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Longitudinal Analysis of U-Shaped Girder Bridge

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Abstract— The concept of U-shaped bridge girder is now being increasingly adopted in urban metro rail projects and for replacing old bridges where there is a constraint on vertical clearance. These bridge decks are commonly designed in practice using simplified methods that assume beam action of the webs in the longitudinal direction and similar flexural action of the deck slab in the transverse direction. However, such assumptions can lead to errors. This paper attempts to assess the extent of error in the simplified analysis, by comparing the results with a more rigorous three-dimensional finite element analysis (3DFEA). A typical prototype railway bridge girder has been taken as a case study. The results of the 3DFEA, in terms of load-deflection plots, have been validated by field testing. It is seen that simple beam analysis generally predicts good results, except for some local stress concentrations. Deformation increases as span increases and results are validated with both methods SBM and FEM.

Keywords: U-Girder Bridge Deck, Simplified Methods, Three-Dimensional Finite Element Analysis

I. INTRODUCTION

The U-shaped girder bridge (also called ‘channel bridge’) is a relatively new and innovative concept in bridge deck design. U-shaped girder is appropriate when a new or modified alignment structure requires an increase in the vertical clearance beneath the bridge.

The scope of the present study is limited to the longitudinal analysis of the U-girder bridge deck under vehicular loading. When there is no transverse eccentricity in the loading (as in single track metro rails), then simple beam analysis (SBA) give reasonably good results, except for local shear lag effects, which induce higher longitudinal forces near the web–deck slab junctions. Usually, the U-girders are prestressed, whereby the shear lag effects are marginal. However, under eccentric vehicular loading, the cross-section undergoes twisting, inducing distortion and warping. These effects are not accounted for in SBA, resulting in errors in the estimation of longitudinal stresses.

A finite-element analysis (FEA), using shell elements, and considering a three-dimensional (3D) model, provides an alternative computational method, which addresses both transverse and longitudinal actions integrally, along with torsion, distortion and shear lag effects. However, although a three-dimensional finite element analysis (3DFEA) may offer the most comprehensive treatment, the effort involved in modelling and computation is considerable, and hence is not usually favoured in the design office, especially at the preliminary design stage. Therefore, a need exists for simplified methods of elastic analysis of U-girders. This paper attempts to address this need, with regard to longitudinal analysis. The scope is limited to elastic behaviour of straight U-girder bridge decks.

A. Description of U-girder bridge concept

Structurally, the U-shaped girder bridge can be viewed as the conventional ‘single-cell box girder’ with its top flange removed, as shown in Fig.1.1. The two webs are configured as beams positioned above and on either side of the deck surface. The webs and the deck slab are R.C.C or post-tensioned with longitudinal tendons anchored at the two ends of the bridge deck (with suitable ‘end blocks’). The longitudinal stiffness and strength are obtained from the two webs as well as the connecting passageway slab spans between the webs. The resulting requirement for the depth of girder section below the passageway level is very less than that required for convectional beam-and slab type designs, as shown in Fig.1.2, and herein lies its main functional advantage. The U-girder is essentially a ‘through’ type girder where the train passage occurs on the soffit slab; the side cantilevers serve as ‘key man’ pathways (for maintenance).

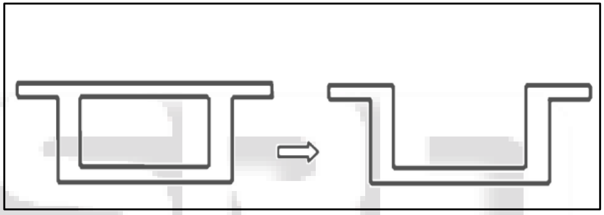


Fig. 1.1: BOX GIRDER Fig. 1.2: U-GIRDER

B. Evolution of ‘Channel Bridge’

The precast segmental concrete “channel” or U-shape Bridge was first developed by Jean Muller in 1990s for the Champ feuillaet Overpass Bridge in France. Subsequently, in the mid-1990s, there was an extensive research evaluation program carried out in USA by the Highway Innovative Technology Evaluation Centre (HITEC). Between 2001 and 2003, the Sorell Causeway Viaduct was built in Australia. It became the first channel bridge viaduct built in the world. The specialist rail consultancy firm, Systra, has developed a precast pre-stressed concrete U-shaped type bridge based on the original channel bridge constructed in France. The Wodonga Rail Bypass project in Australia, designed by Systra uses a simplified U-shaped bridge concept as shown in Fig. 3;

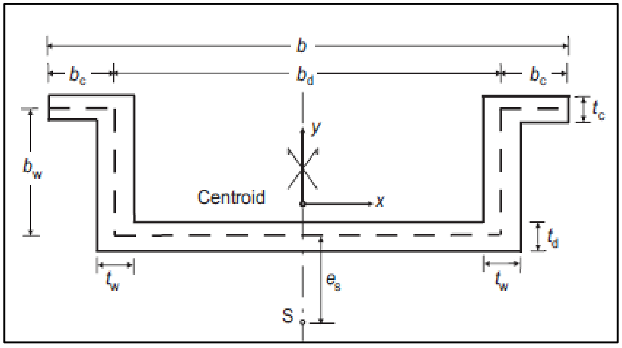


Fig. 1.3: Cross Section of U-shaped girder

II. APPLICATION OF SIMPLE BEAM ANALYSIS FOR ELASTIC ANALYSIS OF U- GIRDER

Elastic method of analysis of single cell box girder bridge, originally proposed by Moisel and roll (1974) is used for elastic analysis of U-girder bridge deck. In this analysis the behaviour of U- Girder bridge deck is divided into two types

1) Longitudinal analysis.
2) Transverse analysis

A. Longitudinal Analysis.

The longitudinal analysis is carried out by using “Simple Beam Analysis” (SBM), assuming the Euler’s Bernulli Hypothesis (plane section remains same even after the bending).

B. Transverse analysis

Transverse analysis is done by considering the deck slab alone to be bend as a one-way slab simply supported between the two webs.

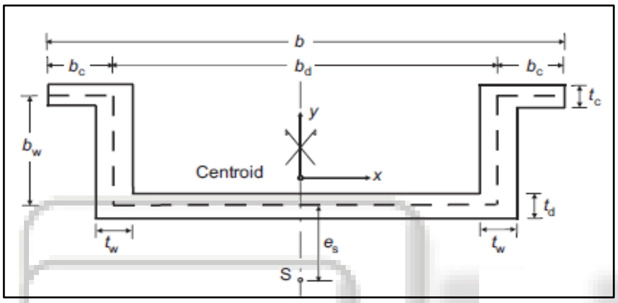


Fig. Cross section of U- girder

Notations: b_c - width of cantilever
t_w – thickness of web
t_c – thickness of cantilever
t_d – thickness of deck slab
b_d- width of deck slab
y_t – depth from the top fibre toneutral axis
y_b – depth from the bottom fibre to neutral axis
d - depth of girder
e_s- eccentricity.

C. Member Properties:

I_{xx} – moment of inertia about x-x axis.

$$I_{xx}=\frac{1}{12}(2b_ct_c^3+2t_wc^3+b_dt_d^3)+\frac{1}{2}(4b_ct_cy_t^2+c(2y_t-c)^2t_w+2(c-y_t)^2b_dt_d)$$

Where,

$$C=\frac{1}{2}(2d-t_c-t_d)$$

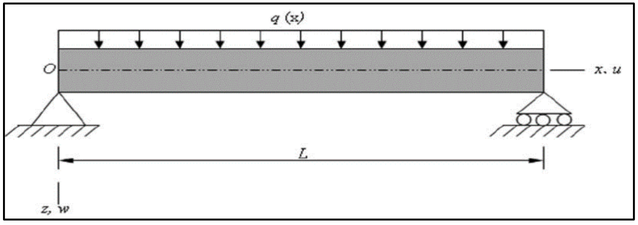
D. Centroid Distance:

y_t from top cantilever

$$y_t=\frac{c(ct_w+b_dt_d)}{2b_{ct_c+2ct_w+b_dt_d}}$$

1) Bending Moment:

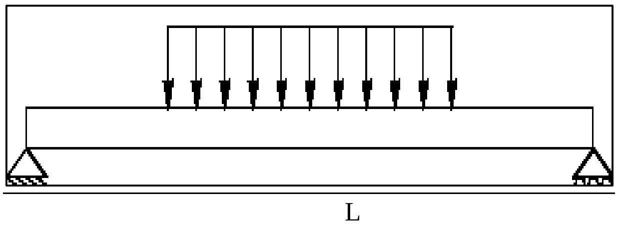
For uniformly distributed load



$$BM_{max}=\frac{ql^2}{8}$$

Max Deflection (Δmax) = $\frac{ql^4}{384EI}$

2) For Patch Load



When C≠0 $BM_{max}=\frac{PC}{4}(L-\frac{C}{2})$

When C=0 $BM=\frac{PL}{4}$

Max deflection= $\frac{PL^3}{48EI}$

3) Longitudinal Stresses:

Stress at top (σ_t)= $\frac{M_x}{I_x}y_t$

Stress at bottom (σ_b)= $\frac{M_x}{I_x}y_b$

Where,
σ_t= stress at top
σ_b= stress at bottom
M_x= max bending moment at x-axis
I_x = second moment of area of the u girder about x- axis
y_t= distance of top from the centroid axis
y_b= distance of bottom from the centroid axis.

4) Shear Stress:

$$\tau_t=\frac{v_y}{I_x}(b_cy_t)$$

$$\tau_b=\frac{v_y}{2I_xt_w}(2b_cy_tt_c+t_wy_t^2+t_wy_b{}^2)$$

$$\tau_{max}=\frac{v_y}{2I_xt_w}(2b_cy_tt_c+t_wy_t^2)$$

Where,
τ_t= shear stress at top
τ_b = shear stress at bottom
τ_{max} = max shear stress at neutral axis.

a) Youngs Modulus:

$$E=5000\sqrt{f_{ck}}$$

b) Longitudinal Action:

To determine the longitudinal stresses shear stresses and deflection of u girder. Under the vehicular loads (highway and railway) the u girder is modelled as a simply supported beam subjected to two typical load cases

1) A uniformly distributed load (q) over entire span applicable for railway loading.
2) A patch load (wheel or tracked) over a variable length “c” at midspan location applicable for highway loading.

III. RESULTS AND DISCUSSIONS

A. Numerical Example

One example is illustrating the application of SBA analysis and the results obtained by the commonly used SBA are compared with those obtained by the 3DFEA and these two examples deals with straight configuration with simply supported end conditions.

1) Example-1

A typical 30m span simply supported concrete U-Girder highway bridge deck subjected to single wheel load (patch) of 350kN (class AA tracked vehicle) with contact dimension of C=3600mm and W=800mm as placed at mid-span on the deck slab with maximum eccentricity (e) of 3250mm as per IRC-6 2014 bridge rule. The dimension of cross section selected is shown below.

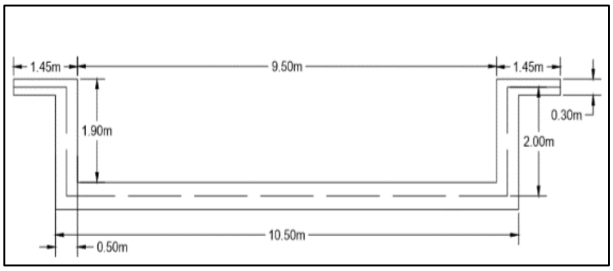
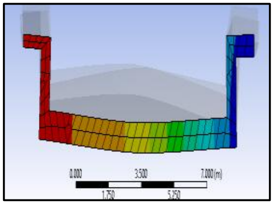
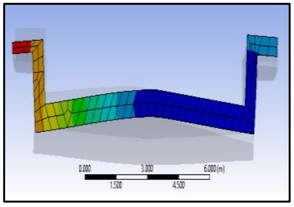


Fig. Cross section of U- shaped girder bridge



deflection at midspan



deflection at support

SPAN		30M	40M	50M
DEFORMATION	SBM	3.13	7.46	14.5
	FEM	4.49	10.5	12.6
EQUIVALENT STRESS SBM	CENTER	2.59	3.52	4.44
	SUPPORT	4.48	6.1	7.69
EQUIVALENT STRESS FEM	CENTER	3.23	3.86	2.81
	SUPPORT	0.002	1.72	0.015
SHEAR STRESS SBM	CENTER	0.49	0.49	0.49
	SUPPORT	0.38	0.38	0.38
SHEAR STRESS FEM	CENTER	0.33	0.63	0.149
	SUPPORT	-0.38	0.08	-0.03

Table 1: Comparison of SBA with FEA for Different Spans

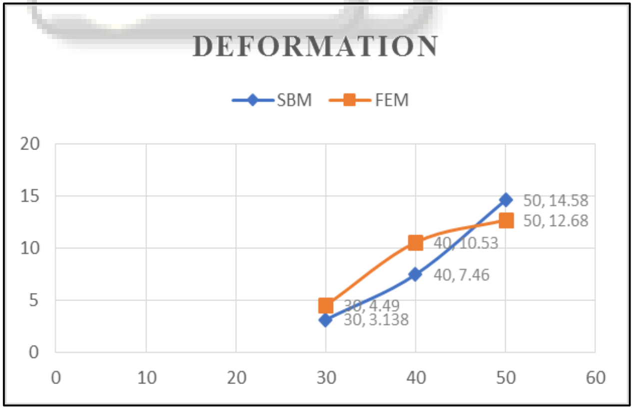


Fig. Deformation graph

The fig shows that stresses obtained by SBM and FEA method at different spans. The deformation value obtained for span 30, 40 & 50 m by using SBM method are 3.138, 7.46 & 14.58 respectively. Similarly the deformation value obtained for span 30, 40 & 50 m by using FEM method are 4.49, 10.53 & 12.6 respectively. Comparing to both the results the only some differences is there this error is because SBA will not account effect due to torsion and shear lag whereas the finite element analysis which considers the effect of shear lag, torsion and distortion.

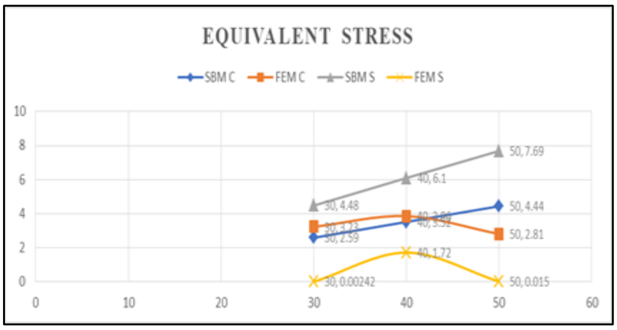


Fig. Equivalent stress graph

The fig shows that stresses obtained by SBM and FEA method at different spans. The deformation value obtained for span 30, 40 & 50 m by using SBM method at centre 2.59, 3.52 & 4.44 and at support 4.48, 6.1 & 7.69 respectively. Similarly the deformation value obtained for span 30, 40 & 50 m by using FEM method at centre 323, 3.86 & 2.81 and at support 0.00242, 1.72 & 0.015 respectively. The conventional simplified beam analysis (SBA), for longitudinal analysis of U-girder bridge decks, is found to give unconservative results under eccentric loading. Although the FEA accounts for torsional effects, still there is some marginal error, which can be traced to the effects of distortion and shear lag.

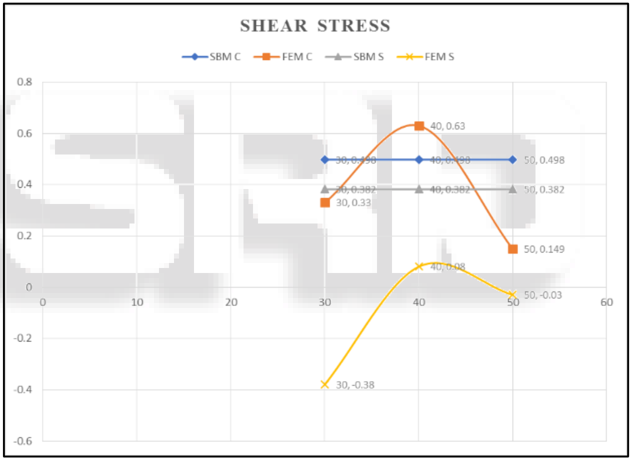


Fig. Shear stress graph

The table shows that stresses obtained by SBM and FEA method at different spans. The deformation value obtained for span 30, 40 & 50 m by using SBM method at centre 0.498, 0.489 & 0.489 and at support 0.382, 0.382 & 0.382 respectively. Similarly the deformation value obtained for span 30, 40 & 50 m by using FEM method at centre 0.33, 0.63 & 0.149 and at support -0.38, 0.08 & -0.03 respectively. When there is no transverse eccentricity in the loading, then simple beam analysis (SBA) gives reasonably good results, except for local shear lag effects, which induce higher longitudinal forces near the web–deck slab junctions.

IV. CONCLUSION

– Deformation increases as span increases and results are validated with both methods SBM and FEM.
– Shear stress in SBM is constant in all spans of u-shaped girder but not in FEM. The longitudinal and transverse behaviour of a simply supported U-girder bridge deck have been studied using the simplified methods of

analysis and compared with more accurate 3DFEA results.

- It is seen that simple beam analysis generally predicts good results, except for some local stress concentrations.
- The simplified longitudinal analysis underestimates the maximum stress in the web-deck slab junction about 12 percent, because it is not able to capture the effects arising from shear lag and transverse bending.
- The simplified transverse analysis over-estimates the sagging moments in the deck slab about 9 percent but fails to capture the hogging moments near the webs and the transverse bending in the webs. These errors can be compensated by the designer, by adopting appropriate corrections while designing and detailing.

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