Wind tunnel tests on plate girder bridges

Prepared for Highways Agency

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Executive Summary

Background

Simple criteria for assessing the susceptibility of bridges to aerodynamic effects first appeared in general form in a paper entitled 'Proposed British Design Rules' (Institution of Civil Engineers, 1981). The rules presented equations for determining critical wind speeds at which vortex shedding or aerodynamic instability (galloping, non-oscillatory divergence) would occur. The critical wind speeds could then be compared with design wind speeds to determine whether they were likely to occur. The rules also presented simplified formulae for the calculation of amplitudes of vibration and loading for vortex excitation and gave guidance on response to turbulence and fatigue assessment.

These simplified rules were used primarily to identify bridges that may be prone to aerodynamic effects without carrying out sophisticated dynamic analysis. Should aerodynamic problems be indicated, then the designer has the option of re-designing or testing in a wind tunnel.

The rules applied to a limited range of bridge size and types, based on the knowledge that existed at that time resulting from wind tunnel tests and practical experience. Further studies were subsequently carried out, including a calibration exercise to derive appropriate partial safety factors for vortex shedding loads, to make the rules applicable to a wider range of structures. The rules were modified accordingly and made available in TRL Contractor Report CR36 (Flint and Neill Partnership 1986), which was widely used in the assessment of bridge stability. The rules were developed further in TRL Contractor Report CR256 (Flint and Neill Partnership 1991) and were eventually published in Departmental Standard BD 49/93.

Scope of the project

Because of the lack of wind tunnel test results, certain bridge types were beyond the scope of BD 49/93. One important category of bridges was omitted, ie, plate girder bridges, for which much of the standard was not applicable. It was also apparent from the many queries posed by bridge engineers using BD 49/93 that the geometric constraints imposed by the rules, particularly those relating to leading edge details, eliminated many typical structures from being covered by the standard. To widen the range of bridge types and configuration covered by the standard, a comprehensive wind tunnel testing programme was carried out. This report summarises the results and conclusions derived from these tests.

The wind tunnel tests were carried out by Flint and Neill Partnership in collaboration with BMT Fluid Mechanics Limited. As well as examining the critical wind speeds, vibration amplitudes and stability of plate girder bridges, other topics were investigated. These included the effect on aerodynamic behaviour of varying edge beam dimensions, parapet height and solidity. The effect of presence of solid parapet over short lengths of the span, as is required for bridges over railway-lines, was also investigated.

Summary

Over 60 wind tunnel tests were carried out on section models of bridge decks of various configuration and edge detail. The tests covered a range of wind speeds and a variety of damping values. The models were mounted on elastic supports that enabled them to move in their fundamental bending and torsional modes of vibration. The tests were mainly carried out in smooth flow since this gives conservative estimates of vortex shedding response and critical wind speeds. Some tests in turbulent flow were included in the programme for reference.

The effect of different edge detail on the aerodynamic response was investigated using parapets of varying height and solidity that could be attached to the different models. Two basic fascia beam configurations were tested, as well as various fascia beam depth and overhang values. Other edge details, such as 'thickening' of the slab were also included.

The models and test configuration are described fully in this report. The report contains the data obtained from the wind tunnel tests and the main conclusions relevant to the 1993 version of BD 49. The tests were subsequently used to produce a revised version of BD 49 (published in 2001). The background to these revisions is presented in a separate report (TRL528).

The data obtained from the wind tunnel tests presented in this report can be used in conjunction with BD 49. This will enable designers to use the data directly rather than in the form of simplified rules, which are necessarily conservative. The data for critical wind speeds, amplitudes of vibration, for both bending and torsion, should only be used where deck configuration and edge details are similar. This may avoid the need for re-design or expensive wind tunnel tests.

Conclusion

The wind tunnel testing programme was used to provide simple rules to determine the aerodynamic behaviour of plate girder bridges of various geometric configurations. These rules are applicable to typical situations and can be used to ascertain the stability of the structure or to identify the situations were more sophisticated studies are required, eg, full dynamic analysis or wind tunnel tests. Where appropriate, the wind tunnel data can be used directly for the assessment of aerodynamic behaviour.

There are still many areas which have not been fully investigated and it is important to note that the need for full dynamic analysis or wind tunnel tests has not been eliminated and is still required in certain situations.

1 Introduction

Flint and Neill Partnership (FNP) in association with BMT Fluid Mechanics Limited (BMT) were awarded a commission by the Transport Research Laboratory (now TRL Limited) to undertake studies and wind tunnel tests on plate girder bridges. The purpose of the investigation was to confirm or extend the content of certain clauses in the simplified design rules for bridge aerodynamics (hereinafter referred to as the Rules), as published in BD 49/93 (Highways Agency, 1993).

During the study it was found that the results were particularly sensitive to edge beam depth and overhang. To address these problems a small programme of further tests was undertaken.

This report sets out the results of the study, proposed modifications to the Rules and general conclusions and recommendations regarding the Rules. As a consequence of this study, the equations used to evaluate critical wind speeds and amplitudes of response were revised. Rules were revised and published as BD 49/01 (Highways Agency 2001). Background to other revisions of BD 49 is presented by Smith *et al.* (2002)

2 Background

All the wind tunnel tests, upon which the aerodynamic Rules have been based, were undertaken by BMT (formerly NMI) and a significant part of the codification of the test results was carried out by Flint and Neill Partnership. The original rules published by the Institution of Civil Engineers (1981) were extended as a result of a calibration study undertaken by Flint and Neill Partnership (1986). A further investigation (Flint and Neill Partnership 1991) modified certain clauses in the Rules and these were subsequently published by the Highways Agency as BD 49/93.

It was recognised however that certain aspects of the Rules required further investigation, particularly those associated with plate girder bridges. Accordingly these aspects were identified and formed the basis of the present investigation.

3 Wind tunnel test procedure

3.1 General

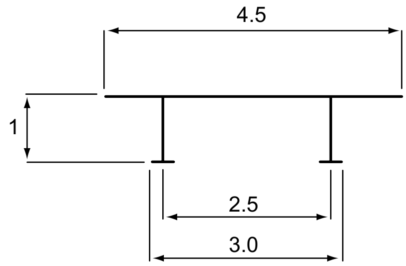
The purpose of the wind tunnel tests was to investigate the aerodynamic behaviour of plate girder bridges in a systematic way so that this category of bridge could be included within the scope of the Rules. The methodology used was to develop a basic matrix of tests covering the parameters to be investigated. The results of the basic matrix were examined as the results became available to assess the sensitivity of changing certain of these parameters. Where it became apparent that small changes had a significant effect on the results the matrix was modified to cover intermediate changes, or to exclude such parameters from the scope of the Rules. The modular form of the models allowed this flexibility. The range of tests within the matrix of configurations is shown in Table 1 and the definitions of the various parameters referred to therein are shown in Figures 1, 2 and 3. The additional tests referred to in Section 1 are shown in Table 2.

Table 1 Matrix of tests, as undertaken

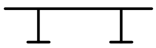
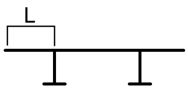
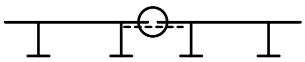
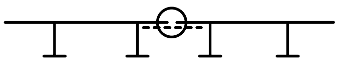
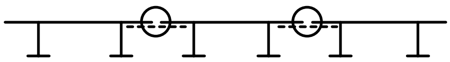
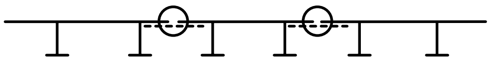
Fascia beam	*Angle*	*Parapet P1*				*Parapet P2*				*Parapet P3*				*Parapet P4*			
		a	*b*	*c*	*d*	*a*	*b*	*c*	*d*	*a*	*b*	*c*	*d*	*a*	*b*	*c*	*d*
Model M1																	
X	-5				✔												
	0	✔	✔		✔*		✔		✔*				✔				✔
	+5				✔												
Y	-5				✔												
	0	✔	✔		✔		✔		✔				✔				✔
	+5				✔												
Model M2																	
X	-5																
	0																
	+5																
Y	-5																
	0																
	+5																
Model M3																	
X	-5																
	0					✔	✔*		✔	✔	✔						
	+5																
Y	-5																
	0					✔	✔		✔	✔	✔		✔				✔
	+5																
Model M4																	
X	-5																
	0																
	+5																
Y	-5																
	0																
	+5																
Model M5																	
X	-5																
	0						✔			✔	✔						
	+5																
Y	-5																
	0						✔			✔	✔						
	+5																
Model M6																	
X	-5																
	0																
	+5																
Y	-5																
	0																
	+5																

* *Tests marked thus undertaken in smooth and turbulent flow. All other tests in smooth flow only.*

Model M1 with parapet P1/a was used to assess the effect of solid barriers over short lengths.



Basic model unit
dimensions are relative only

Model number	Configuration	Overhang $^L/_{d_4}$	Number of basic types	$^b/_{d_4}$	$^{b^*}/_{d_4}$
M1		1.0	1	4.5	3
M2		1.5	1	5.5	3
M3		1.0	2	9	7.5
M4		1.5	2	10	7.5
M5		1.0	3	13.5	12
M6		1.5	3	14.5	12

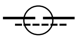
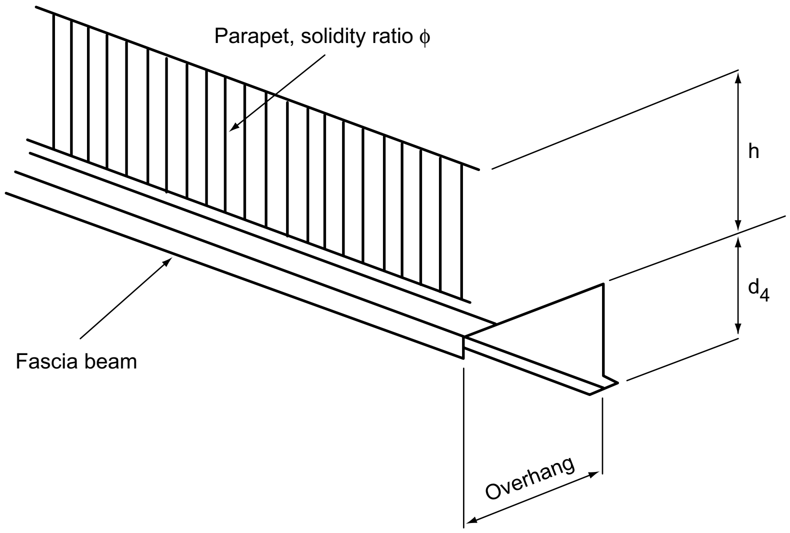
 *Joint in model deck formed by screwing through to stiff backing plate in shadow zone*

Figure 1 Model configurations



Parapet type	$^h/_{d_4}$
P1	0.3
P2	0.7
P3	1.1
P4	1.5

Suffix	ϕ
a	0.25
b	0.50
c	0.75
d	1.00

Figure 2 Edge details

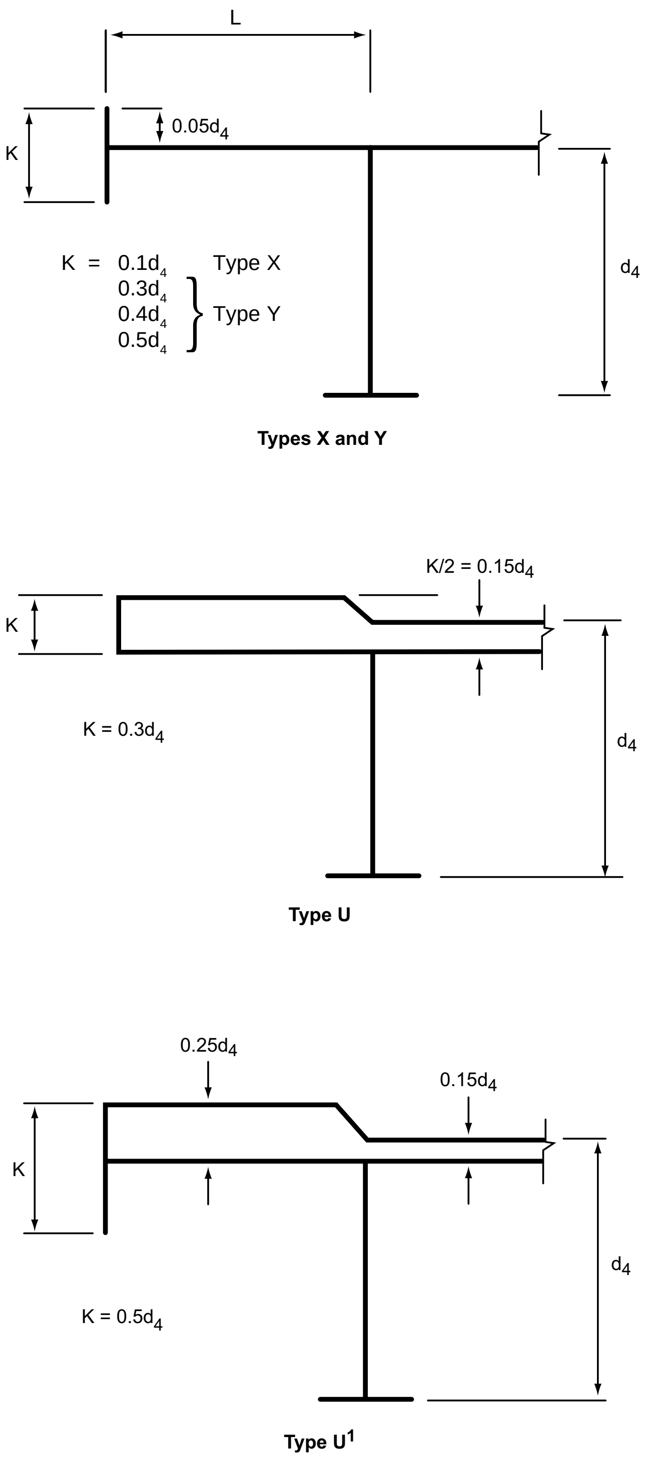


Figure 3 Details of leading edge

Table 2 Matrix of additional tests on model M2 and M3
(All tested at 0° inclination)

Over-hang L/d_4	Parapet type	*Edge detail (k/d_4) or types* 0.1(X)	0.3(Y)	0.4 (Y)	0.5 (Y)	U	U^1
Model M3							
1.0	1a						
	1b						
	2a		✔	✔	✔	✔	✔
	2b						
	3a						
	3b						
0.5	1a						
	1b						
	2a	✔	✔		✔	✔	✔
	2b	✔			✔		
	3a						
	3b						
0.25	1a						
	1b						
	2a		✔		✔		✔
	2b				✔		
	3a						
	3b						
Model M1/M2							
0.5	1a						
	1b						
	2a			✔†	✔		✔
	2b						
	3a						
	3b				✔		✔
0.25	1a						
	1b						
	2a				✔		✔
	2b						
	3a						
	3b			✔		✔	

All tests undertaken in smooth flow
† Test with L/d_4 = 1.5

3.2 The models

The programme of wind tunnel tests was performed using a series of section models of representative plate girder bridge decks. The models were manufactured by BMT's workshop facilities and were constructed, on the whole, from carbon fibre. Two basic units were designed and these were assembled to give the family of models shown in Figure 1. This resulted in a series of deck configurations with constant depth, two overhang details and variable overall width.

Previous tests have shown that aerodynamic behaviour of bridge decks is very dependent on the leading edge detail of the structure. For this reason, parapets of various height and solidity were provided and made interchangeable between the various model decks. These are shown in Figure 2. The solidity ϕ is defined as the ratio of solid area to overall area of the parapet.

In addition to parapet details, two basic fascia beam configurations were tested, named X and Y, as shown in Figure 3. The additional tests to investigate fascia beam depth and overhang concentrated on model M3 with overhangs varying from 0.25 to 1.0 times the depth of the beams. In addition, two edge details, types U and U^1, representing thickening of the slab at the edge, were introduced. These details are commonly found in existing bridges, but were beyond the scope of the aerodynamic Rules due to the unavailability of wind tunnel test data. TRL was also concerned with a specific bridge whose configuration was similar to model M2, when mounted with one of the new edge details. Accordingly this was included in the matrix of tests.

The scale of the models was 1:30 based on 1 unit = 1.5m full scale or 1:40 for 1 unit = 2m full scale. A large scale model is essential in providing reliable results, not only because of the need for sufficiently high Reynold's numbers, but also to enable the accurate representation of small features such as the fascia beam detail at model scale. This is particularly important since slight changes in fascia beam, for example, can have a profound effect on the wind-induced response of a deck section.

However it was still found necessary to use light cross-bracing linking the bottom flanges of the beams, to prevent the sections from distorting.

3.3 The wind tunnels

The tests were undertaken in two of BMT's tunnels:

1 BMT's No 5 wind tunnel, which is regularly used for section model testing of bridge decks and has a test section of 2.74m wide, 2.14m high and 3.5m long and a top wind speed 65m/sec,

2 No 7 environmental wind tunnel, with a test section 4.8m wide, 2.4m high and 15m long, and a top wind speed of 45m/s. Due to the greater width of this wind tunnel, false walls were installed in the test section. These walls spanned the entire height of the test section and were located 2.74m apart. The front end of each wall had a streamlined nose to avoid flow separation at the leading edge. The walls were of suitable length to ensure two-dimensional flow conditions for a sufficient distance downstream of the model. The uniformity of the mean wind speed between the walls was generally better than ± 1%.

For both wind tunnels the dynamic test rig was mounted on the outside surfaces of the walls. All the components of the test rig were shielded from the flow to avoid any unwanted flow-induced excitation. The set up of the false walls and dynamic rig in wind tunnel No 7 is shown in Figure 4.

Cross-calibration of the two tunnels was undertaken to ensure consistency of the results, by repeat testing some of the configurations and good agreement was obtained.

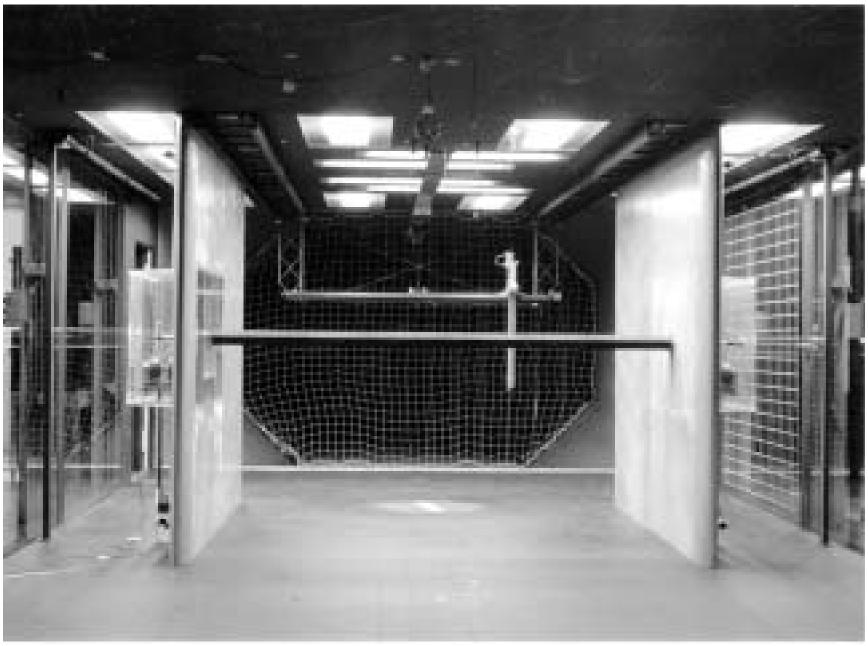


Figure 4 Test set-up in wind tunnel

3.4 Dynamic response measurements

The section models were elastically mounted in the wind tunnel on a dynamic rig incorporating a system of springs to provide two degrees of freedom, ie, vertical bending and torsion. The stiffness of the springs was carefully chosen to provide model scale natural frequencies that result in a convenient wind speed scaling in the wind tunnel. The frequency ratio was not set to a specific value since it was believed that coupled instabilities were unlikely, based on previous experience with plate girder bridge sections. The target values for the mass and inertia were based on full scale data for 22 existing steel plate girder bridges of various widths and spans.

Incorporated in the dynamic rig was an eddy current damping system, which allows the structural damping in both degrees of freedom to be controlled during the test. The dynamic rig also allowed the vertical angle of incidence of the wind relative to the deck to be varied.

In all cases, the test procedure generally consisted of first running through the required wind speed range to provide a general indication of the response. This was followed by measurements of the response amplitudes in bending and torsion at a sufficient number of wind speeds to accurately define any responses due to vortex shedding and the critical wind speeds for the onset of any divergent aeroelastic instabilities such as galloping or flutter. The response was measured using accelerometers mounted on the dynamic rig.

Tests were conducted according to the test matrix defined in Tables 1 and 2. They were generally performed at a wind incidence of 0°, although some measurements were made at ±5°. Tests were performed at up to six levels of structural damping to cover the anticipated range of full scale values.

On the whole, measurements were made in low turbulence flow (nominally smooth flow). Tests in smooth flow are generally recognised to give conservative estimates of the vortex shedding responses and critical wind speeds for divergent instabilities. However, some tests were performed in turbulent flow as defined in the test options to demonstrate the effects of turbulence. Turbulent flow was generated in the wind tunnel using a grid of bars at the entrance to the working section of the wind tunnel.

For the smooth flow tests the longitudinal turbulence intensity (defines as the root mean square of the fluctuating component of the wind divided by the mean wind speed) was less than 1% whereas for the turbulent flow tests the longitudinal turbulence intensity was 7.6%. The longitudinal length scale was of the order of 0.30m.

4 Wind tunnel test results

The results from the wind tunnel tests are presented in full in Appendix A. For each model, with its various fascia beam configurations, the results are tabulated for vortex shedding in bending, vortex shedding in torsion and divergent instability.

For vortex shedding the results are given for various damping values. These generally started at a logarithmic decrement (δ) of 0.01 depending on the set up (eg, minimum δ in torsion for model M3 was 0.0138) and increasing in 0.01 increments until no further response was measured or a maximum logarithmic decrement of 0.06 was reached. Both the non-dimensional critical wind speed and the maximum root mean square amplitude are tabulated.

For divergent instability the non-dimensional wind speed at the onset of instability is tabulated.

5 Assessment of results

The matrix of tests was limited to three of the six possible models (M1, M3 and M5) to enable general trends in aspect ratio of plate girder bridges to be determined.

The matrix also concentrated initially on solid parapets, which unless they are very low in height were excluded from the simplified formulae given in BD 49/93. It was hoped that the scope for plate girder bridges could be widened, as a result of the tests, to enable such configurations to be assessed using the formulae in the Rules.

The tests pertaining to the effect of changes in the leading edge detail focused on the requirement in the Rules for factoring the predicted amplitudes by 3.0 (Clause 3.1.2 of BD 49/93) for 'bluff' configurations. It was felt that this was simplistic and over-conservative and that a factor dependent on edge detail parameters would be more realistic. These tests were used to develop such an approach.

5.1 Vortex excitation

The general trend of the results for model M1 mounted with solid barriers (ie, parapets with suffix d denoting a solidity of 100%) is shown in Figure 5. In these plots the non-dimensional amplitude for bending is plotted against

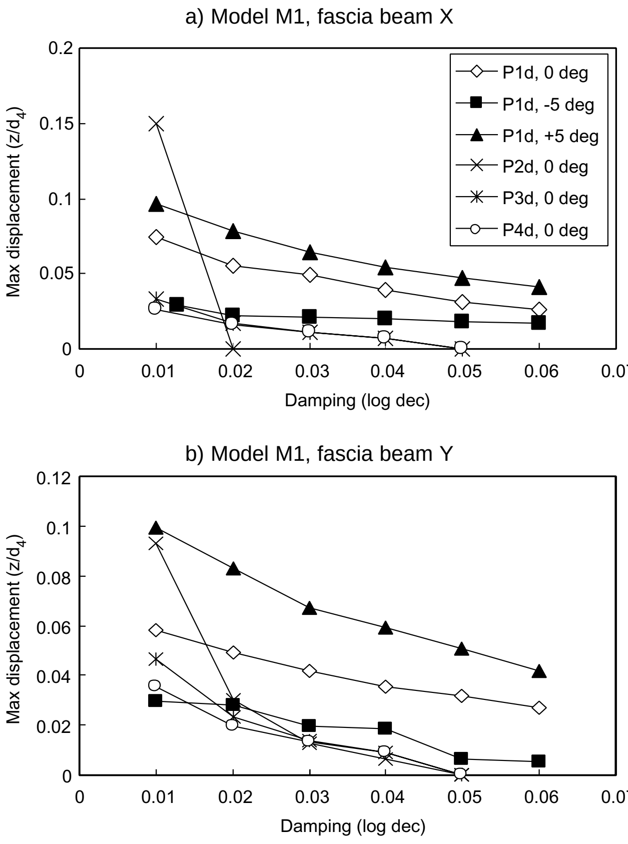


Figure 5 Vortex shedding response in bending with solid parapets

the logarithmic decrement of damping. Figure 5a is for fascia beam X and Figure 5b is for fascia beam Y. As expected the amplitudes decrease with increasing damping. The initially surprising result was that the amplitudes decreased with increasing height of barrier, apart from the single results for P2d at low values of damping. It should be recognised that these results are for the model mounted with solid parapets, a configuration that is outside the scope of the BD 49/93 Rules. The results can probably be explained by the mechanism of vortex shedding which may create strong vortices due to the deep bluff leading face, but a relatively smaller forcing mechanism for higher height to in-wind depth ratios due to a reduction in the effective after-body length.

This trend for reduced amplitudes for higher barriers was reversed for the torsional response, which is plotted in Figure 6a for fascia beam X and in Figure 6b for fascia beam Y.

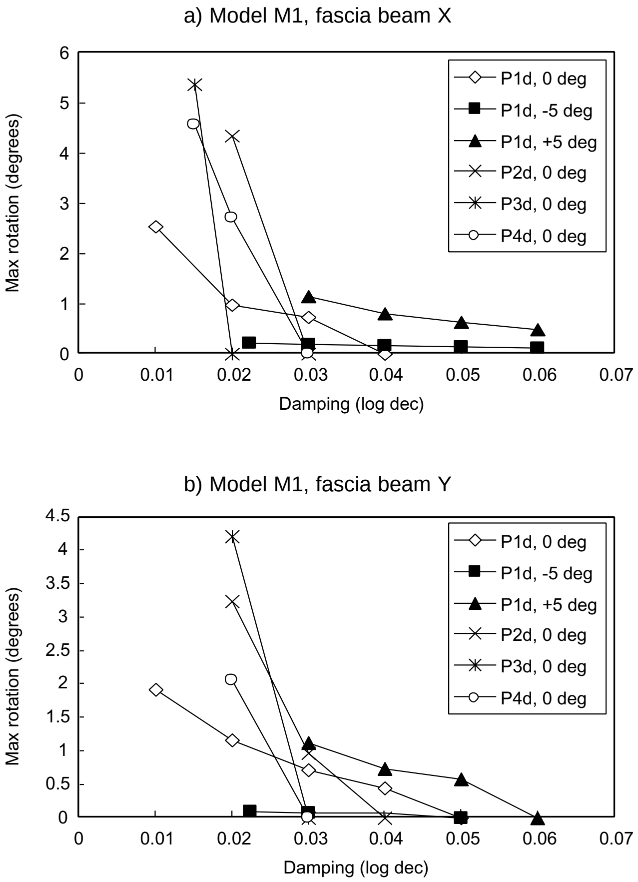


Figure 6 Vortex shedding response in torsion with solid parapets

As may be seen from Figures 5 and 6, amplitudes were higher for positive angles of inclination and lower for negative angles, for an identical configuration (model P1d) for both bending and torsion. Wind inclination can be caused either by topographic effects or by super-elevation of the structure. The design rules have allowed for the effects of up to ±5° inclination. Super-elevation beyond that angle would be extremely unlikely to occur over a long length of the bridge, particularly for the main span which is of most concern. Wind inclination could occur for sites where an elevated bridge runs normal to the slope of a hill. Such cases are unlikely to occur in practice but bridge designers should be aware of such possibilities.

Results for bending, again for model M1, for open parapets (a and b with solidity 25% and 50% respectively) are given in Figures 7a for fascia beam X and 7b for fascia beam Y which show increased response for increased solidity. Equivalent results for torsion are given in Figures 8a and 8b. It can be seen from Figures 7 and 8 that increasing the height of the 50% porous parapet decreased both the bending and torsional response.

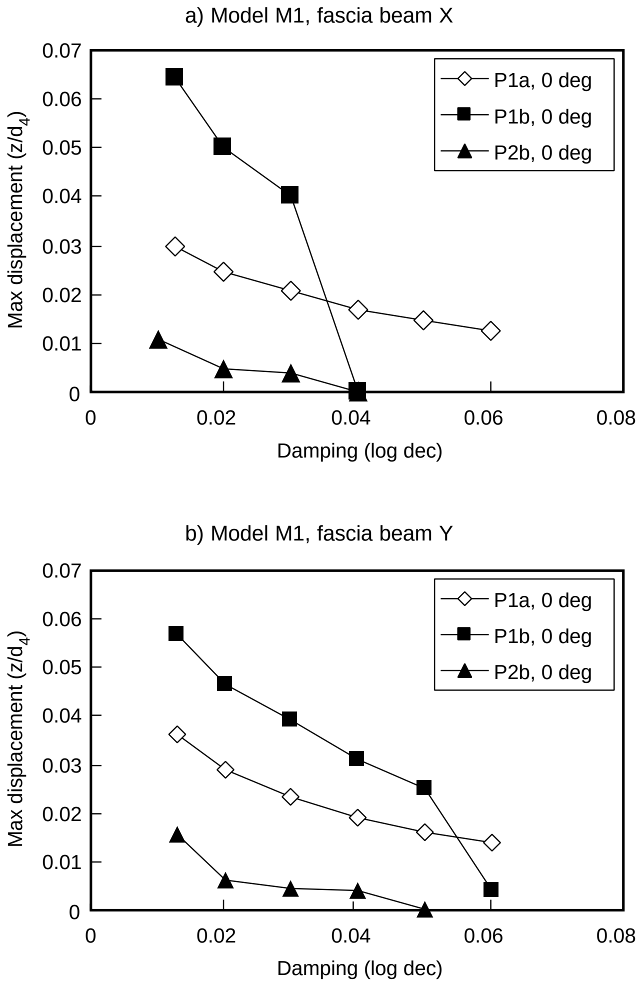


Figure 7 Vortex shedding response in bending with open parapets

Bending results for model M3 with open parapets are summarised in Figure 9a (for fascia beam X) and Figure 9b (for fascia beam Y). For this model it can be seen that:

a the response increases with increasing height of parapet, although negligibly for the lower solidity parapets;

b the response increases with increasing solidity of parapet.

Both these trends are as expected, the width of the deck now probably providing an increased forcing mechanism.

Figure 10 shows the torsional results for model M3 with fascia beam Y where the response is higher for the lowest height parapet. However it can be seen that at practical

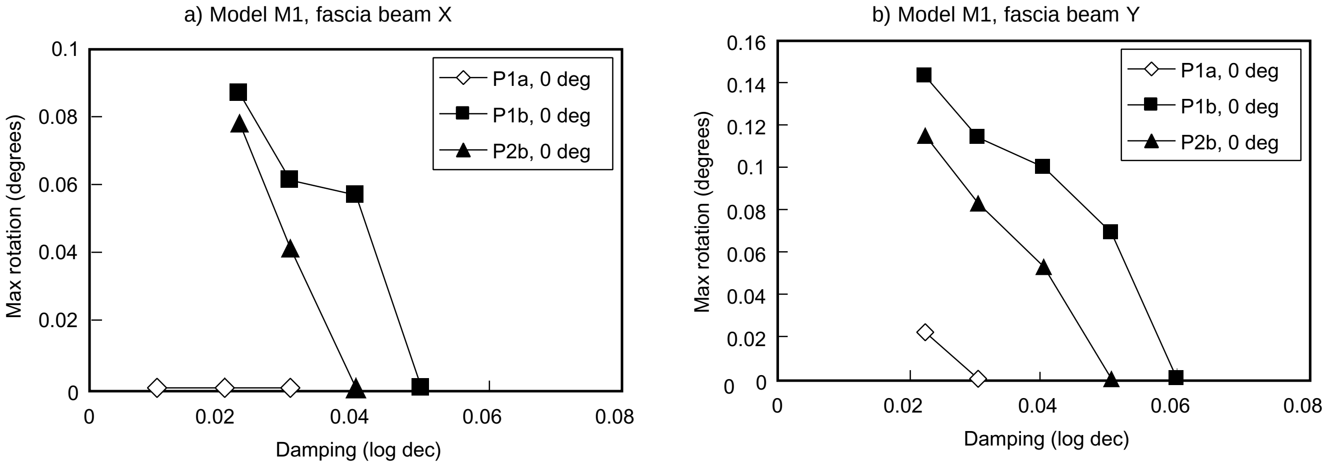


Figure 8 Vortex shedding response in torsion with open parapets

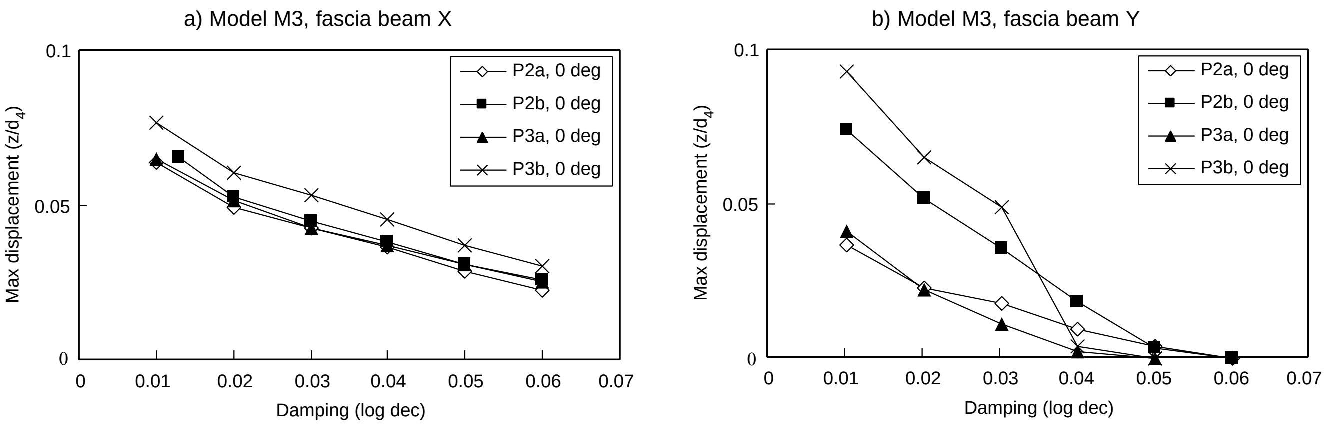


Figure 9 Vortex shedding response in bending with solid parapets

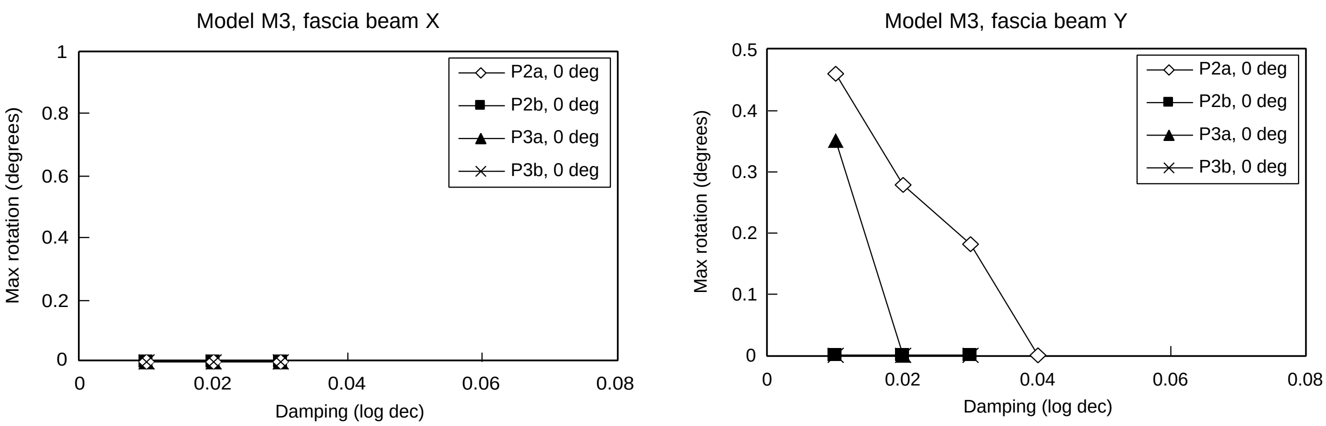


Figure 10 Vortex shedding response in torsion with solid parapets

levels of damping the response is negligible. No torsional response was measured for model M3 with fascia beam X.

For model M3 with solid parapets, large amplitudes were recorded due to vortex shedding in both bending and torsion. For some configurations, the effects of vortex shedding in torsion merged with those of the divergent torsional instability, making the definition of the vortex shedding response almost impossible. Following these initial measurements with model M3, no further configurations were tested with solid parapets. For these reasons the results have not been plotted; the reader is referred to the data given in Appendix A for further details.

Results for the tests with the modified edge details followed the previous pattern in which the amplitudes decrease with increasing damping for both bending and torsion. This may be seen in Figures 11 and 12 for model M3. The amplitudes of vibration for these addition tests, for both bending and torsion, tended to show an increase with the solidity and height of the parapet and with increasing depth of the edge beam. One ‘unusual’ result was for model M3 with parapet 2b, an overhang of 0.5d and $k/d_4 = 0.1$. For this particular case high amplitudes were obtained from the test results, indeed as high as for the similar configuration with $k/d_4 = 0.5$.

Results for model M5, shown in Figures 13 and 14, show no consistent trends. Figures 13a and 13b show the results for bending from which it can be seen that for fascia beam X, parapet P2b provides more severe results than P3a whereas for fascia beam Y this trend is reversed. For fascia beam X the lower parapet P2b provides more severe results than parapet P3b. In torsion the logical trends set out in a) and b) above are followed for fascia beam X but for fascia beam Y the parapet with the highest solidity (P3b) produces less onerous results than parapet P3a (see Figure 14.)

From these limited comparisons it can be seen that general and consistent trends could not always be developed, making codification extremely difficult.

Model M1 with open parapets was tested with a solid infill over the middle third of the model’s length. Comparisons of critical wind speed and bending amplitudes with the same model without the infill are shown in Figures 15a and 15b. It can be seen that the critical wind speed is virtually unaffected but that the amplitude is increased by up to 30% at very low levels of damping. At realistic damping levels, however, the increase is less than 10%. The model without the infill was stable in torsion, whereas with the solid infill very small torsional amplitudes were recorded (see Appendix B Torsion M1X), some 10% of the current Rule value.

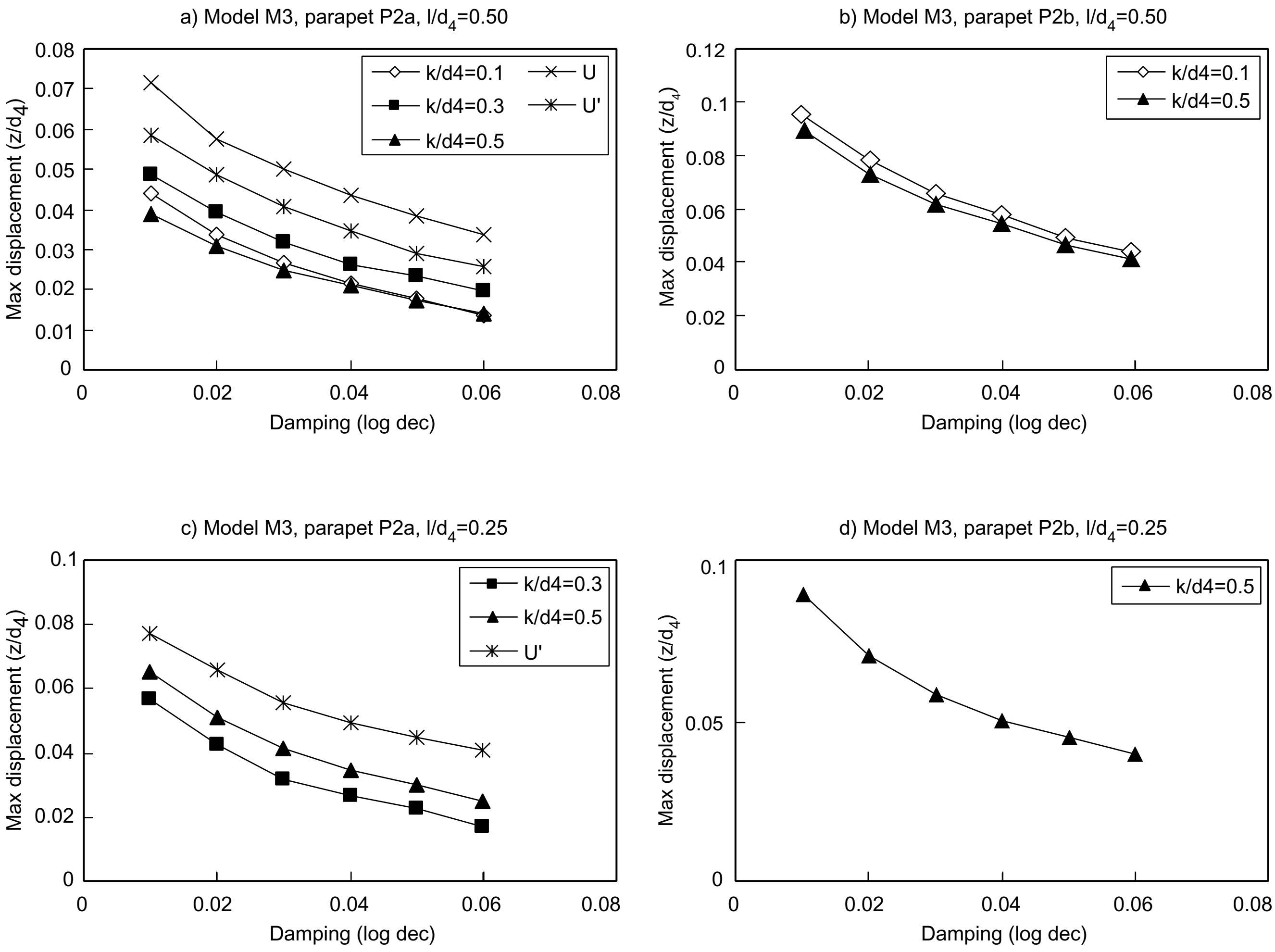


Figure 11 Maximum vortex shedding amplitude in bending as a function of damping

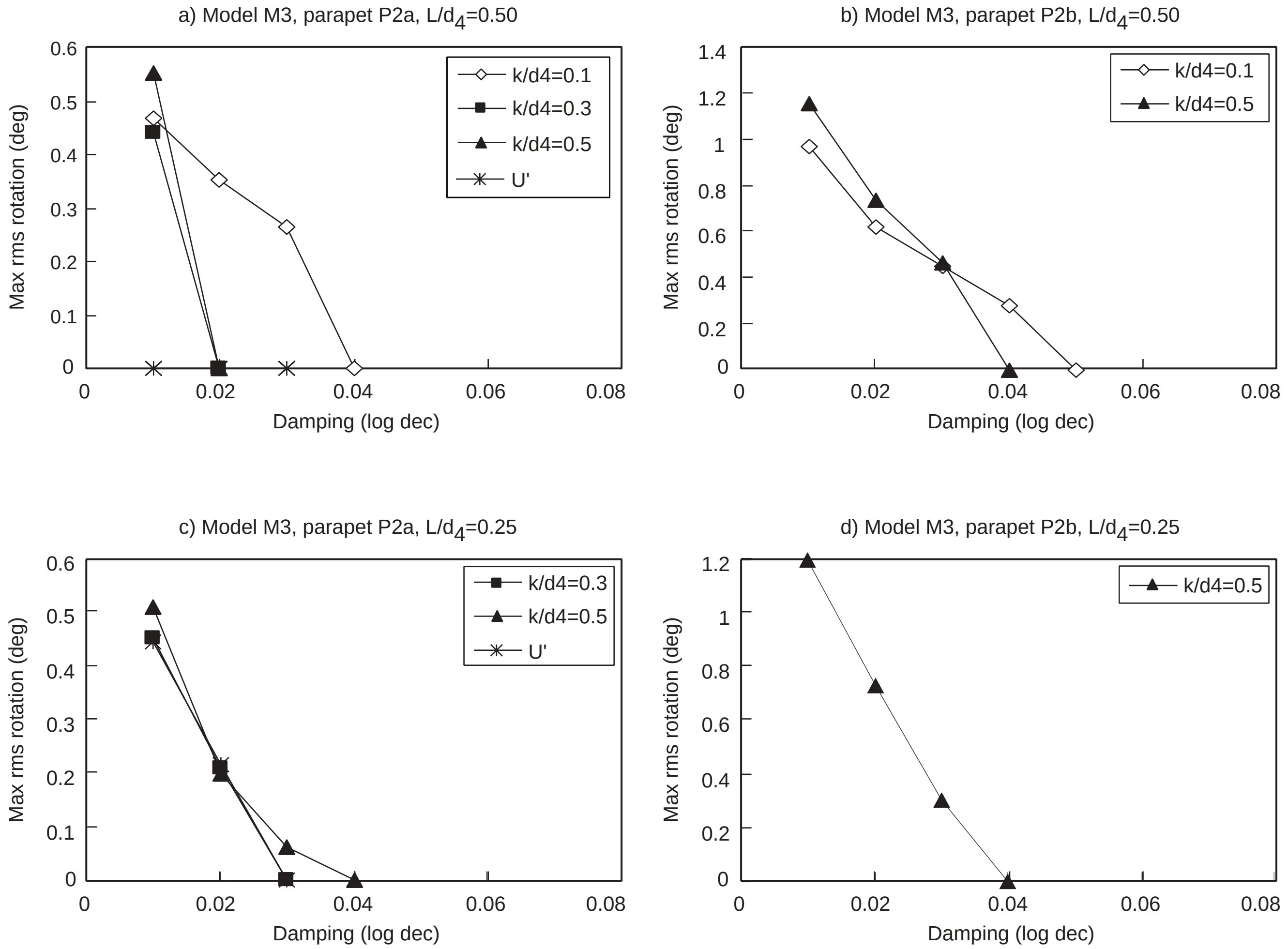


Figure 12 Maximum rotation due to vortex shedding in torsion as a function of damping

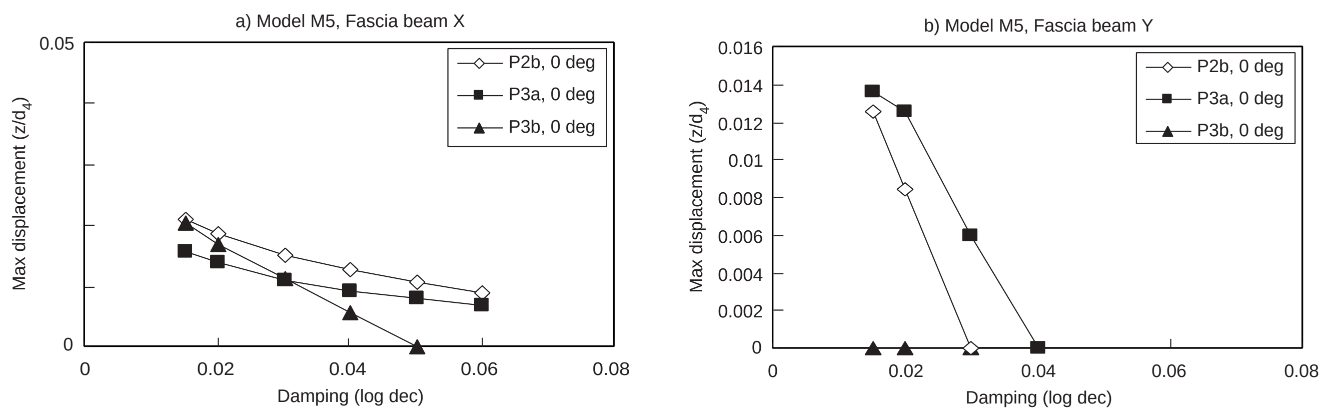


Figure 13 Maximum vortex shedding amplitude in bending with open parapets

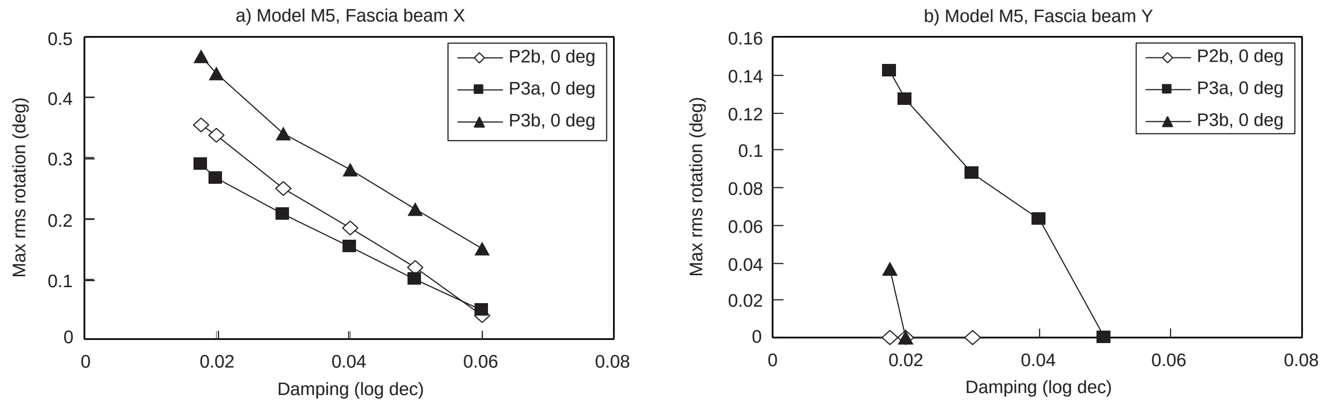


Figure 14 Maximum rotation due to vortex shedding with open parapets

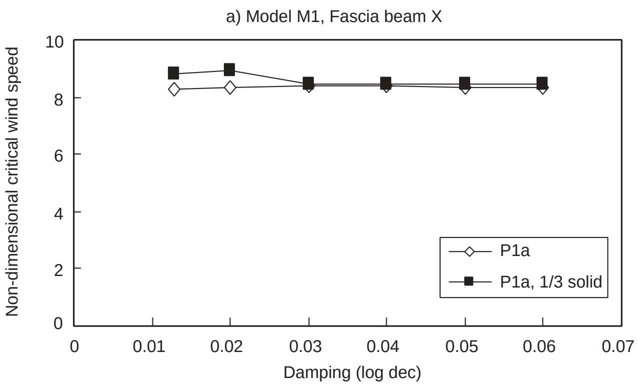


Figure 15a Critical wind speeds for vortex shedding response in bending. Comparison between open parapets and solid infill over 30%

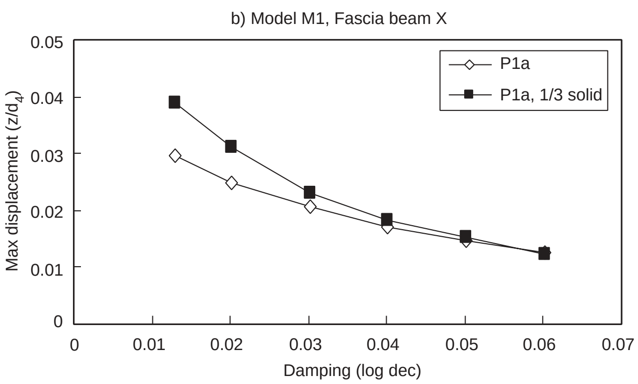


Figure 15b Vortex shedding response in bending with solid parapets. Comparison between open parapets and solid infill over 30%

The effect of turbulent flow was examined on model M1 with fascia beam X and solid parapets P1d and P2d and model M3 with fascia beam X and porous parapet P2b. Results are shown in Figures 16a and 16b for bending and torsion respectively. The bending results show that for parapet P1d the turbulent flow results provide lower amplitudes, as expected, and of the order built into the design rules which allow for turbulent effects. The bending results for P2d only show a single value of response at very low damping, which is suppressed when δ exceeds 0.02.

Whilst the turbulent result figure is marginally higher than the smooth flow result it is not believed that this is a result which can be used for codification purposes. In torsion (see Figure 14b) the turbulence suppresses the response for models with both barriers P1 and P2. Model M3 with fascia beam X and parapet P2b was found to be stable with respect to vortex shedding in both bending and torsion in turbulent flow. In smooth flow, this configuration exhibited a vortex shedding response in bending, but was stable in torsion.

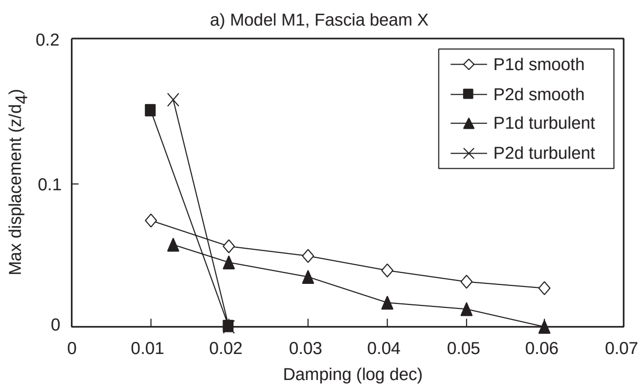


Figure 16a Vortex shedding response in bending with solid parapets. Comparison between smooth and turbulent flow

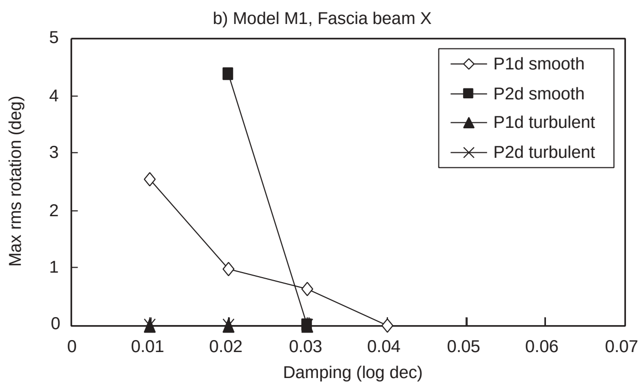


Figure 16b Vortex shedding response in torsion with solid parapets. Comparisons between smooth and turbulent flow

Model M3 exhibited bending response due to a sub-harmonic vortex shedding mode at low damping values. However the resulting amplitudes were extremely small - some 10% of the main response. The cause of this phenomenon is believed to be associated with vortex formation due to reattachment of the separating shear layers from the leading edge of the deck. Other researchers in this field (Naudascher and Wang 1993) have observed similar responses with, on occasions, several sub-harmonic modes exciting the same natural frequency.

Model M5 similarly exhibited torsion response at a sub-harmonic with amplitudes less than half of the main response, at a non-dimensional wind speed of about 7.5 to 8.5. The particular configurations displaying this were:

a fascia beam X with medium parapets (solidity 50%) and medium height (0.7 d_4) (configuration XP2b);

b fascia beam Y with open parapets (solidity 25%) and height (1.1 d_4) (configuration YP3a).

Again no common aspect is apparent between these two configurations.

From a general review of these results it was found that the amplitudes, surprisingly in the light of earlier studies, were sensibly independent of the length of overhang. An effective depth could thus be considered taken as:

$$d_4 + k + \phi h$$

which tended to reflect the variation of amplitude from the tests, and which could be considered as a useful parameter for codification.

5.2 Divergent response

The onset of large amplitude instabilities were detected and the wind speed at which this occurred was recorded. Such response was detected in bending for model M1 only and in torsion for models M1, M3 and M5.

As expected, no coupled mode response was detected, despite the adoption of relatively low frequency ratios ranging from approximately 1.4 to 1.9.

The reduced wind speeds at which large amplitude instabilities were detected are set out in Tables 3a and 3b, covering all fascia beams and parapet configurations within the range tabulated.

For bending there was very little effect of changes in parapet configuration and the critical speeds only increased marginally with increasing damping, up to a maximum of about 8% over a damping range from $\delta = 0.02$ to $\delta = 0.06$.

The only exception was model M1/M2 with an overhang of one quarter the depth and with parapets P3b. For this case, for both $k/d_4 = 0.3$ and 0.5, the galloping wind speed increased approximately linearly with damping, ie:

δ_s	k/d_4	$V/f_B d_4$	$V/f_B d_4 \delta_s$
0.02	0.3	18.8	940
	0.5	18.4	920
0.04	0.3	61.5	1540
	0.5	58.5	1460
0.06	0.3	75.7	1262
	0.5	69.7	1162

For torsion the critical speed increased by up to about 25% over the same damping range.

6 Application to design rules

6.1 General

In order to compare the results from the wind tunnel tests with the predictions from the Rules in the 1993 version of BD 49, all the results were tabulated and compared with these predictions. These comparisons are set out in Appendix B.

These figures were then used to plot the more significant findings and to highlight where the comparisons were satisfactory and/or where the 1993 version of the Rules would need modification.

6.2 Vortex excitation - critical wind speed

As may be seen from Appendix B sheets Vertical Bending/ M1X, M1Y, M3X, M3Y, M5X and M5Y, the critical wind speed for vertical bending was virtually independent of damping. The results are summarised in Figures 17a and 17b, where the non-dimensional wind speed is plotted against b^*/d_4 for fascia beams X and Y respectively. This parameter is used in the Rules and the design curve is also plotted on the figure appropriate to both bending and torsion. The results for each model are plotted over a band of b^*/d_4 for the sake of clarity; in reality the values are:

Model	b^*/d_4
M1	3.0
M3	7.5
M5	12.0

Each set of results, where relevant, contains values for differing damping values.

From this it can be seen that for model M1 the Rules provide a good lower bound to the predicted critical wind speed. For model M3 the Rules can be seen to be conservative but for model M5 they tend to over-estimate the critical wind speed. By comparing Figures 17a and 17b it can be seen that models with the differing fascia beams show very similar behaviour.

Figures 18a and 18b show the corresponding results for torsional response. Ignoring the sub-harmonics, described in Section 5.1, and shown in Figures 18a and 18b, the prediction of critical wind speeds by the Rules can be seen to be reasonable, although in this case the results for model M3 can be seen to straddle the design curve.

The effect of varying the leading edge details on the critical wind speeds are shown in Figures 19 and 20, where the non-dimensional critical wind speed is plotted against the overhang length for models M1 and M3. They tend to show that the critical wind speed is not sensitive to the leading edge detail, although as seen in Figure 19, the results for model M3 in bending again were consistently higher than those for model M1 (M2). The critical wind speeds for torsion however (see Figure 20), for those models which displayed some excitation, whilst again being constant for each basic model for the various edge details tested, showed a marginal decrease from model M1 to M3.

Table 3a Reduced wind speed for large amplitude instabilities

Fascia beam	Angle	Damping	Parapet P1a	P1b	P1d	P2a	P2b	P2d	P3a	P3b	P3d	P4d
Model M3 (torsion) $\frac{V}{f_T b}$												
X	0°	.02				4.90	2.90		4.55	2.22		
		.04				5.22	3.13		4.72	2.80		
		.06				5.35	3.70		5.01	3.01		
Y	0°	.02				4.71	3.13		5.08	2.85		
		.04				4.92	3.48		5.34	3.37		
		.06				5.10	3.69		5.52	3.89		
Model M5 (torsion) $\frac{V}{f_T b}$												
X	0°	.02					3.28		3.82	2.86		
		.04					3.32		3.92	2.95		
		.06					3.42		3.96	3.03		
Y	0°	.02					3.54		4.30	3.18		
		.04					3.61		4.38	3.27		
		.06					3.68		4.43	3.43		

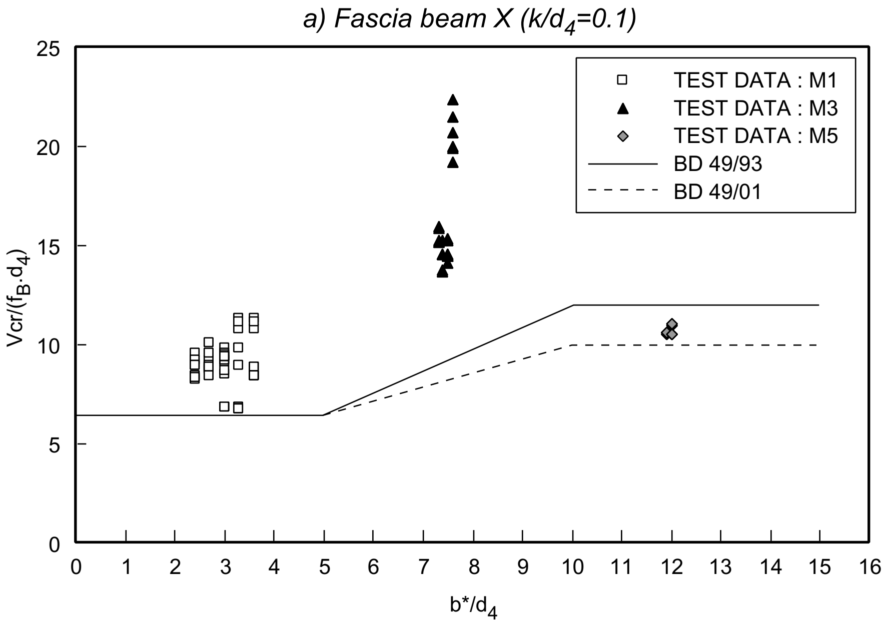
Model M1 (galloping (B)) $\frac{V}{f_B d_4}$ ***or (torsion (T))*** $\frac{V}{f_T b}$

Fascia beam	Angle	Damping	P1a T	P1b	P1d B	P1d T	P2b T	P2d B	P2d T	P3a	P3d	P4d
X	-5°	.02			–	3.15						
		.04			–	3.28						
		.06			–	3.51						
	0°	.02	3.80	3.42	22.5	3.49	3.39	22.1	4.06		21.2	21.0
		.04	4.04	3.66	23.4	3.79	3.65	22.8	4.44		21.8	21.8
		.06	4.40	3.88	23.7	4.11	4.22	23.5	5.00		22.5	22.0
	+5°	.02	3.69*		21.6							
		.04	3.78*		22.1							
		.06	4.03*		22.2							
Y	-5°	.02			–	3.39						
		.04			–	3.48						
		.06			–	4.03						
	0°	.02	3.79*	3.30	20.4		4.24	25.0			21.6	22.0
		.04	3.92*	3.66	–		4.38	26.0			22.3	22.4
		.06	4.15*	3.84	–		4.60	27.0			23.5	22.4
	+5°	.02			25.2							
		.04			25.7							
		.06			25.7							

**values at 0° with middle third solid*

Table 3b Reduced wind speed for large amplitude instabilities *(All tested at 0° inclination)*

Overhang L/d_4	*Parapet*	*Damping* δ_s	*Edge detail* ($^k/_{d4}$) *or type* 0.1(X)	0.3(Y)	0.4(Y)	0.5(Y)	U	U^1
Model M3 (torsion) $\left(\frac{V}{f_T b}\right)$								
1.0	2a	0.02		4.5	4.9	4.5	3.7	4.6
		0.04		4.7	5.2	4.8	3.9	4.9
		0.06		5.0	5.3	4.9	4.1	5.2
0.5	2a	0.02	4.0	3.5		3.7	3.8	3.7
		0.04	4.2	3.8		4.0	4.1	4.0
		0.06	4.5	4.0		4.2	4.3	4.2
	2b	0.02	2.9			3.2		
		0.04	3.5			3.6		
		0.06	3.8			3.8		
0.25	2a	0.02		3.7		3.6		3.0
		0.04		4.0		3.8		3.5
		0.06		4.2		4.0		3.8
	2b	0.02				3.2		
		0.04				3.8		
		0.06				4.1		
M1/M2 (galloping) $\left(\frac{V}{f_B d_4}\right)$								
0.5	2a	0.02				22.2		20.1
		0.04				22.5		21.0
		0.06				23.1		22.0
	3a	0.02				23.0		21.9
		0.04				23.5		22.7
		0.06				24.0		24.3
0.25	2a	0.02				17.5		14.9
		0.04				17.6		15.1
		0.06				17.8		15.2
	3b	0.02		18.8		18.4		
		0.04		61.5		58.5		
		0.06		75.7		69.7		



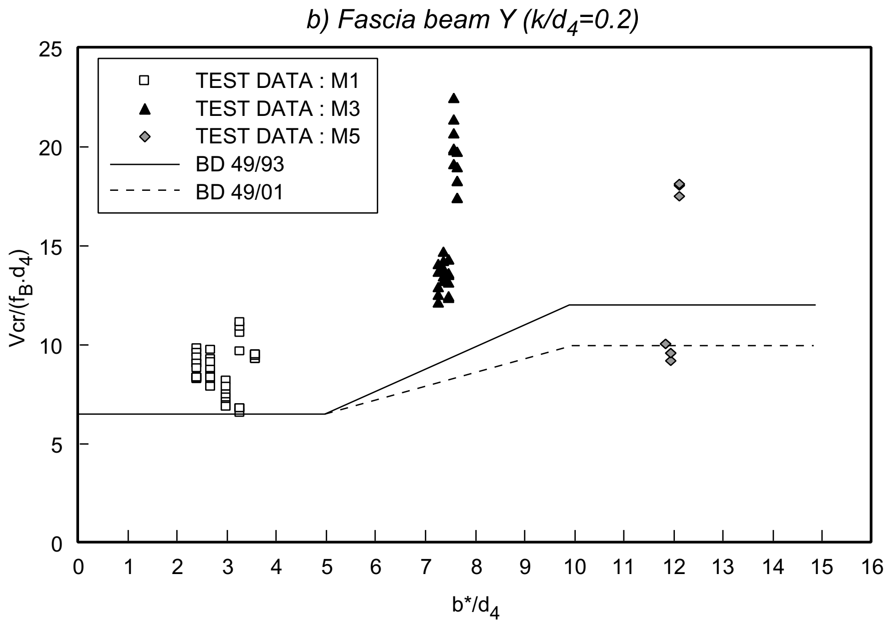


Figure 17 Critical wind speeds for vortex excitation (bending)

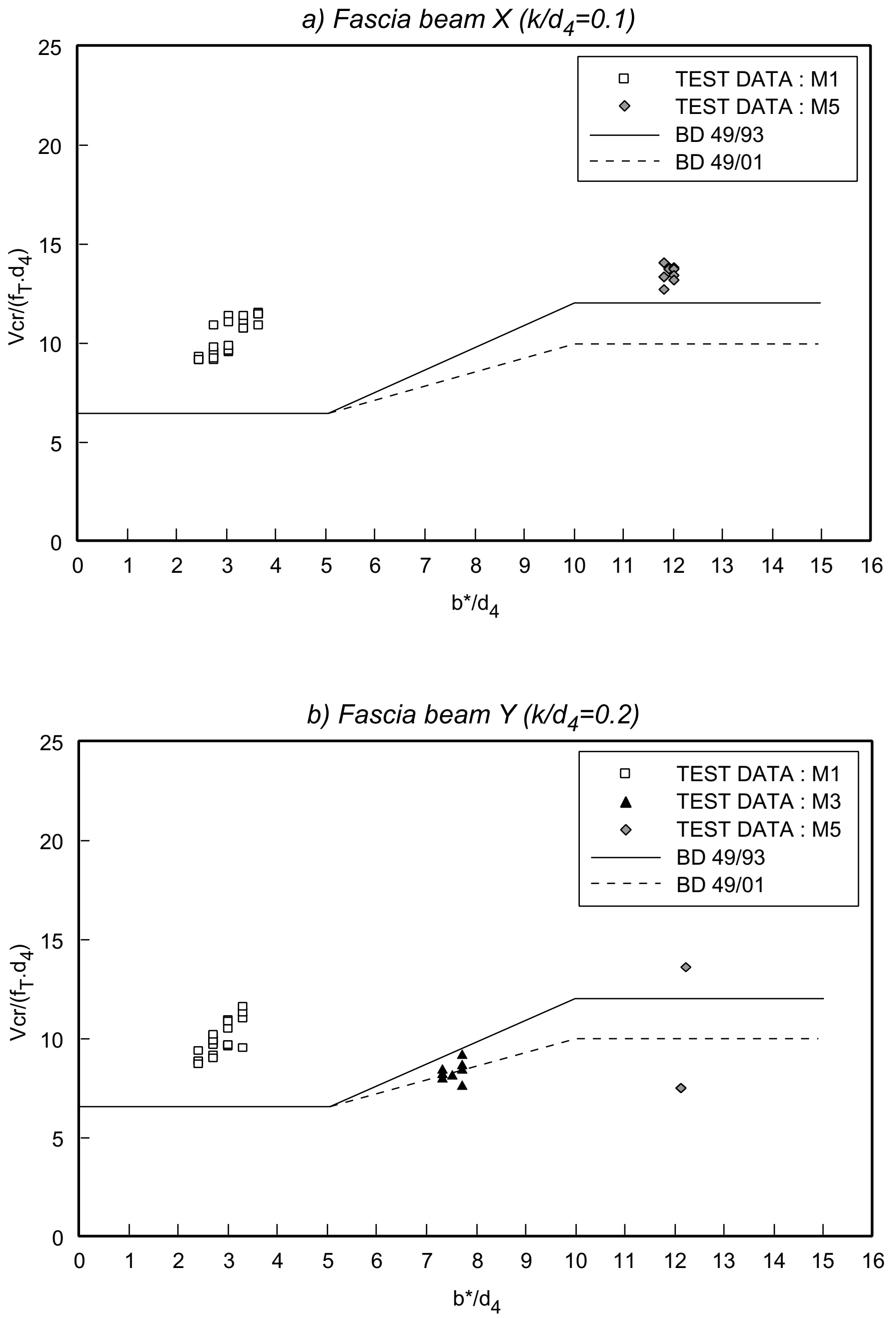


Figure 18 Critical wind speeds for vortex excitation (torsion)

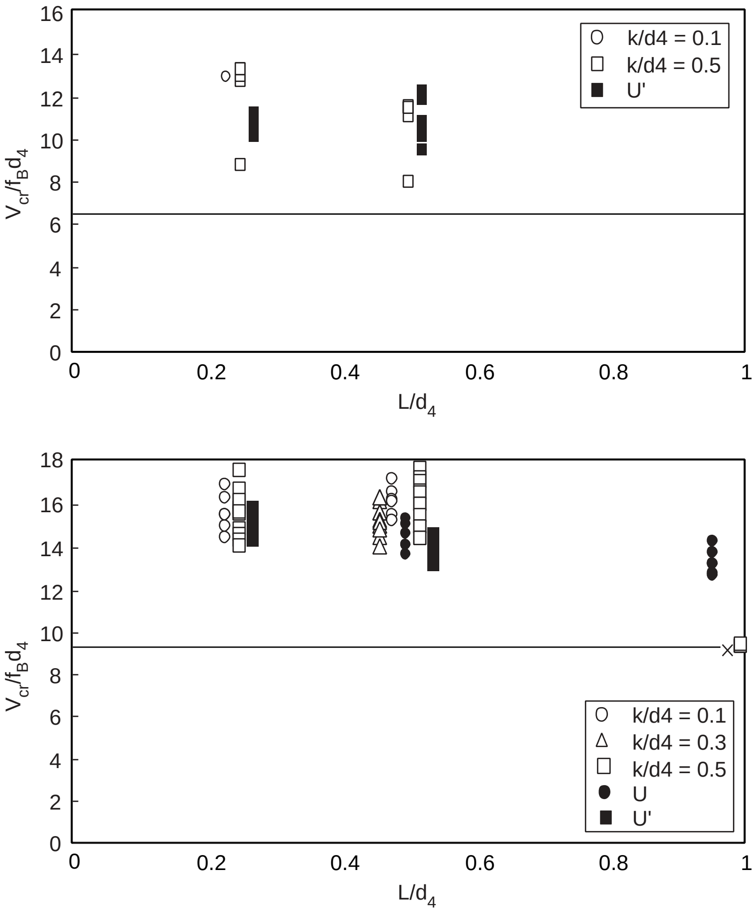


Figure 19 Critical wind speeds (bending)

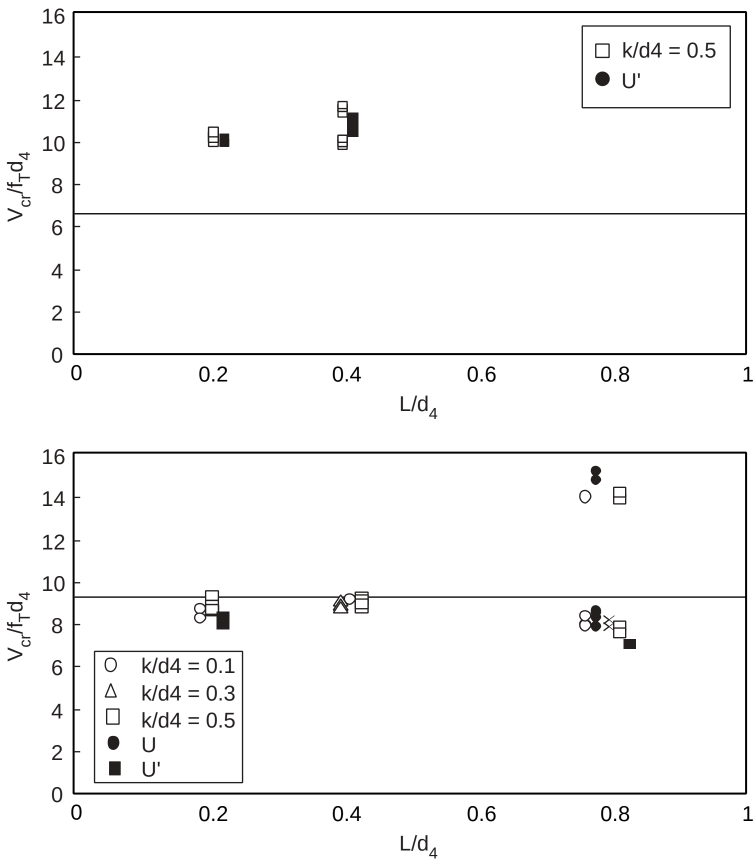


Figure 20 Critical wind speeds (torsion)

These results suggest therefore that it may be prudent to decrease the prediction of critical wind speed, V_{cr}, in bending and torsion for higher b^*/d_4 ratios for plate girders using:

$$V_{cr} = 6.5fd_4 \text{ for } b^*/d_4 < 5$$
$$V_{cr} = fd_4 (0.7\, b^*/d_4 + 3.0) \text{ for } 5 \leq b^*/d_4 < 10$$
$$V_{cr} = 10fd_4 \text{ for } b^*/d_4 \geq 10$$

These revised values are shown on Figures 19 and 20.

6.3 Vortex excitation - amplitudes

6.3.1 Bending

The vertical bending amplitudes for each model are shown in Figure 21a for fascia beam X and Figure 21b for fascia beam Y, plotted against the logarithmic decrement of damping. The relevant curves from the design rules, appropriate to each model are also plotted.

From these figures it can be seen that the amplitudes from many tests exceeded the predicted amplitudes, particularly at the higher levels of damping. However these plots show the results for all tests whereas many of the configurations do not comply with the restraints set out in the current Rules for edge geometry, and only within which the simplified formulae for amplitudes in the Rules apply.

By omitting all those configurations that do not conform to these restraints, the Rules can be seen to apply more satisfactorily, as shown in Figures 22a and 22b. Only the model with parapet heights of 0.7 times the depth and low solidity exceed the design curve at damping values greater than 0.03.

Figure 23 shows the ratio of measured amplitudes to predicted amplitudes for models M1 and M3 normalised to 1.0 at $\delta = 0.03$. This indicates the trend of the test results to increase more rapidly than the accepted linear factor against damping, as incorporated in the Rules.

Comparisons have been made with the earlier tests carried out at BMT (formerly NMI) on box girder bridges which formed the basis of the Rules. These showed that the Rules generally predicted amplitudes between about 100% and 300% of the measured values for those configurations meeting the geometric criteria of the Rules. Typical results, in the form provided for the plate girder results in Appendix B, are given for three models tested in Appendix C.

6.3.2 Torsion

Torsional amplitudes for all test configurations are shown in Figure 24a for fascia beam X and Figure 24b for fascia beam Y. Once again several results are above the curve from the design rules. However when those configurations which do not meet the criteria for edge geometry to the Rules are omitted, as shown in Figures 25a and 25b, then it can be seen that the Rules provide very conservative values of torsional amplitudes. Note that only models M1 and M3 complied with the restraints, and for fascia beam X all the results showed stable behaviour.

6.4 Large amplitude instabilities

The Rules stipulate that plate girder bridges need not be considered for vertical galloping, the instability only being considered appropriate for box girder sections of relatively narrow aspect ratio ($b^*/d < 4$). However the tests showed that vertical bending instability did occur for all configurations of model M1 with solid parapets as shown in Figure 26a for fascia beam X and Figure 26b for fascia beam Y.

The Rules, when applied, assume that the critical wind speed increases with structural damping, but this was not reflected in the test results, as can be seen from these figures. However these models, with solid barriers, would not conform with the geometric criteria of the Rules, so from the point of view of design this is irrelevant. Nevertheless this needs consideration and possibly further study to explain this apparently unexpected result.

Torsional motion was detected in all three models, the results for which are shown in Figures 27a and 27b, for fascia beams X and Y respectively. It can be seen that the Rules overestimate the critical wind speed, which would be non-conservative. However again the edge geometry for many of the test configurations, including that for all of model M5 sections, does not comply with the criteria in the Rules for which the formulation for critical wind speed applies. Figures 28a and 28b give the results for those configurations which do comply from which it can be seen that whereas the results for model M3 are close to the Rules, those for model M1 are significantly below the Rule.

The Rules provide more onerous criteria for box girder sections - particularly for relatively shallow configurations. For model M1, if treated as a box girder, this would produce a non-dimensional critical wind speed $Vg/f_T b$ of 2.6, thereby providing a lower bound to the measured wind speeds. However if applied to models M3 and M5, the values would be 1.3 and 0.9 thus providing very pessimistic estimates of critical wind speed.

In practice the Rules require the designer to undertake a calculation to predict the critical wind speed for classical flutter for all bridge types (Clause 2.1.3.3).

The lower bound non-dimensional wind speed from this calculation is 2.5, so it is possible that the use of the non-conservative clause for the single degree of freedom instability in torsion would be prevented by the value from Clause 2.1.3.3. However, Clause 2.1.3.2(b) should be altered to allow for plate girder bridges, with the value of non-dimensional wind speed obtained from Clause 2.1.3.3 only being used if it is the lower of the two.

7 Amendments to the rules

7.1 Vortex excitation - critical wind speeds

For the plate girder bridge models tested, the critical wind speeds did not follow the trends of the Rules, although for model M1 the Rules provided an excellent lower bound to the results for bending and a reasonable lower bound for torsion. For model M3 the Rules were conservative for bending but marginally non-conservative for torsion. For model M5 they provided over-estimates (that is non-conservative values), compared with the tests, for certain configurations in bending.

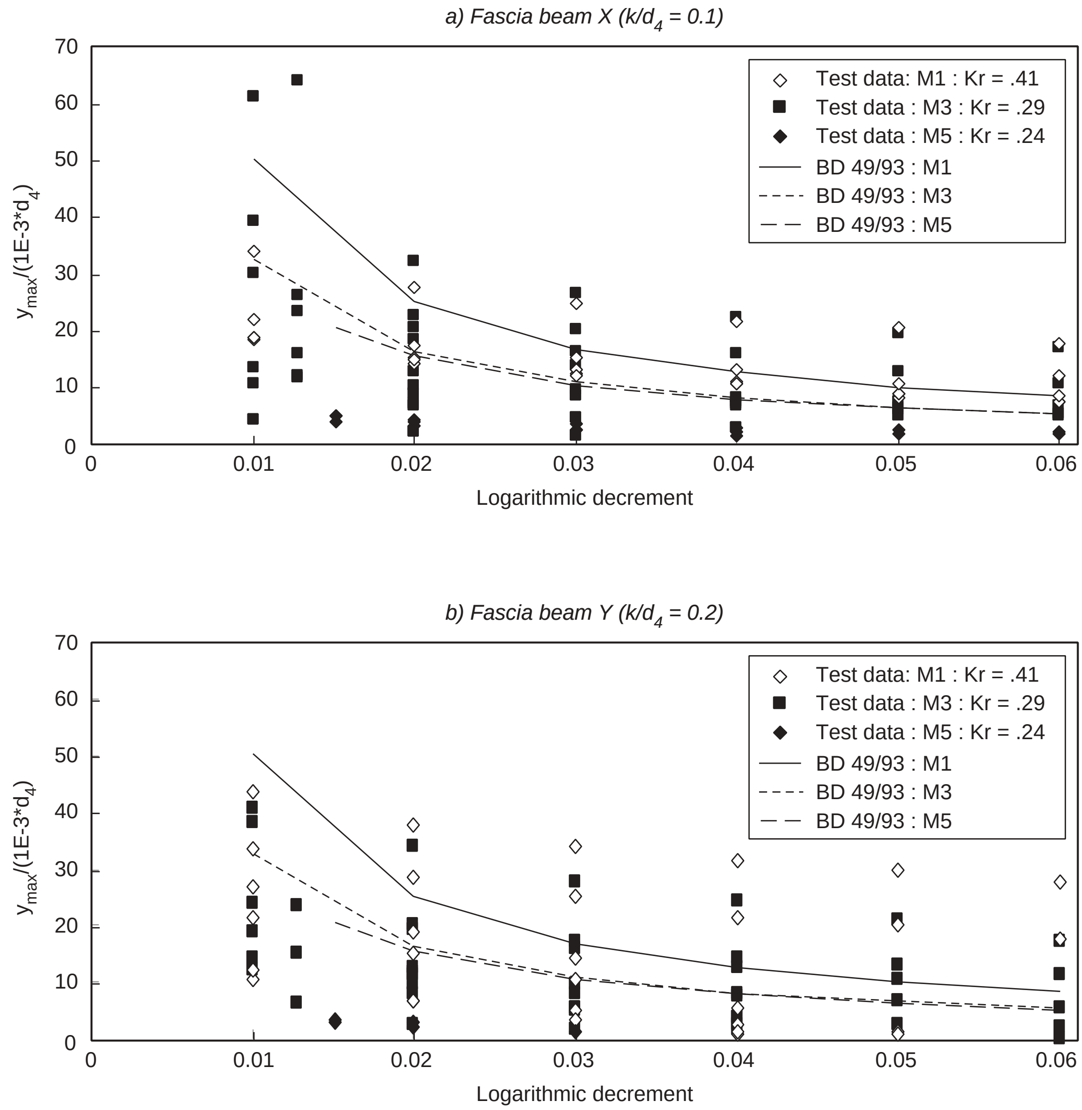


Figure 21 Amplitudes for vortex excitation (bending)

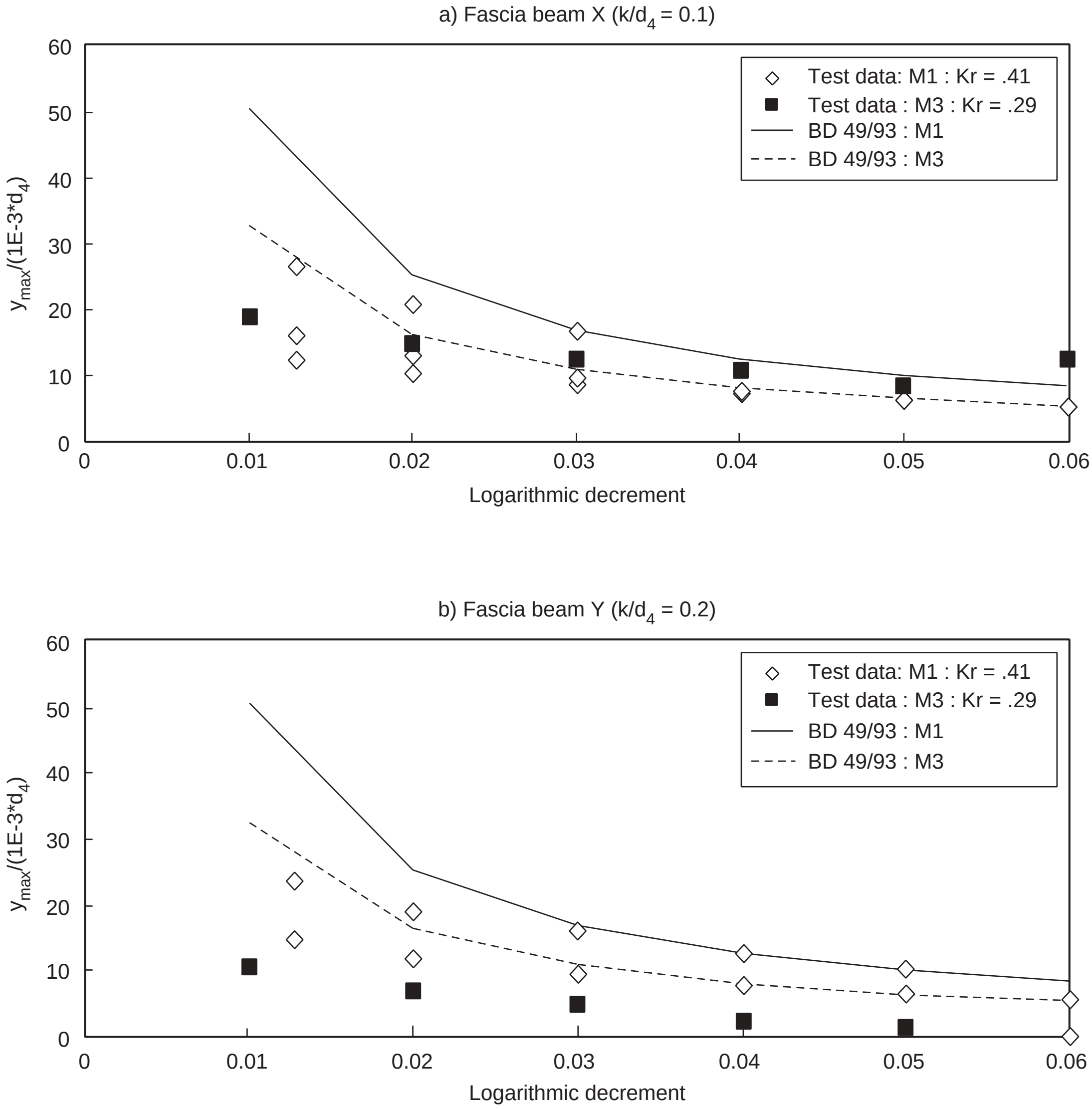


Figure 22 Amplitudes for vortex excitation (bending) – selected results

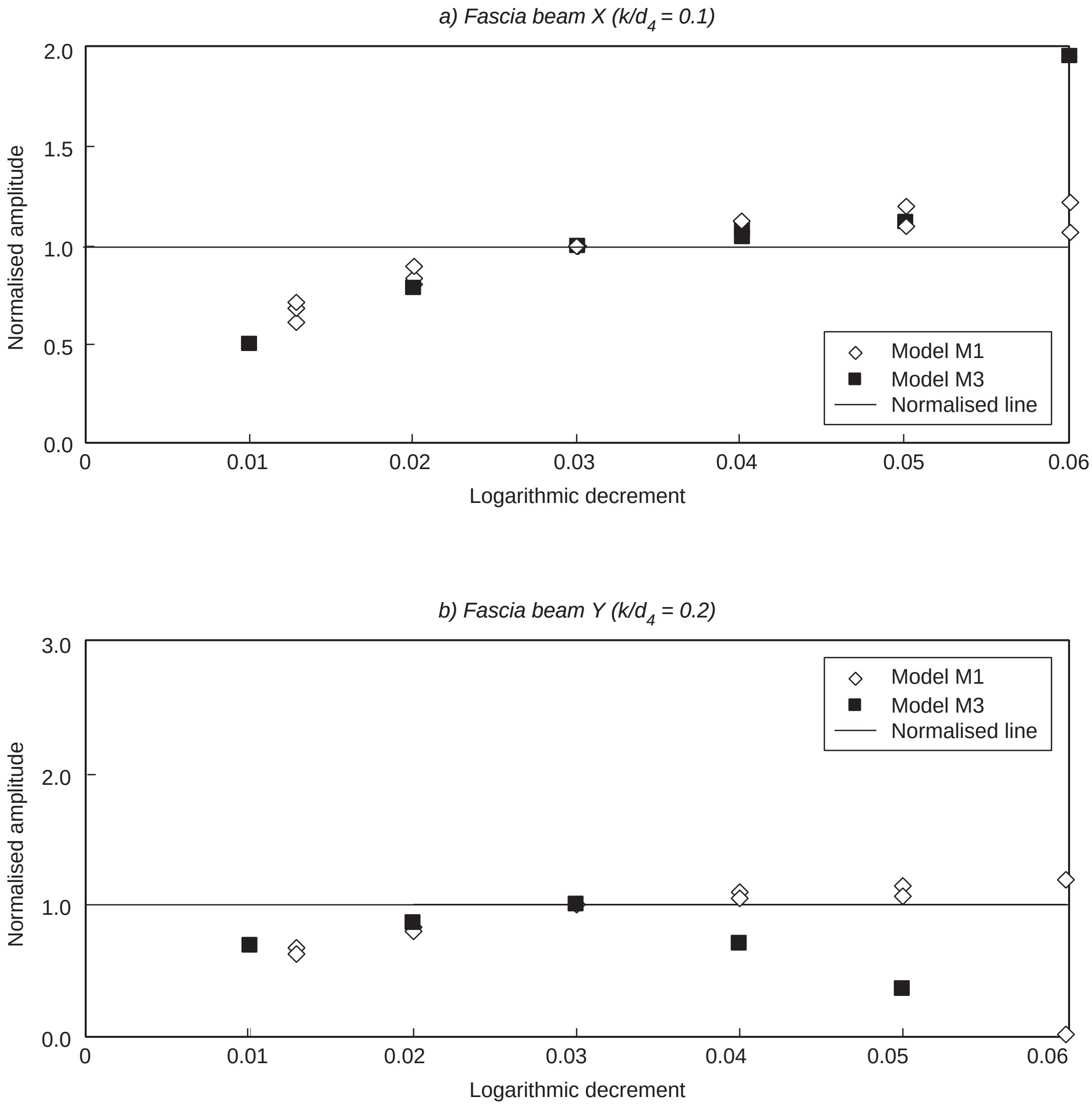


Figure 23 Ratio of test model to code amplitudes for vortex excitation (bending)

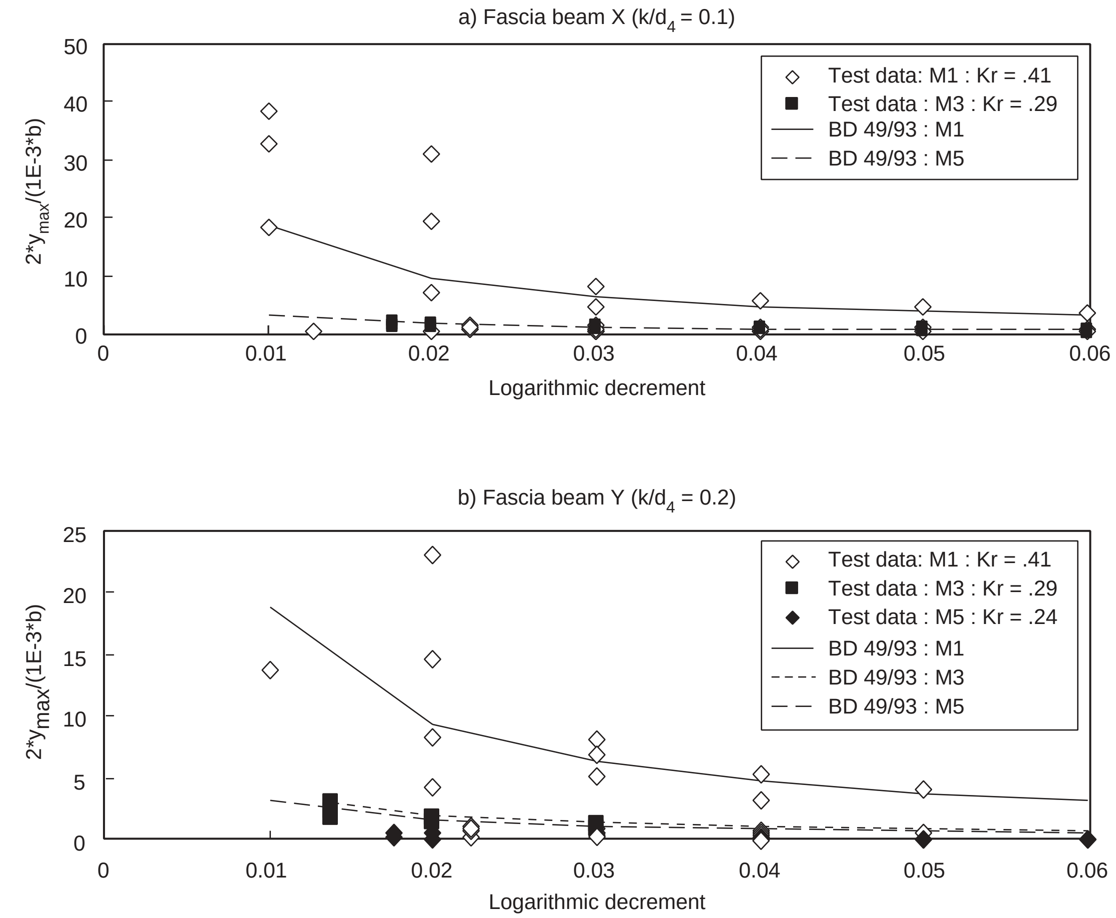


Figure 24 Amplitudes for vortex excitation (torsion)

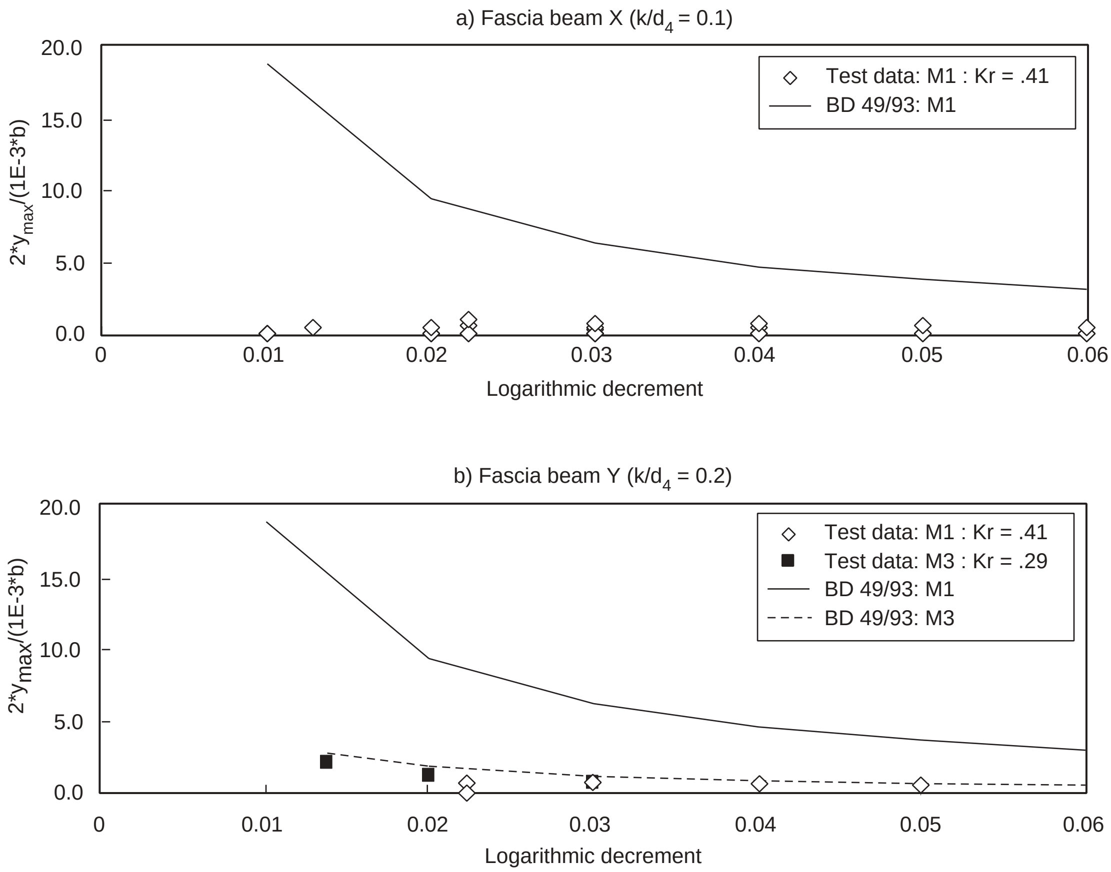
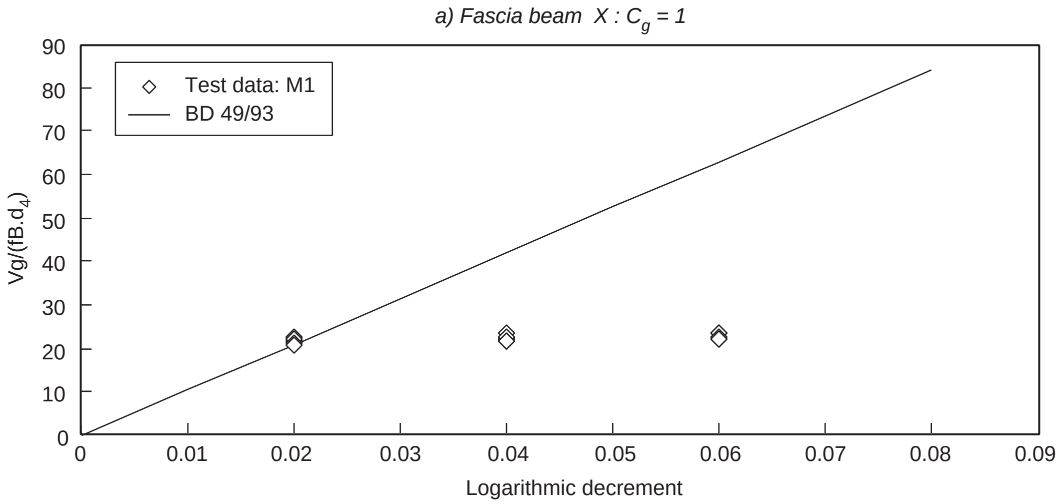


Figure 25 Amplitudes for vortex excitation (torsion)



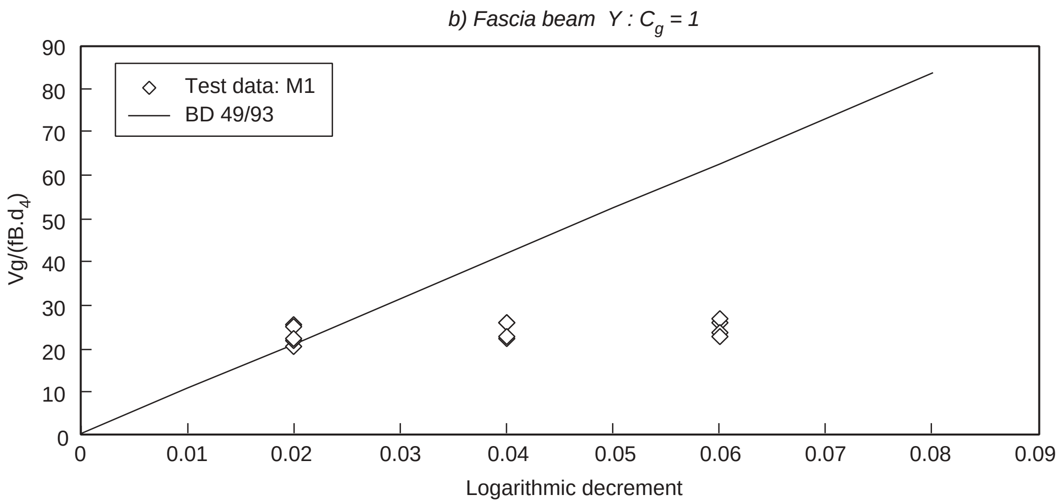
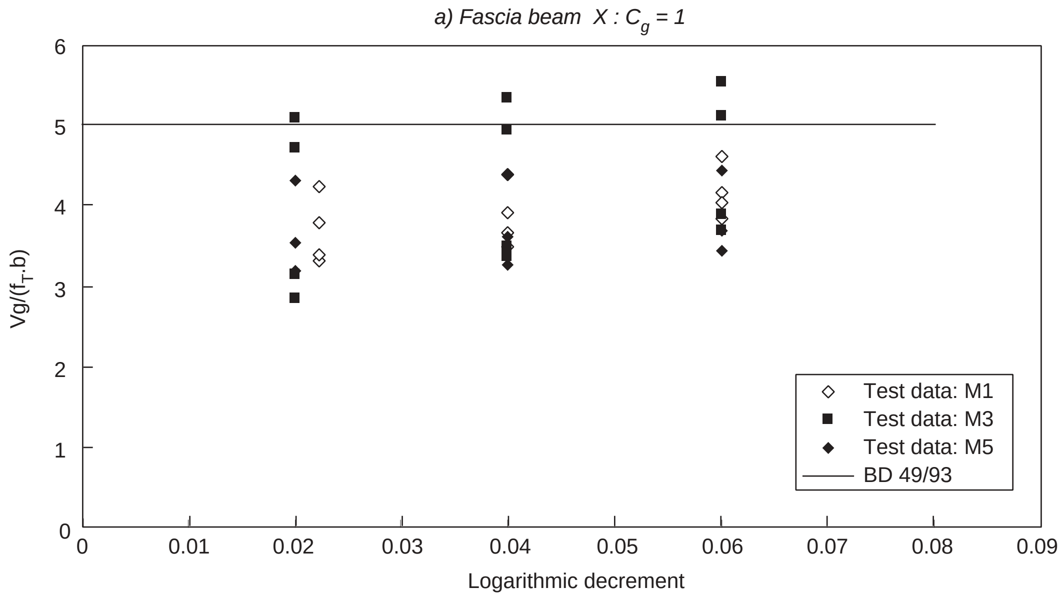


Figure 26 Critical wind speeds for divergent amplitude (bending)



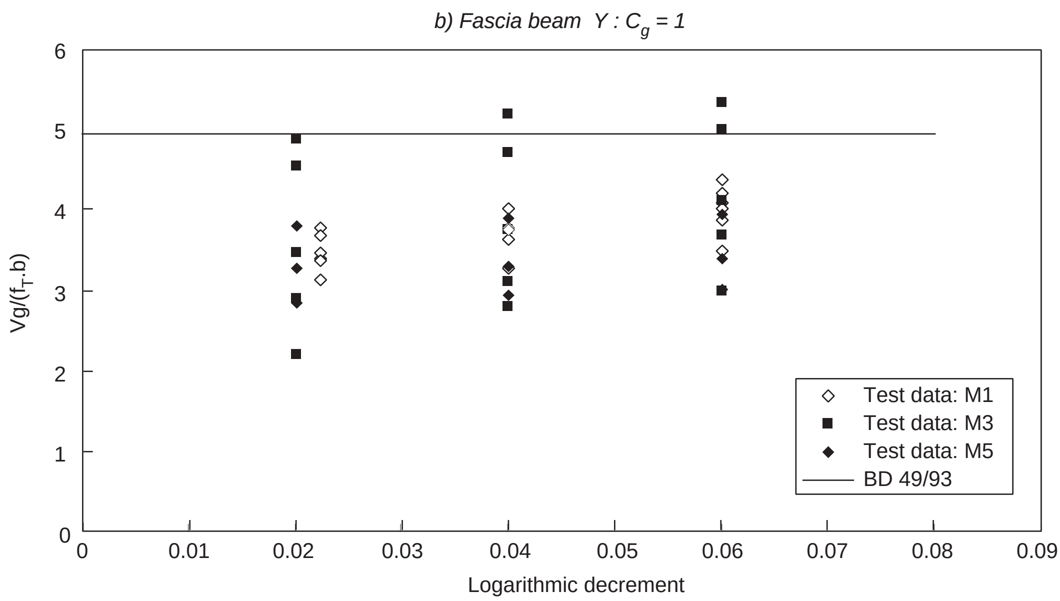
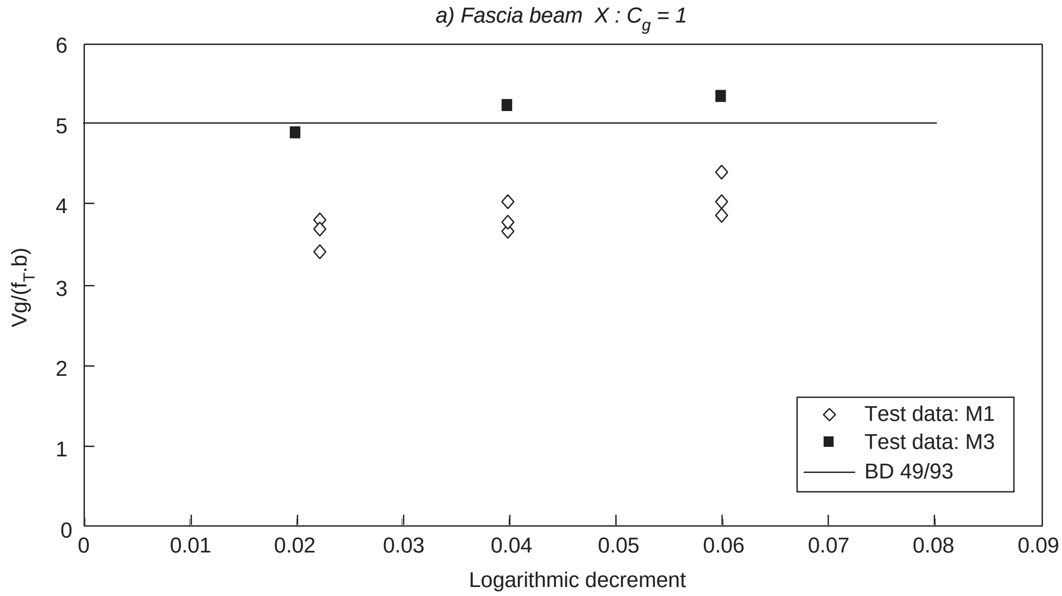


Figure 27 Critical wind speeds for divergent amplitude (torsion)



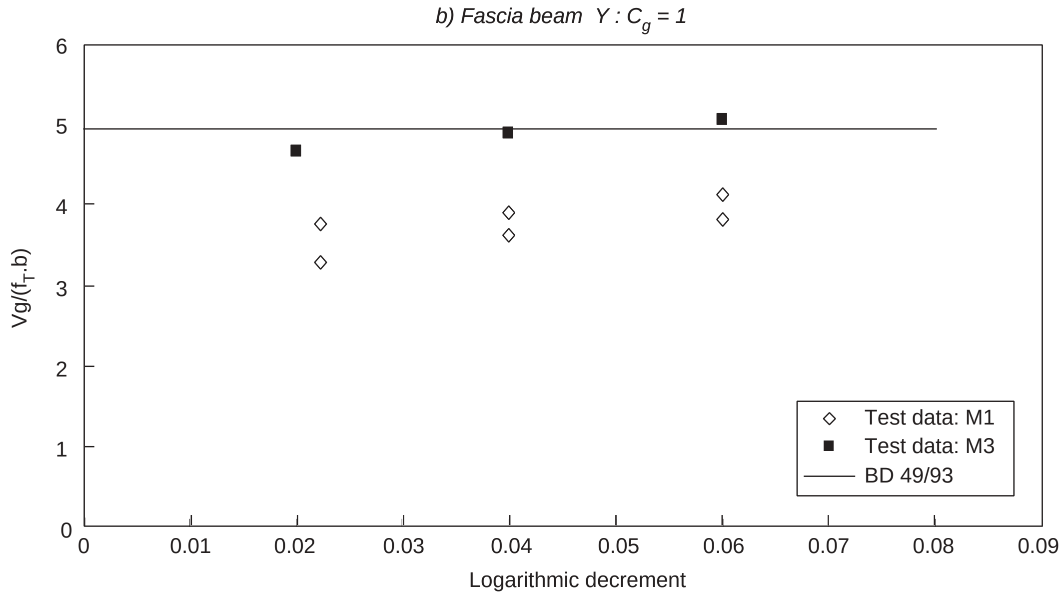


Figure 28 Critical wind speeds for divergent amplitude (torsion)

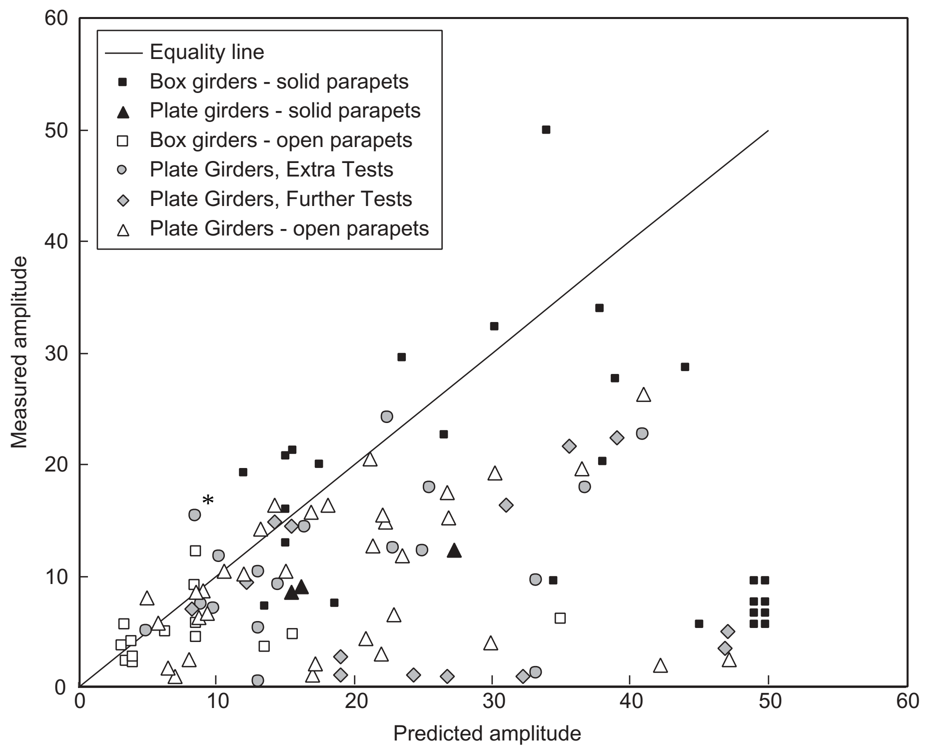


Figure 29 Use of c factor for bending

For torsion one configuration of model M5 provided results below the design Rule prediction, but this appeared to be associated with a sub-harmonic vortex shedding mechanism. The amplitudes associated with this were very small (below the primary results obtained) and it is considered that, for codification purposes, this particular result could be ignored.

Accordingly, for plate girder bridges, the Rule for critical wind speeds is modified to:

V_{cr} = 6.5 fd_4 for $b^*/d_4 < 5$

V_{cr} = fd_4 (0.7 b^*/d_4 + 3.0) for $5 \leq b^*/d_4 < 10$

V_{cr} = $10fd_4$ for $b^*/d_4 \geq 10$

In general terms, the equations for V_{cr} in clause 2.1.1.2 may be written as:

For $b^*/d_4 < 5$:

V_{cr} = $6.5fd_4$

For $5 \leq b^*/d_4 < 10$:

V_{cr} = fd_4 (1.1 b^*/d_4 + 1.0) for box girder bridges (types 1, 1A, 3, 3A, 4, 4A)

= fd_4 (0.7 b^*/d_4 + 3.0) for plate girder bridges (types 2, 5 and 6)

For $10 \leq b^*/d_4$:

V_{cr} = $12fd_4$ for box girder bridges

= $10fd_4$ for plate girder bridges

7.2 Vortex excitation - amplitudes

The test results showed that the Rules provide upper bound predictions of amplitude for configurations whose edge deck geometry complies with the restraints of the present Rules. However it was not feasible to relax these restraints as large amplitudes were recorded for several of such configurations, although no consistent pattern emerged.

The only possible relaxation for plate girders was to increase the limit of the product hϕ in Clause 2.1.3.2(a)(ii) from $0.25d_4$ as at present to $0.35d_4$. This relaxation would only apply to plate girders, but may be of value, particularly for shallow bridge sections.

Whilst undertaking the study it was pointed out that the restriction of edge beams to be less than $0.2d_4$ deep (Clause 2.1.3.2(a)(i)) was leading to anomalies in design where, for example a 300mm deep slab on a 1m deep section was acceptable provided there was no upstand at the edge. However if the slab was thickened at the edge, to say 320mm, then the design would not meet this criteria, having to be treated as an ‘edge beam’. It is proposed that for the purposes of defining such members, edge stiffening of the slab to, say, half the slab depth could be ignored.

The amplitudes in the current Rules need to be factored by 3.0 for beams without overhangs but no guidance is given concerning the minimum overhang which would qualify to escape this threefold multiplication of the response. For galloping behaviour the threshold for more severe behaviour was set when the overhang is less than 0.7d and the results of the tests were used to assess whether this limitation should be adopted for vortex excitation. The results of the tests with varying overhang and fascia beam depths which showed the variation of amplitude with ‘effective depth’, as noted in Section 6.1 above however, led to the consideration of a modification of the Rules which would incorporate both this parameter, and the above factor of 3.0.

The result of this study is that a factor on the predicted amplitudes could be adopted for *all* sections of:

$$c = 3\left[\frac{k}{d_4} + \frac{h_\phi}{d_4}\right] \text{ but not less than 1.0}$$

where k = depth of fascia beam, or edge slab;
d_4 = reference depth of the bridge;
h = height of parapet or other edge member above normal deck level;
ϕ = solidity ratio of parapet;

all as defined in Figures 2 and 3, with h, k and d_4 in consistent units.

This would eliminate the necessity of the factor 3.0 and would allow dense, and even solid, barriers to come within the scope of the Rules. However as the tests did not comprehensively cover wind inclinations of up to ±5°, which on previous studies had been shown to be critical, it is proposed that solid barriers are still excluded for the present.

The validity of this proposal is shown in Figure 29, for bending and Figure 30 for torsion for *all* tests undertaken on both box girder and plate girder bridges; the results are given for the range of damping, considered appropriate for steel or composite structures.

In Figure 29 the measured amplitude is plotted against the predicted amplitude incorporating the factor c. The rule is satisfied for all tests which lie below the 45° line shown on the graph. It can be seen that the rule is thus generally satisfied with outliers being either sections with solid parapets (which are not covered by the Rules) or where the factor c being not less than 1 would ensure the rule was satisfied.

An exception to this is the test on plate girder model M3 noted in 6.1 above and asterisked on the figure. This result was carefully re-examined, but appears to have been correctly tabulated. The high value may possibly be due to coupled motion between bending and torsion. Figure 30 shows the equivalent figure for torsion.

Figure 31 shows the results for both bending and torsion plotted non-dimensionally as the ratio of the maximum measured value to the predicted value by the current rule for the damping range δ = 0.02 to 0.05, against factor c. Here it can be seen that the use of the factor provides a good envelope to the majority of the results, but again highlighting the same test (denoted with an asterisk) as an outlier.

The proposed factor c for the configurations tested is shown in Table 4 from which it can be seen that a factor less than unity would be obtained for five configurations if a lower limit were not used. The lower value was 0.5, which still appeared to provide a satisfactory factor. Without testing values with a lower factor it is proposed to use this as a lower bound. In addition the factor is greater than 3 for several of the configurations in such cases specific tests could provide more beneficial results as the proposed rule becomes more penal.

What was significant was that the torsional amplitudes for configurations which comply with the Rules were almost negligible and it is suggested that torsional response due to vortex shedding for such plate girder bridges could be ignored.

The tabulated results from the series of tests can be used for design profiles that closely match a tested configuration, thereby avoiding the use of over-conservative design rules contained in BD 49.

7.3 General

The wind tunnel test results for bending using solid parapets resulted in critical wind speeds for divergence which were, surprisingly, independent of damping. At the lowest value of damping d = 0.02 the Rules provided a good estimate of the critical speed. However at higher values of damping the Rules predicted higher critical wind speeds (in inverse proportion to the damping). The Rules however, as written, do not require a check for plate girders in vertical bending divergence, and galloping

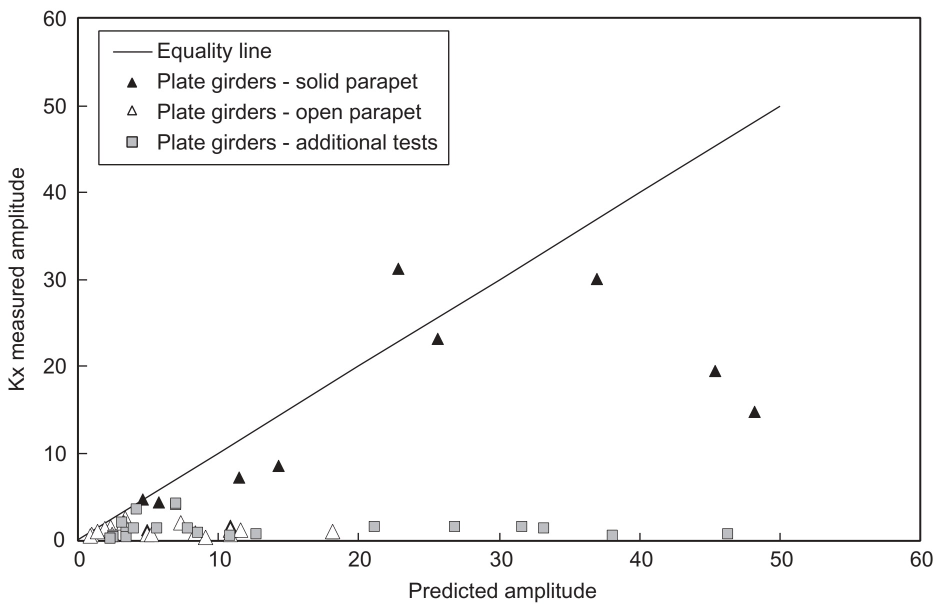


Figure 30 Use of c factor for torsion

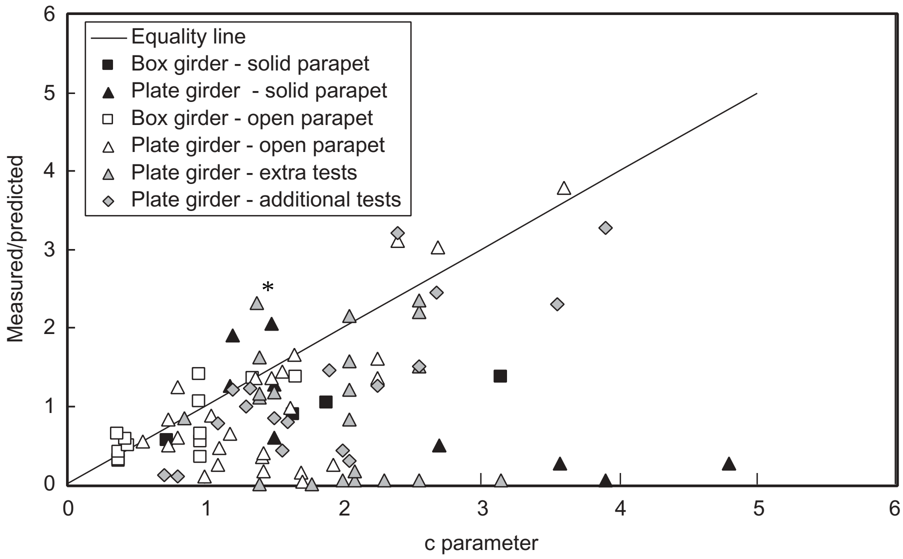


Figure 31 Non-dimensional plot of c factor

Table 4 Proposed factor *c* for various configurations of edge details and barriers

				k/d_4 [see Figure 3]				
	Barrier solidity	*Parapet P-type*	$h\phi/d_4$	*0.1 or 'X'*	*0.2 or 'Y'*	*U - type or 0.3 Y type*	*0.4 Y type*	*U' - type or 0.5 Y type*
Any overall width of bridge	'Open' barriers $\phi \leq {}^1/_2$	1a	0.075	0.525	0.825	1.125	1.425	1.725
		1b	0.150	0.750	1.050	1.350	1.650	1.950
		2a	0.175	0.825	1.125	1.425	1.725	2.025
		2b	0.350	1.350	1.650	1.950	2.250	2.550
		3a	0.275	1.125	1.425	1.725	2.025	2.325
		3b	0.550	1.950	2.250	2.550	2.850	3.150
		4a	0.375	1.425	1.725	2.025	2.325	2.625
		4b	0.750	2.550	2.850	3.150	3.450	3.750
Any overall width of bridge	'Dense' barriers $\phi > {}^1/_2$	1c	0.225	0.975	1.275	1.575	1.875	2.175
		1d	0.300	1.200	1.500	1.800	2.100	2.400
		2c	0.525	1.875	2.175	2.475	2.775	3.075
		2d	0.700	2.400	2.700	3.000	3.300	3.600
		3c	0.825	2.775	3.075	3.375	3.675	3.975
		3d	1.100	3.600	3.900	4.200	4.500	4.800
		4c	1.125	3.675	3.975	4.275	4.575	4.875
		4d	1.500	4.800	5.100	5.400	5.700	6.000
See Figure 1		See Figure 2				Values of *c* factor		

$h\phi/d_4$ may be taken as $h\phi/d_4 + a\phi_b/b_4$ in cases where there are barriers of height a as well as parapets of height h.

[shaded] Shows where factor is > 3.0 , where tests may be more appropriate, and may reap appreciable benefits when the factors are high. Note: the majority of these are with 'dense' barriers, which should be less common in practice.

(particularly for the wider sections) seems unlikely. In any event these results were with solid parapets and are therefore outside the scope of the Rules. It is not believed at this stage that modifications to the Rules can be justified on the basis of these tests, but that further study of the mechanism causing this divergence is recommended.

For torsion the Rules tend to provide a non-conservative prediction of the critical wind speed. Whilst it is likely that this is being partly catered for by the need to calculate the wind speed for classical flutter (as detailed in Section 7.4), Clause 2.3.1.2(b) has been modified as follows:

$V_g = 3.3\ f_T b$, for plate girder bridges

$V_g = 5.0\ f_T b$, for all other bridges

8 Conclusions

The wind tunnel tests described have provided, for the first time, a parametric study of the aerodynamic behaviour of plate girder bridges. Additional tests were undertaken on plate girder bridges with relatively short overhangs and edge details conforming more closely to typical highway bridges and footbridges. The results of the wind tunnel tests, whilst limited in scope from the complete matrix of tests for the models envisaged, have confirmed the general trend of the Rules and provided added confidence in their wider use to plate girder bridges. However there have been unexpected results and inconsistencies, making sound general design guidance extremely difficult.

Whereas it was hoped that some relaxation of the Rules could be produced for plate girder bridges, this has generally not been the case, apart from torsional vibrations due to vortex shedding which it is proposed could be ignored.

As a result of these tests, modified rules have been developed for the prediction of vortex excited amplitudes which provide better agreement with test results. These modified rules have now been incorporated into the revised version of BD 49 (Highways Agency 2001).

It should be noted however that this form of response is very sensitive to small changes in edge details, making codified rules very conservative in many cases. The BD 49 clauses provide reasonable rules which the majority of sections will satisfy. However, it must be recognised that a few sections which satisfy the rules may subsequently show some signs of response in service.

The study has shown the inconsistent patterns that can be obtained due to small changes in leading edge detail. Whilst some 61 different configurations were tested, this covered a wide range of parameters and frequently trends had to be predicted from only two tests on the variation of one of those parameters.

The matrix of tests undertaken as reported here provides a valuable set of data, which can be used in those cases where the design closely matches one of the tested configurations. This permits a much less conservative analysis to be used.

9 References

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Appendix A: Wind tunnel test results

Definition of Terms

B – Overall width of model (b in rules)

d_4 – Depth of girder (including deck slab)

M – Mass/m of model set-up (m in rules)

I – Mass moment of inertia/m of model set-up (equivalent to mr^2 in rules)

U – Mean wind speed at model location (V in rules)

n_z – Natural frequency in bending (f_B in rules)

n_θ – Natural frequency in torsion (f_T in rules)

z – Maximum rms deflection due to vortex shedding (y_{max} in rules)

θ – Maximum rms rotation due to vortex shedding (expressed in terms of y_{max} in rules)

δ – Logarithmic decrement of structural damping (δ_s in rules)

ρ – Density of air

Model M1, B = 225mm, Edge Detail X, d_4 = 50mm, Parapet P1b, Angle 0°

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.0128	0.582	8.83	0.0644
0.02	0.909	8.87	0.0502
0.03	1.363	8.42	0.0402

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	θ(°)
0.0223	0.119	9.55	0.087
0.03	0.160	9.81	0.061
0.04	0.214	9.28	0.057

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.0223	0.119	3.42
0.04	0.214	3.66
0.06	0.320	3.88

Model M1, B = 225mm, Edge Detail X, d_4 = 50mm, Parapet P1a, Angle 0°

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.0128	0.582	8.28	0.0296
0.02	0.909	8.33	0.0248
0.03	1.363	8.39	0.0206
0.04	1.818	8.39	0.0170
0.05	2.272	8.36	0.0148
0.06	2.726	8.31	0.0126

Vortex Shedding in Torsion

Stable

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.0223	0.119	3.80
0.04	0.214	4.04
0.06	0.320	4.40

Model M1, B = 225mm, Edge Detail X, d_4 = 50mm Parapet P2b, Angle 0°

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.518	10.80	0.0106
0.02	1.035	11.32	0.0048
0.03	1.553	11.14	0.0038

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	$\theta(°)$
0.0223	0.119	11.17	0.078
0.03	0.160	11.40	0.041

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.0223	0.119	3.39
0.04	0.214	3.65
0.06	0.320	4.22

Model M1, Angle 0° Edge Detail X, B = 225mm, Parapet P1a (middle third solid) d_4 = 50mm

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.0128	0.582	8.83	0.0388
0.02	0.909	8.90	0.0310
0.03	1.363	8.43	0.0232
0.04	1.818	8.46	0.0184
0.05	2.272	8.46	0.0152
0.06	2.726	8.45	0.0124

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	$\theta(°)$
0.0223	0.119	10.94	0.140
0.03	0.160	11.52	0.105
0.04	0.214	11.51	0.089
0.05	0.267	11.51	0.070
0.06	0.320	11.49	0.061

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.0223	0.119	3.69
0.04	0.214	3.78
0.06	0.320	4.03

Model M1, B = 225mm, Edge Detail X, d_4 = 50mm Parapet P1d, Angle 0°

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.518	10.08	0.0740
0.02	1.035	9.23	0.0554
0.03	1.553	9.53	0.0494
0.04	2.071	8.98	0.0392
0.05	2.589	8.74	0.0312
0.06	3.107	8.75	0.0264

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	θ(°)
0.01	0.069	10.92	2.540
0.02	0.137	9.50	0.986
0.03	0.206	9.20	0.637

Divergent Instability

Galloping (Bending)

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$
0.02	1.035	22.5
0.04	2.071	23.4
0.06	3.107	23.7

Model M1, B = 225mm, Edge Detail X, d_4 = 50mm Parapet P1d, Angle -5°

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.0128	0.582	9.18	0.0288
0.02	0.909	9.18	0.0220
0.03	1.363	9.41	0.0212
0.04	1.818	9.39	0.0198
0.05	2.272	9.42	0.0180
0.06	2.726	9.39	0.0166

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	θ(°)
0.0223	0.119	9.62	0.215
0.03	0.160	9.61	0.194
0.04	0.214	9.62	0.165
0.05	0.267	9.63	0.137
0.06	0.320	9.90	0.122

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.0223	0.119	3.15
0.04	0.214	3.28
0.06	0.320	3.51

Model M1, B = 225mm, Edge Detail X, d_4 = 50mm Parapet P1d, Angle +5°

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.518	9.01	0.0964
0.02	1.035	9.52	0.0788
0.03	1.553	9.24	0.0646
0.04	2.071	9.23	0.0542
0.05	2.589	8.98	0.0474
0.06	3.107	8.98	0.0416

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	$\theta(°)$
0.03	0.206	9.32	1.147
0.04	0.274	9.20	0.808
0.05	0.343	9.19	0.635
0.06	0.412	9.18	0.499

Divergent Instability

Galloping (Bending)

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$
0.02	1.035	21.6
0.04	2.071	22.1
0.06	3.107	22.2

Model M1, B = 225mm, Edge Detail X, d_4 = 50mm Parapet P2d, Angle 0°

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.518	9.79	0.1498

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	$\theta(°)$
0.02	0.137	11.42	4.350

Divergent Instability

Galloping (Bending)

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$
0.02	1.035	22.1
0.04	2.071	22.8
0.06	3.107	23.5

Model M1, B = 225mm, Edge Detail X, d_4 = 50mm Parapet P3d, Angle 0°

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.518	6.85	0.0330
0.02	1.035	6.85	0.0174
0.03	1.553	6.83	0.0114
0.04	2.071	6.80	0.0068

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	$\theta(°)$
0.015	0.103	11.09	5.360

Divergent Instability

Galloping (Bending)

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$
0.02	1.035	21.2
0.04	2.071	21.8
0.06	3.107	22.5

Model M1, B = 225mm, Edge Detail X, d_4 = 50mm Parapet P4d, Angle 0°

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.518	6.80	0.0262
0.02	1.035	6.78	0.0164
0.03	1.553	6.75	0.0112
0.04	2.071	6.78	0.0072

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	$\theta(°)$
0.015	0.103	10.75	4.551
0.02	0.137	10.75	2.709

Divergent Instability

Galloping (Bending)

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$
0.02	1.035	21.0
0.04	2.071	21.8
0.06	3.107	22.0

Model M1, Edge Detail X, Parapet P1d, Angle 0°
B = 225mm, d_4 = 50mm

In Turbulent Flow

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.0128	0.582	9.58	0.0570
0.02	0.909	9.46	0.0452
0.03	1.363	9.13	0.0342
0.04	1.818	8.49	0.0164
0.05	2.272	8.67	0.0122

Vortex Shedding in Torsion

Stable

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.0223	0.119	3.49
0.04	0.214	3.79
0.06	0.320	4.11

Model M1, Edge Detail X, Parapet P2d, Angle 0°
B = 225mm, d_4 = 50mm

In Turbulent Flow

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.0128	0.582	8.99	0.1572

Vortex Shedding in Torsion

Stable

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.0223	0.119	4.06
0.04	0.214	4.44
0.06	0.320	5.00

Model M1, B = 225mm, Edge Detail Y, d_4 = 50mm, Parapet P1a, Angle 0°

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.0128	0.582	8.28	0.0364
0.02	0.909	8.33	0.0290
0.03	1.363	8.23	0.0232
0.04	1.818	8.33	0.0190
0.05	2.272	8.35	0.0160
0.06	2.726	8.35	0.0138

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	θ(°)
0.0223	0.119	9.35	0.022

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.0223	0.119	3.79
0.04	0.214	3.92
0.06	0.321	4.15

Model M1, B = 225mm, Edge Detail Y, d_4 = 50mm, Parapet P1b, Angle 0°

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.0128	0.582	8.37	0.0572
0.02	0.909	8.29	0.0468
0.03	1.363	8.32	0.0392
0.04	1.818	8.36	0.0310
0.05	2.272	7.83	0.0252
0.06	2.726	7.89	0.0004

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	θ(°)
0.0223	0.119	9.59	0.143
0.03	0.160	9.88	0.114
0.04	0.214	9.87	0.100
0.05	0.267	10.15	0.069

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.0223	0.119	3.30
0.04	0.214	3.66
0.06	0.321	3.84

Model M1, B = 225mm, Edge Detail Y, d_4 = 50mm Parapet P2b, Angle 0°

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.0128	0.582	9.62	0.0154
0.02	0.909	10.61	0.0062
0.03	1.363	10.93	0.0044
0.04	1.818	11.10	0.0038

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	$\theta(°)$
0.0223	0.119	11.00	0.115
0.03	0.160	11.29	0.083
0.04	0.214	11.53	0.053

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.0223	0.119	4.24
0.04	0.214	4.38
0.06	0.321	4.60

Model M1, B = 225mm, Edge Detail Y, d_4 = 50mm Parapet P1d, Angle 0°

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.518	9.76	0.0580
0.02	1.035	9.24	0.0492
0.03	1.553	9.11	0.0416
0.04	2.071	8.68	0.0352
0.05	2.589	8.70	0.0316
0.06	3.107	8.42	0.0272

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	$\theta(°)$
0.01	0.069	10.08	1.915
0.02	0.137	9.67	1.168
0.03	0.206	9.09	0.715
0.04	0.274	8.94	0.451

Divergent Instabilities

Galloping (Bending)

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$
0.02	0.909	26.6
0.04	1.818	26.9
0.06	2.726	27.2

Model M1, B = 225mm, Edge Detail Y, d_4 = 50mm, Parapet P1d, Angle +5°

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.518	9.85	0.0996
0.02	1.035	9.57	0.0832
0.03	1.553	9.05	0.0670
0.04	2.071	9.31	0.0590
0.05	2.589	9.04	0.0508
0.06	3.107	8.79	0.0416

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	$\theta(°)$
0.03	0.206	8.80	1.120
0.04	0.274	8.81	0.731
0.05	0.343	8.66	0.578

Divergent Instability

Galloping (Bending)

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$
0.02	1.035	25.2
0.04	2.071	25.7
0.06	3.107	25.7

Model M1, B = 225mm, Edge Detail Y, d_4 = 50mm, Parapet P1d, Angle -5°

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.518	9.50	0.0296
0.02	1.035	9.52	0.0278
0.03	1.553	9.23	0.0196
0.04	2.071	9.23	0.0186
0.05	2.589	9.45	0.0064
0.06	3.107	9.49	0.0052

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	$\theta(°)$
0.0223	0.119	9.59	0.099
0.03	0.160	9.58	0.078
0.04	0.214	9.59	0.073

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.0223	0.119	3.39
0.04	0.214	3.48
0.06	0.320	4.03

Model M1, B = 225mm, Edge Detail Y, d_4 = 50mm Parapet P2d, Angle 0°

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.518	8.21	0.0932
0.02	1.035	7.85	0.0302
0.03	1.553	7.45	0.0126
0.04	2.071	7.34	0.0064

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	$\theta(°)$
0.02	0.137	10.86	3.222
0.03	0.206	10.46	0.968

Divergent Instability

Galloping (Bending)

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$
0.02	1.035	25.0
0.04	2.071	26.0
0.06	3.107	26.7

Model M1, B = 225mm, Edge Detail Y, d_4 = 50mm Parapet P3d, Angle 0°

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.518	7.12	0.0464
0.02	1.035	6.91	0.0232
0.03	1.553	6.89	0.0138
0.04	2.071	6.87	0.0090

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	$\theta(°)$
0.02	0.137	10.82	4.20

Divergent Instability

Galloping (Bending)

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$
0.02	1.035	21.6
0.04	2.071	22.3
0.06	3.107	23.5

Model M1, B = 225mm, Edge Detail Y, d_4 = 50mm Parapet P4d, Angle 0°

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.518	6.58	0.0352
0.02	1.035	6.78	0.0194
0.03	1.553	6.78	0.0130
0.04	2.071	6.75	0.0092

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	θ(°)
0.02	0.137	9.50	2.043

Divergent Instability

Galloping (Bending)

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$
0.02	1.035	22.0
0.04	2.071	22.4
0.06	3.107	22.4

Model M3, B = 450mm, Edge Detail X, d_4 = 50mm Parapet P2a, Angle 0°

1st Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.283	7.08	0.0194

2nd Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.283	15.94	0.0636
0.02	0.565	15.92	0.0494
0.03	0.848	15.17	0.0424
0.04	1.130	15.19	0.0362
0.05	1.413	15.23	0.0284
0.06	1.696	15.19	0.0226

Vortex Shedding in Torsion

Stable

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.02	0.0569	4.90
0.04	0.1138	5.22
0.06	0.1707	5.35

Model M3, Edge Detail X, Parapet P2b, Angle 0°
$B = 450mm$, $d_4 = 50mm$

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.283	15.28	0.0654
0.02	0.565	14.52	0.0526
0.03	0.848	14.52	0.0448
0.04	1.130	14.54	0.0378
0.05	1.413	13.77	0.0308
0.06	1.696	13.72	0.0258

Vortex Shedding in Torsion

Stable

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.02	0.0569	2.90
0.04	0.1138	3.13
0.06	0.1707	3.70

Model M3, Edge Detail X, Parapet P2b, Angle 0°
$B = 450mm$, $d_4 = 50mm$

In Turbulent Flow

Vortex Shedding in Bending

Stable

Vortex Shedding in Torsion

Stable

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.02	0.0569	3.47
0.04	0.1138	3.76
0.06	0.1707	4.12

Model M3, B = 450mm, Edge Detail X, d_4 = 50mm Parapet P3a, Angle 0°

1st Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.283	6.67	0.0148

2nd Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.283	15.31	0.0650
0.02	0.565	15.29	0.0512
0.03	0.848	14.52	0.0422
0.04	1.130	14.52	0.0370
0.05	1.413	14.52	0.0306
0.06	1.696	14.12	0.0252

Vortex Shedding in Torsion

Stable

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.02	0.0569	4.55
0.04	0.1138	4.72
0.06	0.1707	5.01

Model M3, B = 450mm, Edge Detail X, d_4 = 50mm Parapet P3b, Angle 0°

1st Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.283	7.04	0.0102
0.02	0.565	6.67	0.0052
0.03	0.848	6.67	0.0032

2nd Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.283	15.26	0.0764
0.02	0.565	14.47	0.0604
0.03	0.848	14.44	0.0532
0.04	1.130	14.44	0.0452
0.05	1.413	14.44	0.0366
0.06	1.696	14.48	0.0300

Vortex Shedding in Torsion

Stable

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.02	0.0569	2.22
0.04	0.1138	2.80
0.06	0.1707	3.01

Model M3, Edge Detail X, Parapet P2d, Angle 0°
B = 450mm, d_4 = 50mm

1st Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.283	8.20	0.0132
0.02	0.565	7.42	0.0082
0.03	0.848	7.42	0.0062
0.04	1.130	7.45	0.0038

2nd Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.283	22.36	0.1172
0.02	0.565	21.45	0.0960
0.03	0.848	20.72	0.0856
0.04	1.130	19.95	0.0750
0.05	1.413	19.99	0.0712
0.06	1.696	19.23	0.0618

Vortex Shedding in Torsion

Stable

Model M3, Edge Detail Y, Parapet P2a, Angle 0°
B = 450mm, d_4 = 50mm

1st Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.283	7.11	0.0162

2nd Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.283	14.13	0.0366
0.02	0.565	13.73	0.0228
0.03	0.848	12.92	0.0176
0.04	1.130	12.53	0.0094
0.05	1.413	12.15	0.0038

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	$\theta(°)$
0.0138	0.0393	8.45	0.460
0.02	0.0569	8.18	0.280
0.03	0.0854	7.96	0.183

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.02	0.0569	4.71
0.04	0.1138	4.92
0.06	0.1707	5.10

Model M3, $B = 450mm$, Edge Detail Y, $d_4 = 50mm$ Parapet P2b, Angle 0°

1st Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.283	6.46	0.0104

2nd Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.283	14.72	0.0744
0.02	0.565	14.26	0.0520
0.03	0.848	13.89	0.0356
0.04	1.130	13.50	0.0184
0.05	1.413	13.23	0.0034

Vortex Shedding in Torsion

Stable

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.02	0.0569	3.13
0.04	0.1138	3.48
0.06	0.1707	3.69

Model M3, $B = 450mm$, Edge Detail Y, $d_4 = 50mm$ Parapet P3a, Angle 0°

1st Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.283	6.98	0.0124
0.02	0.565	6.67	0.0088
0.03	0.848	6.65	0.0062

2nd Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.283	13.66	0.0416
0.02	0.565	13.20	0.0226
0.03	0.848	12.42	0.0112
0.04	1.130	12.46	0.0022

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	$\theta(°)$
0.0138	0.0393	8.14	0.353

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.02	0.0569	5.08
0.04	0.1138	5.34
0.06	0.1707	5.52

Model M3, Edge Detail Y, Parapet P3b, Angle 0°
B = 450mm, d_4 = 50mm

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.283	14.31	0.0932
0.02	0.565	14.31	0.0654
0.03	0.848	13.54	0.0492
0.04	1.130	13.54	0.0040

Vortex Shedding in Torsion

Stable

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.02	0.0569	2.85
0.04	0.1138	3.37
0.06	0.1707	3.89

Model M3, Edge Detail Y, Parapet P2d, Angle 0°
B = 450mm, d_4 = 50mm

1st Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.283	8.19	0.0146
0.02	0.565	7.80	0.0080

2nd Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.283	22.54	0.1160
0.02	0.565	21.42	0.0990
0.03	0.848	20.72	0.0868
0.04	1.130	19.90	0.0742
0.05	1.413	19.88	0.0696
0.06	1.696	19.13	0.0602

Vortex Shedding in Torsion

Stable

Model M3, B = 450mm, Edge Detail Y, d_4 = 50mm, Parapet P3d, Angle 0°

1st Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.283	7.38	0.0156
0.02	0.565	7.06	0.0068

2nd Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.283	19.80	0.1500
0.02	0.565	18.98	0.1304
0.03	0.848	18.31	0.1170
0.04	1.130	18.30	0.1090
0.05	1.413	17.46	0.1026
0.06	1.696	17.47	0.0958

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	$\theta(°)$
0.0138	0.0393	9.15	0.596
0.02	0.0569	8.65	0.357
0.03	0.0854	8.42	0.250

Model M3, B = 450mm, Edge Detail Y, d_4 = 50mm, Parapet P4d, Angle 0°

1st Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.283	7.02	0.0156
0.02	0.565	6.99	0.0086

2nd Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.04	1.130	18.08	0.1962
0.05	1.413	18.12	0.1756
0.06	1.696	17.49	0.1590

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	$\theta(°)$
0.0138	0.0393	7.64	0.338

Model M5, B = 675mm, Edge Detail X, d_4 = 50mm Parapet P2b, Angle 0°

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.0151	0.2441	10.51	0.0210
0.02	0.3234	10.57	0.0186
0.03	0.4850	10.59	0.0150
0.04	0.6467	10.59	0.0126
0.05	0.8084	10.61	0.0106
0.06	0.9701	10.60	0.0090

1st Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	$\theta(°)$
0.0176	0.0153	8.50	0.196
0.02	0.0174	8.51	0.171
0.03	0.0261	8.44	0.115
0.04	0.0347	8.44	0.078
0.05	0.0434	8.46	0.047

2nd Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	$\theta(°)$
0.0176	0.0153	14.12	0.354
0.02	0.0174	14.11	0.337
0.03	0.0261	13.38	0.251
0.04	0.0347	13.38	0.184
0.05	0.0434	13.40	0.119
0.06	0.0521	12.76	0.041

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.02	0.0174	3.28
0.04	0.0347	3.32
0.06	0.0521	3.42

Model M5, B = 675mm, Edge Detail X, d_4 = 50mm Parapet P3a, Angle 0°

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.0151	0.2441	11.00	0.0158
0.02	0.3234	10.98	0.0140
0.03	0.4850	11.02	0.0110
0.04	0.6467	10.55	0.0092
0.05	0.8084	11.01	0.0080
0.06	0.9701	11.05	0.0068

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	$\theta(°)$
0.0176	0.0153	13.86	0.289
0.02	0.0174	13.86	0.268
0.03	0.0261	13.77	0.208
0.04	0.0347	13.78	0.153
0.05	0.0434	13.78	0.099
0.06	0.0521	13.79	0.049

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.02	0.0174	3.82
0.04	0.0347	3.92
0.06	0.0521	3.96

Model M5, B = 675mm, Edge Detail X, d_4 = 50mm, Parapet P3b, Angle 0°

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.0151	0.2441	10.51	0.0204
0.02	0.3234	10.51	0.0170
0.03	0.4850	10.51	0.0112
0.04	0.6467	10.49	0.0056

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	$\theta(°)$
0.0176	0.0153	13.83	0.469
0.02	0.0174	13.77	0.441
0.03	0.0261	13.79	0.340
0.04	0.0347	13.47	0.280
0.05	0.0434	13.18	0.217
0.06	0.0521	13.18	0.151

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.02	0.0174	2.86
0.04	0.0347	2.95
0.06	0.0521	3.03

Model M5, B = 675mm, Edge Detail Y, d_4 = 50mm, Parapet P2b, Angle 0°

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.0151	0.2441	10.03	0.0126
0.02	0.3234	10.03	0.0084

Vortex Shedding in Torsion

Stable

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.02	0.0174	3.54
0.04	0.0347	3.61
0.06	0.0521	3.68

Model M5, Edge Detail Y, Parapet P3a, Angle 0°
$B = 675mm$, $d_4 = 50mm$

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.0151	0.2441	9.22	0.0136
0.02	0.3234	9.60	0.0126
0.03	0.4850	9.57	0.0060

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	$\theta(°)$
0.0176	0.0153	7.44	0.142
0.02	0.0174	7.47	0.127
0.03	0.0261	7.49	0.088
0.04	0.0347	7.44	0.063

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.02	0.0174	4.30
0.04	0.0347	4.38
0.06	0.0521	4.43

Model M5, Edge Detail Y, Parapet P3b, Angle 0°
$B = 675mm$, $d_4 = 50mm$

Vortex Shedding in Bending

Stable

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	$\theta(°)$
0.0176	0.0153	13.56	0.037

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.02	0.0174	3.18
0.04	0.0347	3.27
0.06	0.0521	3.43

Model M1 — Overhang $l/d_4 = 0.25$, Edge Detail $k/d_4 = 0.3$ (Y type) — Parapet P3b — Angle 0°

$B = 150$mm
$d_4 = 50$mm

1st Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.957	4.48	0.0027

2nd Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.957	12.92	0.0028
0.02	1.914	12.92	0.0027
0.03	2.870	12.92	0.0025
0.04	3.827	12.92	0.0022
0.05	4.784	12.92	0.0020
0.06	5.741	12.92	0.0017

Divergent Instability

Galloping

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$
0.02	1.914	18.75
0.04	3.827	61.47
0.06	5.741	75.74

PLATE GIRDER BRIDGES - FURTHER WORK

Model M1 — U' — Parapet P2a — Angle 0°

$B = 150$mm
$d_4 = 54.6$mm

1st Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	1.169	4.69	0.0064
0.02	2.338	4.31	0.0022

2nd Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	1.169	10.13	0.0127
0.02	2.338	10.59	0.0095
0.03	3.508	10.51	0.0087
0.04	4.677	10.89	0.0061
0.05	5.846	10.89	0.0053
0.06	7.015	11.27	0.0031

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	$\theta(°)$
0.0153	0.243	10.08	0.06
0.02	0.317	9.81	0.059
0.03	0.476	9.81	0.024

Divergent Instability

Galloping

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$
0.02	2.338	14.90
0.04	4.677	15.12
0.06	7.015	15.20

PLATE GIRDER BRIDGES - FURTHER WORK

Model M1 | Overhang l/d_4 = 0.25, Edge Detail k/d_4 = 0.5 (Y-type) | Parapet P2a | Angle 0°

B = 150mm
d_4 = 50mm

1st Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.947	5.65	0.0153
0.02	1.894	4.91	0.0027

2nd Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.947	8.77	0.0203

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	θ(°)
0.015	0.302	9.83	0.174
0.02	0.403	9.83	0.159
0.03	0.605	10.01	0.088
0.04	0.807	10.01	0.086
0.05	1.008	10.25	0.048
0.06	1.210	10.34	0.037

Divergent Instability

Galloping

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$
0.02	1.894	17.46
0.04	3.789	17.61
0.06	5.683	17.76

PLATE GIRDER BRIDGES - FURTHER WORK

Model M1 | Overhang l/d_4 = 0.25, Edge Detail k/d_4 = 0.5 (Y-type) | Parapet P3b | Angle 0°

B= 150mm
d_4 = 50mm

1st Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.963	4.50	0.0028

2nd Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.963	12.96	0.0035
0.02	1.926	12.74	0.0030
0.03	2.889	13.04	0.0029
0.04	3.852	12.96	0.0028
0.05	4.815	13.338	0.0022
0.06	5.777	13.338	0.0022

Divergent Instability

Galloping

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$
0.02	1.926	18.36
0.04	3.852	58.45
0.06	5.777	69.69

PLATE GIRDER BRIDGES - FURTHER WORK

Model M1 Overhang $l/d_4 = 0.50$ Parapet P2a Angle 0°
Edge Detail $k/d_4 = 0.5$ (Y-type)

B= 175mm
d_4 = 50mm

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.720	8.01	0.0138

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	θ(°)
0.011	0.165	9.65	0.221
0.02	0.300	9.82	0.166
0.03	0.449	9.82	0.123
0.04	0.599	9.98	0.078
0.05	0.749	9.98	0.073
0.06	0.899	9.98	0.047

Divergent Instability

Galloping

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$
0.02	1.44	22.16
0.04	2.88	22.54
0.06	4.32	23.07

PLATE GIRDER BRIDGES - FURTHER WORK

Model M1 U' Parapet P2a Angle 0°

B= 175mm
d_4 = 54.6mm

1st Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.925	6.12	0.0057

2nd Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.925	9.49	0.0162
0.02	1.850	10.12	0.0071
0.03	2.774	10.51	0.0047
0.04	3.699	10.83	0.0027
0.05	4.624	10.83	0.0025
0.06	5.549	10.83	0.0021

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	θ(°)
0.0146	0.189	10.33	0.176
0.02	0.259	10.56	0.144
0.03	0.388	10.33	0.048

Divergent Instability

Galloping

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$
0.02	1.850	18.37
0.04	3.699	19.23
0.06	5.549	20.10

PLATE GIRDER BRIDGES - FURTHER WORK

Model M1 Overhang $l/d_4 = 0.50$ Parapet P3a Angle 0°
Edge Detail $k/d_4 = 0.5$ (Y-type)

B= 175mm
d_4 = 50mm

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.725	11.07	0.0070
0.02	1.450	11.45	0.0041
0.03	2.175	11.45	0.0034
0.04	2.900	11.45	0.0030
0.05	3.625	11.53	0.0023
0.06	4.349	11.45	0.0015

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	$\theta(°)$
0.0197	0.227	11.16	0.157
0.03	0.346	11.40	0.090
0.04	0.461	11.40	0.075
0.05	0.576	11.40	0.064
0.06	0.691	11.59	0.036

Divergent Instability

Galloping

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$
0.02	1.450	23.00
0.04	2.900	23.45
0.06	4.349	23.98

PLATE GIRDER BRIDGES - FURTHER WORK

Model M1 U' Parapet P3a Angle 0°

B = 175mm
d_4 = 54.6mm

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.01	0.933	11.98	0.0054
0.02	1.866	11.98	0.0047
0.03	2.799	12.29	0.0031
0.04	3.732	12.29	0.0026
0.05	4.666	11.9	0.0021
0.03	5.599	11.9	0.0020

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	$\theta(°)$
0.0145	0.191	10.96	0.090
0.02	0.263	10.77	0.039

Divergent Instability

Galloping

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$
0.02	1.866	20.03
0.04	3.732	20.80
0.06	5.599	22.21

PLATE GIRDER BRIDGES - FURTHER WORK

Model M3 Overhang $l/d_4 = 0.25$ Parapet P2a Angle 0°
Edge detail $k/d_4 = 0.30$ (Y-type)

B= 375mm
d_4 = 50m

1st Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_b d_4$	z/d_4
0.01	0.398	7.01	0.0174
0.02	0.795	6.78	0.0098
0.03	1.193	6.55	0.0053

2nd Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_b d_4$	z/d_4
0.01	0.398	16.83	0.0566
0.02	0.795	16.25	0.0426
0.03	1.193	15.45	0.0319
0.04	1.590	15.45	0.0265
0.05	1.988	14.87	0.0227
0.06	2.385	14.36	0.0171

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_t d_4$	$\theta(°)$
0.01	0.0399	8.55	0.451
0.02	0.0799	8.19	0.207

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_t B$
0.02	0.0815	3.70
0.04	0.1630	3.97
0.06	0.2445	4.22

PLATE GIRDER BRIDGES - FURTHER WORK

Model M3 Overhang $l/d_4 = 0.25$ Parapet P2a Angle 0°
Edge detail $k/d_4 = 0.50$ (Y-type)

B= 375mm
d_4 = 50mm

1st Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_b d_4$	z/d_4
0.01	0.398	7.18	0.0192

2nd Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_b d_4$	z/d_4
0.01	0.398	17.52	0.0652
0.02	0.795	16.65	0.0511
0.03	1.193	16.07	0.0413
0.04	1.590	15.79	0.0349
0.05	1.988	15.51	0.0299
0.06	2.385	15.51	0.0249

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_t d_4$	$\theta(°)$
0.01	0.0399	8.55	0.508
0.02	0.0799	8.55	0.198
0.03	0.1198	9.24	0.061

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_t B$
0.02	0.0815	3.56
0.04	0.1630	3.81
0.06	0.2445	4.04

PLATE GIRDER BRIDGES - FURTHER WORK

Model M3   U'   Parapet P2a   Angle 0°

B= 375mm
d_4 = 54.6mm

1st Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	U/n_bd_4	z/d_4
0.01	0.394	6.18	0.0142
0.02	0.788	6.18	0.0085
0.03	1.182	5.71	0.0038
0.04	1.576	5.71	0.0005

2nd Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	U/n_bd_4	z/d_4
0.01	0.394	15.76	0.0774
0.02	0.788	15.23	0.0657
0.03	1.182	14.71	0.0554
0.04	1.576	14.45	0.0492
0.05	1.969	14.24	0.0450
0.06	2.363	14.24	0.0407

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	U/n_td_4	$\theta(°)$
0.01	0.0387	7.87	0.442
0.02	0.0774	8.28	0.216

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	U/n_tB
0.02	0.0774	3.04
0.04	0.1547	3.53
0.06	0.2321	3.78

PLATE GIRDER BRIDGES - FURTHER WORK

Model M3   Overhang l/d_4 = 0.25   Parapet P2b   Angle 0°
Edge detail k/d_4 = 0.50 (Y-type)

B= 375mm
d_4 = 50m

1st Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	U/n_bd_4	z/d_4
0.01	0.398	7.24	0.0340
0.02	0.795	7.01	0.0181
0.03	1.193	6.78	0.0112
0.04	1.590	6.55	0.0073
0.05	1.988	6.26	0.0036

2nd Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	U/n_bd_4	z/d_4
0.01	0.398	16.14	0.0898
0.02	0.795	15.62	0.0706
0.03	1.193	14.76	0.0582
0.04	1.590	14.53	0.0503
0.05	1.988	14.24	0.0451
0.06	2.385	13.96	0.0398

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	U/n_td_4	$\theta(°)$
0.01	0.0399	8.78	1.190
0.02	0.0799	8.59	0.730
0.03	0.1198	8.60	0.299

PLATE GIRDER BRIDGES - FURTHER WORK

Model M3 Overhang $l/d_4 = 0.25$ Parapet P2b Angle 0°
Edge detail $k/d_4 = 0.50$ (Y-type)

B= 375mm
d_4 = 50m

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_t B$
0.02	0.0838	3.22
0.04	0.1675	3.77
0.06	0.2513	4.10

PLATE GIRDER BRIDGES - FURTHER WORK

Model M3 Edge Detail $k = 0.1d_4$(X-type) Parapet P2a Angle 0°
B = 400mm d_4 = 50mm

1st Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_v d_4$	z/d_4
0.01	0.342	6.99	0.0141
0.02	0.685	6.59	0.0071
0.03	1.027	6.59	0.0018

2nd Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_v d_4$	z/d_4
0.01	0.342	16.15	0.0442
0.02	0.685	15.58	0.0337
0.03	1.027	15.01	0.0266
0.04	1.370	15.01	0.0217
0.05	1.712	14.44	0.0176
0.06	2.054	13.99	0.0138

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_t d_4$	θ(°)
0.01	0.029	8.95	0.468
0.02	0.057	8.95	0.353
0.03	0.086	8.69	0.265

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_t B$
0.02	0.080	4.00
0.04	0.160	4.22
0.06	0.239	4.52

Model M3 — Edge Detail $k = 0.3d_4$(Y-type) — Parapet P2a — Angle 0°
$B = 400$mm — $d_4 = 50$mm

1st Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	U/n_zd_4	z/d_4
0.01	0.342	7.05	0.0133

2nd Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	U/n_zd_4	z/d_4
0.01	0.342	17.11	0.0488
0.02	0.685	16.49	0.0395
0.03	1.027	16.09	0.0320
0.04	1.370	16.03	0.0262
0.05	1.712	15.41	0.0236
0.06	2.054	15.18	0.0195

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	θ(°)
0.01	0.029	8.95	0.440

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.02	0.080	3.49
0.04	0.160	3.77
0.06	0.239	3.99

Model M3 — Edge Detail $k = 0.5d_4$(Y-type) — Parapet P2a — Angle 0°
$B = 400$mm — $d_4 = 50$mm

1st Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	U/n_zd_4	z/d_4
0.01	0.342	7.16	0.0061

2nd Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	U/n_zd_4	z/d_4
0.01	0.342	17.68	0.0390
0.02	0.685	17.23	0.0310
0.03	1.027	17.06	0.0247
0.04	1.370	16.54	0.0212
0.05	1.712	16.49	0.0172
0.06	2.054	15.97	0.0142

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	θ(°)
0.01	0.029	8.63	0.551

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.02	0.080	3.72
0.04	0.160	3.98
0.06	0.239	4.22

Model M3 — U — Parapet P2a — Angle 0°

$B = 400mm$ — $d_4 = 54.6mm$

1st Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_1 d_4$	z/d_4
0.01	0.346	6.27	0.0119
0.02	0.692	5.86	0.0042

2nd Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_2 d_4$	z/d_4
0.01	0.342	15.22	0.0715
0.02	0.692	15.01	0.0575
0.03	1.037	14.49	0.0501
0.04	1.383	14.02	0.0434
0.05	1.729	14.02	0.0384
0.06	2.075	13.55	0.0336

Vortex Shedding in Torsion

STABLE

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.02	0.059	3.82
0.04	0.118	4.11
0.06	0.176	4.34

Model M3 — U' — Parapet P2a — Angle 0°

$B = 400mm$ — $d_4 = 54.6mm$

1st Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_1 d_4$	z/d_4
0.01	0.346	6.33	0.0120

2nd Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_2 d_4$	z/d_4
0.01	0.346	14.49	0.0583
0.02	0.692	14.02	0.0488
0.03	1.037	13.55	0.0409
0.04	1.383	13.55	0.0347
0.05	1.729	13.55	0.0288
0.06	2.075	13.08	0.0256

Vortex Shedding in Torsion

STABLE

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.02	0.059	3.72
0.04	0.118	3.97
0.06	0.176	4.18

PLATE GIRDER BRIDGES - FURTHER WORK

Model M3 Edge Detail $k = 0.1d_4$(X-type) Parapet P2b Angle 0°
$B = 400$mm $d_4 = 50$mm

1st Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_v d_4$	z/d_4
0.01	0.342	7.56	0.0259
0.02	0.685	6.99	0.0149
0.03	1.027	7.05	0.0099

2nd Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_v d_4$	z/d_4
0.01	0.342	16.32	0.0954
0.02	0.685	16.32	0.0785
0.03	1.027	15.58	0.0657
0.04	1.370	15.23	0.0576
0.05	1.712	15.17	0.0492
0.06	2.054	14.78	0.0438

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	θ(°)
0.01	0.029	9.07	0.963
0.02	0.057	8.84	0.616
0.03	0.086	8.87	0.450
0.04	0.114	8.72	0.279

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.02	0.057	2.91
0.04	0.114	3.51
0.06	0.171	3.78

PLATE GIRDER BRIDGES - FURTHER WORK

Model M3 Edge Detail $k = 0.5d_4$(Y-type) Parapet P2b Angle 0°
$B = 400$mm $d_4 = 50$mm

1st Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_v d_4$	z/d_4
0.01	0.342	7.56	0.0292
0.02	0.685	6.82	0.0138
0.03	1.027	6.59	0.0053

2nd Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_v d_4$	z/d_4
0.01	0.342	15.92	0.0897
0.02	0.685	15.41	0.0731
0.03	1.027	14.89	0.0615
0.04	1.370	14.84	0.0545
0.05	1.712	14.38	0.0461
0.06	2.054	14.33	0.0412

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	θ(°)
0.01	0.029	9.16	1.151
0.02	0.057	9.01	0.737
0.03	0.086	8.87	0.462

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.02	0.057	3.16
0.04	0.114	3.57
0.06	0.171	3.78

PLATE GIRDER BRIDGES - FURTHER WORK

Model M3	Edge Detail k = 0.3 d_4(Y - type)	Parapet P2a	Angle 0°
B = 450mm	d_4 = 50mm		

Vortex Shedding in Bending

STABLE

1st Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_t d_4$	$\theta^{(o)}$
0.0104 0.02 0.03	0.028 0.054 0.080	7.86 7.86 8.19	0.283 0.066 0.004

2nd Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_t d_4$	$\theta^{(o)}$
0.0104	0.028	14.10	0.019

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_t B$
0.02 0.04 0.06	0.054 0.107 0.161	4.46 4.69 4.95

PLATE GIRDER BRIDGES - FURTHER WORK

Model M3	Edge Detail k = 0.4 d_4(Y - type)	Parapet P2a	Angle 0°
B = 450mm	d_4 = 50mm		

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_v d_4$	z/d_4
0.01	0.277	9.08	0.0017

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_t d_4$	$\theta^{(o)}$
0.0104 0.02	0.028 0.054	8.14 7.78	0.225 0.022

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_t B$
0.02 0.04 0.06	0.054 0.107 0.161	4.90 5.15 5.32

Model M3 — Edge Detail k = 0.5 d_4(Y - type) — Parapet P2a — Angle 0°
B = 450mm — d_4 = 50mm

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_b d_4$	z/d_4
0.01	0.277	9.25	0.0076
0.02	0.544	9.31	0.0042
0.03	0.831	9.31	0.0025
0.04	1.108	9.31	0.0016
0.05	1.384	9.37	0.0010

1st Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_t d_4$	θ^{o}
0.0104	0.028	7.78	0.188
0.02	0.054	7.45	0.007

2nd Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_t d_4$	θ^{oo}
0.0104	0.028	13.81	0.249
0.02	0.054	14.10	0.014

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_t B$
0.02	0.054	4.52
0.04	0.107	4.77
0.06	0.161	4.94

Model M3 — U — Parapet P2a — Angle 0°
B = 450mm — d_4 = 54.6mm

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_b d_4$	z/d_4
0.01	0.300	14.13	0.0511
0.02	0.599	13.59	0.0420
0.03	0.899	13.09	0.0327
0.04	1.199	13.09	0.0268
0.05	1.498	12.66	0.0234
0.06	1.798	12.60	0.0201

1st Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_t d_4$	θ^{o}
0.01	0.023	7.83	0.296
0.02	0.047	8.12	0.139
0.03	0.070	8.40	0.037
0.04	0.094	8.40	0.009

2nd Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_t d_4$	θ^{oo}
0.01	0.023	15.01	0.123
0.02	0.047	14.73	0.033

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_t B$
0.02	0.047	3.65
0.04	0.094	3.89
0.06	0.141	4.10

Model M3 U^* Parapet P2a Angle 0°
B = 450mm d_4 = 54.6mm

Vortex Shedding in Bending

STABLE

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	θ^{m}
0.01	0.023	6.93	0.122

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.02 0.04 0.06	0.047 0.094 0.141	4.55 4.86 5.15

PLATE GIRDER BRIDGES - FURTHER WORK

Repeat Tests

Model M3 Edge Detail Y = (K=0.2 d_4) Parapet P2a Angle 0°
B = 450mm d_4 = 50mm

1st Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.0102	0.283	7.41	0.0143

2nd Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_z d_4$	z/d_4
0.0102	0.283	14.37	0.0361

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.0213	0.057	5.28

Model M2 Edge Detail $k = 0.4\ d_4$ Angle 0°

Aire Valley Viaduct

$B = 275mm$ $d_4 = 50mm$

Vortex Shedding in Bending

STABLE

Vortex Shedding in Torsion

Logdec	$I\delta/\rho B^4$	$U/n_\theta d_4$	$\Theta°$
0.0193	0.048	8.836	0.064
0.03	0.075	8.836	0.028
0.04	0.150	8.876	0.010

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.02	0.050	5.00
0.04	0.100	5.18
0.06	0.150	5.30

Model M2 Edge Detail $k = 0.4\ d_4$ Angle -5°

Vortex Shedding in Bending

STABLE

Vortex Shedding in Torsion

STABLE

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.02	0.050	10.11
0.04	0.100	10.18
0.06	0.150	10.39

Model M2 Edge Detail $k = 0.4\ d_4$ Angle $+5°$

Vortex Shedding in Bending

Logdec	$M\delta/\rho B^2$	$U/n_v d_4$	z/d_4
0.0135	0.461	14.73	0.0823
0.02	0.683	14.32	0.0706
0.03	1.025	13.91	0.0591
0.04	1.367	13.58	0.0493
0.05	1.708	13.18	0.0421
0.06	2.050	13.09	0.0367

Vortex Shedding in Torsion

STABLE

Divergent Instability

Torsional Instability

Logdec	$I\delta/\rho B^4$	$U/n_\theta B$
0.02	0.050	2.96
0.04	0.100	3.44
0.06	0.150	3.74

Appendix B: Comparison between test results and design rules

Further Tests Results v. Current Rules - Vertical Bending - Table M1F1

EP ref. = Edge / Parapet reference					
Edge	K/d_4	Parapet	h/d_4	suffix	ϕ
X	0.05	P1	0.3	a	$^1/_4$
	U.N.O	P2	0.7	b	$^1/_2$
Y	0.20	P3	1.1	c	$^3/_4$
	U.N.O	P4	1.5	d	1

Model		Units	l/d_4	b^*/d_4	b/d_4	$(b/d_4)^{1.5}$	$m/\rho b^2$	K_R
M1	●	1	$^1/_2$	3	3 $^1/_2$	6.5	471 (534U')	0.43
M2	○	1	1 $^1/_2$	3	5 $^1/_2$	12.9		0.37
M3	○	2	$^1/_4$	7 $^1/_2$	9	27.0		0.29
M4	○	2	1 $^1/_2$	7 $^1/_2$	10	31.6		0.27
M5	○	3	1	12	13 $^1/_2$	49.6		0.24
M6	○	3	1 $^1/_2$	12	14 $^1/_2$	55.2		0.23

NOTE :

GENERAL NOTES	PARAPETS	MODEL REF.	
reduction for rough flow , $K_R = \frac{0.87}{\sqrt{3\,^1/_2}} = 0.465$ (0.486 for U')	P2a, P3a	Reduced overhang	**M1**

mode	EP Ref.	Edge d	δ_S	∠	$\frac{m\delta_S}{\rho h^2}$	$\frac{V}{f_t d_4}$	measured/predicted rule[1]	measured/predicted proposed[2]	$\left(\frac{y_{max}}{d_4}\right)_S$	$\frac{K_R\, y_{max}}{10^{-3} d_4}$	$\left(\frac{\rho h^2}{m}\right)\frac{10}{45}\left(\frac{d_4}{b}\right)^{1.5}$	measured/predicted rule[3]	measured/predicted proposed[4]
	YP		0.01										
	YP		0.02										
	YP		0.03										
	YP		0.04										
	YP		0.05										
	YP		0.06										
1st	YP 2a	k/d_4 = 0.5 (Y)	0.01	0	0.720	8.01	1.23		.0138	6.4	53.1	.12	.06
	YP		0.02	0									
	YP		0.03	0									
	YP		0.04	0									
	YP		0.05	0									
	YP		0.06	0									
1st	YP 3a	k/d_4 = 0.5 (Y)	0.01	0	0.720	11.07	1.70		.0070	3.3	53.1	.06	.03
1st	YP 3a		0.02	0	1.450	11.45	1.76		.0041	1.9	26.5	.07	.03
1st	YP 3a		0.03	0	2.175	11.45	1.76		.0034	1.6	17.7	.09	.04
1st	YP 3a		0.04	0	2.900	11.45	1.76		.0030	1.4	13.3	.10	.04
1st	YP 3a		0.05	0	3.625	11.53	1.77		.0023	1.1	10.6	.10	.04
1st	YP 3a		0.06	0	4.349	11.45	1.76		.0015	0.7	8.8	.08	.03
	YP		0.01										
	YP		0.02										
	YP		0.03										
	YP		0.04										
	YP		0.05										
1st	UP' 2a	U'	0.01	0	0.925	6.12	0.94		.0057	2.8	46.8	.06	.03
2nd	U'P 2a	Edge U'	0.01	0	0.925	9.49	1.46		.0162	7.9	46.8	.17	.08
2nd	U'P 2a		0.02	0	1.850	10.12	1.56		.0071	3.5	23.4	.15	.07
2nd	U'P 2a		0.03	0	2.774	10.51	1.62		.0047	2.3	15.6	.15	.07
2nd	U'P 2a		0.04	0	3.699	10.83	1.67		.0027	1.3	11.7	.11	.05
2nd	U'P 2a		0.05	0	4.624	10.83	1.67		.0025	1.2	9.4	.13	.06
2nd	U'P 2a		0.06	0	5.549	10.83	1.67		.0021	1.0	7.8	.13	.06
1st	U'P 3a	Edge U'	0.01	0	0.933	11.98	1.84		.0054	2.6	46.8	.06	.03
1st	U'P 3a		0.02	0	1.866	11.98	1.84		.0047	2.3	23.4	.10	.04
1st	U'P 3a		0.03	0	2.799	12.29	1.89		.0031	1.5	15.6	.10	.04
1st	U'P 3a		0.04	0	3.732	12.29	1.89		.0026	1.3	11.7	.11	.05
1st	U'P 3a		0.05	0	4.666	11.90	1.83		.0021	1.0	9.4	.11	.05
1st	U'P 3a		0.06	0	5.599	11.90	1.83		.0020	1.0	7.8	.12	.05

[1] c.f. 6.5
[2] still 6.5
[3] without 3.0 factor
[4] with c factor

Further Test Results v. Current Rules - Galloping - Table M1F1

EP ref. = Edge / Parapet reference					
Edge	K/d_4	Parapet	h/d_4	suffix	φ
X	0.05	P1	0.3	a	1/4
	U.N.O	P2	0.7	b	1/2
Y	0.20	P3	1.1	c	3/4
	U.N.O	P4	1.5	d	1

Model	Units	l/d_4	b^*/d_4	b/d_4	$(b/d)^{1.5}$	$(b/d)^{3.5}$	
M1 ●	1	1 1/2	3	3 1/3	12 1/2	882 (955 U')	
M2 ○	1	1 1/2	3	5 1/3	12.9		
M3 ○	2	1	7 1/2	9	27.0		
M4 ○	2	1 1/2	7 1/2	10	31.6		
M5 ○	3	1	12	13 1/2	49.6		
M6 ○	3	1 1/2	12	14 1/2	55.2		

NOTE :

GENERAL NOTES	PARAPETS	MODEL REF.	
Cg → 1.0 Galloping	P2a, P3a	Reduced overhang	**M1**

EP Ref.	Edge P'	δ_s	∠	$\frac{m\delta_s}{\rho b^2}$	$\frac{V_g}{f_g d_4}$	$C_G = \left(\frac{m}{\rho b^2}\right)\delta_s\left(\frac{b}{d_4}\right)^2$	measured / predicted				
YP		0.01									
YP		0.02									
YP		0.03									
YP		0.04									
YP		0.05									
YP		0.06									
YP	$k/d_4 = 0.5$ (Y)	0.01	0								
YP 2a		0.02	0	1.44	22.16	17.64	1.26				
YP		0.03	0								
YP 2a		0.04	0	2.88	22.54	35.28	.64				
YP		0.05	0								
YP 2a		0.06	0	4.32	23.06	52.92	.44				
YP	$k/d_4 = 0.5$ (Y)	0.01	0								
YP 3a		0.02	0	1.45	23.00	17.64	1.30				
YP		0.03	0								
YP 3a		0.04	0	2.90	23.45	35.28	.66				
YP		0.05	0								
YP 3a		0.06	0	4.35	23.98	52.92	.45				
YP		0.01									
YP		0.02									
YP		0.03									
YP		0.04									
YP		0.05									
YP		0.06									
P	Edge U'	0.01	0								
P 2a		0.02	0	1.85	20.06	19.1	1.05				
P		0.03	0								
P 2a		0.04	0	3.70	21.00	38.2	.55				
P		0.05	0								
P 2a		0.06	0	5.55	21.95	57.3	.38				
P	Edge U'	0.01	0								
P 3a		0.02	0	1.87	21.88	19.1	1.15				
P		0.03	0								
P 3a		0.04	0	3.73	22.72	38.2	.59				
P		0.05	0								
P 3a		0.06	0	5.60	24.26	57.3	.42				

Futher Test Results *v.* Current Rules - Torsion - Table M1F1

EP ref. = Edge / Parapet reference					
Edge	K/d_4	Parapet	h/d_4	suffix	ϕ
X	0.05	P1	0.3	a	$^1/_4$
	U.N.O	P2	0.7	b	$^1/_2$
Y	0.20	P3	1.1	c	$^3/_4$
	U.N.O	P4	1.5	d	1

Model		Units	l/d_4	b^*/d_4	b/d_4	$(b/d_4)^{2.5}$	$m/\rho b^2$	K_B
M1	●	1	$^1/_2$	3	3 $^1/_2$	80	1203 912 766 U'	0.43
M2	○	1	1 $^1/_2$	3	5 $^1/_2$	390		0.37
M3	○	2	$^1/_4$	7 $^1/_2$	9	2187		0.29
M4	○	2	1 $^1/_2$	7 $^1/_2$	10	3162		0.27
M5	○	3	1	12	13 $^1/_2$	9040		0.24
M6	○	3	1 $^1/_2$	12	14 $^1/_2$	11609		0.23

NOTE :

GENERAL NOTES	PARAPETS	MODEL REF.	
$\theta = \frac{2y_{max}^{T}}{b}$; K_B as for vertical bending	P2a. P3a	Reduced Overhang	**M1**

EP Ref.	Edge d	δ_S	∠	$\frac{Im\delta_S}{\rho b^4}$	$\frac{V}{f_t d_4}$	measured / predicted: rule[1]	measured / predicted: proposed[2]	$(\theta^T)_S$	$\frac{2K_B y_{max}}{10^{-3} b}$	$\left(\frac{\rho b^4}{Im}\right)\frac{10^3}{4\delta s}\left(\frac{d_4}{b}\right)^{2.5}$	measured / predicted: rule[3]	measured / predicted: proposed[4]
YP		0.01										
YP		0.02										
YP		0.03										
YP		0.04										
YP		0.05										
YP		0.06										
YP 2a	k/d_4 = 0.5 (Y)	0.011	0	0.165	9.65	1.48		.221	1.79	18.89	.09	.04
YP 2a		0.02	0	0.300	9.82	1.51		.166	1.35	10.39	.13	.06
YP 2a		0.03	0	0.449	9.82	1.51		.123	1.00	6.92	.14	.07
YP 2a		0.04	0	0.599	9.98	1.54		.078	0.63	5.20	.12	.06
YP 2a		0.05	0	0.749	9.98	1.54		.073	0.59	4.16	.14	.07
YP 2a		0.06	0	0.899	9.98	1.54		.047	0.38	3.46	.11	.05
YP	k/d_4 = 0.5 (Y)	0.01	0									
YP 3a		0.02	0	0.227	11.16	1.72		.157	1.29	13.56	.09	.04
YP 3a		0.03	0	0.346	11.40	1.75		.090	0.73	9.04	.08	.03
YP 3a		0.04	0	0.461	11.40	1.75		.075	0.61	6.78	.09	.04
YP 3a		0.05	0	0.576	11.40	1.75		.064	0.52	5.42	.10	.04
YP 3a		0.06	0	0.691	11.59	1.75		.036	0.29	4.52	.06	.03
YP		0.01										
YP		0.02										
YP		0.03										
YP		0.04										
YP		0.05										
YP		0.06										
U'P 2a	Edge U'	0.015	0	0.189	10.33	1.59		.176	1.49	21.75	.07	.03
U'P 2a		0.02	0	0.259	10.56	1.62		.144	1.22	16.31	.07	.03
U'P 2a		0.03	0	0.388	10.33	1.59		.048	0.41	10.87	.04	.02
U'P		0.04	0									
U'P		0.05	0									
U'P		0.06	0									
U'P 3a	Edge U'	0.015	0	0.191	10.96	1.68		.090	0.76	21.76	.03	.01
U'P 3a		0.02	0	0.263	10.77	1.66		.039	0.33	16.32	.02	.01
U'P		0.03	0									
U'P		0.04	0									
U'P		0.05	0									
U'P		0.06	0									

[1] c.f. 6.50
[2] still 6.50
[3] without 3.0 factor
[4] with c factor

Test Results v. Current Rules - Vertical Bending - Table M1F2

EP ref. = Edge / Parapet reference					
Edge	K/d_4	Parapet	b/d_4	suffix	φ
X	0.05	P1	0.3	a	1/4
	U.N.O	P2	0.7	b	1/2
Y	0.20	P3	1.1	c	3/4
	U.N.O	P4	1.5	d	1

Model		Units	l/d_4	b*/d_4	b/d_4	$(b/d_4)^{1.5}$	m/ρb^2	K_4
M1	●	1	1/4	3	3	5.2	[illegible]	0.5
M2	○	1	1 1/2	3	5 1/2	12.9		0.37
M3	○	2	1/4	7 1/2	9	27.0		0.29
M4	○	2	1 1/2	7 1/2	10	31.6		0.27
M5	○	3	1	12	13 1/2	49.6		0.24
M6	○	3	1 1/2	12	14 1/2	55.2		0.23

NOTE :

GENERAL NOTES	PARAPETS	MODEL REF.	
reduction for rough flow , $K_R = \frac{0.87}{\sqrt{3}} = 0.50$ (0.525 for U')	P2a, P3a	further reduced overhang	**M1**

mode	EP Ref.	Edge d	δ_S	∠	$\frac{m\delta_S}{\rho b^2}$	$\frac{V}{f_s d_4}$	measured/predicted rule[1]	measured/predicted proposed[2]	$\left(\frac{y_{max}}{d_s}\right)_s$	$\frac{K_R y_{max}}{10^{-3} d_4}$	$\left(\frac{\rho b^2}{m}\right)\frac{10^3}{48s}\left(\frac{d_4}{b}\right)^{1.5}$	measured/predicted rule[3]	measured/predicted proposed[4]
	YP		0.01										
	YP		0.02										
	YP		0.03										
	YP		0.04										
	YP		0.05										
	YP		0.06										
2nd	YP 3b	k/d_4 = 0.3 (Y)	0.01	0	0.957	12.92	1.99		.0028	1.4	50.1	.03	.01
2nd	YP 3b		0.02	0	1.914	12.92	1.99		.0027	1.4	25.1	.06	.02
2nd	YP 3b		0.03	0	2.870	12.92	1.99		.0025	1.3	16.7	.08	.03
2nd	YP 3b		0.04	0	3.827	12.92	1.99		.0022	1.1	12.5	.09	.04
2nd	YP 3b		0.05	0	4.784	12.92	1.99		.0020	1.0	10.5	.10	.04
2nd	YP 3b		0.06	0	5.741	12.92	1.99		.0017	0.9	8.4	.11	.04
2nd	YP 2a	k/d_4 = 0.5 (Y)	0.01	0	0.947	8.77	1.35		.0203	10.2	50.1	.20	.10
2nd	YP 2a		0.02	0									
2nd	YP		0.03	0									
2nd	YP		0.04	0									
2nd	YP		0.05	0									
2nd	YP		0.06	0									
2nd	YP 3b	k/d_4 = 0.5 (Y)	0.01	0	0.963	12.96	1.99		.0035	1.8	50.1	.04	
2nd	YP 3b		0.02	0	1.926	12.74	1.96		.0030	1.5	25.1	.06	
2nd	YP 3b		0.03	0	2.889	13.04	2.01		.0029	1.5	16.7	.09	
2nd	YP 3b		0.04	0	3.852	12.96	1.99		.0028	1.4	12.5	.11	
2nd	YP 3b		0.05	0	4.815	13.34	2.05		.0022	1.1	10.5	.10	
2nd	YP 3b		0.01	0	5.777	13.34	2.05		.0022	1.1	8.4	.13	
	YP		0.01										
	YP		0.02										
	YP		0.03										
	YP		0.04										
	YP		0.05										
	YP		0.06										
2nd	U'P 2a	Edge U'	0.01	0	1.169	10.13	1.56		.0127	6.7	46.9	.14	.07
2nd	U'P 2a		0.02	0	2.338	10.59	1.63		.0095	5.0	23.4	.21	.10
2nd	U'P 2a		0.03	0	3.508	10.51	1.62		.0087	4.6	15.6	.28	.14
2nd	U'P 2a		0.04	0	4.677	10.89	1.67		.0061	3.2	11.7	.27	.13
2nd	U'P 2a		0.05	0	5.846	10.89	1.67		.0053	2.8	9.4	.29	.14
2nd	U'P 2a		0.06	0	7.015	11.27	1.73		.0031	1.6	7.8	.21	.10

[1] c.f. 6.5
[2] still 6.5
[3] without 3.0 factor
[4] with c factor

Test Results *v.* Current Rules - Galloping - Table M1F2

EP ref. = Edge / Parapet reference					
Edge	K/d_s	Parapet	h/d_s	suffix	ö
X	0.05	P1	0.3	a	$^1/_4$
	U.N.O	P2	0.7	b	$^1/_2$
Y	0.20	P3	1.1	c	$^3/_4$
	U.N.O	P4	1.5	d	1

Model		Units	l/d_s	b*/d_s	b/d_s	$(b/d)^{1.5}$	$(b/d)^{3.5}$	m/ρd^2
M1	●	1	$^1/_4$	3	3	9	864 (885 U')	
M2	○	1	1 $^1/_2$	3	5 $^1/_2$	12.9		
M3	○	2	1	7 $^1/_2$	9	27.0		
M4	○	2	1 $^1/_2$	7 $^1/_2$	10	31.6		
M5	○	3	1	12	13 $^1/_2$	49.6		
M6	○	3	1 $^1/_2$	12	14 $^1/_2$	55.2		

NOTE :

GENERAL NOTES	PARAPETS	MODEL REF.	
Cg → 1.0 Galloping	P2a, P3b	further reduced overhang	**M1**

EP Ref.	Edge P'	δ_S	∠	$\frac{m\delta_S}{\rho b^2}$	$\frac{V_z}{f_0 d_s}$	$C_G = \left(\frac{m}{\rho b^2}\right)\delta_S\left(\frac{b}{d_s}\right)^2$	measured / predicted		measured / predicted (5.0)	measured / predicted (N/A)	3.3	
YP		0.01										
YP		0.02										
YP		0.03										
YP		0.04										
YP		0.05										
YP		0.06										
YP	k/d_s = 0.3 (Y)	0.01	0									
YP 3b		0.02	0	1.914	18.75	17.28	1.09					
YP		0.03	0									
YP 3b		0.04	0	3.827	61.47	34.56	1.78					
YP		0.05	0									
YP 3b		0.06	0	5.741	75.74	51.84	1.46					
YP	k/d_s = 0.5 (Y)	0.01	0									
YP 2a		0.02	0	1.894	17.46	17.28	1.01					
YP		0.03	0									
YP 2a		0.04	0	3.789	17.61	34.56	.51					
YP		0.05	0									
YP 2a		0.06	0	5.683	17.76	57.84	.34					
YP	k/d_s = 0.5 (Y)	0.01	0									
YP 3b		0.02	0	1.926	18.36	17.28	1.06					
YP		0.03	0									
YP 3b		0.04	0	3.852	58.45	34.56	1.69					
YP		0.05	0									
YP 3b		0.06	0	5.777	69.69	51.84	1.34					
YP		0.01										
YP		0.02										
YP		0.03										
YP		0.04										
YP		0.05										
YP		0.06										
U'P	Edge U'	0.01	0									
U'P 2a		0.02	0	2.338	14.90	17.7	.84					
U'P		0.03	0									
U'P 2a		0.04	0	4.677	15.12	35.4	.43					
U'P		0.05	0									
U'P 2a		0.06	0	7.015	15.20	53.1	.29					

Test Results v. Current Rules - Torsion - Table M1F2

EP ref. = Edge / Parapet reference					
Edge	K/d_4	Parapet	h/d_4	suffix	ϕ
X	0.05	P1	0.3	a	$^1/_4$
	U.N.O	P2	0.7	b	$^1/_2$
Y	0.20	P3	1.1	c	$^3/_4$
	U.N.O	P4	1.5	d	1

Model		Units	l/d_4	b*/d_4	b/d_4	$(b/d_4)^{1.5}$	m/ρb^2	K_R
M1	●	1	$^1/_4$	3	3	47	948 (548) U*	0.50
M2	○	1	1 $^1/_2$	3	5 $^1/_2$	390		0.37
M3	○	2	1	7 $^1/_2$	9	2187		0.29
M4	○	2	1 $^1/_2$	7 $^1/_2$	10	3162		0.27
M5	○	3	1	12	13 $^1/_2$	9040		0.24
M6	○	3	1 $^1/_2$	12	14 $^1/_2$	11609		0.23

NOTE :

GENERAL NOTES	PARAPETS	MODEL REF.	
$\theta = \frac{2y_{max}^{T}}{b}$; K_R as for vertical bending	P2a, P3b	Reduced overhang	**M1**

mode	EP Ref.	Edge Def.	δ_S	∠	$\frac{Im\delta_S}{\rho b^4}$	$\frac{V}{f_T d_4}$	measured/predicted rule[1]	measured/predicted proposed[2]	$(\theta^o)_S$	$\frac{2K_R y_{max}}{10^{-3}b}$	$\left(\frac{\rho b^4}{Im}\right)\frac{10^3}{48s}\left(\frac{d_4}{b}\right)^{1.5}$	measured/predicted rule[3]	measured/predicted proposed[4]
	YP		0.01										
	YP		0.02										
	YP		0.03										
	YP		0.04										
	YP		0.05										
	YP		0.06										
	YP 3b	k/d_4 = 0.3 (Y)	0.01	0									
	YP 3b		0.02	0									
	YP 3b		0.03	0	Stable				Stable				
	YP 3b		0.04	0									
	YP 3b		0.05	0									
	YP 3b		0.06	0									
	YP 2a	k/d_4 = 0.5 (Y)	.015	0	0.302	9.83	1.51		.174	1.52	17.58	.09	.04
	YP 2a		0.02	0	0.403	9.83	1.51		.159	1.39	13.19	.11	.05
	YP 2a		0.03	0	0.605	10.01	1.54		.088	0.77	8.79	.09	.04
	YP 2a		0.04	0	0.807	10.01	1.54		.086	0.75	6.59	.11	.05
	YP 2a		0.05	0	1.008	10.25	1.58		.048	0.42	5.27	.08	.04
	YP 2a		0.06	0	1.210	10.34	1.58		.037	0.32	4.40	.07	.03
	YP 3b	k/d_4 = 0.5 (Y)	0.01	0									
	YP 3b		0.02	0									
	YP 3b		0.03	0	Stable				Stable				
	YP 3b		0.04	0									
	YP 3b		0.05	0									
	YP 3b		0.06	0									
	YP	Edge U	0.01	0									
	YP		0.02	0									
	YP		0.03	0									
	YP		0.04	0									
	YP		0.05	0									
	YP		0.06	0									
	U'P 2a	Edge U'	.015	0	0.243	10.08	1.55		.060	0.55	29.80	.02	.01
	U'P 2a		0.02	0	0.317	9.81	1.51		.059	0.54	22.80	.02	.01
	U'P 2a		0.03	0	0.476	9.81	1.51		.024	0.22	15.30	.02	.01
	U'P 2a		0.04	0									
	U'P 2a		0.05	0									
	U'P 2a		0.06	0									

[1] c.f. 6.5
[2] still 6.5

[3] without 3.0 factor
[4] with c factor

Test Results *v.* Current Rules - Divergent TI - M1X & Y (continued)

EP ref. = Edge / Parapet reference					
Edge	K/d_4	Parapet	h/d_4	suffix	ϕ
X	0.05	P1	0.3	a	$^1/_4$
		P2	0.7	b	$^1/_2$
Y	0.20	P3	1.1	c	$^3/_4$
		P4	1.5	d	1

Model	Units	l/d_4	b^*/d_4	b/d_4	$(b/d)^2$	$m/\rho b^2$	
M1 ●	1	1	3	4 $^1/_2$	20		
M2 ○	1	1 $^1/_2$	3	5 $^1/_2$	30		
M3 ○	2	1	7 $^1/_2$	9	81		
M4 ○	2	1 $^1/_2$	7 $^1/_2$	10	100		
M5 ○	3	1	12	13 $^1/_2$	182		
M6 ○	3	1 $^1/_2$	12	14 $^1/_2$	210		

NOTE :

GENERAL NOTES	PARAPETS	MODEL REF.	
Initially C_g = 1.0	X & YP 1 & 2		**M1**

EP Ref.	δ_S	∠	$\frac{Im\delta_S}{\rho b^4}$	$\frac{V_g}{f_r d}$	predicted	or		measured / predicted (5.0)	(2.6)	3.3	
XP 1a	0.023	0	0.119	3.80	5 (or 2.6)	3.3		.76	1.46	1.15	
YP 1a	0.023	0	0.119	3.79	5 (or 2.6)	3.3		.76	1.46	1.15	
XP 1a	0.040	0	0.214	4.04	5 (or 2.6)	3.3		.81	1.55	1.23	
YP 1a	0.040	0	0.214	3.92	5 (or 2.6)	3.3		.78	1.51	1.18	
XP 1a	0.060	0	0.320	4.40	5 (or 2.6)	3.3		.88	1.69	1.33	
YP 1a	0.060	0	0.320	4.15	5 (or 2.6)	3.3		.83	1.60	1.26	
XP 1b	0.023	0	0.119	3.42	5 (or 2.6)	3.3		.68	1.32	1.03	
YP 1b	0.023	0	0.119	3.30	5 (or 2.6)	3.3		.66	1.27	1.00	
XP 1b	0.040	0	0.214	3.66	5 (or 2.6)	3.3		.73	1.41	1.11	
YP 1b	0.040	0	0.214	3.66	5 (or 2.6)	3.3		.73	1.41	1.11	
XP 1b	0.060	0	0.320	3.88	5 (or 2.6)	3.3		.78	1.49	1.18	
YP 1b	0.060	0	0.320	3.84	5 (or 2.6)	3.3		.77	1.48	1.17	
XP 1d	0.023	0	0.119	3.49	5 (or 2.6)	3.3		.70	1.34	1.06	
XP 2d	0.023	0	0.119	4.06	5 (or 2.6)	3.3		.81	1.56	1.23	
XP 1d	0.040	0	0.214	3.79	5 (or 2.6)	3.3		.76	1.46	1.15	
XP 2d	0.040	0	0.214	4.44	5 (or 2.6)	3.3		.89	1.71	1.35	
XP 1d	0.060	0	0.320	4.11	5 (or 2.6)	3.3		.82	1.58	1.24	
XP 2d	0.060	0	0.320	5.00	5 (or 2.6)	3.3		1.00	1.92	1.52	
XP 1d	0.023	-5	0.119	3.15	5 (or 2.6) Turbulent Flow	3.3		.63	1.21	.95	
YP 1d	0.023	-5	0.119	3.39	5 (or 2.6)	3.3		.68	1.30	1.03	
XP 1d	0.040	-5	0.214	3.28	5 (or 2.6)	3.3		.66	1.26	1.00	
YP 1d	0.040	-5	0.214	3.48	5 (or 2.6)	3.3		.70	1.34	1.06	
XP 1d	0.060	-5	0.320	3.51	5 (or 2.6)	3.3		.70	1.34	1.06	
YP 1d	0.060	-5	0.320	4.03	5 (or 2.6)	3.3		.81	1.55	1.23	
XP 2b	0.023		0.119	3.39	5 (or 2.6)	3.3		.68	1.30	1.03	
YP 2b	0.023		0.119	4.24	5 (or 2.6)	3.3		.85	1.63	1.29	
XP 2b	0.040		0.214	3.65	5 (or 2.6)	3.3		.73	1.40	1.11	
YP 2b	0.040		0.214	4.38	5 (or 2.6)	3.3		.88	1.68	1.33	
XP 2b	0.060		0.320	4.22	5 (or 2.6)	3.3		.85	1.63	1.29	
YP 2b	0.060		0.320	4.60	5 (or 2.6)	3.3		.92	1.77	1.39	
XP 1a*	0.023	0	0.119	3.69	5 (or 2.6)	3.3		.74	1.42	1.12	
XP	0.023	0									
XP 1a*	0.040	0	0.214	3.78	5 (or 2.6)	3.3		.76	1.46	1.15	* Middle Third Solid
XP	0.040	0									
XP 1a*	0.060	0	0.320	4.03	5 (or 2.6)	3.3		.81	1.55	1.23	
XP	0.060	0									

Test Results v. Current Rules - Vertical Bending - Table M1X

EP ref. = Edge / Parapet reference					
Edge	K/d_4	Parapet	h/d_4	suffix	ϕ
X	0.05	P1	0.3	a	1/4
		P2	0.7	b	1/2
Y	0.20	P3	1.1	c	3/4
		P4	1.5	d	1

Model		Units	l/d_4	b^*/d_4	b/d_4	$(b/d_4)^{1.5}$	$m/\rho b^2$	K_R
M1	●	1	1	3	4 1/2	9.5	492	0.41
M2	○	1	1 1/2	3	5 1/2	12.9		
M3	○	2	1	7 1/2	9	27.0		
M4	○	2	1 1/2	7 1/2	10	31.6		
M5	○	3	1	12	13 1/2	49.6		
M6	○	3	1 1/2	12	14 1/2	55.2		

NOTE :

GENERAL NOTES	PARAPETS	MODEL REF.
K_R (red^n for rough flow) $= \frac{0.87}{\sqrt{4.5}} = 0.41$	XP1 - 4d & XP 2b	**M1**

EP Ref.	δ	∠	$\frac{m\delta_s}{\rho b^2}$	$\frac{V}{f_b d_4}$	measured/predicted rule[1]	measured/predicted proposed[2]	$\left(\frac{y_{max}}{d_4}\right)_S$	$\frac{K_R y_{max}}{10^{-3} d_4}$	$\left(\frac{\rho b^2}{m}\right) \frac{10^5}{4\delta s} \left(\frac{d^4}{b}\right)^{1.5}$	measured/predicted rule[3]	measured/predicted proposed[4]
XP 1d	0.01	5	0.518	9.01	1.39		.0964	39.5	50.8	.78	.65 *
XP 1d	0.02	5	1.035	9.52	1.46		.0788	32.3	25.4	1.27	1.06 *
XP 1d	0.03	5	1.553	9.24	1.42		.0646	26.5	16.9	1.56	1.30 *
XP 1d	0.04	5	2.071	9.23	1.42		.0542	22.2	12.7	1.75	1.46 *
XP 1d	0.05	5	2.589	8.98	1.38		.0474	19.4	10.2	1.90	1.58 *
XP 1d	0.06	5	3.107	8.98	1.38		.0416	17.1	8.5	2.01	1.68 *
XP 1d	0.01	0	0.518	10.08	1.55		.0740	30.3	50.8	0.60	.50
XP 1d	0.02	0	1.035	9.23	1.42		.0554	22.7	25.4	0.89	.74
XP 1d	0.03	0	1.553	9.53	1.46		.0494	20.3	16.9	1.20	1.00
XP 1d	0.04	0	2.071	8.98	1.38		.0392	16.1	12.7	1.27	1.06
XP 1d	0.05	0	2.589	8.74	1.34		.0312	12.8	10.2	1.25	1.04
XP 1d	0.06	0	3.107	8.75	1.35		.0264	10.8	8.5	1.27	1.06
XP 2d	0.01	0	0.518	9.79	1.51		.1498	61.4	50.8	1.21	.50
XP	0.02	0									
XP	0.03	0									
XP	0.04	0									
XP	0.05	0									
XP	0.06	0									
XP 3d	0.01	0	0.518	6.85	1.05		.0330	13.5	50.8	0.27	.08
XP 3d	0.02	0	1.035	6.85	1.05		.0174	7.1	25.4	0.28	.08
XP 3d	0.03	0	1.553	6.83	1.05		.0114	4.7	16.9	0.28	.08
XP 3d	0.04	0	2.071	6.80	1.05		.0068	2.8	12.7	0.22	.06
XP	0.05	0									
XP	0.06	0									
XP 4d	0.01	0	0.518	6.80	1.05		.0262	10.7	50.8	0.21	.04
XP 4d	0.02	0	1.035	6.78	1.04		.0164	6.7	25.4	0.26	.06
XP 4d	0.03	0	1.553	6.75	1.04		.0112	4.6	16.9	0.27	.06
XP 4d	0.04	0	2.071	6.78	1.04		.0072	3.0	12.7	0.23	.05
XP	0.05	0									
XP	0.06	0									
XP 2b	0.01	0	0.518	10.80	1.66		.0106	4.3	50.8	0.09	.07
XP 2b	0.02	0	1.035	11.32	1.74		.0048	2.0	25.4	0.08	.06
XP 2b	0.03	0	1.553	11.14	1.71		.0038	0.6	16.9	0.09	.07
XP	0.04										
XP	0.05										
XP	0.06										

[1] c.f. 6.50
[2] still 6.50

[3] without 3.0 factor
[4] with c factor
* Note ∠ = +5°

Test Results *v.* Current Rules - Vertical Bending - Table M1X (continued)

EP ref. = Edge / Parapet reference					
Edge	K/d_4	Parapet	h/d_4	suffix	δ
X	0.05	P1	0.3	a	1/4
		P2	0.7	b	1/2
Y	0.20	P3	1.1	c	3/4
		P4	1.5	d	1

Model	Units	l/d_4	b^*/d_4	b/d_4	$(b/d_4)^{1.5}$	m/ρb^2	K_R
M1 ●	1	1	3	4 1/2	9.5	432	0.41
M2 ○	1	1 1/2	3	5 1/2	12.9		
M3 ○	2	1	7 1/2	9	27.0		
M4 ○	2	1 1/2	7 1/2	10	31.6		
M5 ○	3	1	12	13 1/2	49.6		
M6 ○	3	1 1/2	12	14 1/2	55.2		

NOTE :

GENERAL NOTES	PARAPETS	MODEL REF.
K_R = 0.41	XP1a-d ; 2a-d	**M1**

EP Ref.	δ	∠	$\frac{m\delta_s}{\rho h^2}$	$\frac{V}{f_s d_4}$	measured/predicted rule[1]	measured/predicted proposed[2]	$\left(\frac{y_{max}}{d_4}\right)_s$	$\frac{K_R y_{max}}{10^{-3} d_4}$	$\left(\frac{\rho h^2}{m}\right)\frac{10^3}{45s}$	$\left(\frac{d^4}{b}\right)^{1.5}$	measured/predicted rule[3]	measured/predicted proposed[4]
XP 1a	.0128	0	0.582	8.28	1.27		.0296	12.1	45.2		.27	.51
XP 1a	0.02	0	0.909	8.33	1.28		.0248	10.2	29.0		.35	.67
XP 1a	0.03	0	1.363	8.39	1.29		.0206	8.5	19.3		.44	.84
XP 1a	0.04	0	1.818	8.39	1.29		.0542	7.0	14.5		.48	.91
XP 1a	0.05	0	2.272	8.36	1.29		.0170	6.1	11.6		.52	.99
XP 1a	0.06	0	2.726	8.31	1.28		.0126	5.2	9.6		.53	1.01
XP 1b	.0128	0	0.582	8.83	1.36		.0644	26.4	45.2		.58	.78
XP 1b	0.02	0	0.909	8.87	1.36		.0502	20.6	29.0		.71	.95
XP 1b	0.03	0	1.363	8.42	1.30		.0402	16.5	19.3		.85	1.13
XP	0.04											
XP	0.05											
XP	0.06											
XP 1d	.0128	0	0.582	9.58	1.47	Turbulent Flow	.0570	57.0	45.2	(0.60)	1.26	1.05*
XP 1d	0.02	0	0.909	9.46	1.45		.0452	45.2	29.0	(0.89)	1.56	1.30*
XP 1d	0.03	0	1.363	9.13	1.40		.0342	34.2	19.3	(1.20)	1.77	1.47*
XP 1d	0.04	0	1.818	8.49	1.31		.0164	16.4	14.5	(1.27)	1.13	.94*
XP 1d	0.05	0	2.272	8.67	1.33		.0122	12.2	11.6	(1.25)	1.05	.88*
YP	0.06	0					→ i.e	K_R → 1.0		smooth m/ρ		
XP 1d	.0128	-5	0.582	9.18	1.41		.0288	11.8	45.2		.26	.22*
XP 1d	0.02	-5	0.909	9.18	1.41		.0220	9.0	29.0		.31	.26*
XP 1d	0.03	-5	1.363	9.41	1.45		.0212	8.7	19.3		.45	.38*
XP 1d	0.04	-5	1.818	9.39	1.44		.0198	8.1	14.5		.56	.47*
XP 1d	0.05	-5	2.272	9.42	1.45		.0180	7.4	11.6		.64	.53*
XP 1d	0.06	-5	2.726	9.39	1.44		.0166	6.8	9.6		.71	.59*
XP 2b	0.01	0	0.518	10.80	1.66		.0106	4.3	50.8		.09	See
XP 2b	0.02	0	1.035	11.32	1.74		.0048	2.0	25.4		.08	P. M1X
XP 2b	0.03	0	1.553	11.14	1.71		.0038	1.6	16.9		.09	
XP 2d	0.01	0	0.518	9.79	1.51		.1498	61.4	50.8		1.21	
XP 2d	.0128	0	0.582	8.99	1.38	Turb.	.1572	157.20	45.2	(1.21)	3.47	1.45*
XP							→ i.e	K_R → 1.0				
XP 1a#	.0128	0	0.582	8.83	1.36		.0388	15.9	45.2		.35	.47#
XP 1a#	0.02	0	0.909	8.90	1.37		.0310	12.7	29.0		.44	.59#
XP 1a#	0.03	0	1.363	8.43	1.30		.0232	9.5	19.3		.49	.65#
XP 1a#	0.04	0	1.818	8.46	1.30		.0184	7.5	14.5		.52	.69#
XP 1a#	0.05	0	2.272	8.46	1.30		.0152	6.2	11.6		.54	.72#
XP 1a#	0.06	0	2.726	8.45	1.30		.0124	5.1	9.6		.53	.71#

[1] c.f. 6.50
[2] still 6.50
middle third solid (proposed rule averaged 1/3 & 2/3)
* Note turbulent flow or -5° ∠
[3] without 3.0 factor
[4] with c factor

Test Results *v.* Current Rules - Galloping - M1X

EP ref. = Edge / Parapet reference					
Edge	K/d_4	Parapet	h/d_4	suffix	ϕ
X	0.05	P1	0.3	a	$^1/_4$
		P2	0.7	b	$^1/_2$
Y	0.20	P3	1.1	c	$^3/_4$
		P4	1.5	d	1

Model	Units	l/d_4	b^*/d_4	b/d_4	$(b/d)^2$	$m/\rho b^2$	
M1 ●	1	1	3	4 $^1/_2$	20	1049	
M2 ○	1	1 $^1/_2$	3	5 $^1/_2$	30		
M3 ○	2	1	7 $^1/_2$	9	81		
M4 ○	2	1 $^1/_2$	7 $^1/_2$	10	100		
M5 ○	3	1	12	13 $^1/_2$	182		
M6 ○	3	1 $^1/_2$	12	14 $^1/_2$	210		

NOTE :

GENERAL NOTES	PARAPETS	MODEL REF.
Initially C_g = 1.0	XP 1-4d	**M1**

EP Ref.	δ_s	∠	$\frac{m\delta_s}{\rho b^2}$	$\frac{V_g}{f_b d_4}$	$C_G = \left(\frac{m}{\rho b^2}\right)\delta_s\left(\frac{b}{d_4}\right)^2$	$\frac{m}{\rho}$
XP	0.01	5				
XP 1d	0.02	5	1.035	21.6	21.0	1.03
XP	0.03	5				
XP 1d	0.04	5	2.071	22.1	42.0	.53
XP	0.05	5				
XP 1d	0.06	5	3.107	22.2	62.9	.35
XP	0.01	0				
XP 1d	0.02	0	1.035	22.5	21.0	1.07
XP	0.03	0				
XP 1d	0.04	0	2.071	23.4	42.0	.56
XP	0.05	0				
XP 1d	0.06	0	3.107	23.7	62.9	.38
XP	0.01	0				
XP 2d	0.02	0	1.035	22.1	21.0	1.05
XP	0.03	0				
XP 2d	0.04	0	2.071	22.8	42.0	.54
XP	0.05	0				
XP 2d	0.06	0	3.107	23.5	62.9	.37
XP	0.01	0				
XP 3d	0.02	0	1.035	21.2	21.0	1.01
XP	0.03	0				
XP 3d	0.04	0	2.071	21.8	42.0	.52
XP	0.05	0				
XP 3d	0.06	0	3.107	22.5	62.9	.36
XP	0.01	0				
XP 4d	0.02	0	1.035	21.0	21.0	1.00
XP	0.03	0				
XP 4d	0.04	0	2.071	21.8	42.0	.52
XP	0.05	0				
XP 4d	0.06	0	3.107	22.0	62.9	.35
XP	0.01					
XP	0.02					
XP	0.03					
XP	0.04					
XP	0.05					
XP	0.06					

Test Results *v.* Current Rules - Torsion - Table M1X

EP ref. = Edge / Parapet reference					
Edge	K/d_4	Parapet	h/d_4	suffix	ϕ
X	0.05	P1	0.3	a	$^1/_4$
		P2	0.7	b	$^1/_2$
Y	0.20	P3	1.1	c	$^3/_4$
		P4	1.5	d	1

Model	Units	l/d_4	b^*/d_4	b/d_4	$(b/d_4)^{3.5}$	$m/\rho b^2$	K_R
M1 ●	1	1	3	4 $^1/_2$	193	1326	0.41
M2 ○	1	1 $^1/_2$	3	5 $^1/_2$	390		0.37
M3 ○	2	1	7 $^1/_2$	9	2187		0.29
M4 ○	2	1 $^1/_2$	7 $^1/_2$	10	3162		0.27
M5 ○	3	1	12	13 $^1/_2$	9040		0.24
M6 ○	3	1 $^1/_2$	12	14 $^1/_2$	11609		0.23

NOTE :

GENERAL NOTES	PARAPETS	MODEL REF.
$\theta = \frac{2y_{max}^{T}}{b}$; K_R as for vertical bending	XP 1-4d	**M1**

EP Ref.	δ_S	∠	$\frac{Im\delta_S}{\rho b^4}$	$\frac{V}{f_T d_4}$	measured / predicted		$(\theta'')_S$	$\frac{2K_R y_{max}^T}{10^{-4} b}$	$\left(\frac{\rho b^4}{Im}\right)\frac{10^3}{4\delta s}\left(\frac{d_4}{b}\right)^{1.5}$	measured / predicted	
					rule[1]	proposed[2]				rule[3]	proposed[4]
XP	0.01										
XP	0.02										
XP 1d	0.03	5	0.206	9.32	1.43		1.147	8.21	6.28	1.31	1.09
XP 1d	0.04	5	0.274	9.20	1.42		0.808	5.78	4.71	1.23	1.02
XP 1d	0.05	5	0.343	9.19	1.42		0.635	4.54	3.77	1.20	1.00
XP 1d	0.06	5	0.412	9.18	1.41		0.499	3.57	3.14	1.14	.95
XP 1d	0.01	0	0.069	10.92	1.68		2.540	18.17	18.85	.96	.80
XP 1d	0.02	0	0.137	9.50	1.46		0.986	7.06	9.43	.75	.63
XP 1d	0.03	0	0.206	9.20	1.42		0.637	4.56	6.28	.73	.61
XP	0.04	0									
XP	0.05	0									
XP	0.06	0									
XP	0.01	0									
XP 2d	0.02	0	0.137	11.42	1.76		4.350	31.12	9.43	3.30	1.38
XP	0.03	0									
XP	0.04	0									
XP	0.05	0									
XP	0.06	0									
XP 3d	0.01	0	0.103	11.09	1.70		5.360	38.36	18.85	2.03	.56
XP	0.02	0									
XP	0.03	0									
XP	0.04	0									
XP	0.05	0									
XP	0.06	0									
XP 4d	0.01	0	0.103	10.75	1.65		4.551	32.57	18.85	1.73	.36
XP 4d	0.02	0	0.137	10.75	1.65		2.709	19.39	9.43	2.06	.43
XP	0.03	0									
XP	0.04	0									
XP	0.05	0									
XP	0.06	0									
XP	0.01										
XP	0.02										
XP	0.03										
XP	0.04										
XP	0.05										
XP	0.06										

[1] c.f. 6.5
[2] still 6.5
[3] without 3.0 factor
[4] with c factor

Test Results v. Current Rules - Torsion - Table M1X(continued)

EP ref. = Edge / Parapet reference					
Edge	K/d_4	Parapet	h/d_4	suffix	ϕ
X	0.05	P1	0.3	a	$^1/_4$
		P2	0.7	b	$^1/_2$
Y	0.20	P3	1.1	c	$^3/_4$
		P4	1.5	d	1

Model		Units	l/d_1	b^*/d_1	b/d_4	$(b/d_4)^{3.5}$	$m/\rho b^2$	K_θ
M1	●	1	1	3	4 $^1/_2$	193	1029	0.41
M2	○	1	1 $^1/_2$	3	5 $^1/_2$	390		0.37
M3	○	2	1	7 $^1/_2$	9	2187		0.29
M4	○	2	1 $^1/_2$	7 $^1/_2$	10	3162		0.27
M5	○	3	1	12	13 $^1/_2$	9040		0.24
M6	○	3	1 $^1/_2$	12	14 $^1/_2$	11609		0.23

NOTE :

GENERAL NOTES	PARAPETS	MODEL REF.
$\theta = \frac{2y_{max}^T}{b}$; K_θ as for vertical bending	XP 1a-d, 2a-d	**M1**

EP Ref.	δ_S	∠	$\frac{I_m \delta_S}{\rho b^4}$	$\frac{V}{f_T d_4}$	measured/predicted rule[1]	measured/predicted proposed[2]	$(\theta^\circ)_S$	$\frac{2K_\theta y_{max}^T}{10^{-3} b}$	$\left(\frac{\rho b^4}{I_m}\right)\frac{10^3}{4\delta_S}\left(\frac{d_4}{b}\right)^{1.5}$	measured/predicted rule[3]	measured/predicted proposed[4]
XP 1a	0.01	0	Stable				Stable				
XP	0.02										
XP	0.03										
XP	0.04										
XP	0.05										
XP	0.06										
XP	0.01										
XP 1b	.0223	0	0.119	9.55	1.47		.0870	0.62	10.89	.06	.08
XP 1b	0.03	0	0.160	9.81	1.51		.0610	0.44	8.10	.05	.07
XP 1b	0.04	0	0.214	9.28	1.43		.0570	0.41	6.07	.07	.09
XP	0.05										
XP	0.06										
XP 1d	0.01	0	Stable			Turbulent Flow	Stable				Turbulent Flow
XP	0.02										
XP	0.03										
XP	0.04										
XP	0.05										(see M1X
XP	0.06										for smooth)
XP	0.01	-5									
XP 1d	.0223	-5	0.119	9.62	1.48		.2150	1.54	10.89	.14	.12
XP 1d	0.03	-5	0.160	9.61	1.48		.1940	1.39	8.10	.17	.14
XP 1d	0.04	-5	0.214	9.62	1.48		.1650	1.18	6.07	.19	.16
XP 1d	0.05	-5	0.267	9.63	1.48		.1370	0.98	4.86	.20	.17
XP 1d	0.06	-5	0.320	9.90	1.52		.1220	0.87	4.05	.22	.18
XP	0.01										
XP 2b	.0223		0.119	11.17	1.72		.0780	0.56	10.89	.05	.04
XP 2b	0.03		0.160	11.40	1.75		.0410	0.29	8.10	.04	.03
XP	0.01		Stable			Turb	Stable				Turb. Fl.
XP 2d	0.02										(See M1X)
XP	0.03										for smooth
XP 1a*	0.01										
XP 1a*	.0223		0.119	10.94	1.68		.1400	1.00	10.89	.09	0.12*
XP 1a*	0.03		0.160	11.52	1.77		.1050	0.75	8.10	.09	0.12*
XP 1a*	0.04		0.214	11.51	1.77		.0890	0.64	6.07	.10	0.13*
XP 1a*	0.05		0.267	11.51	1.77		.0700	0.50	4.86	.10	0.13*
XP 1a*	0.06		0.320	11.49	1.77		.0610	0.44	4.05	.11	0.15*

[1] c.f. 6.5

[2] still 6.5

[3] without 3.0 factor

[4] with c factor

* middle third solid (prposed rule averaged 1/3 & 2/3)

Test Results *v.* Current Rules - Vertical Bending - Table M1Y (continued)

EP ref. = Edge / Parapet reference					
Edge	K/d_4	Parapet	h/d_4	suffix	ϕ
X	0.05	P1	0.3	a	1/4
		P2	0.7	b	1/2
Y	0.20	P3	1.1	c	3/4
		P4	1.5	d	1

Model		Units	l/d_4	b^*/d_4	b/d_4	$(b/d_4)^{1.5}$	$m/\rho b^2$	K_R
M1	●	1	1	3	4 1/2	09.5	432	0.41
M2	○	1	1 1/2	3	5 1/2	12.9		
M3	○	2	1	7 1/2	9	27.0		
M4	○	2	1 1/2	7 1/2	10	31.6		
M5	○	3	1	12	13 1/2	49.6		
M6	○	3	1 1/2	12	14 1/2	55.2		

NOTE :

GENERAL NOTES	PARAPETS	MODEL REF.
K_R = 0.41 (as for M1Y) ; $m/\rho b^2$ is now 45.4, was 57.8	YP1a, b ; 2a, b	**M1**

EP Ref.	δ_S	∠	$\frac{m\delta_S}{\rho b^2}$	$\frac{V}{f_k d_4}$	measured/predicted: rule[1]	measured/predicted: proposed[2]	$\left(\frac{y_{max}}{d_4}\right)_S$	$\frac{K_R y_{max}}{10^{-3} d_4}$	$\left(\frac{\rho b^2}{m}\right) \frac{10^3}{4\delta_S} \left(\frac{d^4}{b}\right)^{1.5}$	measured/predicted: rule[3]	measured/predicted: proposed[4]
YP 1a	.0128	0	0.582	8.28	1.27		.0364	14.9	45.2	.33	.40
YP 1a	0.02	0	0.909	8.33	1.28		.0290	11.9	29.0	.41	.50
YP 1a	0.03	0	1.363	8.23	1.27		.0232	9.5	19.3	.49	.59
YP 1a	0.04	0	1.818	8.33	1.28		.0190	7.8	14.5	.54	.65
YP 1a	0.05	0	2.272	8.35	1.29		.0160	6.6	11.6	.57	.69
YP 1a	0.06	0	2.726	8.35	1.29		.0138	5.7	9.6	.59	.72
YP 1b	.0128	0	0.582	8.37	1.29		.0572	23.5	45.2	.52	.50
YP 1b	0.02	0	0.909	8.29	1.27		.0468	19.2	29.0	.66	.63
YP 1b	0.03	0	1.363	8.32	1.28		.0392	16.1	19.3	.83	.79
YP 1b	0.04	0	1.818	8.36	1.29		.0310	12.7	14.5	.88	.84
YP 1b	0.05	0	2.272	7.83	1.20		.0252	10.3	11.6	.89	.85
YP 1b	0.06	0	2.726	7.89	1.21		.0004	0.2	9.6	.02	.02
YP	.0128										
YP	0.02										
YP	0.03										
YP	0.04										
YP	0.05										
YP	0.06										
YP	.0128										
YP	0.02										
YP	0.03										
YP	0.04										
YP	0.05										
YP	0.06										
YP 2b	.0128	0	0.582	9.62	1.48		.0154	6.3	45.2	.14	.08
YP 2b	0.02	0	0.909	10.61	1.63		.0062	2.5	29.0	.09	.05
YP 2b	0.03	0	1.363	10.93	1.68		.0044	1.8	19.3	.09	.05
YP 2b	0.04	0	1.818	11.10	1.71		.0038	1.6	14.5	.11	.07
YP	0.05	0									
YP	0.06	0									
YP	.0128										
YP	0.02										
YP	0.03										
YP	0.04										
YP	0.05										
YP	0.06										

[1] c.f. 6.5
[2] also 6.5
[3] without 3.0 factor
[4] with c factor

Test Results *v.* Current Rules - Galloping - Table M1Y

EP ref. = Edge / Parapet reference					
Edge	K/d_4	Parapet	h/d_4	suffix	φ
X	0.05	P1	0.3	a	$^1/_4$
		P2	0.7	b	$^1/_2$
Y	0.20	P3	1.1	c	$^3/_4$
		P4	1.5	d	1

Model	Units	l/d_4	b^*/d_4	b/d_4	$(b/d)^2$	$m/\rho b^2$	
M1 ●	1	1	3	4 $^1/_2$	20	1049	
M2 ○	1	1 $^1/_2$	3	5 $^1/_2$	30		
M3 ○	2	1	7 $^1/_2$	9	81		
M4 ○	2	1 $^1/_2$	7 $^1/_2$	10	100		
M5 ○	3	1	12	13 $^1/_2$	182		
M6 ○	3	1 $^1/_2$	12	14 $^1/_2$	210		

NOTE :

GENERAL NOTES	PARAPETS	MODEL REF.
Initially $C_g \rightarrow 1.0$	YP 1-4d	**M1**

EP Ref.	δ_S	∠	$\frac{m\delta_s}{\rho b^2}$	$\frac{V_g}{f_s d_4}$	$C_G = \left(\frac{m}{\rho b^2}\right)\delta_s\left(\frac{b}{d_4}\right)^2$	$\frac{m}{\rho}$		$\left(\frac{m}{\rho}\right)$ Torsion		
YP	0.01	5								
YP 1d	0.02	5	1.035	25.2	21.0	1.20				
YP	0.03	5								
YP 1d	0.04	5	2.071	25.7	42.0	.61				
YP	0.05	5								
YP 1d	0.06	5	3.107	25.7	62.9	.41				
YP	0.01									
YP 1d	0.02		1.035	20.4	21.0	.97				
YP	0.03									
YP	0.04									
YP	0.05									
YP 1d	0.06	T	0.056	2.95	5 or 2.6 ——▶			.59 or 1.13		Torsion
YP	0.01									
YP 2d	0.02		1.035	25	21.0	1.19				
YP	0.03									
YP 2d	0.04		2.071	26.0	42.0	.62				
YP	0.05									
YP 2d	0.06		3.107	27	62.9	.43				
YP	0.01									
YP 3d	0.02		1.035	21.6	21.0	1.03				
YP	0.03									
YP 3d	0.04		2.071	22.3	42.0	.53				
YP	0.05									
YP 3d	0.06		3.107	23.5	62.9	.37				
YP	0.01									
YP 4d	0.02		1.035	22.0	21.0	1.05				
YP	0.03									
YP 4d	0.04		2.071	22.4	42.0	.53				
YP	0.05									
YP 4d	0.06		3.107	22.4	62.9	.36				
YP	0.01									
YP	0.02									
YP	0.03									
YP	0.04									
YP	0.05									
YP	0.06	T	0.137	03.25	5 or 2.6 ——▶			.65 or 1.25		Torsion

Torsion cases shown T

Test Results v. Current Rules - Torsion - Table M1Y

EP ref. = Edge / Parapet reference					
Edge	K/d_4	Parapet	h/d_4	suffix	ϕ
X	0.05	P1	0.3	a	1/4
		P2	0.7	b	1/2
Y	0.20	P3	1.1	c	3/4
		P4	1.5	d	1

Model		Units	l/d_4	b^*/d_4	b/d_4	$(b/d_4)^{1.5}$	$m/\rho b^2$	K_R
M1	●	1	1	3	4 1/2	193	1326	0.41
M2	○	1	1 1/2	3	5 1/2	390		0.37
M3	○	2	1	7 1/2	9	2187		0.29
M4	○	2	1 1/2	7 1/2	10	3162		0.27
M5	○	3	1	12	13 1/2	9040		0.24
M6	○	3	1 1/2	12	14 1/2	11609		0.23

NOTE :

GENERAL NOTES	PARAPETS	MODEL REF.	
$\theta = \frac{2y_{mm}}{b}^{T}$; K_R as for vertical bending	YP 1-4d		**M1**

EP Ref.	δ_S	∠	$\frac{Im\delta_S}{\rho b^4}$	$\frac{V}{f_r d_4}$	measured/predicted rule[1]	measured/predicted proposed[2]	$\left(\theta^o\right)_S$	$\frac{2K_R y_{max}}{10^{-3} b}^{T}$	$\left(\frac{\rho b^4}{Im}\right)\frac{10^3}{4\delta s}\left(\frac{d_4}{b}\right)^{1.5}$	measured/predicted rule[3]	measured/predicted proposed[4]
YP	0.01										
YP	0.02										
YP 1d	0.03	5	0.206	8.80	1.35		1.120	8.01	6.28	1.27	0.85*
YP 1d	0.04	5	0.274	8.81	1.36		0.731	5.23	4.71	1.11	0.74*
YP 1d	0.05	5	0.343	8.66	1.33		0.578	4.14	3.77	1.10	0.73*
YP	0.06										
YP 1d	0.01	0	0.069	10.08	1.55		1.915	13.70	18.85	.73	.49
YP 1d	0.02	0	0.137	9.67	1.49		1.168	8.36	9.43	.89	.59
YP 1d	0.03	0	0.206	9.09	1.40		0.715	5.12	6.28	.82	.55
YP 1d	0.04	0	0.274	8.94	1.38		0.451	3.23	4.71	.69	.46
YP	0.05	0									
YP	0.06	0									
YP	0.01	0									
YP 2d	0.02	0	0.137	10.86	1.67		3.222	23.06	9.43	2.45	.91
YP 2d	0.03	0	0.206	10.46	1.61		0.968	6.93	6.28	1.10	.41
YP	0.04	0									
YP	0.05	0									
YP	0.06	0									
YP	0.01	0									
YP 3d	0.02	0	0.137	10.82	1.66		4.200	30.05	9.43	3.19	.82
YP	0.03	0									
YP	0.04	0									
YP	0.05	0									
YP	0.06	0									
YP	0.01	0									
YP 4d	0.02	0	0.137	9.50	1.46		2.043	14.62	9.43	1.55	.30
YP	0.03	0									
YP	0.04	0									
YP	0.05	0									
YP	0.06	0									
YP	0.01	-5	No Results								
YP	0.02										
YP	0.03										
YP	0.04										
YP	0.05										
YP	0.06										

[1] c.f. 6.5
[2] still 6.5

[3] without 3.0 factor
[4] with c factor
* Note : ∠ +5°

Test Results *v.* Current Rules - Torsion - Table M1Y(continued)

EP ref. = Edge / Parapet reference					
Edge	K/d_4	Parapet	h/d_4	suffix	ϕ
X	0.05	P1	0.3	a	$^1/_4$
		P2	0.7	b	$^1/_2$
Y	0.20	P3	1.1	c	$^3/_4$
		P4	1.5	d	1

Model	Units	l/d_4	b^*/d_4	b/d_4	$(b/d_4)^{1.5}$	$m/\rho b^2$	K_R
M1 ●	1	1	3	4 $^1/_2$	193	1029	0.41
M2 ○	1	1 $^1/_2$	3	5 $^1/_2$	390		0.37
M3 ○	2	1	7 $^1/_2$	9	2187		0.29
M4 ○	2	1 $^1/_2$	7 $^1/_2$	10	3162		0.27
M5 ○	3	1	12	13 $^1/_2$	9040		0.24
M6 ○	3	1 $^1/_2$	12	14 $^1/_2$	11609		0.23

NOTE :

GENERAL NOTES	PARAPETS	MODEL REF.
$\theta = \frac{2y_{max}^T}{b}$; K_R as for vertical bending	YP 1a-d. 2b	**M1**

EP Ref.	δ_S	∠	$\frac{Im\delta_S}{\rho b^4}$	$\frac{V}{f_t d_4}$	measured / predicted: rule[1]	measured / predicted: proposed[2]	$(\theta^o)_S$	$\frac{2K_R y_{max}^T}{10^{-3} b}$	$\left(\frac{\rho b^4}{Im}\right)\frac{10^3}{4\delta_S}\left(\frac{d_4}{b}\right)^{1.5}$	measured / predicted: rule[3]	measured / predicted: proposed[4]
YP	0.01										
YP 1a	.0223	0	0.119	9.35	1.44		.0220	.16	10.89	.01	.01
YP	0.03										
YP	0.04										
YP	0.05										
YP	0.06										
YP	0.01										
YP 1b	.0223	0	0.119	9.59	1.47		.1430	1.02	10.89	.09	.09
YP 1b	0.03	0	0.160	9.88	1.52		.1140	0.82	8.10	.10	.10
YP 1b	0.04	0	0.214	9.87	1.52		.1000	0.72	6.07	.12	.11
YP 1b	0.05	0	0.267	10.15	1.56		.0690	0.49	4.86	.10	.10
YP	0.06	0									
YP	0.01										
YP	0.02										
YP	0.03										
YP	0.04										
YP	0.05										
YP	0.06										
YP	0.01										
YP 1d	.0223	-5	0.119	9.59	1.47		.0990	0.71	10.89	.07	0.05*
YP 1d	0.03		0.160	9.58	1.47		.0780	0.56	8.10	.07	0.05*
YP 1d	0.04		0.214	9.59	1.47		.0730	0.52	6.07	.09	0.06*
YP	0.05										
YP	0.06										
YP	0.01										
YP 2b	.0223	0	0.119	11.00	1.69		.1150	0.82	10.89	.08	.05
YP 2b	0.03	0	0.160	11.29	1.74		.0830	0.59	8.10	.07	.04
YP 2b	0.04	0	0.214	11.53	1.77		.0530	0.38	6.07	.06	.04
YP	0.05										
YP	0.06										
YP	0.01										
YP	0.02										
YP	0.03										
YP	0.04										
YP	0.05										
YP	0.06										

[1] c.f. 6.5
[2] still 6.5

[3] without 3.0 factor
[4] with c factor
* Note : ∠ -5°

Test Results v. Current Rules - Vertical Bending - Table M3E1

EP ref. = Edge / Parapet reference					
Edge	K/d_4	Parapet	h/d_4	suffix	ϕ
X	0.05	P1	0.3	a	1/4
	U.N.O	P2	0.7	b	1/2
Y	0.20	P3	1.1	c	3/4
	U.N.O	P4	1.5	d	1

Model	Units	l/d_4	b^*/d_4	b/d_4	$(b/d_4)^{1.5}$	$m/\rho b^2$	K_R
M1 ○	1	1	3	4 1/2	9.5	748 or (810)	0.41
M2 ○	1	1 1/2	3	5 1/2	12.9		0.37
M3 ●	2	1	7 1/2	9	27.0		0.29
M4 ○	2	1 1/2	7 1/2	10	31.6		0.27
M5 ○	3	1	12	13 1/2	49.6		0.24
M6 ○	3	1 1/2	12	14 1/2	55.2		0.23

NOTE :

GENERAL NOTES	PARAPETS	MODEL REF.	
reduction for rough flow , $K_R = \frac{0.87}{\sqrt{9}} = 0.290$:	all P2a	(unmodified)	**M3**

mode	EP Ref.		δ_S	∠	$\frac{m\delta_S}{\rho b^2}$	$\frac{V}{f_s d_4}$	measured / predicted: rule[1]	measured / predicted: proposed[2]	$\left(\frac{y_{max}}{d_4}\right)_S$	$\frac{K_R\, y_{max}}{10^{-3} d_4}$	$\left(\frac{\rho b^2}{m}\right)\frac{10^3}{4\delta_S}\left(\frac{d^4}{b}\right)^{1.5}$	measured / predicted: rule[3]	measured / predicted: proposed[4]
	XP 2a	k/d₄ = 0.1	0.01	0									
	XP		0.02	0									
	XP		0.03	0									
	XP		0.04	0									
	XP		0.05	0									
	XP		0.06	0									
	YP 2a	k/d₄ = 0.3	0.01	0			stable						
	YP		0.02	0									
	YP		0.03	0									
	YP		0.04	0									
	YP		0.05	0									
	YP		0.06	0									
1st	YP 2a	k/d₄ = 0.4	0.01	0	0.277	9.08	0.98	1.10	.0017	0.5	33.4	.01	.01
	YP		0.02	0									
	YP		0.03	0									
	YP		0.04	0									
	YP		0.05	0									
	YP		0.06	0									
1st	YP 2a	k/d₄ = 0.5	0.01	0	0.277	9.25	1.00	1.12	.0076	2.2	33.4	.07	.04
1st	YP 2a		0.02	0	0.544	9.31	1.01		.0042	1.2	16.7	.07	.04
1st	YP 2a		0.03	0	0.831	9.31	1.01		.0025	0.7	11.1	.06	.03
1st	YP 2a		0.04	0	1.108	9.31	1.01		.0016	0.5	8.4	.06	.03
1st	YP 2a		0.05	0	1.384	9.37	1.01	1.13	.0010	0.3	6.7	.04	.02
	YP		0.06	0							5.6		
1st	UP 2a	Edge U	0.01	0	0.300	14.13	1.53	1.72	.0511	14.8	35.2	.42	.29
1st	UP 2a		0.02	0	0.599	13.59	1.47		.0420	12.2	17.6	.69	.48
1st	UP 2a		0.03	0	0.899	13.09	1.42		.0327	9.5	11.7	.81	.57
1st	UP 2a		0.04	0	1.199	13.09	1.42		.2680	7.8	8.8	.89	.62
1st	UP 2a		0.05	0	1.498	12.66	1.37		.0234	6.8	7.0	.97	.68
1st	UP 2a		0.06	0	1.798	12.60	1.36	1.52	.0201	5.8	5.9	.98	.69
	U'P 2a	Edge U'	0.01	0			stable						
	U'P 2a		0.02	0									
	U'P 2a		0.03	0									
	U'P 2a		0.04	0									
	U'P 2a		0.05	0									
	U'P 2a		0.06	0									

[1] c.f. 9.25
[2] c.f. 8.25
[3] without 3.0 factor
[4] with c factor

Test Results *v.* Current Rules - Vertical Bending - Table M3E2

EP ref. = Edge / Parapet reference					
Edge	K/d_4	Parapet	h/d_4	suffix	ϕ
X	0.05	P1	0.3	a	$^1/_4$
	U.N.O	P2	0.7	b	$^1/_2$
Y	0.20	P3	1.1	c	$^3/_4$
	U.N.O	P4	1.5	d	1

Model		Units	l/d_4	b^*/d_4	b/d_4	$(b/d_4)^{1.5}$	m/pb^2	K_B
M1	○	1	1	3	4 $^1/_2$	9.5		0.41
M2	○	1	1 $^1/_2$	3	5 $^1/_2$	12.9		0.37
M3	●	**2**	$^1/_2$	7 $^1/_2$	**8**	**22.6**	773 or (780)	**0.31**
M4	○	2	1 $^1/_2$	7 $^1/_2$	10	31.6		0.27
M5	○	3	1	12	13 $^1/_2$	49.6		0.24
M6	○	3	1 $^1/_2$	12	14 $^1/_2$	55.2		0.23

NOTE :

GENERAL NOTES	PARAPETS	MODEL REF.	
reduction for rough flow , $K_a = \frac{0.87}{\sqrt{8}} = 0.3076$;	all P2a	Reduced overhang	**M3**

mode	EP Ref.		δ	∠	$\frac{m\delta_s}{pb^2}$	$\frac{V}{f_y d_4}$	measured / predicted: rule[1]	measured / predicted: proposed[2]	$\left(\frac{y_{max}}{d_4}\right)_s$	$\frac{K_B\, y_{max}}{10^{-3} d_4}$	$\left(\frac{pb^2}{m}\right) \frac{10^3}{4\delta s} \left(\frac{d^*}{b}\right)^{1.5}$	measured / predicted: rule[3]	measured / predicted: proposed[4]
2nd	XP 2a	$k/d_4 = 0.1$	0.01	0	0.342	16.15	1.75	1.96	.0442	13.6	32.3	.42	.51
2nd	XP		0.02	0	0.685	15.58	1.68		.0337	10.4	16.2	.64	.78
2nd	XP		0.03	0	1.027	15.01	1.62		.0266	8.2	10.8	.76	.92
2nd	XP		0.04	0	1.370	15.01	1.62		.0217	6.7	8.1	.83	1.01
2nd	XP		0.05	0	1.712	14.44	1.56		.0176	5.4	6.5	.83	1.01
2nd	XP		0.06	0	2.054	13.99	1.51	1.69	.0138	4.2	5.4	.78	.94
2nd	YP 2a	$k/d_4 = 0.3$	0.01	0	0.342	17.11	1.85	2.07	.0488	15.0	32.3	.46	.32
2nd	YP		0.02	0	0.685	16.49	1.78		.0395	12.2	16.2	.75	.53
2nd	YP		0.03	0	1.027	16.09	1.74		.0320	9.8	10.8	.91	.64
2nd	YP		0.04	0	1.370	16.03	1.73		.0262	8.1	8.1	1.00	.70
2nd	YP		0.05	0	1.712	15.41	1.66		.0236	7.3	6.5	1.12	.79
2nd	YP		0.06	0	2.054	15.18	1.64	1.84	.0195	6.0	5.4	1.11	.78
	YP 2a	$k/d_4 = 0.4$	0.01	0									
	YP		0.02	0									
	YP		0.03	0									
	YP		0.04	0									
	YP		0.05	0									
	YP		0.06	0									
2nd	YP 2a	$k/d_4 = 0.5$	0.01	0	0.342	17.68	1.91	2.14	.0390	12.0	32.3	.37	.18
2nd	YP 2a		0.02	0	0.685	17.23	1.86		.0310	9.5	16.0	.57	.28
2nd	YP 2a		0.03	0	1.027	17.06	1.84		.0247	7.6	10.8	.70	.35
2nd	YP 2a		0.04	0	1.370	16.54	1.79		.0212	6.5	8.1	.80	.40
2nd	YP 2a		0.05	0	1.712	16.49	1.78		.0172	5.3	6.5	.82	.41
2nd	YP		0.06	0	2.054	15.97	1.73	1.94	.0142	4.4	5.4	.81	.40
2nd	UP 2a	Edge U	0.01	0	0.344	15.22	1.65	1.85	.0715	22.0	36.4	.60	.42
2nd	UP 2a		0.02	0	0.692	15.01	1.62		.0575	17.7	18.2	.97	.68
2nd	UP 2a		0.03	0	1.037	14.49	1.57		.0501	15.4	12.1	1.27	.89
2nd	UP 2a		0.04	0	1.382	14.02	1.51		.0434	13.3	9.1	1.46	1.02
2nd	UP 2a		0.05	0	1.729	14.02	1.51		.0384	11.8	7.3	1.62	1.14
2nd	UP 2a		0.06	0	2.075	13.55	1.46	1.64	.0336	10.3	6.1	1.69	1.18
2nd	U'P 2a	Edge U'	0.01	0	0.346	14.49	1.57	1.76	.0583	17.9	36.4	.49	.24
2nd	U'P 2a		0.02	0	0.692	14.02	1.51		.0488	15.0	18.2	.82	.40
2nd	U'P 2a		0.03	0	1.037	13.55	1.46		.0409	12.6	12.1	1.04	.51
2nd	U'P 2a		0.04	0	1.383	13.55	1.46		.0347	10.7	9.1	1.18	.58
2nd	U'P 2a		0.05	0	1.729	13.55	1.46		.0288	8.8	7.3	1.21	.60
2nd	U'P 2a		0.06	0	2.075	13.08	1.41	1.58	.0256	7.9	6.1	1.30	.64

[1] c.f. 9.25
[2] c.f. 8.25
[3] without 3.0 factor
[4] with c factor

Test Results *v.* Current Rules - Divergent TI - Table M3E2

EP ref. = Edge / Parapet reference					
Edge	K/d_4	Parapet	h/d_4	suffix	ϕ
X	0.05	P1	0.3	a	$^1/_4$
	U.N.O	P2	0.7	b	$^1/_2$
Y	0.20	P3	1.1	c	$^3/_4$
	U.N.O	P4	1.5	d	1

Model		Units	l/d_4	b^*/d_4	b/d_4	$(b/d)^{1.5}$	$(b/d)^{3.5}$	
M1	○	1	1	3	4 $^1/_2$	9.5	193	
M2	○	1	1 $^1/_2$	3	5 $^1/_2$	12.9	390	
M3	●	**2**	**$^1/_2$**	**7 $^1/_2$**	**8**	**22.6**	**1448**	
M4	○	2	1 $^1/_2$	7 $^1/_2$	10	31.6	3162	
M5	○	3	1	12	13 $^1/_2$	49.6	9040	
M6	○	3	1 $^1/_2$	12	14 $^1/_2$	55.2	11609	

NOTE :

GENERAL NOTES	PARAPETS	MODEL REF.	
Divergent Torsional Instability	all P2a	Reduced overhang	**M3**

EP Ref.		δ_S	∠	$\frac{Im\delta_S}{\rho b^4}$	$\frac{V_{gTI}}{f_T b}$	predicted	or		measured / predicted (5.0)	(1.5)	3.3	
XP	$k/d_4 = 0.1$	0.01	0									
XP 2a		0.02	0	0.080	4.00	5 (or 1.5)[NA]	3.3		.80	2.67	1.21	
XP		0.03	0									
XP 2a		0.04	0	0.160	4.22	(NA - not applied	3.3		.84	2.81	1.28	
XP		0.05	0			here since						
XP 2a		0.06	0	0.239	4.52	$h/d_4 > 4$)	3.3		.90	3.01	1.37	
YP	$k/d_4 = 0.3$	0.01	0									
YP 2a		0.02	0	0.080	3.49	5 (or 1.5)	3.3		.70	2.33	1.06	
YP		0.03	0									
YP 2a		0.04	0	0.160	3.77	5 (or 1.5)	3.3		.75	2.51	1.14	
YP		0.05	0									
YP 2a		0.06	0	0.239	3.99	5 (or 1.5)	3.3		.80	2.66	1.21	
YP	$k/d_4 = 0.4$	0.01	0									
YP 2a		0.02	0									
YP		0.03	0									
YP 2a		0.04	0									
YP		0.05	0									
YP 2a		0.06	0									
YP	$k/d_4 = 0.5$	0.01	0									
YP 2a		0.02	0	0.080	3.72	5 (or 1.5)	3.3		.74	2.48	1.13	
YP		0.03	0									
YP 2a		0.04	0	0.160	3.98	5 (or 1.5)	3.3		.80	2.65	1.21	
YP		0.05	0									
YP 2a		0.06	0	0.239	4.22	5 (or 1.5)	3.3		.84	2.81	1.28	
UP	Edge U	0.01	0									
UP 2a		0.02	0	0.059	3.82	5 (or 1.5)	3.3		.76	2.54	1.16	
UP		0.03	0									
UP 2a		0.04	0	0.118	4.11	5 (or 1.5)	3.3		.82	2.74	1.25	
UP		0.05	0									
UP 2a		0.06	0	0.176	4.34	5 (or 1.5)	3.3		.87	2.89	1.32	
U'P	Edge U'	0.01	0									
U'P 2a		0.02	0	0.059	3.72	5 (or 1.5)	3.3		.74	2.48	1.13	
U'P		0.03	0									
U'P 2a		0.04	0	0.118	3.97	5 (or 1.5)	3.3		.79	2.65	1.20	
U'P		0.05	0									
U'P 2a		0.06	0	0.176	4.18	5 (or 1.5)	3.3		.84	2.79	1.27	

Test Results *v.* Current Rules - Torsion - Table M3E2

EP ref. = Edge / Parapet reference					
Edge	K/d₄	Parapet	h/d₄	suffix	ϕ
X	0.05	P1	0.3	a	$^1/_4$
	U.N.O	P2	0.7	b	$^1/_2$
Y	0.20	P3	1.1	c	$^3/_4$
	U.N.O	P4	1.5	d	1

Model		Units	l/d₄	b*/d₄	h/d₄	$(b/d_4)^{1.5}$	$m/\rho b^2$	K_a
M1	○	1	1	3	4 ½	193		0.41
M2	○	1	1 ½	3	5 ½	390		0.37
M3	●	**2**	**½**	**7 ½**	**8**	**1448**	**4156**	**0.29**
M4	○	2	1 ½	7 ½	10	3162		0.27
M5	○	3	1	12	13 ½	9040		0.24
M6	○	3	1 ½	12	14 ½	11609		0.23

NOTE :

GENERAL NOTES	PARAPETS	MODEL REF.	
$\theta = \frac{2y_{max}^{T}}{b}$; K_B as for vertical bending	all P2a	Reduced overhang	**M3**

mode	EP Ref.		δ_S	∠	$\frac{Im\delta_S}{\rho b^4}$	$\frac{V}{f_T d_4}$	measured/predicted rule[1]	measured/predicted proposed[2]	$(\theta^\circ)_S$	$\frac{2K_a y_{max}}{10^{-3} b}$	$\left(\frac{\rho b^4}{Im}\right)\frac{10^3}{4\delta_S}\left(\frac{d_4}{b}\right)^{3.5}$	measured/predicted rule[3]	measured/predicted proposed[4]
1st	XP 2a	k/d₄ = 0.1	0.01	0	0.029	8.95	0.97	1.08	.4680	2.51	6.02	.42	.51
1st	XP 2a		0.02	0	0.057	8.95	0.97	1.08	.3530	1.90	3.01	.63	.76
1st	XP 2a		0.03	0	0.086	8.69	0.94	1.05	.2650	1.42	2.01	.71	.86
1st	XP		0.04	0							1.50		
1st	XP		0.05	0							1.20		
1st	XP		0.06	0							1.00		
1st	YP 2a	k/d₄ = 0.3	0.01	0	0.029	8.95	0.27	1.08	.4400	2.36	6.02	.39	.27
1st	YP		0.02	0									
1st	YP		0.03	0									
1st	YP		0.04	0									
1st	YP		0.05	0									
1st	YP		0.06	0									
1st	YP	k/d₄ = 0.4	0.01	0									
1st	YP		0.02	0									
1st	YP		0.03	0									
1st	YP		0.04	0									
1st	YP		0.05	0									
1st	YP		0.06	0									
1st	YP 2a	k/d₄ = 0.5	0.01	0	0.029	8.63	0.93	1.05	.5510	2.96	6.02	.49	.24
1st	YP		0.02	0									
1st	YP		0.03	0									
1st	YP		0.04	0									
1st	YP		0.05	0									
1st	YP		0.06	0									
1st	UP	Edge U	0.01	0				Stable					
1st	UP		0.02	0									
1st	UP		0.03	0									
1st	UP		0.04	0									
1st	UP		0.05	0									
1st	UP		0.06	0									
1st	U'P	Edge U'	0.01	0				Stable					
1st	U'P		0.02	0									
1st	U'P		0.03	0									
1st	U'P		0.04	0									
1st	U'P		0.05	0									
1st	U'P		0.06	0									

[1] c.f. 9.25
[2] c.f. 8.25
[3] without 3.0 factor
[4] with c factor

Test Results v. Current Rules - Vertical Bending - Table M3E3

EP ref. = Edge / Parapet reference					
Edge	K/d4	Parapet	h/d4	suffix	φ
X	0.05	P1	0.3	a	1/4
	U.N.O	P2	0.7	b	1/2
Y	0.20	P3	1.1	c	3/4
	U.N.O	P4	1.5	d	1

Model		Units	l/d4	b*/d4	b/d4	$(b/d_4)^{1.5}$	m/ρb²	K_R
M1	○	1	1	3	4 1/2	9.5		0.41
M2	○	1	1 1/2	3	5 1/2	12.9		0.37
M3	●	**2**	**1/2**	**7 1/2**	**8**	**22.6**	774	**0.31**
M4	○	2	1 1/2	7 1/2	10	31.6		0.27
M5	○	3	1	12	13 1/2	49.6		0.24
M6	○	3	1 1/2	12	14 1/2	55.2		0.23

-**NOTE :**

GENERAL NOTES	PARAPETS	MODEL REF.	
reduction for rough flow , $K_R = \frac{0.87}{\sqrt{8}} = 0.3076$;	additional P2b	Reduced overhang	**M3**

mode	EP Ref.		δ	∠	$\frac{m\delta_5}{\rho b^2}$	$\frac{V}{f_k d_4}$	measured/predicted rule[1]	measured/predicted proposed[2]	$\left(\frac{y_{max}}{d_4}\right)_5$	$\frac{K_R\, y_{max}}{10^{-3} d_4}$	$\left(\frac{\rho b^2}{m}\right)\frac{10^3}{4\delta s}\left(\frac{d^4}{b}\right)^{1.5}$	measured/predicted rule[3]	measured/predicted proposed[4]
2nd	XP 2b	k/d4 = 0.1	0.01	0	0.342	16.32	1.76	1.97	.0954	29.3	32.3	.91	.67
2nd	XP 2b		0.02	0	0.685	16.32	1.76		.0785	24.1	16.1	1.50	1.11
2nd	XP 2b		0.03	0	1.027	15.58	1.68		.0657	20.2	10.8	1.87	1.39
2nd	XP 2b		0.04	0	1.370	15.23	1.65		.0576	17.7	8.1	2.19	1.62
2nd	XP 2b		0.05	0	1.712	15.17	1.64		.0492	15.1	6.5	2.32	1.72
2nd	XP 2b		0.06	0	2.054	14.78	1.60	1.79	.0438	13.5	5.4	2.50	1.85
	YP	k/d4 = 0.3	0.01										
	YP		0.02										
	YP		0.03										
	YP		0.04										
	YP		0.05										
	YP		0.06										
	YP	k/d4 = 0.4	0.01										
	YP		0.02										
	YP		0.03										
	YP		0.04										
	YP		0.05										
	YP		0.06										
2nd	YP 2b	k/d4 = 0.5	0.01	0	0.342	15.92	1.72	1.93	.0890	27.6	32.3	.85	.33
2nd	YP 2b		0.02	0	0.685	15.41	1.66		.0731	22.5	16.1	1.40	.55
2nd	YP 2b		0.03	0	1.027	14.89	1.61		.0615	18.9	10.8	1.75	.69
2nd	YP 2b		0.04	0	1.370	14.84	1.60		.0545	16.8	8.1	2.07	.81
2nd	YP 2b		0.05	0	1.712	14.38	1.55		.0461	14.2	6.5	2.18	.85
2nd	YP 2b		0.06	0	2.054	14.33	1.55	1.74	.0412	12.7	5.4	2.35	.92
	UP 2a	Edge U	0.01										
	UP 2a		0.02										
	UP 2a		0.03										
	UP 2a		0.04										
	UP 2a		0.05										
	UP 2a		0.06										
	UP' 2a	Edge U'	0.01										
	UP' 2a		0.02										
	UP' 2a		0.03										
	UP' 2a		0.04										
	UP' 2a		0.05										
	UP' 2a		0.06										

[1] c.f. 9.25
[2] c.f. 8.25
[3] without 3.0 factor
[4] with c factor

Test Results v. Current Rules - Divergent TI - Table M3E3

EP ref. = Edge / Parapet reference					
Edge	K/d_1	Parapet	h/d_1	suffix	ϕ
X	0.05	P1	0.3	a	$^1/_4$
	U.N.O	P2	0.7	b	$^1/_2$
Y	0.20	P3	1.1	c	$^3/_4$
	U.N.O	P4	1.5	d	1

Model		Units	l/d_1	$h^* d_1$	b/d_1	$(b/d)^{1.5}$	$(b/d)^{3.5}$	
M1	○	1	1	3	4 $^1/_2$	9.5	193	
M2	○	1	1 $^1/_2$	3	5 $^1/_2$	12.9	390	
M3	●	2	$^1/_2$	7 $^1/_2$	8	22.6	1448	
M4	○	2	1 $^1/_2$	7 $^1/_2$	10	31.6	3162	
M5	○	3	1	12	13 $^1/_2$	49.6	9040	
M6	○	3	1 $^1/_2$	12	14 $^1/_2$	55.2	11609	

NOTE :

GENERAL NOTES	PARAPETS	MODEL REF.	
Divergent Torsional Instability	additional 2b	Reduced overhang	**M3**

EP Ref.		δ_S	∠	$\frac{Im\delta_S}{\rho b^4}$	$\frac{V_{crit}}{f_T b}$	predicted			measured / predicted (5.0)	measured / predicted (1.5)	3.3	
XP	$k/d_1 = 0.1$	0.01	0									
XP 2b		0.02	0	0.057	2.91	5 (or 1.5)	3.3		.58	1.94	.88	
XP		0.03	0									
XP 2b		0.04	0	0.114	3.51	5 (or 1.5)	3.3		.70	2.34	1.06	
XP		0.05	0									
XP 2b		0.06	0	0.171	3.78	5 (or 1.5)	3.3		.76	2.52	1.15	
YP	$k/d_1 = 0.3$	0.01	0									
YP		0.02	0									
YP		0.03	0									
YP		0.04	0									
YP		0.05	0									
YP		0.06	0									
YP	$k/d_1 = 0.4$	0.01	0									
YP		0.02	0									
YP		0.03	0									
YP		0.04	0									
YP		0.05	0									
YP		0.06	0									
YP	$k/d_1 = 0.5$	0.01	0									
YP 2a		0.02	0	0.057	3.16	5 (or 1.5)	3.3		.63	2.11	.96	
YP		0.03	0									
YP 2a		0.04	0	0.114	3.57	5 (or 1.5)	3.3		.71	2.38	1.08	
YP		0.05	0									
YP 2a		0.06	0	0.171	3.78	5 (or 1.5)	3.3		.76	2.52	1.15	
UP	Edge U	0.01	0									
UP		0.02	0									
UP		0.03	0									
UP		0.04	0									
UP		0.05	0									
UP		0.06	0									
U'P	Edge U'	0.01	0									
U'P		0.02	0									
U'P		0.03	0									
U'P		0.04	0									
U'P		0.05	0									
U'P		0.06	0									

Test Results *v.* Current Rules - Torsion - M3E3

EP ref. = Edge / Parapet reference					
Edge	K/d_s	Parapet	h/d_s	suffix	ϕ
X	0.05	P1	0.3	a	$^1/_4$
	U.N.O	P2	0.7	b	$^1/_2$
Y	0.20	P3	1.1	c	$^3/_4$
	U.N.O	P4	1.5	d	1

Model		Units	l/d_s	b^*/d_s	b/d_s	$(b/d_s)^{1.5}$	m/pb^2	K_R
M1	○	1	1	3	4 $^1/_2$	193		0.41
M2	○	1	1 $^1/_2$	3	5 $^1/_2$	390		0.37
M3	●	**2**	$^1/_2$	7 $^1/_2$	**8**	**1448**	**4127**	**0.31**
M4	○	2	1 $^1/_2$	7 $^1/_2$	10	3162		0.27
M5	○	3	1	12	13 $^1/_2$	9040		0.24
M6	○	3	1 $^1/_2$	12	14 $^1/_2$	11609		0.23

--NOTE :

GENERAL NOTES	PARAPETS	MODEL REF.	
$\theta = \frac{2y_{mm}}{b}^{T}$; K_R as for vertical bending	additional 2b	Reduced Overhang	**M3**

mode	EP Ref.		δ_S	∠	$\frac{Im\delta_S}{\rho b^4}$	$\frac{V}{f_1 d_s}$	measured / predicted rule[1]	measured / predicted proposed[2]	$(\theta^o)_S$	$\frac{2K_R y_{max}}{10^{-3} h}$	$\left(\frac{\rho b^4}{Im}\right)\frac{10^3}{45s}\left(\frac{d_s}{h}\right)^{1.5}$	measured / predicted rule[1]	measured / predicted proposed[4]
1st	XP 2b	$k/d_s = 0.1$	0.01	0	0.029	9.07	0.98	1.10	.9630	5.17	6.06	.85	.63
1st	XP 2b		0.02	0	0.057	8.84	0.96	1.07	.6160	3.31	3.03	1.09	.81
1st	XP 2b		0.03	0	0.086	8.87	0.96	1.08	.4500	2.42	2.02	1.20	.89
1st	XP 2b		0.04	0	0.114	8.72	0.94	1.06	.2790	1.50	1.51	.99	.73
1st	XP		0.05	0							1.21		
1st	XP		0.06	0							1.01		
	YP	$k/d_s = 0.3$	0.01	0									
	YP		0.02	0									
	YP		0.03	0									
	YP		0.04	0									
	YP		0.05	0									
	YP		0.06	0									
	YP	$k/d_s = 0.4$	0.01	0									
	YP		0.02	0									
	YP		0.03	0									
	YP		0.04	0									
	YP		0.05	0									
	YP		0.06	0									
1st	YP 2b	$k/d_s = 0.5$	0.01	0	0.029	9.16	0.99	1.11	1.151	6.18	6.06	1.02	.40
1st	YP 2b		0.02	0	0.057	9.01	0.97	1.09	0.737	3.96	3.03	1.31	.51
1st	YP 2b		0.03	0	0.086	8.87	0.96	1.08	0.462	2.48	2.02	1.23	.48
1st	YP		0.04	0									
1st	YP		0.05	0									
1st	YP		0.06	0									
	UP	Edge U	0.01	0									
	UP		0.02	0									
	UP		0.03	0									
	UP		0.04	0									
	UP		0.05	0									
	UP		0.06	0									
	U'P	Edge U'	0.01	0									
	U'P		0.02	0									
	U'P		0.03	0									
	U'P		0.04	0									
	U'P		0.05	0									
	U'P		0.06	0									

[1] c.f. 9.25
[2] c.f. 8.25
[3] without 3.0 factor
[4] with c factor

Futher Test Results *v.* Current Rules - Vertical Bending - Table M3F1

EP ref. = Edge / Parapet reference					
Edge	K/d_4	Parapet	h/d_4	suffix	ϕ
X	0.05	P1	0.3	a	1/4
	U.N.O	P2	0.7	b	1/2
Y	0.20	P3	1.1	c	3/4
	U.N.O	P4	1.5	d	1

Model	Units	l/d_4	b^*/d_4	b/d_4	$(b/d_4)^{1.5}$	$m/\rho b^2$	K_R
M1 ○	1	1	3	4 1/2	9.5		0.41
M2 ○	1	1 1/2	3	5 1/2	12.9		0.37
M3 ●	**2**	**1/4**	**7 1/2**	**7 1/2**	**20.5**	**816 or (709)**	**0.32**
M4 ○	2	1 1/2	7 1/2	10	31.6		0.27
M5 ○	3	1	12	13 1/2	49.6		0.24
M6 ○	3	1 1/2	12	14 1/2	55.2		0.23

NOTE :

GENERAL NOTES	PARAPETS	MODEL REF.	
reduction for rough flow , $K_R = \frac{0.87}{\sqrt{7\frac{1}{2}}} = 0.318$:	P2a, P2b	further reduced overhang.	**M3**

mode	EP Ref.	Edge d	δ_S	∠	$\frac{m\delta_S}{\rho b^2}$	$\frac{V}{f_b d_4}$	measured/predicted rule[1]	measured/predicted proposed[2]	$\left(\frac{y_{max}}{d_4}\right)_S$	$\frac{K_R y_{max}}{10^{-3} d_4}$	$\left(\frac{\rho b^2}{m}\right)\frac{10^3}{4\delta s}\left(\frac{d_4}{b}\right)^{1.5}$	measured/predicted rule[3]	measured/predicted proposed[4]
2nd	YP 2a	$b/d_4 = 0.3$	0.01	0	0.398	16.83	1.82	2.04	.0566	18.0	30.6	.59	.41
2nd	YP 2a		0.02	0	0.795	16.25	1.76		.0426	13.5	15.3	.89	.62
2nd	YP 2a		0.03	0	1.193	15.45	1.67		.0319	10.1	10.2	.99	.69
2nd	YP 2a		0.04	0	1.590	15.45	1.67		.0265	8.4	7.7	1.09	.76
2nd	YP 2a		0.05	0	1.988	14.87	1.61		.0227	7.2	6.1	1.18	.83
2nd	YP 2a		0.06	0	2.385	14.36	1.55	1.74	.0171	5.4	5.1	1.07	.75
	YP		0.01										
	YP		0.02										
	YP		0.03										
	YP		0.04										
	YP		0.05										
	YP		0.06										
2nd	YP 2a	$b/d_4 = 0.5$	0.01	0	0.398	17.52	1.89	2.12	.0652	20.7	30.6	.68	.34
2nd	YP 2a		0.02	0	0.795	16.65	1.80		.0511	16.2	15.3	1.06	.53
2nd	YP 2a		0.03	0	1.193	16.07	1.74		.0413	13.1	10.2	1.29	.64
2nd	YP 2a		0.04	0	1.590	15.79	0.17		.0349	11.1	7.7	1.44	.72
2nd	YP 2a		0.05	0	1.988	15.51	1.68		.0299	9.5	6.1	1.56	.77
2nd	YP 2a		0.06	0	2.385	15.51	1.68	1.88	.0249	7.9	5.1	1.55	.77
2nd	YP 2b	$K/d_4 = 0.5$	0.01	0	0.398	16.14	1.74	1.95	.0898	28.6	30.6	.93	.36
2nd	YP 2b		0.02	0	0.795	15.62	1.69		.0706	22.4	15.3	1.47	.58
2nd	YP 2b		0.03	0	1.193	14.76	1.60		.0582	18.5	10.2	1.81	.71
2nd	YP 2b		0.04	0	1.590	14.53	1.57		.0503	16.0	7.7	2.08	.82
2nd	YP 2b		0.05	0	1.988	14.24	1.54		.0451	14.3	6.1	2.35	.92
2nd	YP 2b		0.06	0	2.385	13.96	1.51	1.69	.0398	12.7	5.1	2.48	.97
	P		0.01										
	P		0.02										
	P		0.03										
	P		0.04										
	P		0.05										
	P		0.06										
2nd	U'P 2a	Edge U'	0.01	0	0.394	15.76	1.84	2.06	.0774	25.7	35.2	.73	.36
2nd	U'P 2a		0.02	0	0.788	15.23	1.78		.0657	21.8	17.6	1.24	.61
2nd	U'P 2a		0.03	0	1.182	14.71	1.72		.0554	18.4	11.7	1.57	.78
2nd	U'P 2a		0.04	0	1.576	14.45	1.69		.0492	16.3	8.8	1.86	.92
2nd	U'P 2a		0.05	0	1.969	15.24	1.66		.0450	14.9	7.0	2.13	1.05
2nd	U'P 2a		0.06	0	2.363	14.24	1.66	1.86	.0407	13.5	5.9	2.29	1.13

[1] c.f. 9.25
[2] c.f. 8.25
[3] without 3.0 factor
[4] with c factor

Further Test Results *v.* Current Rules - Divergent TI - Table M3F1

EP ref. = Edge / Parapet reference					
Edge	K/d_4	Parapet	h/d_4	suffix	ϕ
X	0.05	P1	0.3	a	$^1/_4$
	U.N.O	P2	0.7	b	$^1/_2$
Y	0.20	P3	1.1	c	$^3/_4$
	U.N.O	P4	1.5	d	1

Model		Units	l/d_4	b*/d_4	b/d_4	$(b/d)^{1.5}$	$(b/d)^{3.5}$	
M1	○	1	1	3	4 $^1/_2$	9.5	193	
M2	○	1	1 $^1/_2$	3	5 $^1/_2$	12.9	390	
M3	●	**2**	$^1/_4$	**7 $^1/_2$**	**7 $^1/_2$**	**20.5**	**1155**	
M4	○	2	1 $^1/_2$	7 $^1/_2$	10	31.6	3162	
M5	○	3	1	12	13 $^1/_2$	49.6	9040	
M6	○	3	1 $^1/_2$	12	14 $^1/_2$	55.2	11609	

NOTE :

GENERAL NOTES	PARAPETS	MODEL REF.	
Divergent Torsional Instability	P2a, 2b	further Reduced overhang	**M3**

EP Ref.		δ_S	∠	$\frac{Im\delta_S}{pb^4}$	$\frac{V_{dTI}}{f_t b}$	*predicted	or 3.3		measured / predicted (5.0)	(N/A)	3.3	
XP	h/d_4 = 0.3	**0.01**	**0**									
XP 2b		**0.02**	**0**	**.0815**	**3.70**	**5.0**	**3.3**		**.74**		**1.12**	
XP		**0.03**	**0**									
XP 2b		**0.04**	**0**	**.1630**	**3.97**	**5.0**	**3.3**		**.79**		**1.20**	
XP		**0.05**	**0**									
XP 2b		**0.06**	**0**	**.2445**	**4.22**	**5.0**	**3.3**		**.84**		**1.28**	
YP		**0.01**	**0**									
YP		**0.02**	**0**									
YP		**0.03**	**0**									
YP		**0.04**	**0**									
YP		**0.05**	**0**									
YP		**0.06**	**0**									
YP	h/d_4 = 0.5	**0.01**	**0**									
YP 2a		**0.02**	**0**	**.0815**	**3.56**	**5.0**	**3.3**		**.71**		**1.08**	
YP		**0.03**	**0**									
YP 2a		**0.04**	**0**	**.1630**	**3.81**	**5.0**	**3.3**		**.76**		**1.15**	
YP		**0.05**	**0**									
YP 2a		**0.06**	**0**	**.2445**	**4.04**	**5.0**	**3.3**		**.81**		**1.22**	
YP	h/d_4 = 0.5	**0.01**	**0**									
YP 2b		**0.02**	**0**	**.0838**	**3.22**	**5.0**	**3.3**		**.64**		**.98**	
YP		**0.03**	**0**									
YP 2b		**0.04**	**0**	**.1675**	**3.77**	**5.0**	**3.3**		**.75**		**1.14**	
YP		**0.05**	**0**									
YP 2b		**0.06**	**0**	**.2513**	**4.10**	**5.0**	**3.3**		**.82**		**1.24**	
UP		**0.01**	**0**									
UP		**0.02**	**0**									
UP		**0.03**	**0**									
UP		**0.04**	**0**									
UP		**0.05**	**0**									
UP		**0.06**	**0**									
YP	Edge U'	**0.01**	**0**									
YP 2a		**0.02**	**0**	**.0774**	**3.04**	**5.0**	**3.3**		**.61**		**.92**	
YP		**0.03**	**0**									
YP 2a		**0.04**	**0**	**.1547**	**3.53**	**5.0**	**3.3**		**.71**		**1.07**	
YP		**0.05**	**0**									
YP 2a		**0.06**	**0**	**.2321**	**3.78**	**5.0**	**3.3**		**.76**		**1.14**	

Futher Test Results v. Current Rules - Torsion - Table M3F1

EP ref. = Edge / Parapet reference					
Edge	K/d_4	Parapet	h/d_4	suffix	φ
X	0.05	P1	0.3	a	$^1/_4$
	U.N.O	P2	0.7	b	$^1/_2$
Y	0.20	P3	1.1	c	$^3/_4$
	U.N.O	P4	1.5	d	1

Model	Units	l/d_4	b*/d_4	b/d_4	$(b/d_4)^{1.5}$	m/ρb^2	K_B
M1 ○	1	1	3	4 $^1/_2$	193		0.41
M2 ○	1	1 $^1/_2$	3	5 $^1/_2$	390		0.37
M3 ●	2	$^3/_4$	7 $^1/_2$	7 $^1/_2$	1155	4608 or 3289	0.32
M4 ○	2	1 $^1/_2$	7 $^1/_2$	10	3162		0.27
M5 ○	3	1	12	13 $^1/_2$	9040		0.24
M6 ○	3	1 $^1/_2$	12	14 $^1/_2$	11609		0.23

NOTE :

GENERAL NOTES	PARAPETS	MODEL REF.	
$\theta = \frac{2y_{max}}{b}^{T}$; K_H as for vertical bending	P2a, P2b	further reduced overhang	**M3**

mode	EP Ref.	Edge d	δ_S	∠	$\frac{Im\delta_S}{\rho b^4}$	$\frac{V}{f_1 d_4}$	measured/predicted rule[1]	measured/predicted proposed[2]	$(\theta^o)_S$	$\frac{2K_H y_{max}}{10^{-3}b}$	$\left(\frac{\rho b^4}{Im}\right)\frac{10^3}{45s}\left(\frac{d_4}{b}\right)^{1.5}$	measured/predicted rule[3]	measured/predicted proposed[4]
	YP 2a	k/d_4 = 0.3	0.01	0	0.040	8.55	0.92	1.04	0.451	2.52	5.43	.46	.32
	YP 2a		0.02	0	0.080	8.19	0.88	0.99	0.207	1.16	2.71	.43	.30
	YP		0.03	0							1.81		
	YP		0.04	0							1.36		
	YP		0.05	0							1.09		
	YP		0.06	0							0.90		
	YP		0.01										
	YP		0.02										
	YP		0.03										
	YP		0.04										
	YP		0.05										
	YP		0.06										
	YP 2a	k/d_4 = 0.5	0.01	0	0.040	8.55	0.92	1.04	0.508	2.84	5.43	.52	.26
	YP 2a		0.02	0	0.080	8.55	0.92	1.04	0.198	1.11	2.71	.41	.20
	YP 2a		0.03	0	0.120	9.24	1.00	1.12	0.061	0.34	1.81	.19	.09
	YP		0.04	0									
	YP		0.05	0									
	YP		0.06	0									
	YP 2b	k/d_4 = 0.5	0.01	0	0.040	8.78	0.95	1.06	1.190	6.64	5.43	1.22	.48
	YP 2b		0.02	0	0.080	8.59	0.93	1.04	0.730	4.08	2.71	1.50	.59
	YP 2b		0.03	0	0.120	8.60	0.93	1.04	0.299	1.67	1.81	.92	.36
	YP		0.04	0									
	YP		0.05	0									
	YP		0.06	0									
	YP		0.01										
	YP		0.02										
	YP		0.03										
	YP		0.04										
	YP		0.05										
	YP		0.06										
	YP 2a	Edge U'	0.01	0	0.039	7.87	0.92	1.01	.442	2.56	7.60	.34	.17
	YP 2a		0.02	0	0.077	8.28	0.97	1.06	.216	1.25	3.80	.33	.16
	YP		0.03	0									
	YP		0.04	0									
	YP		0.05	0									
	YP		0.06	0									

[1] c.f. 9.25
[2] c.f. 8.25
[3] without 3.0 factor
[4] with c factor

Test Results *v.* Current Rules - Divergent TI - Table M3X & Y

EP ref. = Edge / Parapet reference					
Edge	K/d_4	Parapet	h/d_4	suffix	ϕ
X	0.05	P1	0.3	a	$^1/_4$
		P2	0.7	b	$^1/_2$
Y	0.20	P3	1.1	c	$^3/_4$
		P4	1.5	d	1

Model		Units	l/d_4	b^*/d_4	b/d_4	$(b/d)^2$	$m/\rho b^2$	
M1	●	1	1	3	4 $^1/_2$	20		
M2	○	1	1 $^1/_2$	3	5 $^1/_2$	30		
M3	○	2	1	7 $^1/_2$	9	81		
M4	○	2	1 $^1/_2$	7 $^1/_2$	10	100		
M5	○	3	1	12	13 $^1/_2$	182		
M6	○	3	1 $^1/_2$	12	14 $^1/_2$	210		

NOTE :

GENERAL NOTES	PARAPETS	MODEL REF.
Initially $C_g \rightarrow 1.0$	X & Y: 2a,b; 3a,b	**M3**

EP Ref.	δ_S	∠	$\frac{Im\delta_s}{\rho b^4}$	$\frac{V_g}{f_f d}$		<u>or</u>		measured / predicted (5.0)	(1.3)	<u>3.3</u>	
XP 2a	0.02	0	.0569	4.90	5 (or 1.3)	3.3		.98	3.8	1.48	
YP 2a	0.02	0	.0569	4.71	5 (or 1.3)	3.3		.94	3.6	1.42	
XP 2a	0.04	0	.1138	5.22	5 (or 1.3)	3.3		1.04	4.0	1.58	
YP 2a	0.04	0	.1138	4.92	5 (or 1.3)	3.3		.98	3.8	1.48	
XP 2a	0.06	0	.1707	5.35	5 (or 1.3)	3.3		1.07	4.1	1.62	
YP 2a	0.06	0	.1707	5.10	5 (or 1.3)	3.3		1.02	3.9	1.55	
XP 2b	0.02	0	.0569	2.90	5 (or 1.3)	3.3		.58	2.2	.88	
YP 2b	0.02	0	.0569	3.13	5 (or 1.3)	3.3		.63	2.4	.95	
XP 2b	0.04	0	.1138	3.13	5 (or 1.3)	3.3		.63	2.4	.95	
YP 2b	0.04	0	.1138	3.48	5 (or 1.3)	3.3		.70	2.7	1.06	
XP 2b	0.06	0	.1707	3.70	5 (or 1.3)	3.3		.74	2.8	1.12	
YP 2b	0.06	0	.1707	3.69	5 (or 1.3)	3.3		.74	2.8	1.12	
XP 3a	0.02	0	.0569	4.55	5 (or 1.3)	3.3		.91	3.5	1.38	
XP 3a	0.02	0	.0569	5.08	5 (or 1.3)	3.3		1.02	3.9	1.55	
XP 3a	0.04	0	.1138	4.72	5 (or 1.3)	3.3		.94	3.6	1.42	
XP 3a	0.04	0	.1138	5.34	5 (or 1.3)	3.3		1.07	4.1	1.62	
XP 3a	0.06	0	.1707	5.01	5 (or 1.3)	3.3		1.00	3.8	1.52	
XP 3a	0.06	0	.1707	5.52	5 (or 1.3)	3.3		1.10	4.2	1.67	
XP 3b	0.02	0	.0569	2.22	5 (or 1.3)	3.3		.44	1.7	.67	
YP 3b	0.02	0	.0569	2.85	5 (or 1.3)	3.3		.57	2.2	.86	
XP 3b	0.04	0	.1138	2.80	5 (or 1.3)	3.3		.56	2.1	.85	
YP 3b	0.04	0	.1138	3.37	5 (or 1.3)	3.3		.67	2.6	1.02	
XP 3b	0.06	0	.1707	3.01	5 (or 1.3)	3.3		.60	2.3	.91	
YP 3b	0.06	0	.1707	3.89	5 (or 1.3)	3.3		.78	3.0	1.18	
XP	0.02										
YP	0.02										
XP	0.04										
YP	0.04										
XP	0.06										
YP	0.06										
XP 2b	0.02	0	.0569	3.47	5 (or 1.3) Turbulent Flow	3.3		.69	2.7	1.05	Turbulent Flow
YP	0.02	0									
XP 2b	0.04	0	.1138	3.76	5 (or 1.3)	3.3		.75	2.9	1.14	
YP	0.04	0									
XP 2b	0.06	0	.1707	4.12	5 (or 1.3)	3.3		.82	3.2	1.24	
YP	0.06	0									

Test Results *v.* Current Rules - Torsion - Table M3X & Y

EP ref. = Edge / Parapet reference					
Edge	K/d_4	Parapet	h/d_4	suffix	ϕ
X	0.05	P1	0.3	a	$^1/_4$
		P2	0.7	b	$^1/_2$
Y	0.20	P3	1.1	c	$^3/_4$
		P4	1.5	d	1

Model	Units	l/d_4	b^*/d_4	b/d_4	$(b/d_4)^{1.5}$	$m/\rho b^2$	K_R
M1 ○	1	1	3	4 $^1/_2$	193		0.41
M2 ○	1	1 $^1/_2$	3	5 $^1/_2$	390		0.37
M3 ●	2	1	7 $^1/_2$	9	2187	6233	0.29
M4 ○	2	1 $^1/_2$	7 $^1/_2$	10	3162		0.27
M5 ○	3	1	12	13 $^1/_2$	9040		0.24
M6 ○	3	1 $^1/_2$	12	14 $^1/_2$	11609		0.23

NOTE :

GENERAL NOTES	PARAPETS	MODEL REF.
$\theta = \frac{2y_{max}}{b}^{T}$; K_R as for vertical bending	X & Y : P2, 3, 4	**M3**

EP Ref.	δ_S	∠	$\frac{Im\delta_S}{\rho b^4}$	$\frac{V}{f_T d_4}$	measured/predicted rule[1]	measured/predicted proposed[2]	$(\theta^o)_{\delta}$	$\frac{2K_R y_{max}}{10^{-3}b}$	$\left(\frac{\rho b^4}{Im}\right)\frac{10^3}{4\delta s}\left(\frac{d_4}{b}\right)^{1.5}$	measured/predicted rule[3]	measured/predicted proposed[4]
YP 2a	.0138	0	.0393	8.45	0.91	1.02	.460	2.33	2.91	.80	.71
YP 2a	0.02	0	.0569	8.18	0.88		.280	1.42	2.00	.71	.63
YP 2a	0.03	0	.0854	7.96	0.86	0.96	.183	0.93	1.34	.69	.61
YP	0.04										
YP	0.05										
XP 2a	.01 - .06	0	All Stable				All Stable				
YP 2b	.0138	0	Stable				Stable				
YP	0.02				NB Also stable in				NB All M3X		
YP	0.03				Turbulent Flow				Results STABLE		
YP	0.04				(M3Xp2b)						
YP	0.05										
XP 2b	.01 - .06	0	All Stable				All Stable				
YP 3a	.0138	0	.0393	8.14	0.88	0.96	.353	1.79	2.91	.61	.43
YP	0.02										
YP	0.03										
YP	0.04										
YP	0.05										
XP 3a	.01 - .06	0	All Stable				All Stable				
YP 3b	.0138	0	Stable				Stable				
YP	0.02										
YP	0.03										
YP	0.04										
YP	0.05										
XP 3b	.01 - .06	0	All Stable				All Stable				
YP 2d	.0138	0	Stable				Stable				
YP	0.02										
YP	0.03										
YP	0.04										
YP	0.05										
XP 2d	.01 - .06	0	All Stable				All Stable				
YP 3d	.0138	0	.0393	9.15	0.99	1.11	.596	3.02	2.91	1.04	.27
YP	0.02	0	.0569	8.65	0.94		.357	1.81	2.00	.90	.23
YP	0.03	0	.0854	8.42	0.91	1.02	.250	1.27	1.34	.94	.24
YP	0.04										
YP 4d	.0138	0	.0393	7.64	0.83	0.93	.338	1.71	2.91	.59	.16
YP	0.02										

[1] c.f. 9.25
[2] c.f. 8.25
[3] without 3.0 factor
[4] with c factor

Test Results v. Current Rules - Vertical Bending - Table M3X

EP ref. = Edge / Parapet reference					
Edge	K/d_4	Parapet	h/d_4	suffix	ϕ
X	0.05	P1	0.3	a	$^1/_4$
		P2	0.7	b	$^1/_2$
Y	0.20	P3	1.1	c	$^3/_4$
		P4	1.5	d	1

Model	Units	l/d_4	b^*/d_4	b/d_4	$(b/d_4)^{1.5}$	$m/\rho b^2$	K_n
M1 ○	1	1	3	4 $^1/_2$	9.5		0.41
M2 ○	1	1 $^1/_2$	3	5 $^1/_2$	12.9		0.37
M3 ●	2	1	7 $^1/_2$	9	27.0	763	0.29
M4 ○	2	1 $^1/_2$	7 $^1/_2$	10	31.6		0.27
M5 ○	3	1	12	13 $^1/_2$	49.6		0.24
M6 ○	3	1 $^1/_2$	12	14 $^1/_2$	55.2		0.23

-**NOTE :**

GENERAL NOTES	PARAPETS	MODEL REF.
$K_n = 0.29$; Note changes 1st to 2nd mode	XP 2a-d, 3a, b	**M3**

	EP Ref.	δ	∠	$\frac{m\delta_s}{\rho h^2}$	$\frac{V}{f_n d_4}$	measured / predicted: rule[1]	measured / predicted: proposed[2]	$\left(\frac{y_{max}}{d_4}\right)_S$	$\frac{K_n y_{max}}{10^{-3} d_4}$	$\left(\frac{\rho h^2}{m}\right)\frac{10^3}{4\delta s}$	$\left(\frac{d^4}{h}\right)^{1.2}$	measured / predicted: rule[3]	measured / predicted: proposed[4]
2nd Vortex B	XP 2a	0.01	0	0.283	15.94	1.72	1.93	.0636	18.4	32.8	.17	.56	.68
	XP 2a	0.02	0	0.565	15.92	1.72		.0494	14.3	16.4		.87	1.05
	XP 2a	0.03	0	0.848	15.17	1.64		.0424	12.3	10.9		1.13	1.37
	XP 2a	0.04	0	1.130	15.19	1.64		.0362	10.5	8.2		1.28	1.55
	XP 2a	0.05	0	1.413	15.23	1.65		.0284	8.2	6.6		1.25	1.51
	XP 2a	0.06	0	1.696	15.19	1.64	1.84	.0226	6.6	5.5		1.19	1.44
1st Vortex B	XP 2b	0.01	0	0.283	15.28	1.65	1.85	.0654	19.0	32.8		.58	.43
	XP 2b	0.02	0	0.565	14.52	1.57		.0526	15.3	16.4		.93	.69
	XP 2b	0.03	0	0.848	14.52	1.57	Note Also:-	.0448	13.0	10.9		1.19	.88
	XP 2b	0.04	0	1.130	14.54	1.57	Stable in	.0378	11.0	8.2		1.34	.99
	XP 2b	0.05	0	1.413	13.77	1.49	Turbulent	.0308	8.9	6.6		1.35	1.00
	XP 2b	0.06	0	1.696	13.72	1.48	Flow	.0258	7.5	5.5		1.36	1.01
2nd Vortex B	XP 3a	0.01	0	0.283	15.31	1.65	1.85	.0650	18.8	32.8		.57	.51
	XP 3a	0.02	0	0.565	15.29	1.65		.0572	14.8	16.4		.91	.81
	XP 3a	0.03	0	0.848	14.52	1.57		.0422	12.2	10.9		1.12	.99
	XP 3a	0.04	0	1.130	14.52	1.57		.0370	10.7	8.2		1.31	1.16
	XP 3a	0.05	0	1.413	14.52	1.57		.0306	8.9	6.6		1.35	1.20
	XP 3a	0.06	0	1.696	14.12	1.53	1.72	.0252	7.3	5.5		1.33	1.18
2nd Vortex B	XP 3b	0.01	0	0.283	15.26	1.65	1.85	.0764	22.2	32.8		.68	.35
	XP 3b	0.02	0	0.565	14.47	1.56		.0604	17.5	16.4		1.07	.55
	XP 3b	0.03	0	0.848	14.44	1.56		.0532	15.4	10.9		1.42	.73
	XP 3b	0.04	0	1.130	14.44	1.56		.0452	13.1	8.2		1.60	.82
	XP 3b	0.05	0	1.413	14.44	1.56		.0366	10.6	6.6		1.61	.83
	XP 3b	0.06	0	1.696	14.48	1.56	1.75	.0300	8.7	5.5		1.58	.81
2nd Vortex B	XP 2d	0.01	0	0.283	22.36	2.42	2.71	.1172	34.0	32.8		1.04	.43
	XP 2d	0.02	0	0.565	21.45	2.32		.0960	27.8	16.4		1.70	.71
	XP 2d	0.03	0	0.848	20.72	2.24		.0856	24.8	10.9		2.28	.95
	XP 2d	0.04	0	1.130	19.95	2.16		.0750	21.7	8.2		2.65	1.10
	XP 2d	0.05	0	1.413	19.99	2.16		.0712	20.6	6.6		3.13	1.30
	XP 2d	0.06	0	1.696	19.23	2.08	2.33	.0618		5.5		3.26	1.36
	XP	0.01											
	XP	0.02											
	XP	0.03											
	XP	0.04											
	XP	0.05											
	XP	0.06											

[1] c.f. 9.25
[2] c.f. 8.25
[3] without 3.0 factor
[4] with c factor

Test Results *v.* Current Rules - Vertical Bending - Table M3Y

EP ref. = Edge / Parapet reference					
Edge	K/d_4	Parapet	h/d_4	suffix	ϕ
X	0.05	P1	0.3	a	$^1/_4$
		P2	0.7	b	$^1/_2$
Y	0.20	P3	1.1	c	$^3/_4$
		P4	1.5	d	1

Model	Units	l/d_4	b^*/d_4	b/d_4	$(b/d_4)^{1.5}$	$m/\rho b^2$	K_n
M1 ○	1	1	3	4 $^1/_2$	9.5		0.41
M2 ○	1	1 $^1/_2$	3	5 $^1/_2$	12.9		0.37
M3 ●	2	1	7 $^1/_2$	9	27.0	763	0.29
M4 ○	2	1 $^1/_2$	7 $^1/_2$	10	31.6		0.27
M5 ○	3	1	12	13 $^1/_2$	49.6		0.24
M6 ○	3	1 $^1/_2$	12	14 $^1/_2$	55.2		0.23

- **NOTE :**

GENERAL NOTES	PARAPETS	MODEL REF.
K_n = 0.29 : Note changes 1st to 2nd mode	YP 2a to d, 3a to d	**M3**

	EP Ref.	δ	∠	$\frac{m\delta_s}{\rho b^2}$	$\frac{V}{f_s d_4}$	measured / predicted: rule[1]	measured / predicted: proposed[2]	$\left(\frac{y_{max}}{d_4}\right)_S$	$\frac{K_n y_{max}}{10^{-3} d_4}$	$\left(\frac{\rho b^2}{m}\right)\frac{10^3}{4\delta s}\left(\frac{d^4}{b}\right)^{1.5}$	measured / predicted: rule[3]	measured / predicted: proposed[4]
All Second Vortex Bending	YP 2a	0.01	0	0.283	14.13	1.53	1.71	.0366	10.6	32.8	.32	.28
	YP 2a	0.02	0	0.565	13.73	1.48		.0228	6.6	16.4	.40	.36
	YP 2a	0.03	0	0.848	12.92	1.40		.0176	5.1	10.9	.47	.42
	YP 2a	0.04	0	1.130	12.53	1.35		.0094	2.7	8.2	.33	.29
	YP 2a	0.05	0	1.413	12.15	1.31	1.47	.0038	1.1	6.6	.17	.15
	YP	0.06	0									
	YP 2b	0.01	0	0.283	14.72	1.59	1.78	.0744	21.6	32.8	.66	.40
	YP 2b	0.02	0	0.565	14.26	1.54		.0520	15.1	16.4	.92	.56
	YP 2b	0.03	0	0.848	13.89	1.50		.0356	10.3	10.9	.95	.58
	YP 2b	0.04	0	1.130	13.50	1.46		.0184	5.3	8.2	.65	.39
	YP 2b	0.05	0	1.413	13.23	1.43	1.60	.0034	1.0	6.6	.15	.09
	YP	0.06	0									
	YP 3a	0.01	0	0.283	13.66	1.55	1.74	.0932	12.1	32.8	.37	.26
	YP 3a	0.02	0	0.565	13.20	1.55		.0654	6.6	16.4	.40	.28
	YP 3a	0.03	0	0.848	12.42	1.46		.0492	3.2	10.9	.30	.21
	YP 3a	0.04	0	1.130	12.46	1.46	1.64	.0040	0.6	8.2	.08	.06
	YP	0.05	0									
	YP	0.06	0									
1st Vortex B	YP 3b	0.01	0	0.283	14.31	1.55	1.74	.0932	27.0	32.8	.82	.36
	YP 3b	0.02	0	0.565	14.31	1.55		.0654	19.0	16.4	1.16	.52
	YP 3b	0.03	0	0.848	13.54	1.46		.0492	14.3	10.9	1.31	.58
	YP 3b	0.04	0	1.130	13.54	1.46	1.64	.0040	1.2	8.2	.14	.06
	YP	0.05	0									
	YP	0.06	0									
2nd Vortex B	YP 2d	0.01	0	0.283	22.54	2.44	2.74	.1160	33.6	32.8	1.03	.38
	YP 2d	0.02	0	0.565	21.42	2.22		.0990	28.7	16.4	1.75	.65
	YP 2d	0.03	0	0.848	20.72	2.24		.0868	25.2	10.9	2.31	.86
	YP 2d	0.04	0	1.130	19.90	2.15		.0742	21.5	8.2	2.62	.97
	YP 2d	0.05	0	1.413	19.88	2.15		.0696	20.2	6.6	3.06	1.13
	YP 2d	0.06	0	1.696	19.13	2.07	2.32	.0602	17.5	5.5	3.17	1.17
2nd Vortex B	YP 3d	0.01	0	0.283	19.80	2.14	2.39	.1500	43.5	32.8	1.33	.34
	YP 3d	0.02	0	0.565	18.98	2.05		.1304	37.8	16.4	2.31	.59
	YP 3d	0.03	0	0.848	18.31	1.98		.1170	33.9	10.9	3.11	.80
	YP 3d	0.04	0	1.130	18.30	1.98		.1090	31.6	8.2	3.85	.99
	YP 3d	0.05	0	1.413	17.46	1.89		.1026	29.8	6.6	4.51	1.16
	YP 3d	0.06	0	1.696	17.47	1.89	2.12	.0958	27.8	5.5	5.05	1.29

5

[1] c.f. 9.25

[2] c.f. 8.25

[3] without 3.0 factor

[4] with c factor

[5] Note : for M3:YP4d see table M5Y

Test Results *v.* Current Rules - Divergent TI - Table M5X & Y

EP ref. = Edge / Parapet reference					
Edge	K/d_4	Parapet	h/d_4	suffix	ϕ
X	0.05	P1	0.3	a	$^1/_4$
		P2	0.7	b	$^1/_2$
Y	0.20	P3	1.1	c	$^3/_4$
		P4	1.5	d	1

Model	Units	l/d_s	b^*/d_s	b/d_s	$(b/d)^2$	$m/\rho h^2$	
M1 ○	1	1	3	4 $^1/_2$	20		
M2 ○	1	1 $^1/_2$	3	5 $^1/_2$	30		
M3 ○	2	1	7 $^1/_2$	9	81		
M4 ○	2	1 $^1/_2$	7 $^1/_2$	10	100		
M5 ●	**3**	**1**	**12**	**13 $^1/_2$**	**182**		
M6 ○	3	1 $^1/_2$	12	14 $^1/_2$	210		

NOTE :

GENERAL NOTES	PARAPETS	MODEL REF.
Initially $C_s \rightarrow 1.0$	X & Y : 2b, 3a, 3b	**M5**

EP Ref.	δ_S	∠	$\frac{Im\delta_s}{\rho h^2}$	$\frac{V_s}{f_r d}$		or		measured / predicted (5.0)	(0.9)	3.3	
YP	0.01										
YP	0.02										
YP	0.03										
YP	0.04										
YP	0.05										
YP	0.06										
XP 2b	0.02	0	.0174	3.28	5 (or 0.9)	3.3		.66	3.6	1.00	
YP 2b	0.02	0	.0170	3.54	5 (or 0.9)	3.3		.71	3.9	1.08	
XP 2b	0.04	0	.0347	3.32	5 (or 0.9)	3.3		.66	3.6	1.00	
YP 2b	0.04	0	.0347	3.61	5 (or 0.9)	3.3		.72	4.0	1.09	
XP 2b	0.06	0	.0521	3.42	5 (or 0.9)	3.3		.68	3.8	1.03	
YP 2b	0.06	0	.0521	3.68	5 (or 0.9)	3.3		.74	4.1	1.12	
XP 3a	0.02	0	.0174	3.82	5 (or 0.9)	3.3		.76	4.2	1.15	
YP 3a	0.02	0	.0170	4.30	5 (or 0.9)	3.3		.86	4.8	1.30	
XP 3a	0.04	0	.0347	3.92	5 (or 0.9)	3.3		.78	4.4	1.18	
YP 3a	0.04	0	.0347	4.38	5 (or 0.9)	3.3		.88	4.9	1.33	
XP 3a	0.06	0	.0521	3.96	5 (or 0.9)	3.3		.79	4.4	1.20	
YP 3a	0.06	0	.0521	4.43	5 (or 0.9)	3.3		.89	4.9	1.35	
XP 3b	0.02	0	.0174	2.86	5 (or 0.9)	3.3		.57	3.2	.86	
YP 3b	0.02	0	.0170	3.18	5 (or 0.9)	3.3		.64	3.5	.97	
XP 3b	0.04	0	.0347	2.95	5 (or 0.9)	3.3		.59	3.3	.89	
YP 3b	0.04	0	.0347	3.27	5 (or 0.9)	3.3		.65	3.6	.98	
XP 3b	0.06	0	.0521	3.03	5 (or 0.9)	3.3		.61	3.4	.92	
YP 3b	0.06	0	.0521	3.43	5 (or 0.9)	3.3		.69	3.8	1.05	
YP	0.01										
YP	0.02										
YP	0.03										
YP	0.04										
YP	0.05										
YP	0.06										
YP	0.01										
YP	0.02										
YP	0.03										
YP	0.04										
YP	0.05										
YP	0.06										

Test Results *v.* Current Rules - Divergent TI - Table M5X & Y

EP ref. = Edge / Parapet reference					
Edge	K/d_4	Parapet	h/d_4	suffix	ϕ
X	0.05	P1	0.3	a	$^1/_4$
		P2	0.7	b	$^1/_2$
Y	0.20	P3	1.1	c	$^3/_4$
		P4	1.5	d	1

Model	Units	l/d_4	b^*/d_4	b/d_4	$(b/d)^2$	$m/\rho b^2$	
M1 ○	1	1	3	4 $^1/_2$	20		
M2 ○	1	1 $^1/_2$	3	5 $^1/_2$	30		
M3 ○	2	1	7 $^1/_2$	9	81		
M4 ○	2	1 $^1/_2$	7 $^1/_2$	10	100		
M5 ●	**3**	**1**	**12**	**13 $^1/_2$**	**182**		
M6 ○	3	1 $^1/_2$	12	14 $^1/_2$	210		

NOTE :

GENERAL NOTES	PARAPETS	MODEL REF.
Initially C_g = 1.0	X & Y : 2b, 3a, 3b	**M5**

EP Ref.	δ_S	∠	$\frac{Im\delta_S}{\rho b^4}$	$\frac{V_g}{f_r d}$		or		measured / predicted (5.0)	(0.9)	3.3	
YP	0.01										
YP	0.02										
YP	0.03										
YP	0.04										
YP	0.05										
YP	0.06										
XP 2b	0.02	0	.0174	3.28	5 (or 0.9)	3.3		.66	3.6	1.00	
YP 2b	0.02	0	.0170	3.54	5 (or 0.9)	3.3		.71	3.9	1.08	
XP 2b	0.04	0	.0347	3.32	5 (or 0.9)	3.3		.66	3.6	1.00	
YP 2b	0.04	0	.0347	3.61	5 (or 0.9)	3.3		.72	4.0	1.09	
XP 2b	0.06	0	.0521	3.42	5 (or 0.9)	3.3		.68	3.8	1.03	
YP 2b	0.06	0	.0521	3.68	5 (or 0.9)	3.3		.74	4.1	1.12	
XP 3a	0.02	0	.0174	3.82	5 (or 0.9)	3.3		.76	4.2	1.15	
YP 3a	0.02	0	.0170	4.30	5 (or 0.9)	3.3		.86	4.8	1.30	
XP 3a	0.04	0	.0347	3.92	5 (or 0.9)	3.3		.78	4.4	1.18	
YP 3a	0.04	0	.0347	4.38	5 (or 0.9)	3.3		.88	4.9	1.33	
XP 3a	0.06	0	.0521	3.96	5 (or 0.9)	3.3		.79	4.4	1.20	
YP 3a	0.06	0	.0521	4.43	5 (or 0.9)	3.3		.89	4.9	1.35	
XP 3b	0.02	0	.0174	2.86	5 (or 0.9)	3.3		.57	3.2	.86	
YP 3b	0.02	0	.0170	3.18	5 (or 0.9)	3.3		.64	3.5	.97	
XP 3b	0.04	0	.0347	2.95	5 (or 0.9)	3.3		.59	3.3	.89	
YP 3b	0.04	0	.0347	3.27	5 (or 0.9)	3.3		.65	3.6	.98	
XP 3b	0.06	0	.0521	3.03	5 (or 0.9)	3.3		.61	3.4	.92	
YP 3b	0.06	0	.0521	3.43	5 (or 0.9)	3.3		.69	3.8	1.05	
YP	0.01										
YP	0.02										
YP	0.03										
YP	0.04										
YP	0.05										
YP	0.06										
YP	0.01										
YP	0.02										
YP	0.03										
YP	0.04										
YP	0.05										
YP	0.06										

Test Results *v.* Current Rules - Torsion - Table M5X & Y

EP ref. = Edge / Parapet reference					
Edge	K/d_4	Parapet	h/d_4	suffix	ϕ
X	0.05	P1	0.3	a	$^1/_4$
		P2	0.7	b	$^1/_2$
Y	0.20	P3	1.1	c	$^3/_4$
		P4	1.5	d	1

Model	Units	l/d_4	b^*/d_4	b/d_4	$(b/d_4)^{1.5}$	$m/\rho b^2$	K_B
M1 ○	1	1	3	4 $^1/_2$	193		0.41
M2 ○	1	1 $^1/_2$	3	5 $^1/_2$	390		0.37
M3 ○	2	1	7 $^1/_2$	9	2187		0.29
M4 ○	2	1 $^1/_2$	7 $^1/_2$	10	3162		0.27
M5 ●	**3**	**1**	**12**	**13 $^1/_2$**	**9040**	**7865**	**0.24**
M6 ○	3	1 $^1/_2$	12	14 $^1/_2$	11609		0.23

- **NOTE :**

GENERAL NOTES	PARAPETS	MODEL REF.
$\theta = \frac{2y_{max}}{b}^{T}$; K_B as for vertical bending	X & Y : P2, 3	**M5**

	EP Ref.	δ_S	∠	$\frac{Im\delta_S}{\rho b^4}$	$\frac{V}{f_2 d_4}$	measured / predicted: rule[1]	measured / predicted: proposed[2]	$(\theta^0)_S$	$\frac{2K_B y_{max}}{10^{-3} b}$	$\left(\frac{\rho b^4}{Im}\right)\frac{10^3}{4\delta s}\left(\frac{d_4}{b}\right)^{1.5}$	measured / predicted: rule[3]	measured / predicted: proposed[4]
	YP 2b	0.01	0	Stable				Stable				
	YP	0.02										
	YP	0.03										
	YP	0.04										
	YP	0.05										
	YP	0.06										
2nd Vortex T.	XP 2b	.0176	0	.0153	14.12	1.18	1.41	.354	1.48	1.81	.82	.61
2nd Vortex T.	XP 2b	0.02	0	.0174	14.11	1.18		.337	1.41	1.59	.89	.66
2nd Vortex T.	XP 2b	0.03	0	.0261	13.38	1.12		.251	1.05	1.06	.99	.73
2nd Vortex T.	XP 2b	0.04	0	.0347	13.38	1.12		.184	0.77	0.80	.96	.71
2nd Vortex T.	XP 2b	0.05	0	.0434	13.40	1.12		.119	0.50	0.64	.78	.58
2nd Vortex T.	XP 2b	0.06	0	.0521	12.76	1.06	1.28	.041	0.17	0.53	.32	.24
1st Vortex T.	XP 3a	.0176	0	.0153	13.86	1.16	1.39	.289	1.21	1.81	.67	.60
1st Vortex T.	XP 3a	0.02	0	.0174	13.86	1.16		.268	1.12	1.59	.71	.63
1st Vortex T.	XP 3a	0.03	0	.0261	13.77	1.16		.208	0.87	1.06	.82	.73
1st Vortex T.	XP 3a	0.04	0	.0347	13.78	1.15		.153	0.64	0.80	.80	.71
1st Vortex T.	XP 3a	0.05	0	.0434	13.78	1.15		.099	0.41	0.64	.65	.58
1st Vortex T.	XP 3a	0.06	0	.0521	13.79	1.15	1.38	.049	0.21	0.53	.39	.35
1st Vortex T.	XP 3b	.0176	0	.0153	13.83	1.16	1.38	.469	1.96	1.81	1.08	.55
1st Vortex T.	XP 3b	0.02	0	.0174	13.77	1.15		.441	1.85	1.59	1.16	.59
1st Vortex T.	XP 3b	0.03	0	.0261	13.79	1.15		.340	1.42	1.06	1.34	.69
1st Vortex T.	XP 3b	0.04	0	.0347	13.47	1.12		.280	1.17	0.80	1.47	.75
1st Vortex T.	XP 3b	0.05	0	.0434	13.18	1.10		.217	0.91	0.64	1.42	.73
1st Vortex T.	XP 3b	0.06	0	.0521	13.18	1.10	1.32	.151	0.63	0.53	1.19	.61
	YP 3a	.0176		.0153	7.44	0.62	0.74	.142	0.59	1.81	.33	.23
	YP 3a	0.02		.0174	7.47	0.62		.127	0.53	1.59	.33	.23
	YP 3a	0.03		.0261	7.49	0.62		.088	0.37	1.06	.35	.25
	YP 3a	0.04		.0347	7.44	0.62	0.74	.063	0.26	0.80	.33	.23
	YP	0.05										
	YP	0.06		All Stable				All Stable				
	YP 3b	.0176		.0153	13.56	1.13	1.36	.037	0.15	1.81	.09	.05
	YP	0.02										
	YP	0.03										
	YP	0.04										
	YP	0.05										
	YP	0.06										

[1] c.f. 12.0
[2] c.f. 10.0
[3] without 3.0 factor
[4] with c factor

Test Results *v.* Current Rules - Vertical Bending - Table M5X

EP ref. = Edge / Parapet reference					
Edge	K/d_4	Parapet	h/d_4	suffix	ϕ
X	0.05	P1	0.3	a	1/4
		P2	0.7	b	1/2
Y	0.20	P3	1.1	c	3/4
		P4	1.5	d	1

Model		Units	l/d_4	h^*/d_4	b/d_4	$(b/d_4)^{1.5}$	$m/\rho b^2$	K_R
M1	○	1	1	3	4 1/2	9.5		
M2	○	1	1 1/2	3	5 1/2	12.9		
M3	○	2	1	7 1/2	9	27.0		
M4	○	2	1 1/2	7 1/2	10	31.6		
M5	●	**3**	**1**	**12**	**13 1/2**	**49.6**	**802**	**0.24**
M6	○	3	1 1/2	12	14 1/2	55.2		

NOTE :

GENERAL NOTES	PARAPETS	MODEL REF.
$K_R = 0.24$	XP 2b, 3a, 3b	**M5**

EP Ref.	δ_S	∠	$\frac{m\delta_S}{\rho b^2}$	$\frac{V}{f_h d_4}$	measured/predicted		$\left(\frac{y_{max}}{d_4}\right)_S$	$\frac{K_R\, y_{max}}{10^{-3} d_4}$	$\left(\frac{\rho b^2}{m}\right)\frac{10^3}{45s}\left(\frac{d^4}{b}\right)^{1.5}$	measured/predicted	
					rule[1]	proposed[2]				rule[3]	proposed[4]
XP	0.01										
XP	0.02										
XP	0.03										
XP	0.04										
XP	0.05										
XP	0.06										
XP 2b	.0151	0	0.244	10.51	0.88	1.05	.0210	5.0	20.6	.24	.18
XP 2b	0.02	0	0.323	10.57	0.88		.0186	4.5	15.6	.29	.21
XP 2b	0.03	0	0.485	10.59	0.88		.0150	3.6	10.4	.35	.26
XP 2b	0.04	0	0.647	10.59	0.88		.0126	3.0	7.8	.39	.29
XP 2b	0.05	0	0.808	10.61	0.88		.0106	2.5	6.2	.41	.30
XP 2b	0.06	0	0.970	10.60	0.88	1.06	.0090	2.2	5.2	.42	.31
XP 3a	.0151	0	0.244	11.00	0.92	1.10	.0158	3.8	20.6	.18	.16
XP 3a	0.02	0	0.323	10.98	0.92		.0140	3.4	15.6	.21	.19
XP 3a	0.03	0	0.485	11.02	0.92		.0110	2.6	10.4	.25	.22
XP 3a	0.04	0	0.647	10.55	0.92		.0092	2.2	7.8	.28	.25
XP 3a	0.05	0	0.808	11.01	0.92		.0080	1.9	6.2	.31	.28
XP 3a	0.06	0	0.970	11.05	0.92	1.10	.0068	1.6	5.2	.31	.28
XP 3b	.0151	0	0.244	10.51	0.88	1.05	.0204	4.9	20.6	.24	.13
XP 3b	0.02	0	0.323	10.51	0.88		.0170	4.1	15.6	.26	.13
XP 3b	0.03	0	0.485	10.51	0.88		.0112	2.7	10.4	.26	.13
XP 3b	0.04	0	0.647	10.49	0.88	1.05	.0056	1.3	7.8	.17	.09
XP	0.05	0									
XP	0.06	0									
XP	0.01										
XP	0.02										
XP	0.03										
XP	0.04										
XP	0.05										
XP	0.06										
XP	0.01										
XP	0.02										
XP	0.03										
XP	0.04										
XP	0.05										
XP	0.06										

[1] c.f. 12.0
[2] c.f. 10.0
[3] without 3.0 factor
[4] with c factor

Test Results *v.* Current Rules - Vertical Bending - Table M5Y

EP ref. = Edge / Parapet reference					
Edge	K/d_4	Parapet	h/d_4	suffix	ϕ
X	0.05	P1	0.3	a	$^1/_4$
		P2	0.7	b	$^1/_2$
Y	0.20	P3	1.1	c	$^3/_4$
		P4	1.5	d	1

Model	Units	l/d_4	h^*/d_4	b/d_4	$(b/d_4)^{1.5}$	m/pb^2	K_R
M1 ○	1	1	3	4 $^1/_2$	9.5		
M2 ○	1	1 $^1/_2$	3	5 $^1/_2$	12.9		
M3 ○	2	1	7 $^1/_2$	9	27.0		
M4 ○	2	1 $^1/_2$	7 $^1/_2$	10	31.6		
M5 ●	**3**	**1**	**12**	**13 $^1/_2$**	**49.6**	**802**	**0.24**
M6 ○	3	1 $^1/_2$	12	14 $^1/_2$	55.2		

NOTE :

GENERAL NOTES	PARAPETS	MODEL REF.
$K_R = 0.24$	XP 2b, 3a, 3b	**M5**

EP Ref.	δ_S	∠	$\frac{m\delta_S}{pb^2}$	$\frac{V}{f_y d_4}$	measured / predicted		$\left(\frac{y_{max}}{d_4}\right)_s$	$\frac{K_R\, y_{max}}{10^{-3} d_4}$	$\left(\frac{\rho b^2}{m}\right)\frac{10^3}{48s}\left(\frac{d^4}{b}\right)^{1.5}$	measured / predicted	
					rule[1]	proposed[2]				rule[3]	proposed[4]
YP	0.01										
YP	0.02										
YP	0.03										
YP	0.04										
YP	0.05										
YP	0.06										
YP 2b	.0151	0	0.244	10.03	0.84	1.00	.0126	3.0	20.6	.15	.09
YP 2b	.0200	0	0.323	10.03	0.84	1.00	.0084	2.0	15.6	.13	.08
YP	.0300										
YP	.0400										
YP	.0500										
YP	.0600										
YP 3a	.0151	0	0.244	9.22	0.77	0.92	.0136	3.3	20.6	.16	.11
YP 3a	.0200	0	0.323	9.60	0.80		.0126	3.0	15.6	.19	.14
YP 3a	.0300	0	0.485	9.57	0.80	0.96	.0060	1.4	10.4	.14	.10
YP	.0400										
YP	.0500										
YP	.0600										
YP 3b	.0100		Stable								
YP	.0200										
YP	.0300										
YP	.0400										
YP	.0500										
YP	.0600										

[1] c.f. 12.0

[2] c.f. 10.0

Additional M3Y Test - See Table M3Y

1st V.B.	M3YP 4d	0.01	0	.283				N.A		32.8	N.A	N.A
1st V.B.	M3YP 4d	0.02	0	.565				N.A		16.4	N.A	N.A
	YP	0.03	0	← See notes on table M3Y →							N.A	N.A
2nd V.B.	M3YP 4d	0.04	0	1.130	18.08	1.95	2.19	.1962	56.9	8.2	6.94	1.36
2nd V.B.	M3YP 4d	0.05	0	1.413	18.12	1.96		.1756	50.9	6.6	7.71	1.51
2nd V.B.	M3YP 4d	0.06	0	1.696	17.49	1.89	2.12	.1590	46.1	5.5	8.38	1.64

[3] without 3.0 factor

[4] with c factor

Appendix C: Typical results from earlier studies on box girder bridges

Box Girder Test Results *v.* Current Rules - Vertical Bending - Table 3A

BR ref. = Barrier / Railing reference					
Barrier	b/d_4	Railing	h/d_4	suffix	ϕ
BO	No Barrier				
B1	0.15	R1	0.2	a	0.15
B2	0.34	R2	0.5	b	0.21
B3	0.37	R3	0.7	c	0.50
B4	0.50			d	1.00

Model	Units	l/d_4	b^*/d_4	h/d_4	$(h/d)^{1.5}$	K_R	
$8B_1$		1	4	6	14.7	0.355	
$8B_{1.5}$		$1\frac{1}{2}$	4	7	18.5	0.329	
3A		1	4	6	14.7	0.355	

NOTE :

GENERAL NOTES	Edge Beam	MODEL REF.	
	K/d_4 = 0.05	Box Girder	**3A**

BR ref.	δ_S	∠	$\frac{m\delta_S}{\rho b^2}$	$\frac{V}{f d_4}$		$\frac{y_{max}}{d_4}$	$\frac{K_R y_{max}}{10^{-3} d_4}$	$\left(\frac{\rho b^2}{m}\right)\frac{10}{4\delta_S}\left(\frac{d^4}{b}\right)^{1.5}$	measured / predicted: rule	measured / predicted: proposed
BO R2a	0.014		0.47	9.5		.270	9.59	36.00	.27	.72*
BO R2a	0.058		1.96	9.3		.010	3.55	8.68	.41	1.09*
BO R2a	0.115		3.89	9.6		.005	1.78	4.37	.41	1.09*
B4c R2a	0.014		0.47			.050	17.80	36.00	.49	.44
B4c R2a	0.058		1.96	11.0		.035	12.40	8.68	1.43	1.27
B4c R2a	0.115		3.89	10.4		.014	4.97	4.37	1.14	1.01
B4c R2a	0.173		5.83	10.0		.008	2.84	2.92	.97	.86
B4c R2a	0.014		0.47			.005	1.78	36.00	.05	.04
B4c R2a	0.014		0.47		2nd Peak	.050	17.80	36.00	.49	.44
B4c R2a	0.058		1.96	10.0		.016	5.68	8.68	.65	.58
B4c R2a	0.115		3.89	9.6		.007	2.49	4.37	.57	.51
B4c R2a	0.173		5.83	9.5		.005	1.78	2.92	.61	.54
B2b R2a	0.014		0.47	10.4		.021	7.46	36.00	.21	.41
B2b R2a	0.058		1.96	10.3		.012	4.26	8.68	.49	.95
B2b R2a	0.115		3.89	10.1		.007	2.49	4.37	.57	1.01
B2b R2a	0.173		5.83	10.0		.005	1.78	2.92	.61	1.19
B2b R2c	0.014		0.47	10.1		.031	11.00	36.00	.31	.27
B2b R2c	0.058		1.96	10.1		.026	9.23	8.68	1.06	.93
B2b R2c	0.115		3.89	10.3		.013	4.62	4.37	1.06	.93
B2b R2c	0.173		5.83	10.3		.008	2.84	2.92		
B1b R1c	0.014		0.47	9.5		.024	8.52	36.00	.24	.44
B1b R1c	0.058		1.96	9.2		.014	4.97	8.68	.57	1.05
B1b R1c	0.115		3.89	8.9		.007	2.49	4.37	.57	1.05
B1b R1c	0.173		5.83	8.9		.005	1.78	2.92	.61	1.12
B3d R2c	0.014		0.47	10.5		.050	17.80	36.00	.49	.24
B3d R2c	0.058		1.96	10.5		.025	8.88	8.68	1.02	.51
B3d R2c	0.115		3.89	10.6		.010	3.55	4.37	.81	.40
B3d R2c	0.173		5.83	10.1		.007	2.49	2.92	.85	.42
B1d R1c	0.014		0.47	9.4		.025	8.88	36.00	.25	.28
B1d R1c	0.058		1.96	9.2		.014	4.97	8.68	.57	.63
R1c	0.115		3.89	9.0		.007	2.49	4.37	.57	.63
R1c	0.173		5.83	9.1		.005	1.78	2.92	.61	0.68
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* Note c = 0.375 - very low - see table 3

Box Girder Test Results *v.* Current Rules - Vertical Bending - Table 8B

BR ref. = Barrier / Railing reference					
Barrier	b/d_4	Railing	h/d_4	suffix	ϕ
BO	No Barrier				
B1	0.15	R1	0.2	a	0.15
B2	0.34	R2	0.5	b	0.21
B3	0.37	R3	0.7	c	0.50
B4	0.50			d	1.00

Model	Units	l/d_4	b^*/d_4	b/d_4	$(b/d)^{1.5}$	K_α	
$8B_1$		1	4	6	14.7	0.355	
$8B_{1.5}$		1 ½	4	7	18.5	0.329	
3A		1	4	6	14.7	0.355	

NOTE :

GENERAL NOTES	Edge Beam	MODEL REF.	
$K_\alpha = 0.329$	$K/d_4 = 0.05$	Box Girder	**$8B_{1.5}$**

BR ref.	δ_s	∠	$\frac{m\delta_s}{\rho b^2}$	$\frac{V}{f d_4}$		$\frac{y_{max}}{d_4}$	$\frac{K_n y_{max}}{10^{-3} d_4}$	$\left(\frac{\rho b^2}{m}\right)\frac{10}{4\delta_s}\left(\frac{d^4}{b}\right)^{1.5}$	measured / predicted: rule	measured / predicted: proposed
BO R2a	0.014		0.346	7.3		.007	2.30	39.00	.06	.16*
BO R2a	0.014		0.346	13.3	2nd Peak	.018	5.92	39.00	.15	.40*
BO R2a	0.058		1.432	11.4	2nd Peak	.007	2.30	9.43	.24	.64*
BO R2a	0.014		0.346	9.6		.020	6.58	39.00	.17	.45*
BO R2a	0.058		1.432	9.7		.007	2.30	9.43	.24	.64*
BO R2a	0.014		0.346	9.6		.031	10.19	39.00	.26	.69*
BO R2a	0.058		1.432	9.2		.009	2.96	9.43	.31	.83*
BO R3c	0.014		0.346	10.2		.034	11.18	39.00	.29	.18
BO R3c	0.058		1.432	11.7		.015	4.93	9.43	.52	.19
BO R2d	0.014		0.346	5.5		.006	1.97	39.00	.05	.03
BO R2d	0.014		0.346	14.7	2nd Peak	.044	14.47	39.00	.37	.22
BO R2d	0.058		1.432	13.1		.026	8.55	9.43	.90	.55
BO R2d	0.115		2.840	12.5		.012	5.26	4.75	1.11	.67
BO R2d	0.173		4.270	12.0		.013	4.27	3.16	1.35	.82
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* Note c = 0.375 - very low - see table 3

Box Girder Test Results *v.* Current Rules - Vertical Bending - Table 8B

BR ref. = Barrier / Railing reference					
Barrier	b/d_4	Railing	h/d_4	suffix	ϕ
BO	No Barrier				
B1	0.15	R1	0.2	a	0.15
B2	0.34	R2	0.5	b	0.21
B3	0.37	R3	0.7	c	0.50
B4	0.5			d	1.00

Model	Units	l/d_4	b^*/d_4	b/d_4	$(b/d)^{1.5}$	K_R	
$8B_1$		1	4	6	14.7	0.355	
$8B_{1.5}$		1 ½	4	7	18.5	0.329	
3A		1	4	6	14.7	0.355	

NOTE :

GENERAL NOTES	Edge Beam	MODEL REF.	
	$K/d_4 = 0.05$	Box Girder	**$8B_1$**

BR ref.	δ_S	∠	$\frac{m\delta_S}{\rho b^2}$	$\frac{V}{f d_4}$		$\left(\frac{y_{max}}{d_4}\right)$	$\frac{K_R y_{max}}{10^{-3} d_4}$	$\left(\frac{\rho b^2}{m}\right)\frac{10}{4\delta_S}\left(\frac{d^4}{b}\right)^{1.5}$	measured / predicted: rule	measured / predicted: proposed
Bare Box	0.014		0.472	7.3		.037	13.10	36.00	.36	
	0.014		1.960	13.3		.015	5.33	8.68	.61	Bare Box
	0.058		3.890	11.4		.008	2.84	4.37	.65	rule
	0.014		5.830	9.6		.005	1.78	2.92	.61	N.A
BO R0	0.014		0.472	7.9		.018	6.39	36.00	.18	— II —
BO R2a	0.014		0.472	6.2		.005	1.78	36.00	.05	.13*
BO R2a	0.014		0.472	12.4	2nd Peak	.030	10.66	36.00	.30	.80*
BO R2a	0.058		1.960	11.5	2nd Peak	.016	5.68	8.68	.65	1.73*
BO R2a	0.115		3.890	10.7	2nd Peak	.008	2.84	4.37	.65	1.73*
BO R2a	0.014		0.472	8.9	2nd Peak	.010	3.55	36.00	.10	.27*
BO R2a	0.014		0.472	8.4		.026	9.23	36.00	.26	.69*
BO R2a	0.058		1.960	8.9		.007	2.49	8.68	.29	.77*
BO R3c	0.014		0.472	11.6		.012	4.26	36.00	.12	.07
BO R3d	0.014		0.472	11.7		.054	19.18	36.00	.53	.17
BO R3d	0.058		1.960	10.7		.034	12.08	8.68	1.39	.44
BO R3d	0.115		3.890	9.9		.021	7.46	4.37	1.71	.54
BO R3d	0.173		5.830	9.7		.014	4.97	2.92	1.70	.54
B4c R2a	0.014		0.472	6.4		.012	4.26	36.00	.12	.13
B4c R2a	0.014		0.472	11.9	2nd Peak	.026	9.23	36.00	.26	.28
B4c R2a	0.058		1.960	10.2	2nd Peak	.013	4.62	8.68	.53	.57
B4c R2a	0.115		3.890	9.9	2nd Peak	.007	2.49	4.37	.57	.62
B4c R2a	0.173		5.830	9.9	2nd Peak	.005	1.78	2.92	.61	.67
B4c R										
B4c R2a	0.014		0.472	6.5		.008	2.84	36.00	.08	.09
B4c R2a	0.014		0.472	10.5	2nd Peak	.017	6.04	36.00	.17	.18
B4c R2a	0.058		1.960	10.1		.008	2.84	8.68	.33	.36
B4c R2a										
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* Note c = 0.375 - very low - see table 3

Abstract

Highways Agency Standard BD 49: *Design rules for aerodynamic effects on bridges* was first published in 1993 and contains simplified methods for determining the susceptibility of bridge decks to aerodynamic instability. The standard was devised based on information available at that time. However, it contained a number of caveats for some deck configurations and geometry, particularly in relation to plate girder bridges. Following later studies, experience of application and additional wind tunnel data, some of the clauses of BD 49 were revised and the document was re-published in 2001. The background to this update is reported in TRL Report TRL528.

This report describes a programme of wind tunnel tests that was carried out on plate girder bridges to provide information for this revision. Over 60 different configurations were tests, using different parapets and leading edge details. The report describes the models, the wind tunnel characteristics and the conclusions from the tests. The wind tunnel data are presented in a form that can be used directly by engineers to assess the susceptibility different bridge forms to aerodynamic instability in cases were the simplified rules in BD 49 indicate the possibility of aerodynamic effects.

Related publications

TRL528 *Background to the development of BD 49/01: Design rules for aerodynamic effects on bridges* by B W Smith, T A Wyatt, D K McKenzie, M V Hubband and A F Daly. 2002 (price £25, code E)

CR256 *A re-appraisal of certain aspects of the design rules for bridge aerodynamics* by Flint and Neill Partnership. 1992 (price £25, code E)

CR36 *Partial safety factors for bridge aerodynamics rules and requirements for wind tunnel testing* by Flint and Neill Partnership. 1986 (price £35, code H)

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