
Appendix C Seismic hardware

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C1 Linkage bars

C1.1 Design standards

Linkage assembly design shall be designed and detailed based on these provisions and relevant clauses in AS/NZS 5100.6 *Bridge design* part 6 Steel and composite construction⁽¹⁾ and AS/NZS 5131 *Structural steelwork - Fabrication and erection*⁽²⁾; using the seismic design provisions given in NZS 3404:1997 *Steel structures standard*⁽³⁾, as well as clause 2.2.4 and table 3 of the withdrawn NZS 3404.1:2009 *Steel structures standard* part 1 Materials, fabrication, and construction⁽⁴⁾. (Member connection design is covered by AS/NZS 5100.6⁽¹⁾. However, for earthquake design AS/NZS 5100.6⁽¹⁾ clause 3.11 states that when the loadings given in this *Bridge manual* are applied, steel members and connections shall be designed and detailed in accordance with NZS 3404⁽³⁾.)

A capacity design approach should be used to ensure that any failure occurs in ductile linkage bars rather than in the anchoring brackets or in other members resisting the linkage forces.

Apart from AS/NZS 4671 *Steel for the reinforcement of concrete*⁽⁵⁾ for grade 300E and grade 500E bar, standard steel materials specifications generally do not specify the maximum UTS (ultimate tensile stress) for a grade of steel and within a steel grade a wide variation can be possible in the UTS of steel supplied, especially with stainless steels. Thus the designer will generally need to specify both the minimum yield strength and the maximum UTS of the linkage bars to be provided.

The capacity design force actions applied to the anchorages and resisting element of the linkage system should be based on the specified maximum UTS for the linkage bars. Experience has shown that the UTS given on material batch test certificates can differ by as much as 20% from the UTS of actual material supplied, when tested, and the possibility of this variation should be allowed for in the design by applying an overstrength factor of 1.2 to the specified UTS for the bars when estimating the force actions on the anchorages and resisting elements. Alternatively, tensile testing of the bar material actually supplied should be required to ensure that the specified maximum UTS of the linkage bars is not exceeded.

Strength reduction factors specified in the appropriate material codes should be used for the design of the anchoring brackets and members resisting the linkage forces.

In assessing the performance of the anchors and resisting members of existing linkage systems, an overstrength factor of 1.2 should be applied to the probable ultimate strength of the bar, where estimated based on literature reports of typical strengths or adopted from material batch test certificate records, and strength reduction factors should not be applied.

Guidance on the performance of linkage bars can be found in the report *Performance of linkage bolts for restraining bridge spans in earthquakes*⁽⁶⁾ or in the related summary paper⁽⁷⁾.

C1.2 Materials

C1.2.1 General

Linkage bars, other than cast-in bars protected by concrete in precast hollow core superstructures, should be formed from one of the following materials:

- grade 316 stainless steel, or a duplex grade or better, with equivalent corrosion resistance, having a specified minimum elongation of 25% and complying with BS EN 10088-3 *Stainless steels* part 3 Technical delivery conditions for semi-finished products, bars, rods, wire, sections and bright products of corrosion resisting steels for general purposes⁽⁸⁾ or an equivalent approved standard

C1.2 continued

- grade 300 L15 mild steel, hot dip galvanized and complying with AS/NZS 3679.1 *Structural steel part 1 Hot-rolled bars and sections*⁽⁹⁾
- Macalloy fully threaded S650 grade 316 stainless steel bar
- Reidbar grade 500E, hot dip galvanized.

Linkage bars protected by concrete in precast hollow core superstructures should be formed from grade 500E, micro-alloyed, hot dip galvanized reinforcing bar.

Linkage bars in new bridges, except for bridges with cast-in bars protected by concrete cover in hollow core unit superstructures, should be fabricated from grade 316 stainless steel (or an equivalent duplex grade or better) or Macalloy fully threaded S650 grade 316 stainless steel.

The preferred material is grade 316 stainless steel (or an equivalent duplex grade or better) because of its good elongation, corrosion resistance and good fracture toughness in cold temperatures.

Reidbar should not be used in areas where the AS/NZS 5100.6⁽¹⁾ lowest one-day mean ambient temperature (LODMAT) isotherm is less than 2.5°C.

C1.2.2 Ductility

Linkage bars should be designed to have a plastic elongation of at least 40mm. The test results in *Performance of linkage bolts for restraint of bridge spans in earthquakes*⁽⁶⁾ can be used to estimate the plastic elongations for the recommended linkage bar materials listed in C1.2.1.

When formed into bars of typical lengths used in bridge linkage systems, high strength steels generally do not have sufficient tensile ductility and should not be used unless results of full-scale bar testing demonstrates that the plastic elongations will exceed 40mm. (Certified material elongations do not give a reliable indication of the bar performance in a full-scale linkage system.)

C1.2.3 Fracture toughness

To allow for plastic strains under earthquake loads the steel used in linkage bars should have a minimum impact resistance of 27 joules at 10°C lower than the basic LODMAT isotherm for the site given in AS/NZS 5100.6⁽¹⁾.

It is not necessary to combine extreme low temperatures with design level earthquake loading and the provisions of AS/NZS 5100.6⁽¹⁾ can be interpreted as requiring linkages at sites on most of the coastal South Island regions to have an impact resistance of 27 joules at -10°C.

The steel used in anchoring brackets for linkage bars should have a minimum impact resistance of 27 joules at 5°C lower than the basic LODMAT isotherm for the site given in AS/NZS 5100.6⁽¹⁾. This allows for extreme cold conditions at the bridge site but does not include a plastic strain reduction since brackets should be designed so that they are not subjected to significant plastic strain.

Grade 316 and Macalloy S650 stainless steel have good fracture toughness and can be used for linkage bars at any location in New Zealand. The fracture toughness of mild steels should be assessed before they are used in the South Island and colder regions in the North Island. Grade 300 L15 should be satisfactory in all but the coldest regions of the South Island.

Reidbar assemblies should not be used in the South Island and if used elsewhere the site service temperature needs careful consideration.

C1.3 Bar geometric details

In bridges over 50m in length non-proprietary bars should have turned down shanks. The turned-down length should be a minimum of 10 times, and ideally 15 times, the turned-down diameter. The ratio of the turned-down diameter to nominal thread diameter should not be greater than 0.8.

It is not necessary to turn-down Reidbar or Macalloy bar. Turning down these bars is likely to reduce the total elongation.

If plain round linkage bars are used, they should have a shank diameter no greater than the nominal thread diameter and the loaded lengths of thread at both ends of the bar should be at least 3.5 times the nominal thread diameter. Their use should be restricted to bridges less than 50m in length or for retrofitting older bridges.

C1.4 Linkage bar nuts

It is essential that lock nuts be used on all linkage assemblies. On proprietary bars the proprietary lock-nuts can be used. Other bars should be lock-nutted using two standard nuts.

Nuts should have specified proof loads greater than the ultimate tensile strength (UTS) of the bar. The property class required for the nuts should be included in the bar specification.

C1.5 Rubber pads and washers

When rubber pads are used in the linkage system to accommodate the required temperature movements they should be specifically designed and should not be excessively flexible. The elastic stiffness of the linkage system should be as high as practicable to minimise damage to the span joints and holding down bolts under serviceability level earthquake loading.

Heavy steel washers should be used with rubber pads and should be of sufficient thickness to result in uniform pressures on the pads. Their side dimension, or diameter, should be at least as great as that of the rubber pad.

C1.6 Linkage system corrosion resistance

In new bridges and in bridges being seismically retrofitted, bar hardware and steel anchoring brackets shall be designed to have no significant loss of section in a 40-year service life. If the future life of a bridge being retrofitted is expected to be less than 25 years then the design service life of the linkage system may be reduced to 25 years.

In locations with a surface specific corrosion category of C4, and C5M as given in table 5.1 of *Protective coatings for steel bridges: a guide for bridge and maintenance engineers*⁽¹⁰⁾, grade 316 stainless steel (or an equivalent duplex grade or better) shall be used for new and retrofitted linkage bars. Stainless steel linkage bars shall also be used in specific corrosion category C3 (or above) locations if they are inaccessible for replacement or future maintenance. Linkage bars may yield under severe seismic response and in order to spread yielding along the length of the bar the uniformity of the bar cross-section shall be maintained throughout its design life. Allowing the corrosion of a sacrificial thickness of steel should not be adopted as a means of achieving the design life.

To achieve a 40-year service life it will be necessary to apply a paint coating to galvanized bars, bar hardware and anchoring brackets. Reference should be made to *Protective coatings for steel bridges: a guide for bridge and maintenance engineers*⁽¹⁰⁾ for bridge site atmospheric corrosivity categories and coating systems. In higher corrosivity areas (C3-C5) a high build paint system is required, and its integrity needs to be maintained throughout its service life.

C1.7 Linkage bar design details

C1.7.1 Serviceability limit state stresses

The stresses in the linkage bar system should be less than yield level under the load combinations specified for the serviceability limit state.

Where tight linkages are used they may be subjected to cyclic loading causing fatigue. The stress range in the linkage bar system induced by the worst case combination of all load combination 1A, 1B, 2A or 2B serviceability limit state transient loads in accordance with table 3.2 (ie normal live load with dynamic load impact factor, horizontal and centrifugal effects of traffic loading, wind, and overall and differential temperature effects) shall not exceed 150MPa.

C1.7.2 Bar anchoring at abutments and piers

Anchoring linkage bars and anchor brackets by drilling through the bridge main members and installing nuts is preferred to relying on anchoring bars and bolts with epoxy grout.

C1.7.3 Bar robustness

Thread damage, bending of bars during maintenance operations and corrosion of nuts due to galvanic action are considerations in detailing linkage bars. Diameters of less than 20mm should not be used for either galvanized mild steel or stainless steel linkage bars.

C1.7.4 Bar clearances

Adequate clearances and linkage bar hole sizes should be specified to reduce the risk of damage to linkage bars under combined longitudinal and transverse displacements of the superstructure.

C1.7.5 Linkage systems to be removable

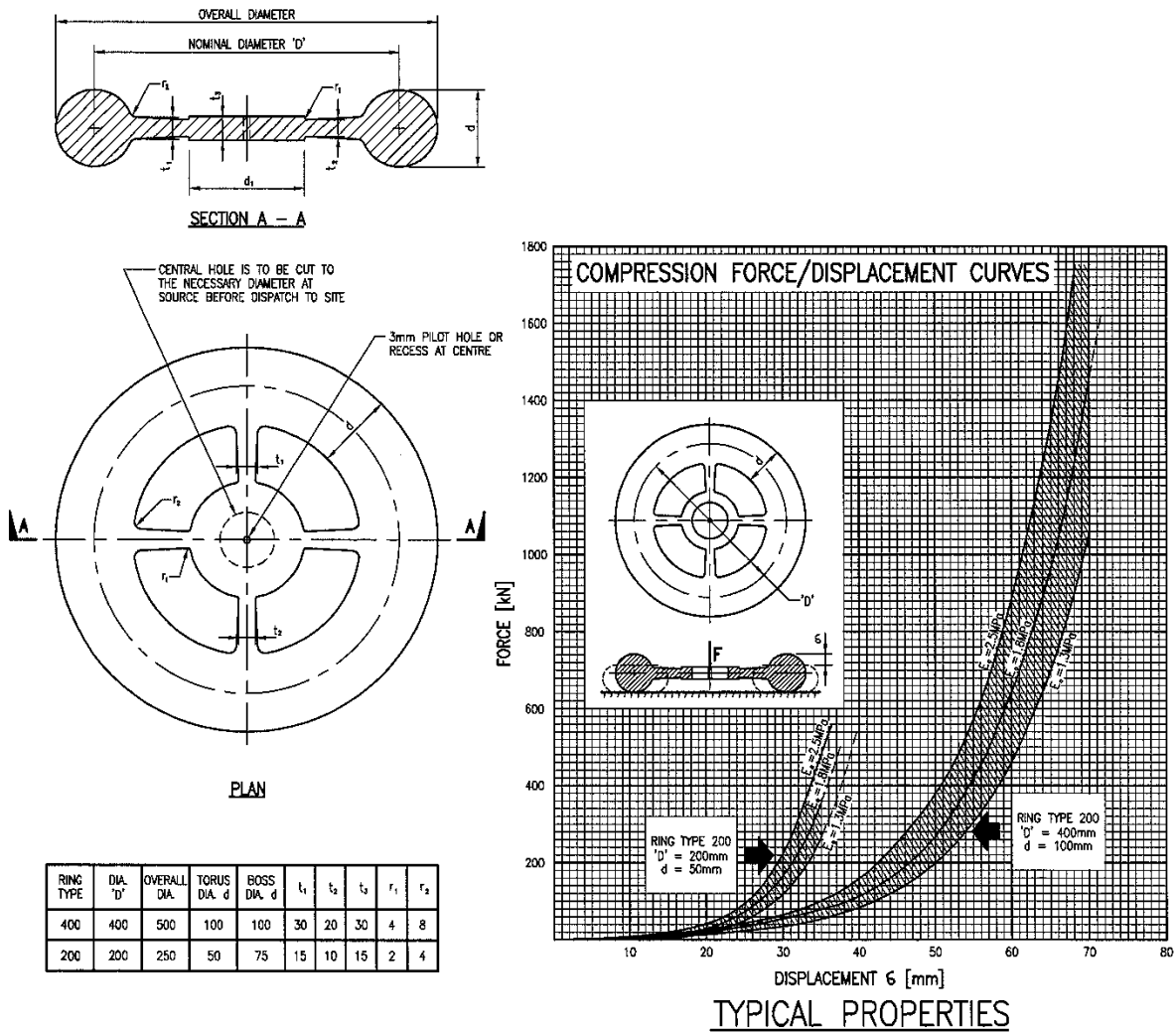
With the exception of hollow core unit bridge superstructures that adopt the linkage detailing presented in Waka Kotahi NZ Transport Agency research report 364 *Standard precast concrete bridge beams*⁽¹⁾, horizontal linkages and hold-down bolts/linkages, shall be designed to be removable and replaceable as they may yield or be damaged under severe seismic response.

C1.7.6 Protection of cast-in bars in hollow core unit bridge superstructures

For galvanized steel bars the debonding sleeve used across the joints between hollow core units at the piers and abutments shall be a viscoelastic wrapping such as the full Denso wrapping system. It shall consist of a paste, petrolatum tape and outer wrap tape. Rubber sleeving may be used to debond grade 316 stainless ribbed reinforcement bars.

C2 Toroidal rubber buffers

Figure C1: Toroidal rubber buffers



Material shall be natural rubber, Designation Z40 to BS 1154⁽¹²⁾

C3 References

- (1) Standards Australia and Standards New Zealand jointly AS/NZS 5100.6:2017 *Bridge design*. Part 6 Steel and composite construction.
 - (2) Standards Australia and Standards New Zealand jointly AS/NZS 5131:2016 *Structural steelwork - Fabrication and erection*. (Incorporating Amendment No. 1: 2020)
 - (3) Standards New Zealand NZS 3404 Parts 1 and 2:1997 *Steel structures standard*.
 - (4) Standards New Zealand NZS 3404.1:2009 *Steel structures standard*. Part 1 Materials, fabrication, and construction. Withdrawn.
 - (5) Standards Australia and Standards New Zealand jointly AS/NZS 4671:2019 *Steel for the reinforcement of concrete*.
 - (6) Wood JH (2012) *Performance of linkage bolts for restraining bridge spans in earthquakes*. Report prepared for Waka Kotahi NZ Transport Agency, Wellington.
 - (7) Wood JH and Chapman HE (2013) *Performance of linkage bars for restraint of bridge spans in earthquakes*. Bulletin of the New Zealand Society for Earthquake Engineering, vol. 46, no. 1.
 - (8) British Standards Institution BS EN 10088-3:2014 *Stainless steels*. Part 3 Technical delivery conditions for semi-finished products, bars, rods, wire, sections and bright products of corrosion resisting steels for general purposes. (Under review)
 - (9) Standards Australia and Standards New Zealand jointly AS/NZS 3679.1:2016 *Structural steel*. Part 1 Hot-rolled bars and sections.
 - (10) Waka Kotahi NZ Transport Agency (2020) *Protective coatings for steel bridges: a guide for bridge and maintenance engineers*. Wellington.
 - (11) Waka Kotahi NZ Transport Agency (2008) *Standard precast concrete bridge beams*. Research report 364, Wellington.
 - (12) British Standards Institution BS 1154: 2003 *Natural rubber compounds. Specification*.
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