Annexure

S02: Modelling Deck Unit Bridge Superstuctures for Tier 1 Assessments

August 2013

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Amendment Register

Issue / Rev no.	Reference section	Description of revision	Authorised by	Date
1.04	All	Editorial changes to reflect new corporate editing requirements	DCE (Structures)	Aug 2013
1.03	Section 2.3.2	Alterations to the calculation of the moment of inertia of kerb units for use in analytical models.	DCE (Structures)	March 2013
1.02	Section A.4	preliminary recommendations regarding the application of wheel loads to deck unit grillage models	DCE (Structures)	Jan 2013

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1 Introduction

1.1 Background

The assessment of deck unit superstructures is sensitive to the analytical model of the superstructure. There is a substantial variation in the modelling of deck unit bridges with a resultant range in assessment outcomes.

This annexure provides recommendations and the background to these recommendations for modelling the Department of Transport and Main Roads deck unit superstructures.

1.2 Purpose

The purpose of this annexure is to:

- provide recommendations for developing models of deck unit bridge superstructures suitable for Tier 1 assessments, which will result in suitably conservative and reliable results for superstructures
- discuss the background to the recommendations.

1.3 Scope

In scope:

- Tier 1 linear elastic grillage/frame modelling of Transport and Main Road's transversely post-tensioned deck unit bridges for assessment purposes.
- Self-weight and vertical traffic loading only, although the models will generally be applicable to all types of loading.

Out-of scope:

- More advanced (Tier 2) modelling of existing deck unit superstructures for assessment purposes.
- Design of new bridges.
- Non deck unit bridges (e.g. girder bridges).
- Deck unit bridges without transverse post-tensioning (e.g. deck units with cast-in-situ slabs).
- The methodology for the application of moving loads to the superstructure.

1.4 Related documents

This annexure is to be read in conjunction with *Annexure S01: Frame Models of Complete Bridge Structures for Tier 1 Assessments*.

1.5 Responsibilities of users

This document is to be applied by structural engineers who use their engineering knowledge and experience to model structures. Engineering organisations and engineers applying this document are to convey any concerns and/or suggested improvements to the Deputy Chief Engineer (Structures Section), in writing, in a timely manner.

Ultimately, it is the responsibility of the engineer to apply reasonable engineering judgement in the development of the models to ensure that the results are appropriate for a Tier 1 assessment of the structure.

1.6 Layout of annexure

This annexure is presented as follows:

- Section 2 – This section provides recommendations for modelling deck unit bridges for Tier 1 assessments. It includes validation and some related issues regarding the strength of transverse members.
- Section 3 – This section highlights areas for possible future work.
- Section 4 – This section provides sources of additional reading.
- *Appendix A* – This section discusses the background to the recommendations for the modelling of deck unit bridges for Tier 1 assessments.

2 Recommendation for the department's projects

2.1 Introduction

These recommendations apply to the modelling of deck unit superstructures for the purpose of a Tier 1 assessment of bridges for vertical traffic loading and self-weight.

2.2 Aim

To produce models which capture, using a linear elastic grillage/frame model, the important behaviours of the deck unit superstructures subjected to vertical traffic loading and which allow a straightforward extraction of information which will be useful for the assessment of the bridge.

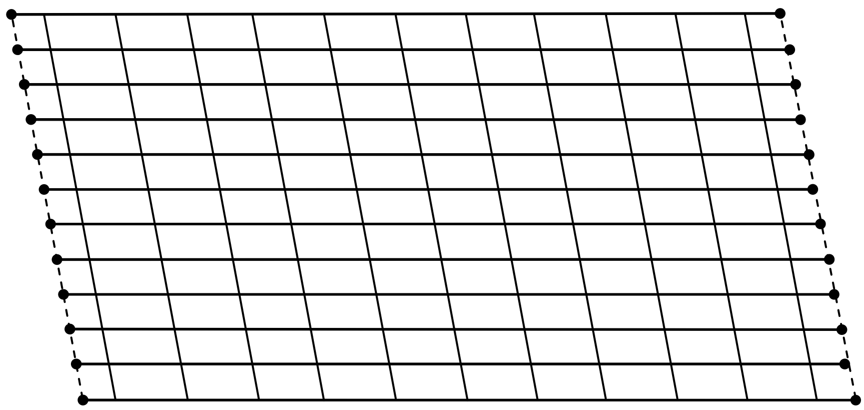
The models should be relatively simple and straightforward to develop, and have a low risk of predicting unrealistic or unreliable behaviours.

2.3 Grillage / frame models

2.3.1 Mesh layout

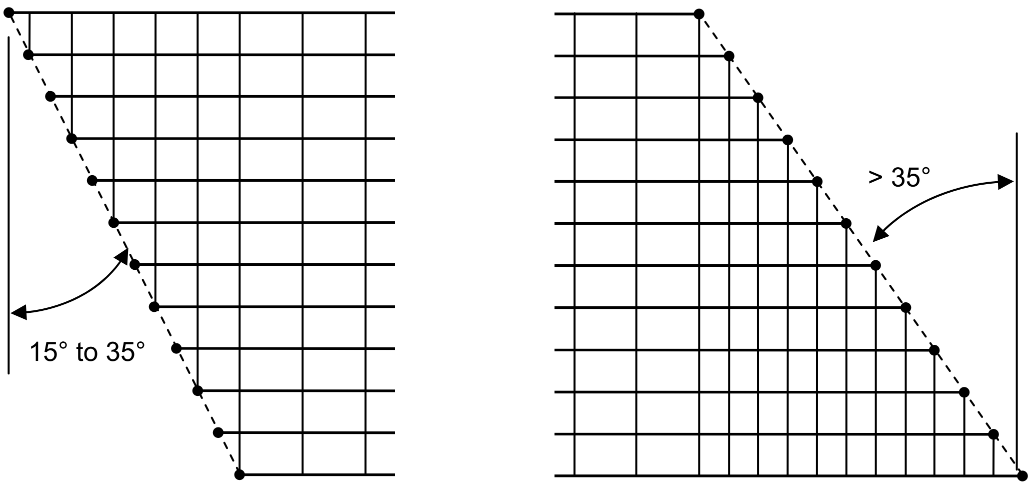
a) For skew angles less than or equal to 15° the deck is to be approximated by a skew or orthogonal mesh consisting of longitudinal and transverse members as illustrated in Figure 2.1 and Figure 2.2 respectively.

Figure 2.1: Layout of a skew mesh for a skew deck with a skew less than or equal to 15°



b) For skew angles greater than 15°: The deck is to be approximated by an orthogonal mesh consisting of longitudinal and transverse members as illustrated in Figure 2.2. The diagonal member at each end is an aid to ensure wheels positioned near the end of the span are actually applied to the structure.

Figure 2.2: Layout of an orthogonal mesh for a skew deck – transverse members corresponding to alternate longitudinal members at left (15 < skew ≤ 35°) and all longitudinal members at right (skew > 35°).



The mesh layout is to be consistent with the following:

Longitudinal members:

- One member per deck unit, kerb unit or deck unit acting compositely with a cast-in-situ kerb located at the centre of each unit.

Transverse members:

- Maximum centre-to-centre spacing of transverse members to be 2.0 times the typical spacing of the longitudinal members (i.e. 1.2 m) or span/10, whichever is the smaller (e.g. refer Figure 2.1).
- In skew meshes (i.e. skew ≤ 15°), place a transverse member at midspan. A transverse member should be located "d" from the support. Consideration should be given to having a number of closely spaced transverse members near the supports to facilitate the appropriate application of wheel loads, the distribution of wheel loads into the deck and the interpretation of the shear forces.
- On skewed structures with orthogonal meshes, reduce the spacing of transverse members near supports so that the transverse members intersect the longitudinal members at the supports (refer Figure 2.2 – right). For skew angles less than 35°, transverse members intersecting alternate longitudinal members will suffice (refer Figure 2.2 – left).

Diagonal end members

- These dummy end members (shown dashed in Figure 2.1 and Figure 2.2) need to be soft relative to the longitudinal and transverse members so as to not participate structurally other than to ensure the SpaceGass moving load generator applies wheel loads near the end of the structure. These dummy diagonal end members may not be required in complete bridge models.

2.3.2 Section properties

a) Longitudinal members (Deck and kerb units)

The centroids of the kerb units and deck units with cast-in-situ kerbs are assumed to be at the same level as the centroid of the deck units (i.e. in the same plane).

Deck units with cast-in-situ kerbs are assumed to act compositely.

A_{long_m} Nominal – say average cross-sectional area of member

J_{long_m} $J_{long.du\_m}$ = Torsion constant of an internal deck unit used in the model
= 20% of the uncracked torsion constant of an internal deck unit

$J_{long.ku\_m}$ = Torsion constant of an external kerb unit used in the model
= 20% of the uncracked torsion constant of an uncracked external kerb unit or external deck unit with cast-in-situ kerb

$I_{y.long\_m}$ Arbitrary (large)

$I_{z.long\_m}$ $I_{z.long.du\_m}$ = Moment of inertia about the horizontal axis of an uncracked internal deck unit used in the model

$= I_{z.long.du}$

$I_{z.long.ku\_m}$ = Effective moment of inertia about the horizontal axis of a kerb member used in the model

$$= \frac{M_{u.ku}}{M_{u.du}} I_{z.long.du} \leq I_{z.long.ku}$$

$I_{z.long.du}$ = Moment of inertia about the horizontal axis of an uncracked deck unit

$I_{z.long.ku}$ = Moment of inertia about the horizontal axis of an uncracked kerb unit (not used in the analytical model)

$M_{u.du}$ = Ultimate bending strength of the deck unit adjoining the kerb units

$M_{u.du}$ = Ultimate bending strength of the kerb unit

b) Transverse members

A_{trans_m} Nominal – say average cross-sectional area of member

J_{trans_m} 0

$I_{y.trans\_m}$ Arbitrary (large)

$I_{z.trans\_m}$ $I_{z.trans\_m}$ = Moment of inertia about the horizontal axis of transverse member used in model

$$= 0.03 \times \frac{S_{trans}}{S_{long}} I_{z.long.du\_m}$$ for 600mm wide deck units.

Adjust appropriately for widths other than 600mm.

where:

s_{trans} = spacing of transverse members in the longitudinal direction, and

s_{long} = spacing of longitudinal members

c) Diagonal end members (dummy)

A_{dummy_m} 1% of minimum area of the transverse members (i.e. soft - should not attract axial loads in complete bridge models)

J_{dummy_m} 0

$I_{y.dummy\_m}$ 1% of minimum moment of inertia of the transverse members (i.e. should not attract bending about the y-axis)

$I_{z.dummy\_m}$ 1% of minimum moment of inertia of the transverse members (i.e. should not attract bending about the z-axis)

2.3.3 Modulus of elasticity

The modulus of elasticity shall be in accordance with AS 5100.5 and shall apply to all members equally.

2.3.4 Supports

a) For grillage models:

Supports are to be provided at both ends of each longitudinal member. The supports are not to provide any rotational restraints. Consideration should be given to providing an appropriate vertical spring rather than a rigid vertical restraint at the supports, especially where the deck unit is supported on elastomeric bearings and/or the skew is significant.

b) For complete bridge models:

Refer to the *Annexure S01: Guidelines for Frame Models of Complete Bridge Structures for Tier 1 Assessment* for further information on modelling complete bridge structures and recommendations regarding modelling the connection of deck models to substructures.

2.3.5 Application of loads

Considerable care is required to:

- position the assessment vehicles to generate the maximum shear in members
- distribute the wheel loads to members.

Consideration should be given to distributing the wheel loads to transverse members only for the assessment of longitudinal members and considering at least one load case where a wheel line is applied directly above a longitudinal member. Small changes in longitudinal and transverse position of wheels can make significant differences, especially for short span bridges. Closely spaced transverse members at the supports assist.

2.3.6 Validation

Each model requires validation. Useful validation checks include:

- ensuring the deflected shapes are appropriate (magnitude and shape)

- ensuring reactions are correct and that the restraints are appropriate
- ensuring the bending, shear and torsion diagrams are appropriate
- checking to confirm that the heavy vehicle peak bending moments and shears per deck unit are reasonable when compared to the bending moments and shears induced in a line element of the same span subjected to the same heavy vehicle
- ensuring the loads, including wheel loads, have been applied appropriately and generate reliable results. Note that grillage models can be sensitive to how the loads are distributed to the members, the lateral position of the vehicle and the moving load generator step size.

2.4 Strength assessment considerations

2.4.1 Longitudinal members

Even though the longitudinal moments of inertia of the kerb units have been modified, the strength of the kerb units is to be assessed as per its actual properties.

The shear capacity of deck units is to be assessed as if the deck units were a slab.

2.4.2 Transverse members

It is acceptable to average the strength in the transverse direction over the transverse members. For example:

$$\phi M_{u.trans} = \frac{s_{trans}}{s_{bar}} \phi M_{u.bar}$$

where:

$\phi M_{u.bar}$ = strength in the transverse direction of an member compromising a single prestressing bar and a length of deck equal to s_{bar}

$\phi M_{u.trans}$ = strength assigned to a transverse member with a spacing of s_{trans}

s_{bar} = spacing of transverse stressing bars in the longitudinal direction

s_{trans} = spacing of transverse members in the longitudinal direction.

When the transverse stressing bars are at an angle (α) to the transverse stressing members, the strength and prestress of the stressing bars is to be reduced by multiplying by cosα before the calculation of the strength.

3 Further work

Other possible proposed work includes:

- detailed numerical modelling review of deck unit bridges
- field testing of deck unit bridges – serviceability loads
- field testing of deck unit bridges – ultimate limit state
- review of this guideline.

4 Bibliography

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Appendix A Background discussion

A.1 Description

Transport and Main Road's deck unit bridges have been in service since the 1950s and represent a dominant and large portion of the road bridges in Queensland bridges. Typical deck unit bridges are characterised by:

- internal deck units: precast pre-tensioned concrete internal deck units nominally 600mm wide
- kerb units: either precast pre-tensioned concrete kerb units nominally 300mm wide, or deck units with cast-in-situ kerbs
- precast pre-tensioned concrete deck units with cast-in-situ kerbs
- the deck units being solid for short spans but incorporate circular or "rectangular" voids for longer spans
- the kerb units and the deck units have smooth sides and utilise transverse post-tensioned bars and friction for load transfer between the units. The gaps between the units are filled with a flowable grout prior to the units being stressed together
- the level of prestress transversely is small in comparison with the longitudinal prestress
- commonly, deck units have no shear reinforcement
- the deck wearing surface is generally asphalt, although in some locations, topping concrete is used
- some bridges have been constructed with a cast-in-situ deck slab acting compositely with the deck units and no transverse prestressing. Modelling of these superstructures is outside the scope of this document
- the deck units are supported on mortar beds, elastomeric bearing strips, or individual bearings depending on the span and the construction era.

A.2 Behaviour

Under general traffic, it is assumed that deck unit bridges tend to behave as a slab with some level of stiffening provided by the kerb units. Shear forces, bending moments and torsions are transmitted as if the deck was a slab.

At higher levels of loading, the transverse extreme fibre bending stresses near midspan exceed the low levels of transverse prestress and the joints between the deck units open on the tension side in those regions. The transverse stiffness reduces in these areas and a larger portion of the load is distributed longitudinally. The joints will continue to open as the load increases, until the transverse bending is resisted by a strip of concrete in compression near the top (or bottom) of the deck units and tension in the transverse bar. At this stage there will be very limited ability to transmit torsion across these joints. This will not be the situation everywhere, as the loading in the bridge varies from point to point and at locations towards the supports the longitudinal joints may remain closed. Thus it is unlikely that a single linear analysis can provide a good model of deck unit superstructure behaviour.

From an assessment perspective, it is important to evaluate how the structure will perform at high levels of overload. In regions where the bending effects are significant, it is expected that the behaviour will be dominated by the longitudinal joints opening between the deck units. This will control how the loads near midspan are distributed between the deck units. Towards the supports, the bending effects are much smaller and the behaviour will be more consistent with slab behaviour although the distribution of wheel loads near the support is expected to the relatively insensitive to the transverse bending stiffness due to the proximity of the support.

A.3 Modelling approaches

Broadly, there are two approaches to the Tier 1 analysis of Transport and Main Road's deck unit superstructures:

- Build a model to match the distribution of load at the serviceability limit state and redistribute the loads away from overloaded members such as kerbs and transverse members.
- Build a model to approximate the distribution of load at the ultimate limit state.

Both of these methods have been used in assessment and design of deck unit bridges. Modelling the bridge to match the behaviour at the serviceability limit state, results in the kerb units and transverse members being overloaded at the ultimate limit state. Even after redistribution of the load away from the kerb units, the transverse members remain overloaded. This requires a further redistribution of the load to the longitudinal members, where it is principally resisted by bending and shear in the deck units.

It has also been observed that modelling the deck using relatively low torsion stiffness in the longitudinal members (i.e. deck units assumed to be cracked at the Ultimate Limit State (ULS)) and modelling the transverse members with low moments of inertia is consistent with the strength of the transverse members at the ultimate limit state, without the need for load redistribution.

The recommended model presented in Section 2 is a compromise aimed at approximating the strength limit state while maintaining a simple approach. The recommended Tier 1 grillage/frame model of the department's deck unit bridge has the following characteristics:

- linear elastic grillage/frame models
- a single longitudinal member per deck unit or kerb unit
- transverse members orthogonal to the longitudinal joint between the deck units (not necessary for small skews – say less than 15°)
- the bending stiffness of internal longitudinal members is to be calculated based on the uncracked properties of a typical internal deck unit
- the bending stiffness of the external longitudinal kerb members is to be determined such that the kerb unit and the adjacent deck unit reach their ultimate bending strength at the same curvature. This is achieved by making the ratio of the ultimate bending strength to the model moment of inertia are equal for both the deck unit and the kerb unit – $\frac{E}{R} = \frac{M}{I} = \frac{M_{u.ku}}{I_{z.long.ku\_m}} = \frac{M_{u.du}}{I_{z.long.du\_m}}$. Hence the stiffness of the kerb unit in the model $I_{z.long.ku\_m} = \frac{M_{u.ku}}{M_{u.du}} I_{z.long.du}$ after noting that $I_{z.long.du} = I_{z.long.du\_m}$. The moment of inertia of the kerb unit used in the model must be less than the moment of inertia of the kerb unit. This assumes that the moment in the kerb unit is redistributed to the deck units. Theoretical studies have shown that the kerb units can support their ultimate bending strength at the curvatures required for the deck units to reach their ultimate bending strength.

- the transverse stiffness in bending is much lower than in the longitudinal direction – 3% of the longitudinal stiffness on a per metre basis
- the torsion stiffness of longitudinal members is 20% of the uncracked properties
- zero torsion stiffness for transverse members.

A.4 Application of wheel loads

The shear forces in grillage members are sensitive to how the wheel loads are applied to the grillage. This is a consequence of approximating a continuum as a series of discrete line elements. For example, if a wheel load is approximated as a point load and applied to a longitudinal member between transverse members then this supporting element must carry the entire shear force from the wheel and the peak shear force within this element will occur when the wheel is a small distance from the transverse member. This effect is not real because the wheel load is applied over a patch and the transverse distribution occurs continually rather than concentrated at transverse members. Significant under and over estimates of shears are possible.

Applying the wheel loads to the nodes can diminish these effects but this requires relatively closely spaced transverse members near supports in order to ensure the wheel loads are applied near the end of the span in order to identify the peak shears in critical regions.