Improving the Reliability when Designing Formwork following Vietnam Standards

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Abstract. In Vietnam, the creation of separate standards for designing formwork to support and mould cast-in-site concrete has not been properly considered, so the calculation of design and the use of formwork is still limited and shortcoming. To help clarify the problem, the paper conducts analysis, compares the current Vietnam standards for designing formwork to the standards of several other countries, which will focus on the content of determining the load and load combination when designing formwork. Based on the assessment and reference from the point of view of reliability, the results show the inadequacies in taking the load factor coefficients in the Vietnam standards, then suggest the adjustment coefficient of the load combination when designing formwork to ensure the safety of the structure.

1. Introduction

Formwork is a structure, usually as temporary, used to support and mould cast-in-site concrete and it has a crucial impact to the quality, cost and time to construct of concrete structures. Besides, a reliable formwork is necessary for safety. Due to the importance of formwork, there are own standards for design and construct formwork in many countries, such as America, EU, UK and Australia etc.

However, there has been many incidents of collapsing formwork, which in half of them happened in the concrete pouring process [1]. Researchers think that there are shortcomings in designing formwork, scaffold and due to the problems of expected load estimation in the concrete pouring process or the durability of formwork. Some authors processed measurements, gathered data about actual action load on workform independently, such as Fattal [2], Ayoub and Karshenas [3], Peng et al [4], Rosowsky et al [5], Ikaheimonen [6]. Their researchs show that, in the concrete pouring process, the actual action load on formwork has a difference to the estimation and modern designing methods have a tendency of under evaluated, especially when the thickness of concrete structure increase. On the other hand, the result of these researchs also show that, due to the randomness of action effect and resistance of structure, there is the necessity of evaluation of the correlation between safety coefficients for action load effects on structure and reliability index, then add to design instructions to be more suitable and reliable.

In Vietnam, there are none of standard is specified for formwork designing. Instead, the TCVN 4453:1995 [7] is used for generally evaluating and combining loads on structure. Even though failures related to formwork are recorded frequently, there are lack of studied focused on the flaw of design.
and such failures. This study attempts to establish the relationship between limited state in TCVN 4453:1995 and reliability level and then proposed adjustment to satisfy such reliability target for steel formwork popular in Vietnam.

2. Materials and Methods

A particular formula for reliability index of formwork is established. This formula then used to compare TCVN 4453:1995 with other standards, which are:

- American Standard ACI 347R-2014 Guide to Formwork for Concrete [8].
- European Standard EN 12812:2008 Falsework - Performance requirements and general design [9].
- British Standard BS 5975:2008 Code of practice for temporary works procedures and the permissible stress design of falsework [10].
- Australian Standard AS 3610-1995 Formwork for Concrete [11].
- Israeli Standard SI 904:1998 Part 1: Formwork for Concrete: Principles [12].

2.1. Concept of reliability

In view of the uncertainties in the problem, satisfactory performance cannot be absolutely ensured. Instead, assurance can only be given in terms of the probability of success in satisfying some performance criterion. In engineering terminology, this probabilistic assurance of performance is referred to as reliability.

An alternative way to look at the problem is to consider unsatisfactory performance of the system. In that case, one might measure the probability of failure to satisfy some performance criterion, and the corresponding term would be risk. Thus, risk and reliability are complementary terms. Reliability or risk assessment of engineering systems uses the methods of probability and statistics.

Figure 1 shows a simple case considering two variables (one relating to the demand on the system, e.g., load on the structure, $S$, and the other to the capacity of the system, e.g., resistance of the structure, $R$). Both $S$ and $R$ are random in nature; their randomness is characterized by their means $\mu_S$ and $\mu_R$, standard deviations $\sigma_S$ and $\sigma_R$, and corresponding probability density functions $f_S(s)$ and $f_R(r)$, respectively, as shown in Figure 1. It also identifies the deterministic (nominal) values of these parameters, $S_N$ and $R_N$, used in a conventional safety factor-based approach.

![Figure 1. Fundamentals of Risk Evaluation [13](412x550)](image)

The shaded area in Figure 1 illustrates the probability of failure, which can be expressed as:

$$P_f = P[(R - S) < 0]$$

(1)

An alternative representation of the probability of failure is:


\[ P_f = P \left[ \ln \left( \frac{R}{S} \right) < 0 \right] \]  

(2)

Rarely is there sufficient data to know the probability distributions of \( R \) and \( S \). Normally, only the means (\( \mu_R \) and \( \mu_S \)) and the standard deviations (\( \sigma_R \) and \( \sigma_S \)) are known. However, by using first order probabilistic methods, a relative measure of the reliability (safety) of a structure can be calculated, such that:

\[ \beta = \frac{\ln \left( \frac{\mu_R}{\mu_S} \right)}{v_R + v_S} \]  

(3)

where \( \beta \) is called the reliability index, and \( v_R \) and \( v_S \) are the coefficients of variation of \( R \) and \( S \), respectively.

The probability of failure in terms of the safety index can be obtained as

\[ P_f = \Phi(-\beta) = 1 - \Phi(\beta) \]  

(4)

**Calibration**

Commonly, limit states design rules are developed using first-order probabilistic techniques or similar methods in a process called “calibration”. First, a target reliability index is chosen after considering the reliability of structural designs using existing methods, often permissible stress methods. Then, new design rules are calibrated to achieve the target index. This approach was first used by Ravindra and Galambos [14] to develop LRFD load and resistance factors.

**Target Reliability Index**

The target reliability index is commonly suggested by standard, however, there are none of them issued in Vietnam. Consequently, reference from other studies is necessary. Kenedy et al [15], El-Shahhat et al [16] and Pham et al [17] recommend target reliability index at 3.0, 2.5;3 and 3.5, respectively. Generally, target reliability index are commonly chosen from 2.5 to 3.5.

**2.2. Loads on formwork**

Prior to concrete work, formwork is designed to carry live load and dead load from itself, other material and the reinforced steel. During the concrete work, the dead load on formwork is added with the concentrated dead load of concrete. The live load on formwork is also increased with the dynamic forces of the concrete work process, tamping, workers and machines etc. During the hardening period, formwork is the main structure for activities on concrete such as masonry work.

Load combination and corresponding load factor from various standards provided in Table 1.

| Code/Standard | Load combination (kN/m²) |
|---------------|-------------------------|
| TCVN 4453⁴   | \( S^a = 1.1G_f + 1.2G_c + 1.3Q_v \) |
| AS 3610⁸     | \( S^a = 1.25G_f + 1.25G_c + Q_v \) |
| ACI 347      | \( S = G_f + G_c + Q_v > 4.8 \) |
| BS 5975      | \( S = G_f + G_c + Q_v + M \) |
| SI 904⁴      | \( S^a = 1.4(G_f + G_c) + 1.6Q_v \) |
| EN 12812²⁴   | \( S^a = 1.35G_f + 1.5G_c + 1.5Q_v + 1.5Q_c \) |

⁴ For limit state design

The general form for load combination presented in Eq.5 and the distinction of standards to evaluate the values of each components.
\[ S = \gamma_f G_f + \gamma_c G_c + \gamma_q Q, \quad (kN/m^2) \]  
(5)

where: \(\gamma_f, \gamma_c\) and \(\gamma_q\) are load factors for formwork, concrete and imposed actions; \(G_f\) is the weight of the formwork; \(G_c\) is the weight of the concrete including an allowance for reinforcement; and \(Q\) is an imposed action for the weight of workmen, equipment and the effects of concrete discharge methods (dynamic and mounding). For permissible stress design, \(\gamma_f = \gamma_c = \gamma_q = 1.0\).

The different between national standards is the quantitative process of the individual load values and values of factors.

2.3. Data of action effect and resistant

- Action effect data: Ikäheimonen [10] suggested that the ratio of mean to the nominal action effect \(\lambda_S = \mu_S / S_N\) is approximately at 0.99 and the coefficient of variation \(\nu_S = 0.31\).
- Resistance data: for permissible stress methods, median values of \(\lambda_R = 2.09\) and \(\nu_R = 0.165\); and for limit states methods, \(\lambda_R = 1.21\) and \(\nu_R = 0.145\) (Pham and Bridger [17]).

The first order probabilistic analysis on the action data sourced proposed by Ikäheimonen [10] is conducted. According to Ikäheimonen, the relationship between mean nomination load and mean load can be found by Eq.6.

\[ \mu_S = \lambda_S (G_f + G_c) \]  
(6)

Eq.5 can be rewritten as:

\[ \gamma S_N = \gamma_f G_f + \gamma_c G_c + \gamma_q Q \]  
(7)

2.4. Formwork Reliability Index \(\beta\)

The relationship between the action effect and resistance can be found by inequality Eq.8

\[ \gamma S_N \leq \phi R_N \]  
(8)

where: \(S_N\) - nomination action effect; \(R_N\) - nomination resistance; \(\gamma\) and \(\phi\) commonly suggested by standards are factor of action effect and resistance, respectively (i.e. reliability coefficients).

According to Ravindra and Galambos [12], the approximation of \(\gamma\) and \(\phi\) can be found by:

\[ \gamma = \lambda_S e^{\alpha \nu_S} \]  
(9)

\[ \phi = \lambda_R e^{\alpha \nu_R} \]  
(10)

where \(\alpha\) is a constant at 0.55.

Once the mean and standard deviation of Action Effect and Resistance obtained, the reliability index can be found in Eq.11.

\[ \ln \left( \frac{\lambda_R \gamma S_N}{\phi \mu_S} \right) = \frac{\ln \gamma S_N}{\sqrt{\nu_R^2 + \nu_S^2}} \]  
(11)

Substitute Eq.6, 7 to Eq.11, the reliability index is

\[ \ln \left[ \frac{\lambda_R \left( \gamma_f G_f + \gamma_c G_c + \gamma_q Q \right)}{\phi \mu_S (G_f + G_c)} \right] = \frac{\ln \gamma S_N}{\sqrt{\nu_R^2 + \nu_S^2}} \]  
(12)

In this study, some assumptions made with a particular thickness of concrete, they are:
- Resistance coefficients when calculates steel formwork are the same and \(\phi = 0.9\);
- Uniformly weight of steel formwork is 0.5kN/m²;
- Uniformly weight of concrete varies with standards;
- \(Q_i\) varies with standards;
- Limitations on the extent of imposed actions for concrete mounding $Q_c$ are ignored.

Based on these assumption, load combination in Table 1 is simplified in Table 2. TCVN 4453(1) and TCVN 4453(2) are the combinations with load of worker/machine/equipment at 2.5$kN/m^2$ and 1.0$kN/m^2$, respectively.

Table 2. Simplified Load combination for formwork

| Code/Standard | Simplified load combination (kN/m²) |
|---------------|-------------------------------------|
| TCVN 4453(1)  | $S_a = 1.1(0.5) + 1.2(26)t + 1.3(2.5) + 1.3(2)$ |
| TCVN 4453(2)  | $S_a = 1.1(0.5) + 1.2(26)t + 1.3(1.0) + 1.3(2)$ |
| AS 3610       | $S_a = 1.25(0.5) + 1.25(24.5)t + 1.0(3.0)$ |
| ACI 347       | $S = 1.0(0.5) + 1.0(23.5)t + 1.0(1.9) \geq 4.8$ |
| BS 5975       | $S = 1.0(0.5) + 1.0(24.5)t + 1.0(1.5)$ |
| SI 904        | $S_a = 1.4(0.5) + 1.4(26)t + 1.6(3.0)$ |
| EN 12812      | $S_a = 1.35(0.5) + 1.5(24.5)t + 1.5(0.75) + 1.5(0.75)$ |

* For limit state design

Table 2 and Eq.12 are used to calculate reliability index $\beta$ with concrete thickness ranging from 0.1 to 1.3.

3. Results

Relationship between reliability index and concrete thickness are shown in figure 2.

![Figure 2](image_url)

**Figure 2.** Relationship between reliability index and concrete thickness with various standards

4. Discussion

In figure 2, reliability index rapidly decreases along with the increase of the concrete thickness. The indexes of American, EU and UK ranged from 2.3 to 4.3 are acceptable with the target reliability index. Australian standard has a significantly low reliability index. The index from TCVN(1) has a wide range from 4.2 to 2.5 with the concrete thickness ranges from 0.4 to 1.8, respectively. TCVN(2) is approximately to AS 3610 with the broader difference between the maximum and minimum.

In this study, an adjusted factor at 1.3 for TCVN 4453 is observed and proposed. The load combination then calculated as:

$$ S = 1.3 \left( 1.1G_f + 1.2G_c + 1.3Q_e \right) $$ (13)

The relationship between reliability index before and after modification is illustrated in figure 3. It shows that it is necessary to have an additional modification for TCVN 4453 with the
external live load of worker/machine/equipment. This load is proposed to use at 1.0kN/m$^2$ to satisfy the target reliability index and equivalent to other standards.

![Figure 3. The relationship between reliability index before and after modification](image)

5. Conclusions
Based on first order probabilistic analysis and guidance from Vietnamese standards TCVN 4453:1995 and other, relationship between reliability index and concrete thickness are obtained with a target reliability index ranging from 2.5 to 3.5.

It is shown that TCVN 4453 is acceptable with low-thickness concrete structures. Compared with other counterparts, design with TCVN 4453 tends to has significantly lower reliability index and fail to satisfy the target reliability index.

Consequently, adjustment for TCVN 4453 is proposed with a general factor at 1.3 with the worker/machine/equipment live load at 1.0kN/m$^2$.

This study only suitable with flawless formwork, degradation due to recycling is not counted and need further study.

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