximum span of the bridge and f_B is the natural frequency in bending.

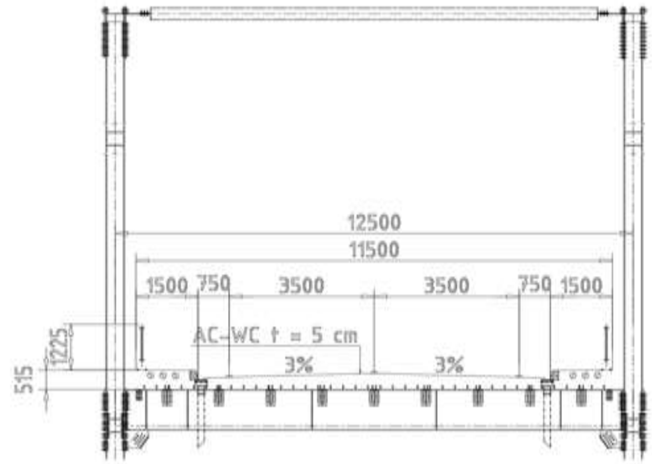
Bridges are considered to have insignificant effects of all forms of aerodynamic excitation when $P_b < 0.04$. Bridges having $0.04 \leq P_b \leq 1.00$ shall be considered to be within the scope of these rules, provided the geometric constraints of the deck are satisfied and considered adequate with regard to each potential types of excitation. Bridges with $P_b > 1.00$ shall be considered to potentially be very susceptible to aerodynamic excitation.

In 2014, the Indonesian Ministry of Public Works developed a draft of Guide of Wind Tunnel Test for Bridges [6]. Although this document was yet to become official until 2018, some of the wind tunnel tests had followed the criteria in the draft document [8].

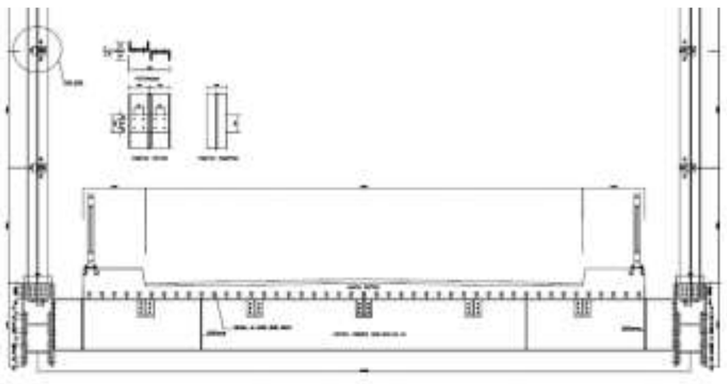
Sectional characteristic



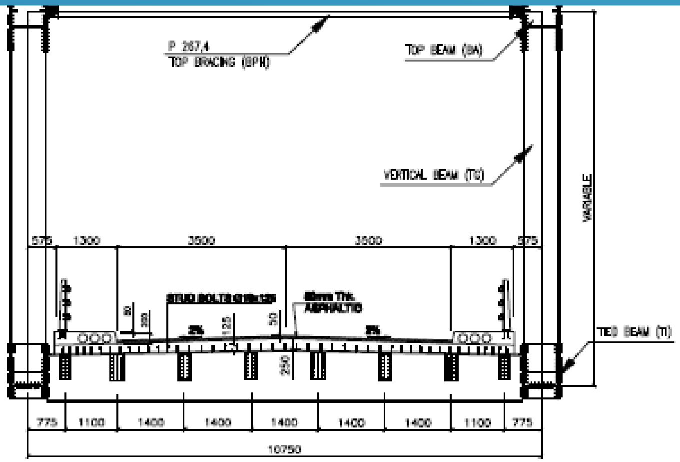
Tayan Kapuas Bridge



Musi VI Bridge



Teluk Mesjid Bridge



Kutai Kartanegara (New) Bridge

Sectional Characteristics

No	Bridge Name	Bridge span (m)	mass per unit length (kg/m)	width of the deck (m)	depth of the deck (m)	span to width ratio	span to depth ratio
1	Tayan Kapuas [3]	200	14,347	12.95	2.00	15.44	100.00
2	Musi VI [7]	200	14,625	12.9	1.94	15.50	103.09
3	Teluk Mesjid [2, 4]	250	11,785	10.45	2.32	23.92	107.76
4	New Kutai Kartanegara [5]	270	10,200	11.54	1.35	23.40	200.00

Dynamic characteristic of the bridges

No	Brideg Name	Length of Main Span (m)	Mass per Unit Length (kg/m)	ω_h (Hz)	ω_α (Hz)	Frequency Ratio $\left(\omega_h / \omega_\alpha\right)$
1	Tayan Kapuas [3]	200	14,347	0.760	1.220	1.605
2	Musi VI [7]	200	14,625	0.750	0.860	1.147
3	Teluk Mesjid [2, 4]	250	11,785	0.794	1.163	1.465
4	New Kutai Kartanegara [5]	270	10,200	0.727	0.734	1.010

Aerodynamic susceptibility based on BD 49/01

No	Bridge Name	bridge main span (m)	the mass per unit length (kg/m)	ω_h (Hz)	P_b (V=20 m/s)	P_b (V=30 m/s)	P_b (V=40 m/s)
1	Tayan Kapuas	200	14,347	0.760	0.061	0.138	0.245
2	Musi VI	200	14,625	0.750	0.061	0.138	0.246
3	Teluk Mesjid	250	11,785	0.794	0.044	0.099	0.176
4	New Kutai Kartanegara	270	10,200	0.727	0.062	0.140	0.249

Result of wind tunnel test

No	**Bridge Name**	**Length of Main Span (m)**	**frequency ratio** $\left(\omega_h/\omega_\alpha\right)$	P_b **(V=40 m/s)**	**Vortex Induced Vibration**	**Flutter Speed (m/s)**
1	Tayan Kapuas	200	1.605	0.245	vertical at 25.3 m/s and torsional at 36.9 m/s [3]	No flutter (149 m/s) [3]
2	Musi VI	200	1.147	0.246	vertical at 10.75 m/s [7]	56 km/s [7]
3	Teluk Mesjid	250	1.465	0.176	-	No flutter [2, 4]
4	New Kutai Kartanegara	270	1.010	0.249	vertical at 15 m/s only at low structural damping [5]	No flutter [5]

Conclusions and recommendations

1) Susceptibility of the Bridges to dynamic wind action P_b has been a good indicator to indicate the stability of the long span steel truss to dynamic wind.
2) Even though steel truss arch bridges are categorized as long span bridges, a susceptibility check of the Bridges using BD 89/01 indicated that the long span steel truss bridge structure of up to 270 m span is less susceptible to aerodynamic excitation and therefore wind tunnel analysis is not mandatory.
3) The frequency ratio is unable to be used to indicate the stability of the bridge to flutter.

Conclusions and recommendations

4) The results of wind tunnel tests agree well with the susceptibility of the bridges to dynamic wind action analysis where the critical flutter speed is much higher or there is no flutter
5) Design wind speed is of a critical parameter for long span bridge design, thus such kind of data and analysis need to be available.
6) Considering the present result of the wind tunnel test, application of longer steel truss bridges is possible in the future, noting that dynamic wind performance needs to be carefully examined.

THANK YOU