Partial factors for shear capacity assessment of in-service RC T-girder bridges

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As the infrastructure age, their assessment to carry the loads they are subjected to becomes increasingly important. Also, assessment is needed as part of a regular monitoring programme. Before carrying out a rigorous probabilistic analysis for assessment, it is often required to make a preliminary assessment using simplified procedures, such as that developed using semi-probabilistic approach, in which partial factors are used. In this article an attempt has been made to evolve a framework to determine the partial factors for safety assessment of the in-service T-girder bridges in India against the limit state of shear. Limit state of shear is considered because it is one of the important ultimate limit states for bridge girder that results in brittle failure. The partial factors are derived using first order reliability method. In order to suggest a simple method for safety assessment, statistical properties of modelling error associated with the simplified equation of shear capacity estimation are estimated using test data of 185 beams reported in the literature. To demonstrate the usefulness of the framework developed, an attempt has been made to determine partial factors for assessment for a typical T-girder bridge designed according to the relevant Indian codes. The loading considered corresponds to actual traffic loads on a typical Chennai flyover. The study reported here gains importance as: (i) general guidelines to assess the reliability of in-service bridges are non-existent in the Indian context and (ii) the partial factors suggested for two consequence classes can be used for quick assessment of the safety of existing similar flyover girders against limit state of shear in a more rational way.

Keywords: Assessment, RC T girder bridges, partial factors, reliability index.

THE safety assessment of bridges plays a key role in a country's economic development. Its increasing importance is felt in most countries. As the processes involved in assessments are complex and time-consuming, various levels of assessment are done; each of the higher level is less conservative and involves more work in terms of computation[1]. When a particular assessment level is found satisfactory, then proceeding through further levels of assessments is not required. The complexity in assessment is thus minimized. Generally, the initial (or preliminary) assessment level is done in a deterministic way using partial factors, evaluated using a probabilistic analysis. Generally, in literature, such methods are referred to as semi-probabilistic methods[2].

Partial factors are commonly used in designing structures. In the assessment, these values are used to determine target resistance values, against which the resistance of an in-service bridge needs to be checked. It is important to note that partial factors to be used in assessment are not the same as the design, because of differences in target reliability indices that are considered[3].

The target reliability levels required for in-service bridges are lower than those of new bridges. The target reliability levels of in-service structures are reduced for two reasons: (i) actual field information of in-service bridges is available, and hence the uncertainty involved in calculations of reliability is reduced, and (ii) a conservative design does not result in significant increase in project cost but a conservative assessment does increase project cost. Various studies are now available that deal with considerations to fix target reliability indices for in-service bridges[4–6]. These considerations are broadly based on economy, human safety and societal criteria.

Based on target reliability indices, partial factors for different limit states were also studied. Researchers have considered shear failure to be important in safety assessment of an in-service bridge because of its brittle nature. Steenbergen[2,7] presented a procedure for calibrating partial factors by tuning the design limit state equation to achieve the target reliability index of in-service bridges. The limit state equation contains design resistance which implicitly contains partial factors used in design. The partial factors are so tuned to get the target reliability index of an in-service bridge. It is noted that the calibration studies attempted[7] are not the same as classical calibration studies reported[8]. Hence, to evolve more rational partial factors for in-service bridges, more realistic case studies need to be considered and this can be the focus of future research in India.

Holicky *et al.*[5] calculated the partial factors considering time-variant models for resistance and loads. The deterioration models of Vu and Stewart[9] and Enright and Frangopol[10] are used to estimate the resistance of in-service structures. They recommend these factors only for assessment and suggest determining partial factors

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Table 1. Target reliability indices for new and in-service bridge

Reliability classes	Failure consequences	Target reliability index for new structure	Target reliability index considering human safety for in-service structure
RC3	CC3	4.3	3.8
RC2	CC2	3.8	3.4
RC1	CC1	3.3	–

related to different limit states and different ratios of load.

Val and Stewart[11] proposed another way of estimating partial factors by acknowledging the main difference between new and in-service structures. It is possible for in-service structures to gain updated information about the present condition of the bridge which can be taken into account when developing the codal partial factors. Information on material properties and resistance is updated through on-site inspection and proof loading test. The Bayesian methods are used for updating information and the partial factors are calculated using the ratio of design value to the characteristic value of the basic random variable.

Bruhwiler[12] used a different concept called proportionality of intervention to assess in-service structures. This is mainly related to decision making regarding the repair of in-service structures when the structure fails to satisfy the safety requirement check using a deterministic approach. This deterministic verification is done by a degree of compliance, i.e. the ratio of updated resistance to updated load effects.

The reliability indices and partial factors required for design of new bridges are generally specified in all design codes and standards. However, the design code for bridges IRC 112-2011, specifies partial factors that can be used in the design of new bridges. The specified partial factors for action and resistance models are based on values specified in other similar international codes. However, the adequacy of partial factors needs to be established based on code calibration studies. Also, these partial factors cannot be used for safety assessment of in-service bridges. Therefore, partial factors for assessment have to be derived for different target reliability indices relevant to in-service bridges.

Considering the present status of IRC 112-2011 and based on the review of literature presented earlier, the following points are noted.

- There is a need to develop a framework for assessment of safety of bridge girders against shear limit state in the Indian context. Shear limit state is important since it can result in brittle failure.
- The framework should be simple to use which the design/decision making engineers can adopt as a first step to screen the safety of bridge stock.
- The partial factors format is widely accepted and is used in the present study.

The organization of the paper is as follows: the next section presents the philosophy involved in fixing the target reliability indices, calculated for Indian traffic conditions for two consequence classes, for in-service bridges. The study then develops the framework for deriving partial factors followed by a numerical example. Later, the results of sensitivity analysis are presented highlighting the importance of understanding the shear behaviour of RC girders. This would result in reducing the modelling uncertainty. This is followed by results and discussion. The section on conclusions also identifies future areas of research.

Target reliability index for in-service bridges

All structures depending upon the consequence of failure are classified into three different classes – CC1, CC2 and CC3 in Eurocode[13], according to this the target reliability indices (β_t) are set for new bridges as given in Table 1 Col. 3. Bridge structures are considered to be important since their failures have a considerable economic and social consequence and hence normally fall under CC3 or CC2. The target reliability indices for in-service bridges (β_{te}), unlike that of new bridges, need to fulfill the criteria for human safety with respect to in-service traffic. β_t is generally lowered to get β_{te} for economic reasons and this reduction should also satisfy human safety[14].

Using the procedure presented by Steenbergen[7], we fixed target reliability indices for in-service bridges located in Chennai and subjected to typical traffic loads. The considerations used were:

- The target reliability index of the in-service bridges was reduced for economic reasons. This target β_{te} was based on consequence of failure and four factors namely, component behaviour, system behaviour, risk factor and inspection level.
- Though the consequence of failure at the design stage dealt with both expected economic loss as well as human loss, for in-service bridges, special attention was required for human safety (β_h) based on existing usage.

The human safety was established using the traffic survey data presented by CCTS report and WHO report. According to the WHO-global status report on road safety[15] probability of fatalities due to accident was 1.94×10^{-4}. Therefore, the annual probability of becoming a victim of

Table 2. Statistical details of variables considered in the study for typical 10 m span T-girder bridge

Variables	Symbols	Units	Distribution	Mean[26]	Coefficient of variation[24,28]
Model uncertainty in dead load calculation	m_D	–	Normal	1	0.07
Model uncertainty in traffic load calculation	m_T	–	Normal	1	0.10
Model uncertainty in shear capacity prediction*	m_S	–	Lognormal	0.82	0.20
Shear force due to dead load	V_D	N	Normal	207,000	0.10
Shear force due to traffic load	V_T	N	Lognormal	434,330	0.12
Shear strength of concrete	τ	MPa	Lognormal	0.893 (calculated from euro code EN1992-1)	0.12
Yield strength of steel	f_y	MPa	Lognormal	415	0.07
Area of stirrups	A_{sv}	mm^2	–	400	–
No. of stirrups	n	–	–	5	–
Cross section area of girder	$b \times d$	mm^2	–	625 × 1000	–

*For the problem considered for which (a/d) is 3.17.

structural failure is taken one order lower than the probability of fatalities due to accident[7]. The annual probability of failure for human safety $P_{f(h)}$ can then be calculated as

$$P_{f(h)} \times P_c^a < 1.94 \times 10^{-05}. \quad (1)$$

P_c^a is the conditional probability for a consequence class to occur given that the structure fails is calculated for Chennai traffic condition using traffic data in the CCTS report[16]. The traffic densities of bridges will vary based on its location and the road that fetches traffic to the bridge. The traffic densities during peak hours at Anna Salai near Saidapet Maraimalai Adigal Bridge and Mount Poonamallee Road near MIOT hospital are considered for CC3 and CC2 respectively. The average speeds of vehicles are assumed to be inversely proportional to the traffic density. Using these assumptions, P_c^a is calculated by

$$P_c^a = \frac{\text{Number of people endangered}}{\text{Total number of people using the bridge}}. \quad (2)$$

The computed target reliability indices for assessment, β_{te}, at the end of 50 years, are given in Table 1 Col. 4.

Derivation of partial factors

The partial factors corresponding to the target reliability indices β_{te} against the limit state of shear, can be derived using reliability analysis method. The corresponding formulations are presented in this section.

Probabilistic framework

In the present study, the safety margin equation is formulated for the shear limit state of the RC T-girder. The same can be expressed as

$$Z = m_S(\tau bd + A_{sv} n f_y) - (m_D V_D + m_T V_T). \quad (3)$$

where τ is shear strength of concrete; f_y the yield strength of stirrup; V_D and V_T the shear forces due to dead and traffic loads; m_S is modelling error associated with the prediction of shear capacity of the cross-section and m_D and m_T are modelling errors associated with prediction of dead load and traffic load effect (i.e. shear force on a cross-section) respectively. These quantities are considered as random variables, whose details are given in Table 2. A_{sv} the area of each stirrup, n is the number of stirrups within each element of length d, bd the cross sectional area of girder section. These quantities are considered to be deterministic.

In this study, the shear capacity model along with its modelling error $[m_S(\tau bd + A_{sv} n f_y)]$ is considered as one variable R and is assumed to follow a lognormal distribution. Shear force due to dead load and its associated modelling error $[m_D V_D]$ is considered as one variable and is assumed to follow normal distribution. Similarly, shear force due to traffic load and its associated modelling error $[m_T V_T]$ is considered as one variable and is assumed to follow extreme type 1 (largest) distribution

$$Z = R - (D + T). \quad (4)$$

The nominal shear strength of the girder cross-section is calculated using the expression given by Euro Code EN1992-1 (ref. 17), for structures free from deterioration.

$$\tau = 0.18k(100\rho_l f_{ckc})^{1/3}, \quad (5)$$

where k is the size effect factor $(1 + (200/d)^{1/2} < 2)$ with d (mm) the effective depth of the section, ρ_l the percentage of longitudinal reinforcement and should be less than 2; f_{ckc} is the cylindrical compressive strength in MPa and is equal to 0.82 times the cube compressive strength.

Since one of the main aims of this paper is to propose a simple method for assessment in eq. (1), the shear capacity of the girder is estimated by superposition of contributions from concrete and stirrups. However, there is a need to characterize the modelling error associated with this simplified equation. This is attempted in the following section.

Modelling error associated with shear capacity estimation: Shear capacity can be calculated using different methods – by conventional superposition of shear capacity contributions of concrete and stirrups[18], Strut and tie method (STM)[19] or by finite element approach. Design codes[17,20] generally suggest the use of the first two methods. Although research in this area has identified STM for the design of deep beams, this method has certain disadvantages like: complexities in idealizing and dimensioning the struts and ties[19]. The truss analogy uses the concept of lower bound theory of plasticity and hence its applicability to brittle materials (viz. concrete – a quasi-brittle material) is questioned[21]. Also in case of slender girders wherein the span is greater than 4 times their depth, the domination of *D* (disturbed) region of STM is not critical. Therefore it is considered satisfactory to use the conventional superposition of shear capacity contributions of concrete and stirrups by also including the modelling error associated with it.

The modelling error associated with this conventional shear capacity relationship was determined from experimental test results on shear capacities of 185 beams, collected from the literature. The considered test database also contained test results of beams of sizes corresponding to actual bridge girders. Some of these beams have side face reinforcement, which again is representative of actual bridge girders. The depth of beams ranged from 150 to 2000 mm and the compressive strength of concrete ranged between 15 and 80 MPa. The values of longitudinal and vertical reinforcement of the beams varied in the range 0.35–4% and 0.045–2.5% respectively. It is to be noted that all beams satisfy the requirement of minimum longitudinal reinforcement of $200/f_y$ and minimum vertical reinforcement of 0.05% as suggested by ACI[22].

The experimental test data was analysed by dividing into three categories depending on shear span to depth ratio. Category I: when $a/d < 1$, Category II: when $1 \leq a/d \leq 2.5$, Category III: when $a/d > 2.5$. The number of beams that belong to categories I, II and III are 50, 85 and 50 respectively. The predictive parameters that may influence the shear capacity include[23]: shear span to depth ratio ($a/d = A_1$), percentage of longitudinal steel reinforcement ($\rho_l = A_2$), percentage of shear reinforcement ($\rho_{sv} = A_3$), and non-dimensional compressive strength of concrete ($f_{ck}\ bd/(V_u)_{\text{estimated}} = X_4$). $(V_u)_{\text{estimated}}$ is the ultimate shear capacity calculated from eq. (3) but, without using the modelling error.

Regression analysis was carried out using simulated annealing technique in Matlab. The objective function for the optimization problem is

$$\text{minimize} \sum_{i=1}^{N} [R_i - \{a_0 + (a_1 A_{1_i}^{a_2}) + (a_3 A_{2_i}^{a_4}) + (a_5 A_{3_i}^{a_6}) + (a_7 A_{4_i}^{a_8})\}]^2, \tag{6}$$

where *N* is the total number of test cases considered for the given range of (a/d); R_i the shear capacity of the *i*th test beam. A significant regression model for category I, for which many initial guesses converged to the same solution, is given by eq. (7) with $R^2 = 0.69$. The standard error associated with this is 0.476 and CoV is 0.22. Similarly the significant regression model for category II is given by eq. (8) with $R^2 = 0.59$. The standard error associated with it is 0.233 and CoV is 0.2. Finally the regression model for category III is given by eq. (9) with $R^2 = 0.78$. The standard error is 0.136 and CoV is 0.2.

$$\overline{m_S} = 3.8943 - (1.2387 X_1^{2.899}) - (0.5819 X_2^{-0.2275}) + (6.8536 X_3^{-0.0423}) - (10.04 X_4^{-0.1027}) \text{ for } \frac{a}{d} < 1, \tag{7}$$

$$\overline{m_S} = 1.2446 - (2.9326 X_1^{0.0532}) + (6.826 X_2^{-0.0483}) - (0.0053 X_3^{-2.3154}) - (5.4426 X_4^{-0.2232}) \text{ for } 1 \leq \frac{a}{d} \leq 2.5, \tag{8}$$

$$\overline{m_S} = -0.5591 - (0.0231 X_1^{2.7138}) + (1.8947 X_2^{0.0800}) - (3.5645 X_3^{5.0690}) - (7.0232 X_4^{-2.9544}) \text{ for } \frac{a}{d} > 2.5. \tag{9}$$

where $\overline{m_S}$ is the mean value of the modelling error. Inherently, the shear capacity of RC beams exhibits large scatter and JCSS[24] also reports a CoV of 0.20 for the modelling error for shear capacity.

To check whether the bounds of the proposed equation for shear capacity, that is, $(\overline{m_S} \pm 3\sigma)(\tau bd + A_{sv} n f_y)$ encloses the experimental values of shear capacity, test data of beams whose results are not used in the regression analysis are considered. Figure 1 shows that the experimental values fall within predicted bounds for all three categories of a/d. Thus, this equation is used to develop simple format and derive partial factors.

Partial factors

When the variables in the safety margin equation (eq. 4) follow non-normal distribution and/or when the safety margin is non-linear, the algorithm developed by Rackwitz and Fissler[25] is used for carrying out the reliability analysis. The partial factor γ_i corresponding to random variables X_i is given by

$$\gamma_i = 1 - \beta_t \alpha_i^* \Omega_{X_i}^N, \tag{10}$$

α_i^* is the direction cosine evaluated at the most probable design point x_i^*. Since the variables follow a non-normal

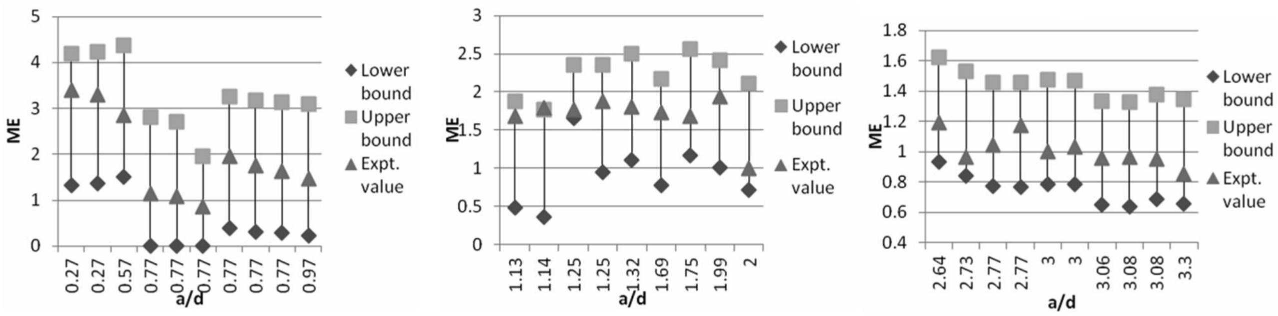

Figure 1. Effectiveness of modelling error in predicting the actual shear capacity for different a/d ratio.

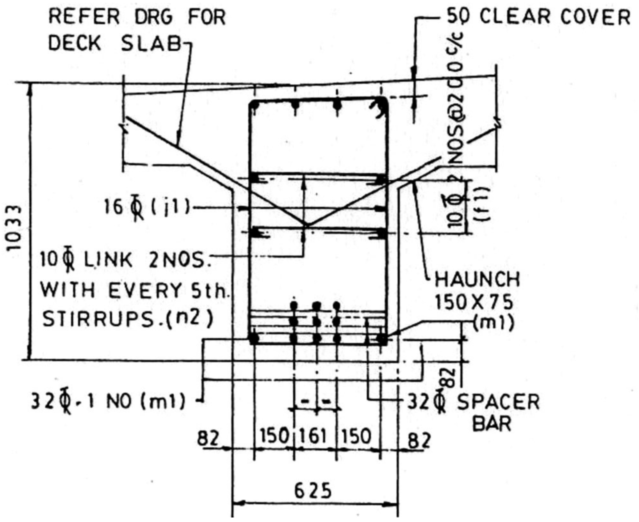

Figure 2. Standard cross-section of T-girder recommended by MORT&H for 10 m.

distribution, x_i^* should be evaluated by an iterative process. The μ_{x_i} and σ_{x_i} of non-normal variates are replaced by their equivalent normal values $\mu_{x_i}^N$ and $\sigma_{x_i}^N$ evaluated at the most probable design point. $\Omega_{X_i}^N$ is the coefficient of variation of equivalent normal variates. The partial factors are determined for the target reliability indices arrived at, based on the philosophy presented previously (Table 1, Col. 4).

The developed framework is presented below by considering a typical example of an in-service bridge girder subjected to Chennai traffic loads.

Illustrative example

The Ministry of Road Transport and Highways (MORT&H)[26] recommends standard drawings for bridge design. An example is illustrated for deriving the partial safety factors for assessment of bridges, built according to standard MORT&H drawing. The shear capacity of the girder is considered to be time-invariant. Reinforced concrete T girder bridge of span 10 m and width 12 m with four main girders is considered (Figure 2). Bridge girders are assumed to be constructed using M25 and Fe415 grades of concrete and steel respectively. The details of all the variables used in the study are presented in Table 2.

In-service loading for determination of partial factors – some considerations: The traffic composition of Chennai consists of different types of vehicles as shown in Figure 3. The motor vehicles are generally classified into: (i) motor cycle, (ii) light motor vehicle and (iii) medium and heavy motor vehicles[27]. The first two types of loads which are predominant in city areas are not significant for design because the traffic loads corresponding to these two vehicle types are small compared to the dead load. Even in the third type, the passenger vehicles are lightly loaded compared to commercial vehicles. Hence, loads coming from commercial vehicles are important for establishing safety. The loading configuration of these commercial vehicles on the bridge is shown in Figure 4. The total load from these commercial vehicles is 35.2 tonnes. Over and above this, an overload factor with a mean 1.4 and standard deviation of 0.55 (ref. 27) are used to arrive at the shear force due to in-service load. It is worth noting here that the bridge girder design is based on IRC loading. An attempt has been made to estimate the reliability of the girder considered against the limit state of shear using first order reliability method (FORM) for both the vehicular load shown in Figure 4 and the standard loading specified in IRC. The computed reliability indices for vehicular and IRC loadings are 3.01 and 2.73 respectively. It is thus noted that the difference in reliability built into the design and demanded by the actual plying loads is not significant (since the corresponding failure probabilities will be of the same order). Therefore, the IRC specified design loads are used to estimate demand shear in deriving partial factors for assessment of existing girder. The value of reliability index (2.73) obtained from the analysis is low when compared to values recommended in Eurocode[13]. However this need not have an alarming effect as the probability of failure is in the order of 10^{-3}. This situation arises because of inclusion of m_s in the analysis. However, if m_s is not included, the reliability index turns out to be 4.63. This suggests that more R&D efforts are required to understand the shear behaviour of RC bridge girders.

Estimation of shear span to determine the modelling error: From the earlier discussion it is inferred that the IRC specified loading is used to estimate the demand shear force. The 70R and class A loads are arranged on the deck such that the worst shear force is realized at the left support. The loading on girders is computed for this loading pattern using Courbon's method. It is noted that the loading on girder consists of uniformly distributed load (due to 70R) and point loads (due to class A loading). In order to estimate the mean value of the modelling error (eqs (7)–(9)), used in the simple approach proposed in this paper, the value of shear span to effective depth is required. The shear span is determined by finding the centre of gravity of the uniformly distributed and point loads acting on the girder. The total load is assumed to act at this point. For the example girder considered, the resultant of load acts at 2.23 m away from the left support; thus the girder has (a/d) of 3.17 and hence the modelling error is computed using eq. (9). The shear demand and capacities can now be estimated. Using the FORM approach the partial factors for safety assessment of in-service RC T-Girder bridge, against shear capacity, are computed and the same are presented in Table 3. These partial factors can be used in conjunction with eq. 11 (presented later) to assess the safety of girder at an age of 50 years. One of the intermediate steps to determine partial factors is to estimate direction cosines that serves as sensitivity measures. The sensitivity analysis is presented below to examine the relative importance of random variables both at the design stage and during assessment.

Sensitivity analysis

The FORM sensitivity factors determined at 1 year and 50 years are compared in Figures 5 and 6 for consequence classes CC2 and CC3 respectively. From these figures it is evident that the sensitivity of safety margin equation with respect to shear resistance increases with the age of structure. On the other hand, the sensitivity with respect to traffic load variations decreases with age. The sensitivity with respect to dead load variations is small compared to sensitivities with respect to the other two variables.

When the sensitivities are compared between the two consequence classes considered, for CC3, the variations in traffic loads are important at the age of 1 year and this is followed by the importance of variations in shear resistance. However, at an age of 50 years, variations in both the shear resistance and traffic loads are equally important.

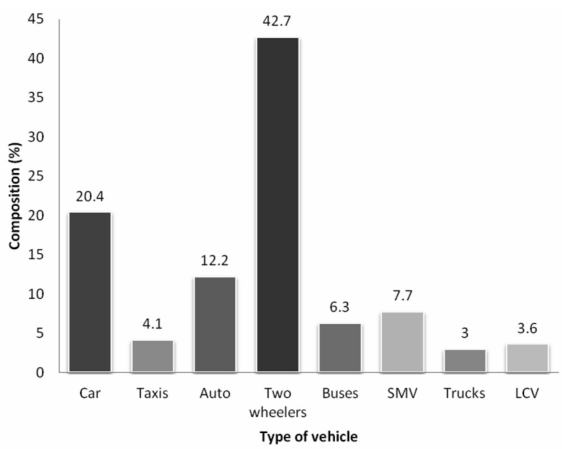

Figure 3. Composition of vehicular traffic in Chennai city.

Table 3. Derived partial factors for shear capacity assessment of in-service RC T-girder bridges

Variables	COV	Target reliability index 3.4 (CC2)	Target reliability index 3.8 (CC3)
γ_{V_R}	0.212	0.469	0.463
γ_{V_D}	0.123	1.051	1.053
γ_{V_T}	0.158	1.360	1.442

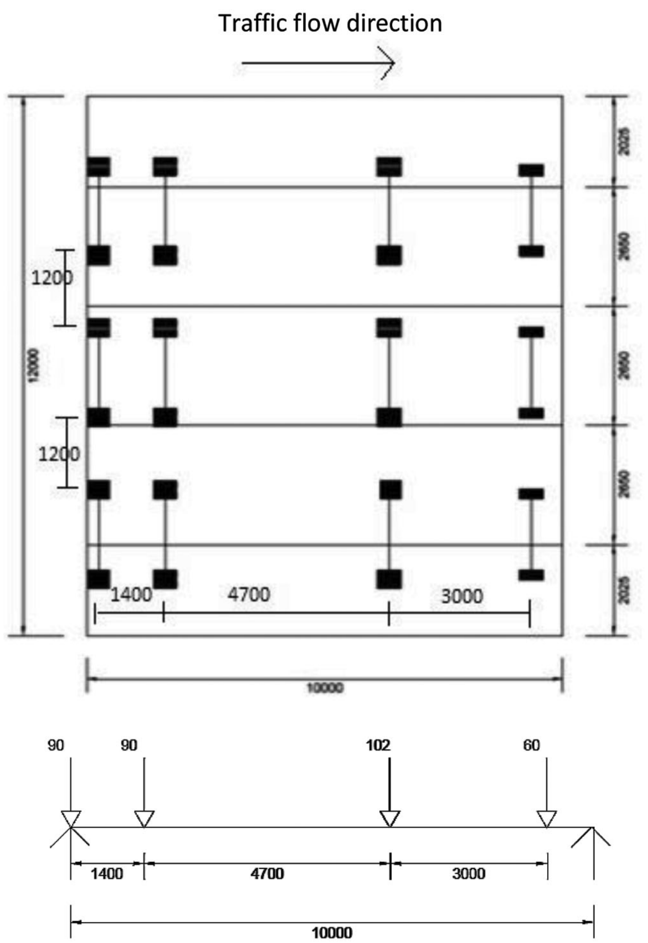

Figure 4. Wheel arrangement of actual commercial vehicles on the bridge for maximum shear force.

Results and discussion

From the results of sensitivity analysis, presented earlier, it is noted that variations in both traffic load and shear resistance are important. From Table 2, it is noted that the CoV of modelling error associated with shear capacity prediction is high (i.e. 0.20) compared to the CoVs of other random variables. Hence, there is a need to study the effect of CoV of modelling error on the values of partial factors. It is noted that a decrease in CoV of modelling error is a reflection of better understanding of the shear capacity estimation of RC girders. The results of this study are shown in Figures 7 and 8. As expected, the partial factor of shear resistance decreases with the CoV of modelling error for both consequence classes considered. The other two partial factors are not significantly affected by the variations in CoV of modelling error.

Though the findings are in line with expectations, the procedure presented to derive the partial factors would be useful in checking the safety of in-service T-girder RC bridges by simply comparing the actual resistance with factored resistance calculated using the partial factors reported here.

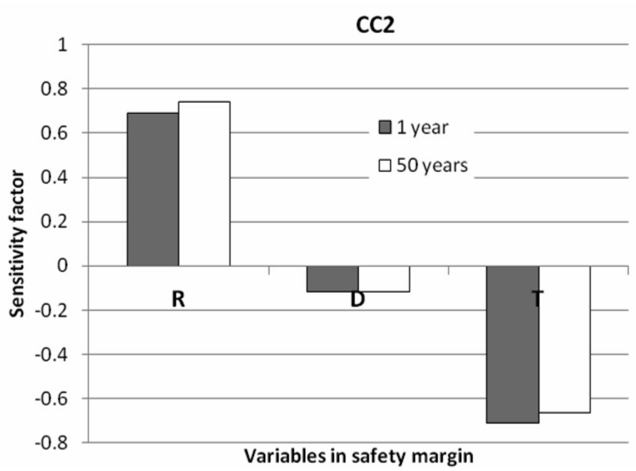

Figure 5. Sensitivity factors of variables during 1 year and 50 years for CC2.

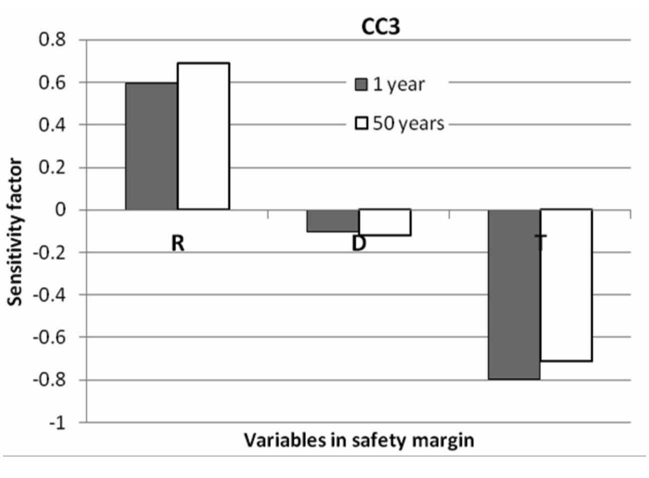

Figure 6. Sensitivity factors of variables during 1 year and 50 years for CC3.

$$R_{\min} = \frac{(\gamma_D \times V_D\ ) + (\gamma_T \times\ V_T)}{\gamma_R}. \quad (11)$$

If R of the in-service girder is less than $R_{\min}$, then the component fails to satisfy the required safety. This means that more detailed assessment involving possibly field experiments need to be carried out. Even then if the component fails to satisfy required safety, repair or retrofit measures have to be taken up.

Conclusion

The article presented a framework to determine partial factors for safety assessment of the in-service T-girder bridges in India against the shear limit state. The aim is to evolve a simple method for assessment and hence shear capacity of the girder is estimated by superposition of contributions from concrete and stirrups. The limitation of simple shear capacity model is overcome by estimating the modelling error associated with it for different ranges of (a/d) using the database of shear tests compiled based on results reported in the literature. After quantifying the variations in modelling error, considerations in fixing the target reliability indices for safety assessment of RC bridge girders against the limit state of shear are presented. Once the shear capacity equation and the target reliability indices are known, the partial factors can be determined using FORM of reliability analysis.

The proposed framework is demonstrated by determining the partial factors for assessment of in-service T-girder bridges that are built according to standard MORT&H drawing. The partial factors for assessment at 50 years, derived for target reliability index of 3.4 (corresponding to the consequence class CC2) are: 0.469 for shear resistance, 1.051 for dead load and 1.360 for traffic load. Similarly for target reliability index of 3.8 (corresponding to the consequence class CC3) the partial factors are: 0.463 for shear resistance, 1.053 for dead load and 1.442 for traffic load. Also, since the CoV of modelling error is high, the partial factors for different values of CoV of modelling error associated with shear resistance are presented. The values of partial factors obtained can be used by designers for safety assessment of the in-service *T*-girder bridges against the shear limit state subjected to traffic load considered in the study (which are typical of urban transport). For this purpose eq. (11) can be used.

In order to evolve partial factors for safety assessment of in-service bridges, more realistic case studies need to be considered and this can be the focus of future research

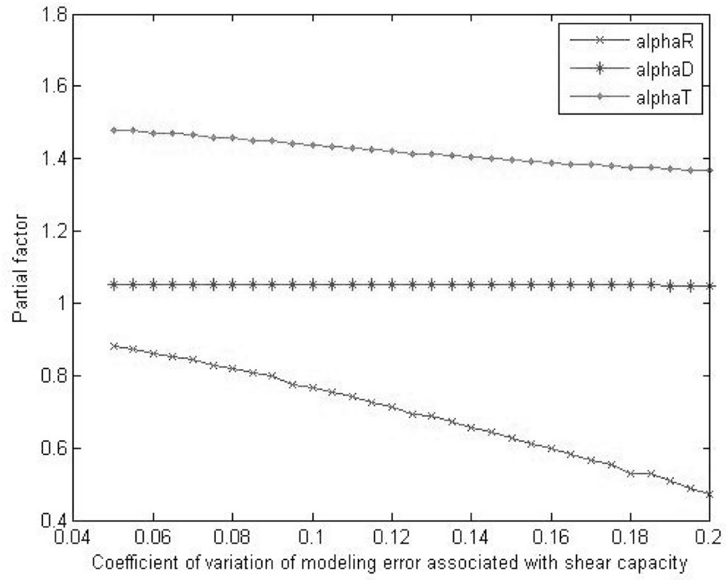

Figure 7. Values of partial factors at 50 years for variation in COV of modelling error associated with shear capacity estimation for $\beta = 3.4$.

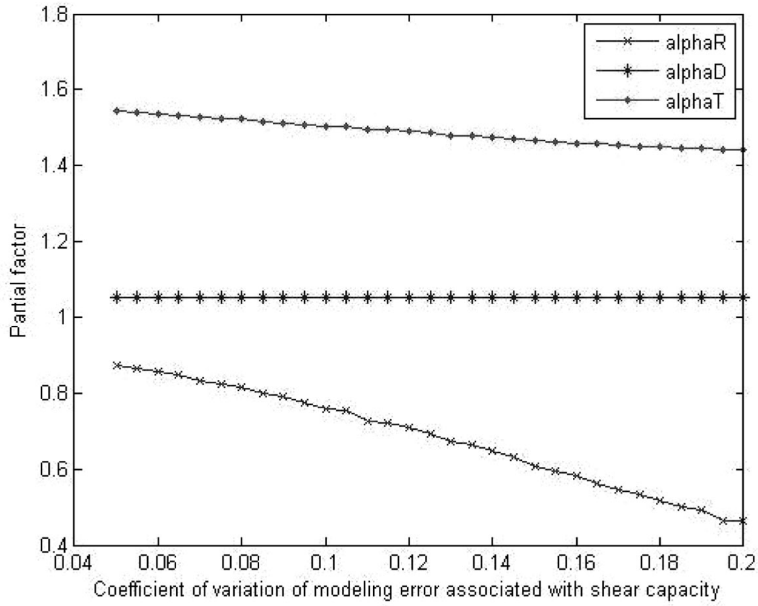

Figure 8. Values of partial factors at 50 years for variation in COV of modelling error associated with shear capacity estimation for $\beta = 3.8$.

in India. The calibration is carried out by considering different ratios of dead load and traffic load for bridges of different spans and different design scenarios for the shear limit state. Better understanding of shear behaviour of RC T-girders of dimensions used in the bridges is another area of future research.

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