MRTS90

Modular Bridge Expansion Joints

APPENDIX A

Design Methodology

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A1 *General*

Appendix A describes the approach to design of the MBEJ in conjunction with the requirements of fatigue, strength and serviceability as outlined in Clause 6 of this Standard.

The provisions of this appendix assume that the MBEJ is perpendicular to the direction of traffic. For a skewed MBEJ, additional considerations shall be necessary as outlined in Clause 1.3 of Annexure MRTS90.1.

A2 *Notation*

If a symbol is not defined locally where it is used, the following general notation shall apply –

Symbols

B_c = width of centre beam at top

B_w = width of tyre footprint in direction perpendicular to traffic

f^* = design stress range

f_5 = Detail Category fatigue strength at cut-off limit (at 10^8 i.e. infinite number of cycles)

f_{rn} (in MPa) = fatigue Detail Category defined in AS 5100.6, which is the uncorrected fatigue strength at 2×106 cycles

f_u = ultimate tensile strength used in design

f_y = yield stress used in design

g_c = gap between centre beams at appropriate joint opening

H* = design longitudinal load

J = joint opening at top (clear gap between edge beams)

L_w = length of tyre footprint in direction parallel to traffic

Q* = design vertical load

R = support reaction

R_{lim} = nominal strength for the appropriate limit state

S* = design action in general

T* = design transverse load

W = Wheel load

α = Dynamic Load Allowance defined in AS 5100.2

β = distribution factor (fraction of wheel load carried by one centre beam)

χ = Dynamic Amplification Factor (DAF)

η = ratio of longitudinal load to vertical load

τ = ratio of transverse load to vertical load

ϕ = capacity reduction factor

γ = load factor

Subscripts

The above symbols may be qualified by one or more of the following subscripts −

f = value at fatigue limit state

s = value at serviceability limit state

u = value at strength limit state

avg = average

dn = downward component

max = maximum

min = minimum

up = upward component

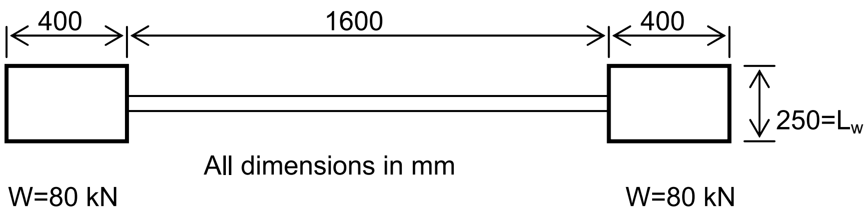
A3 *Joint Opening*

The expansion joint openings for design for the limit states of fatigue (J_f), strength (J_u) and serviceability (J_s) shall be as stated in Clause 1.1 of Annexure MRTS90.1.

A4 *Axle Load*

The static axle load is the A160 axle defined in AS 5100.2 and illustrated below for reference. It comprises two wheel loads of 80 kN with contact areas shown in Figure A4.

Figure A4 – A160 Design Axle



The axle shall be placed anywhere along the centre beam for maximum effects; however, the centre of the wheel need not be closer than 600 mm from the face of the kerb for the fatigue and serviceability limit states and 300 mm for the strength limit states.

A5 *Load Factors*

The axle load shall be factored by γ for the appropriate limit state under consideration, as follows:

$\gamma_f = 0.6$	for the fatigue limit state	*(A.1a)*
$\gamma_u = 1.8$	for the strength limit state	*(A.1b)*
$\gamma_s = 1.0$	for the serviceability limit state	*(A.1c)*

A6 *Distribution Factor*

The maximum wheel load carried by one centre beam is βW where the Distribution Factor (β) is given by

$$\beta = \frac{B_c + g_c}{L_w} \qquad 0.5 \le \beta \le 0.8 \qquad (A.2)$$

The gap g_c shall be calculated for the appropriate joint opening (J_f, J_u or J_c) depending on the limit state under consideration.

The remaining wheel load is divided equally between the two adjacent centre beams or between a centre beam and edge beam, depending on the position of the wheel.

A7 *Horizontal Force Factors*

Horizontal forces at each wheel shall be applied to the top of the centre beams to account for forces due to traction, braking or acceleration, centrifugal force, etc.

The longitudinal force, in the direction of traffic, is given by ηW, where the factor η shall be as stated in Clause 1.2 of Annexure MRTS90.1.

If the MBEJ is located on a curve or significant crossfall, transverse forces shall be applied at the top of the centre beams. The transverse force under each wheel is τW, where the factor τ shall be as stated in Clause 1.2 of Annexure MRTS90.1.

If the MBEJ is skewed to the direction of traffic, the forces ηW and τW shall be resolved in directions normal and axial to the centre beams, for design of the members.

A8 *Dynamic Amplification Factor*

The static axle load is multiplied by a factor (χ) to account for dynamic effects.

For components not subject to vibrations, such as support boxes and edge beams –

$$\chi_o = 1.6 \tag{A.3}$$

For centre beams, support bars and associated components, the DAF shall be derived by one of the three methods outlined in Clause A10. Further, the DAF comprises an upward component (χ_{up}) and a downward component (χ_{dn}), given by –

$$\chi_{up} = 0.33\chi \tag{A.4a}$$

$$\chi_{dn} = 0.67\chi \tag{A.4b}$$

For computing the stress range for the fatigue limit state, the DAF is –

$$\chi_f = \chi_{up} + \chi_{dn} \tag{A.5}$$

For the strength limit state –

$$\chi_u = \chi_{dn} \tag{A.6}$$

For the serviceability limit state –

$$\chi_s = \chi_{dn} \tag{A.7}$$

A9 *Design Loads*

The design loads due to each wheel, applied to the top of the critical centre beam, for each limit state, are as stated below.

The vertical design load is –

$$Q^* = \gamma\beta\chi W \tag{A.8}$$

The longitudinal design load, in the direction of traffic, is –

$$H^* = \gamma\beta\eta W \tag{A.9}$$

The transverse design load, if applicable, is –

$$T^* = \gamma\beta\tau W \tag{A.10}$$

The appropriate values of the factors γ and χ shall be used, as per Clauses A5 and A8, for the limit state under consideration.

The centre beam shall be analysed as a continuous beam on elastic supports, the spring stiffnesses of which are computed from the properties of the bearings of the support bars.

A10 *Alternative Methods for Evaluating DAF*

Evaluate the dynamic amplification factor by one of the following four methods:

Method 1: Design based on the simple static method recommended in NCHRP Report 402, with the following factors in lieu of the factors recommended by NCHRP:

χ = 2.5 for Multiple Support Bar Systems *(A.11a)*

χ = 2.5 for Single Support Bar Systems where damping of lowest frequency mode $\geq$ 0% of critical damping *(A.11b)*

χ = 3.0 for Single Support Bar Systems where damping of lowest frequency mode < 10% of critical damping *(A.11c)*

Method 2: Conduct an experimental modal analysis study in accordance with MRTS90 Appendix B, and obtain the maximum overall dynamic amplification factor, χ_{mod}. The factors to be used for design are –

$$\chi = 0.90\chi_{\text{mod}} \text{ for Multiple Support Bar Systems} \tag{A.12a}$$

$$\chi = 0.90\chi_{\text{mod}} \text{ for Single Support Bar Systems} \tag{A.12b}$$

However, the minimum value for χ_{mod} by this procedure shall not be less than 2.8.

The structural analysis may then be done by the simple static method recommended in NCHRP Report 402.

Method 3: Conduct dynamic strain gauge or 'over-roll' studies where comprehensive strain and/or displacement values for a typical heavy goods vehicle are measured over a range of speeds from slow-roll up to the statutory speed limit. The maximum overall dynamic amplification factor, χ_{dyn} shall be determined from the following relationship –

$$\chi_{dyn} = \frac{\varepsilon_{dyn}}{\varepsilon_{stat}} \tag{A.12c}$$

Where –

χ_{dyn} = dynamic amplification factor;

ε_{dyn} = Maximum strain or displacement due to the vehicle travelling at worst case speed; and

ε_{stat} = Maximum strain or displacement due to vehicle travelling at crawl (slow roll) speed.

However, the minimum value for χ_{dyn} by this procedure shall not be less than 3.125.

A11 *Limit States*

A11.1 General

The procedure for checking the limit states of fatigue, strength and serviceability shall generally comply with AS 5100.6. As a guide to designers not familiar with this Standard, its essential provisions are summarised in the following sections, for items that are expected to be applicable to the design of MBEJs. Nevertheless, all required provisions of AS 5100.6 shall be satisfied.

Equation 6.1 in Clause 6.4 of this Standard shall be satisfied for the three limit states. The design actions (S*) are the effects of Q*, H* and T* specified in Clause A9.

A11.2 Limit State of Fatigue

The action effect is the maximum resultant stress range due to the effects of Q^*_f, H^*_f and T^*_f.

If normal stresses (f_1 and f_2) act in two orthogonal directions, the resultant stress is –

$$f_r = \sqrt{f_1^2 + f_2^2} \tag{A.13}$$

If a normal stress (f) is to be combined with a shear stress (s), the principal stress is given by –

$$f_p = \frac{f}{2} + \sqrt{\left[\left(\frac{f}{2}\right)^2 + s^2\right]} \tag{A.14}$$

It is emphasised that fatigue stresses at connections shall most often be the critical items rather than stresses in main members. Some of the details and connections that need to be checked are detailed in Clause A12.

The capacity factor for fatigue (ϕ_f) shall be 1.0.

The resistance shall be the cut-off limit stress (f_5) defined in Section 13 of AS 5100.6, which is the resistance for infinite number of stress cycles (effectively 10^8 cycles). For certain standard details and connections employed for MBEJs, the fatigue detail categories have been classified in accordance with Table 13.5.1 of AS 5100 and corresponding values of f_5 extracted from Figure 13.6.1 of AS 5100 and the results given in Table A11.2.

Table A11.2 – Detail Classifications for Fatigue Based on AS 5100.6

Item	Member or Connection	Detail Category	Category f_{rn}	Illustration No.	Cut-off limit f_5 (MPa)
1	Centre beam, support bar	Polished steel bar	180		73
2	Flats for yokes	Rolled products	160	(1)	65
3	Yoke to centre beam at bolt hole	Bolted connection	140	(5)	57
4	Sliding plate welded to support bar	Cover plate welded full length, both sides	125	(9)	51
5	Centre beam splice	Butt weld, 100%NDT	112	(16)	45 β_{tf} Note 3
6	Centre beam to support bar	Butt weld with extra fillets	90	Note 1	36
7	Yoke to centre beam	Transverse butt weld	90	Note 2	36
8	Connections of yoke members	Shear stress in fillet weld	80	(39)	32
9	Sliding joint between centre beam and support bar	Local longitudinal weld for sliding device	80	(14)	32
10	Attachment for spring equidistancing buffer	Cleat attachments: t ≤12 mm t > 12 mm (t = thickness of cleat)	80 71	(35)(36)	32 29

Note:

a) The welded connection between centre beam and support bar is classified as Category C of AASHTO by NCHRP. This is approximately equivalent to Detail Category 90 of AS 5100.6.

b) The fatigue category for this connection is assumed equivalent to Category C of AASHTO.

c) β_{tf} is a "thickness correction factor" defined in AS 5100.6 and given by –

$$\beta_{tf} = \left[\frac{25}{t_p}\right]^{0.25}$$

where t_p is the thickness of the plate, i.e. width of the centre beam, in mm.

For details that do not fall into the above categories, an appropriate Detail Category shall be selected from Table 13.5.1 of AS 5100.6 and if no Category is deemed applicable, an authoritative reference shall be submitted to support the value of f_5 adopted.

A11.3 Limit State of Strength

The action effects shall be the bending moment, shear force and axial force due to the effects of Q^*_u, H^*_u and T^*_u.

The design strength shall be the section capacity and member capacity in bending and shear. Axial forces may also require consideration for skewed MBEJ or where T^*_u is significant.

The capacity reduction factor (ϕ_u) shall be as follows –

0.9 for structural steel members

0.8 for bolted connections

0.9 for SP Category complete penetration butt welds

0.8 for SP Category fillet welds

0.85 for shear stud connectors

For details not included in the above, refer to Table 3.2 of AS 5100.6.

The strength is based on the nominal yield stress (f_y) and tensile strength (f_u). For materials supplied to Australian Standards, the values in Table 2.1 of AS 5100.6 shall be used. Where materials are supplied to other Standards, such as ASTM, the values in these Standards are acceptable. The minimum values of f_y specified in Clause 6.4 of this Standard shall be complied with.

The section capacity in bending shall satisfy Clause 5.2 of AS 5100.6.

The member capacity of centre beams and support bars shall satisfy Clause 5.6 of AS 5100. The effective lengths of the members shall be as follows –

- For support bars, the length between centres of bearings at joint opening J_u;
- For overhanging portions of centre beams, twice the length of the cantilever; and
- For internal spans of centre beams, 0.7 times the span for centre beams welded to support bars and 1.2 times the span for centre beams connected to support bars by yokes.

The shear capacity shall be checked in accordance with Clause 5.10 of AS 5100.6.

Requirements for bolted, pin and welded connections are in Section 12 of AS 5100.6.

A11.4 Limit State of Serviceability

The requirements for noise and vibration, as outlined in relevant portions of this Standard, shall comprise the serviceability requirements.

The capacity reduction factor (ϕ_s) shall be 1.0 for structural steel members.

Capacity of bearings shall be checked for the serviceability limit state.

A12 *Fatigue Limit State Details*

A12.1 General

Calculate the stress ranges causing fatigue by applying the following loads to the MBEJ model –

$$Q^*_f = \gamma_f\, \beta_f\, \chi_f\, W \qquad (A.15a)$$

$$H^*_f = \gamma_f\, \beta_f\, \eta\, W \qquad (A.15b)$$

$$T^*_f = \gamma_f\, \beta_f\, \tau\, W \quad \text{if applicable} \qquad (A.15c)$$

A12.2 Centre Beams

The longitudinal bending stress due to vertical and horizontal loads Q^*_f and H^*_f plus the axial stress due to T^*_f, if any, shall comply with Item 1 in Table A5.

If centre beams are spliced, the fatigue stress in the butt weld shall be as per Item 5 in Table A5.

If yokes are connected by bolts to the centre beams, the stresses in the centre beams shall be based on the net section at the bolt holes. The stress range in the centre beam at the bolt hole shall be limited as per Item 3 in Table A5.

A12.3 Support Bars

Support bars shall be designed for the maximum loads transmitted by their individual centre beams in a multiple bar system, or for the total wheel load transmitted through 3 centre beams, in a single bar system. Any forces that may arise from deformations of the elastomers and frictional resistance within the MBEJ shall also be considered.

The stress range in the base metal of the support bar shall comply with Item 1 in Table A5.

To enable the support bar to slide smoothly between its support bearings, the support bar may have stainless steel slider plates welded to its top and bottom surfaces. If the welds are for the full length of the support bar, the maximum stress range shall comply with Item 4 in Table A5, whereas if the welding is near the supports only, with Item 9 in Table A5.

A12.4 Welded Connection Between Support Bar and Centre Beam

All dimensions of the weld connecting the centre beam to the support bar in MSBJ systems shall be detailed on the drawing.

The resultant of the vertical and horizontal stresses in the weld, due to the design load, shall be checked for the three effects, a), b) and c), listed below. The A160 axle shall be positioned on the centre beam for the maximum effect in each of the three cases.

a) Resultant stress at the interface of the weld and soffit of the centre beam;

b) Resultant stress at the interface of the weld and the top of the support bar; and

c) Resultant stress at the throat of the weld between the centre beam and the support bar.

Note: The above stresses are designated as stresses due to Type A, Type B and Type C cracking, respectively, in the NCHRP 402 Report and the method given in this reference may be followed for design. The welded connection is classified as AASHTO Category C, which is approximately equivalent to Item 6 in Table A5.

A12.5 Yoke and its Connections

A12.5.1 General

In a Single support bar MBEJ system the connection between the centre beam and support bar is through a yoke, which enables a sliding joint. All components of the yoke system shall be designed to resist the fatigue stress cycles generated in the system by application of the loads Q^*_f, H^*_f and T^*_f in equations A.15a, A.15b and A.15c. If any pre-compression is applied to the yoke bearings it shall be ensured that the pre-compression is not lost due to stress cycles caused by the above loads.

It shall be demonstrated that the yoke system has the ability to resist the horizontal forces together with overturning moments due to application of the above loads, without causing instability or fatigue failure of any component or connection. (Advantage may be taken of the dynamic characteristics of the system, by employing Method 3 of Clause A10, to account for the reduction in longitudinal force experienced by the system due to the short duration of the applied load).

Alternatively, the adequacy of the yoke shall be demonstrated by performance testing.

A12.5.2 Bolted Yoke Connection

Where the yoke is connected to the centre beam by bolts, a tensile force (Q^*_{up}) shall be applied to the bolts, given by –

$$Q^*_{up} = \gamma_f \, \beta_f \, \chi_{up} \, R \qquad (A.16)$$

where R is the maximum support reaction due to the static A160 axle loads.

The stress range in the bolt due to the force Q^*_{up} shall not exceed 0.3 times the pre-tension in the bolt.

Only high strength bolts complying with 8.8/TF bolting category of AS 5100 (friction grip connection) are acceptable.

A12.5.3 Welded Yoke Connection

Where the yoke members are connected to the centre beam by complete penetration butt welds, the nominal stress range at the welded connection shall be the sum of the longitudinal stress ranges resulting from horizontal and vertical bending of the centre beam. The effects of forces in the yoke need not be added. The stress range at the weld shall comply with Item 7 in Table A5. Fillet welded connections are not acceptable.

A12.5.4 Welded Plates for Sliding Surfaces

The contact surfaces between the support bar and centre beam may require a special sliding arrangement. If the sliding device is welded to the edges of the centre beam by short lengths of longitudinal fillet welds, the flexural stress range in the centre beam at the weld location shall be limited as per Item 9 in Table A5, whereas for continuous welds it shall comply with Item 9 in Table A5.

A12.5.5 Spring Buffer Attachments

Where equidistancing spring buffers are attached to the centrebeam by welded cleats, the nominal stress range at the welded connection shall be the sum of the longitudinal stress ranges resulting from horizontal and vertical bending of the centre beam. The effects of forces in the equidistancing buffers due to thermal movements need not be added. The stress range at the weld shall comply with Item 10 in Table A5.

A12.5.6 Replaceable Items

Replaceable items shall be designed for fatigue as follows –

a) Where a MBEJ of similar type with the same replaceable components (materials, manufacture, design) has sustained 70 hours under the test regime described in NCHRP Report 467, no further design is required; and

b) For all other cases, the component shall be designed to resist the design number of stress cycles calculated as:

$$n_{sc} = 500{,}000(N_c + n_e)D_L \qquad \textit{(A.17)}$$

where –

n_{sc} = the design number of stress cycles caused by the design load;

N_c = the number of centre beams supported on a support bar;

n_e = the number of effective cycles of vibration following excitation and can be derived using the method shown in Appendix B to this Standard; and

D_L = the design life of the component in years.

A12.5.7 Other Types of Connections

MBEJ designers are free to develop appropriate details and connections. All computations shall be submitted for checking by the Principal. All designs and details shall be treated as Commercial-in-Confidence. Fatigue detail categories that cannot be classified in accordance with AS 5100.6 shall be supported by authoritative references for the cut-off limit stress adopted.

A13 *Strength Limit State Details*

A13.1 Centre Beams

If centre beams are subjected to significant axial force, which may arise if the MBEJ is skewed or the transverse force is significant, their capacity shall be checked for axial load with biaxial bending in accordance with Section 11 of AS 5100.6.

A13.2 Edge Beams

Edge beams shall be adequately anchored into the concrete and the anchors shall be able to resist an ultimate horizontal force 60 kN per metre length of the edge beam.

The section of the edge beam that spans across the openings of the support boxes shall be designed in accordance with Clause A13.3.

A13.3 Support Boxes

The top plate of each support box shall be designed to carry an ultimate load given by –

$$P^* = \gamma_u \chi_o W \qquad \textit{(A.18)}$$

Hence –

$$P^* = 1.8 \times 1.6 \times 80 = 230kN$$

This load may be distributed over an area of $(L_w + t) \times (B_w + t)$, where t is the thickness of the overlying concrete and permanent surfacing layer. Composite action with the overlying structural concrete and the edge beam may be taken into consideration, provided all connections and shear studs are adequately designed for this.

On the three sides of each support box, adequate shear studs shall be provided to transfer the vertical load P^* and its horizontal components ηP^* and τP^* into the surrounding concrete, without assuming any support at the base of the box.

The bottom plate of the support box shall be designed to carry one-third ($^1/_3$) of the maximum ultimate bearing reaction of the support bar, treated as a uniformly distributed load, by spanning between the three sides of the support box without any support from the underlying concrete. (This requirement is based on the observation that concrete under the support box is often difficult to consolidate and may contain voids).

A13.4 Connections

All connections, whether by bolts, screws, pins or welds, shall be checked for the strength limit state in accordance with Section 12 of AS 5100.6.

For the strength limit state, assume that the loads Q^*_u, H^*_u and T^*_u act concurrently. Calculate the stresses due to vertical and horizontal bending of the centrebeam or support bar and the stresses at connections such as welds of yokes or equidistancing buffer cleats. Calculate the resultant stress by means of equations A.13 or A.14 and show that it is less than the design strength of the weld or parent material, whichever is lower.

A14 *Serviceability Limit State Details*

A14.1 Structural

Bolts or screws acting in friction grip mode shall be checked for serviceability loads in accordance with AS 5100.6 Clause 12.5.4, in addition to strength.

Shear connectors shall be designed for the serviceability limit state in order to comply with Section 6 of AS 5100.6.

Reference shall be made to Clause 6.9 of this Standard for noise requirements.

Reference shall be made to paragraph (c) of Clause 6.4 of this Standard for vibration damping requirements.

A14.2 Elastomeric Bearings

The physical properties of the elastomer used (durometer hardness, shear modulus and bulk modulus) shall be reported.

Elastomeric bearings shall be designed to resist serviceability loads and movements, in accordance with AS 5100.4 Clause 12.

The stiffness of the bearings may be either –

a) Derived by calculation in accordance with Clause 12 of AS 5100.4, if analysis by Method 1 of Clause A5.10 is adopted; or

b) Obtained by testing in accordance with Clause B2.2 of Appendix B to this Standard if analysis by Method 2 or Method 3 is adopted.

The stiffness of the spring supports for the analytical model shall be derived from the combined stiffness of bearings provided for the support bars.