Comparative Study between Chinese and British Design Codes of Cup-Lock Scaffolding System

Jianbing Hao¹,²*, Tianshi Qu¹, Peng Chang¹ and Xuelin Bi¹
¹ China State Constr. Engrg. Corp. Ltd. (Egypt), 11865 Cairo, Egypt
² The Third Constr. Co., LTD of China Constr. First Group, 100161 Beijing, China
Email: hao_jianbing@chinaconstruction.com

Abstract. A comparison study between Chinese and British codes for cup-lock scaffolding and formwork system were carried out. The analysis results show significant difference between these national codes regarding falsework management and design methodologies. The difference in the management is mainly focusing on whether the execution should be performed by main contractors or the falsework specialists. The difference in design, however, is the design methodologies of concrete lateral pressure on formwork, wind load and the capacity of the cup lock pipes. Mix use of different design codes can cause unreliable change of system safety margin and negative impact to the project cost. A case study is also provided to show the difference in the safety margin which can lead to opposite results if different codes are adopted in the projects.

Keywords. Falsework management, cup-lock system, Chinese codes, British codes.

1. Introduction
Driven by the globalization process and Chinese “The Belt and Road” initiative, more and more Chinese firms in construction industry plays a significant part in the global market. It is consensual in Chinese construction company that a clear understanding of the local codes and standards is one of the most important factors to ensure a good execution of the project, especially since Chinese standard system is significantly different from international standards.

Among the subjects of project construction, falsework, including formwork and scaffolding, typically comprise approximately 5~10% of the project cost and it is one of the most important technical works during execution. However, it is found that both the management and design methodology between Chinese and international market are different, which makes the methodologies and calculations prepared by Chinese company difficult to be approved by international consultants.

A comparative study between Chinese and British codes (as shown in table 1) for falsework is presented in this paper, especially focusing on the cup-lock system. A complete case is also provided to support the study. It should be noted that the comparison results also apply to other international codes such as American and Australian codes.

2. Comparison of Management
In China, all the work related to the falsework, including but not limited to design, procurement, installation, dismantling is carried out by the Contractors [1]. Hence, a lot of national laws, regulations, codes, standards, specifications, etc. were issued by Chinese government to achieve the minimum quality and safety requirements. Such management methodology makes it very convenient for contractors to evaluate cost and conduct technical, quality and safety management. However, the
design and execution are single-target based and not conducive to the research and development of advanced type of falsework.

On the contrary for oversea projects, the design, supply, construction and even pre-inspection of falsework are generally performed by specialist subcontractors [2]. The main Contractor relies on the professionalism of subcontractor to ensure the falsework quality and safety. Such management methodology encourages subcontractors to develop advanced formwork and scaffolding system. However, it requires the Contractor to have strong coordination ability to ensure the compliance between technical, quality and safety management.

| Table 1. Comparison between Chinese and British codes for cup-lock system. |
|------------------|----------------------------------------------------------------------------------|
| Code             | Title                                                                            |
| GB50666-2011     | Code for construction of concrete structures                                     |
| JGJ162-2014      | Technical code for safety of forms in construction                               |
| GB51210-2016     | Unified standard for safety of scaffold in construction                          |
| JGJ166-2016      | Technical code for safety of cup-lock steel tubular scaffolding in construction  |
| BS 5975: 2019    | Code of practice for temporary works procedures and the permissible stress design of falsework |
| BS 12812: 2008   | Falsework—Performance requirements and general design                            |
| BS 5268: 2002    | Structural use of timber                                                          |
| BS 6399: 2002    | Loading for buildings: Code of practice for wind loads                            |

It is obvious, when comparing different management methodologies, that they are complementary to each other. It is also found that Chinese technical engineers have obvious advantages in the falsework management of international projects by their extensive experiences in the falsework designs and inspections. Even if specialist subcontractors are involved to do the design, Chinese technical engineers are capable for design reviews and ensure a high-end work quality and safety.

However, during the preparation or reviewing of the falsework method statement and calculation book, it is often found mix usage of Chinese and international codes, which can lead to either unreasonable increase or decrease of system safety margin or unnecessary cost input to the project.

3. Comparison of Design

3.1. Comparison of Design Theory
Chinese code for falsework adopts LRFD (load and resistance factored design) methodology [3] while the British standard adopts ASD (allowable stress design) methodology [4]. It is obvious that the latter is simpler in design principles but cannot accurately evaluate the safety margin of the system. Furthermore, contemporary trends in falsework design also tend to unify the temporary structures and permanent structures design to the same LRFD methodology [5]. It is believed that the next revision of the British codes shall adopt this advanced design theory as well.

3.2. Comparison of Concrete Lateral Pressure
There is no fundamental difference between Chinese and British codes regarding the load classification and loads imposed on the falsework. The dead load normally includes the self-weight of materials and concrete, and/or the pressure induced by the concrete, either on the bottom or side of the formworks. The live load normally includes the construction loads, wind load, etc [6]. However, the calculations of these loads are obviously different, especially the concrete pressure on the side formwork, wind load and baring capacity of the scaffolding system.

For concrete pressure, both Chinese and British codes use modified hydrostatic pressure. The maximum concrete pressure from Chinese and British codes are given as equations (1-2), respectively.

\[
F = 0.28\frac{\gamma_c t_f S V}{C}^{0.5}
\]
where $\gamma_c$ is density of concrete; $t_0$ is the initial setting time of concrete; $\beta$ is adjustment coefficient for concrete slump; $V$ is the rising velocity of the concrete along the formwork;

$$P = D \left[ C_1 \sqrt{R} + C_2 K (H - C_1 \sqrt{R}) \right]$$ (2)

where $C_1$ is coefficient dependent on the size and shape of the formwork, 1.0 for walls while 1.5 for columns; $C_2$ is coefficient dependent on the constituent materials of concrete, 0.3 for OPC, RHPC or SRPC without admixtures (except a retarder), 0.45 for OPC, RHPC or SRPC with retarder and LHPBFC, PBFC, PPFAC or blends containing less than 70% GGBFS or 40% PFA without admixtures (except a retarder), 0.6 for LHPBFC, PBFC, PPFAC or blends containing less than 70% GGBFS or 40% PFA with a retarder or Blends containing more than 70% GGBFS or 40% PFA; $D$ is weight density of concrete; $H$ is vertical form height; $h$ is vertical pour height; $K$ is temperature coefficient and equal to $\left[\frac{36}{(T+16)}\right]^2$; $R$ is the rate at which the concrete rises vertically up the form; $T$ is concrete temperature at placing; $H$ is effective height of hydrostatic zone.

Although the calculation equation for concrete pressure on side formwork is different, the factors considered for developing the equations are very similar. Both codes considered concrete slump, initial setting time and the casting rate as main parameters to affect the concrete pressure. However, the British codes combined the influence of concrete slump and initial setting time as coefficient $C_2$. Chinese code, on the other hands, induces a more obvious methodology by using these three physical properties directly in the equation (1), which is easily understandable to engineers with no experience in the material engineering.

A case study is provided here to compare the concrete pressure calculated by different equations. Grade C30 concrete using Portland cement, and 16.5 cm slump is considered. The concrete is casted with temperature 20 °C, at rate of 2.5 m/h to a total height of 5 meters. The maximum pressure calculated by Chinese and British Codes is 60.72 kN/m$^2$ and 53.40 kN/m$^2$, respectively, and the effective heights 2.53 m and 2.14 m, respectively.

It should be noted that by inducing the cement type, admixture and additive type in the equation, the feasibility of the equation (2) to some advanced concrete is debatable, as it may not estimate the concrete pressure correctly [7,8].

### 3.3. Comparison of Wind Load

The Chinese and British codes differ greatly in the calculation of wind load, especially the definition of the basic wind speed. Although both codes used mean wind speed at 10 m above ground in approximately same exposure category, different averaging time are used. 10 min mean speed ($V_{10}$) and 1 hour mean speed ($V_{3600}$) were used for Chinese and British codes, respectively. It is necessary, therefore, to make adjustment between different codes to overcome the difference in averaging time.

The most commonly used basic wind speeds are 3s gust speed, 10 min mean speed and 1 hour mean speed. ASCE provides correlation and adjustment between basic wind speed over averaging time $t$ [9]. However, cautions should be given when using 3s gust speed since the gust factor adjustment is not always straightforward.

However, when the adjustment is correctly performed, the wind load calculated from different codes are approximately same. For example, if the basic wind speed is 33 m/s as 3s gust speed $V$, the equivalent $V_{10}$ and $V_{3600}$ are 23.16 m/s and 21.64 m/s. Hence, the wind load calculated by American ($V$), Chinese ($V_{10}$) and British ($V_{3600}$) codes are 0.350 kN/m$^2$, 0.335 kN/m$^2$ and 0.338 kN/m$^2$, respectively, assuming the same structure height (9 meters), shape and exposure category.

### 3.4. Comparison of Scaffolding Capacity

Both Chinese and British codes make it mandatory to check the capacity of the scaffolding. For cup-lock system, the vertical pipes are made of steel tubes, so their capacity checking is based on steel structure theory by considering the joint between vertical pipes and horizontal ledger as a hinge [10-
However, the effective length used in Chinese and British codes are different as shown in equations (3-4), respectively.

\[ l = k \mu (h + 2a) \tag{3} \]
\[ l = h \tag{4} \]

where \( l \) is effective length used to calculate the pipe bearing capacity, \( h \) is nominal distance between horizontal ledgers, \( a \) is cantilever length of pipe at the scaffolding top, \( \mu \) is effective length coefficient related to the ledger distance. \( k \) is adjustment coefficient.

It is obvious that Chinese codes is more accurate and safer to calculate the effective length as it considers the cantilever of scaffolding pipes at the top. More importantly, an adjusting coefficient \( k \) is adopted to balance the safety margin of cup-lock system with different height as it increases when the scaffolding height increases. By using the adjustment coefficient, the Chinese codes manage to increase the system “equivalent” safety factor (based on the system ultimate capacity and design capacity) to be approximately 2.2, which is 1.65 for British codes.

4. Case Study

Case studies was carried out for Central Business District Project of New Administrative Capital of Egypt as this is a high-end project executed by one of the largest Chinese contractors and supervised by international consultant office. The contractor successfully developed the calculation book for different kinds of scaffolding system (cup-lock system, coupler system, shore brace system, etc.) based on both Chinese and British codes. The cup-lock system comparison is given here to clearly identify the different methodologies. It should be mentioned most of the procedures and results applies for other systems as well.

A 300 mm thick slab was considered and the scaffolding height is 8.9 meters. The basic design of the falsework is shown in figure 1. The grid distance for scaffolding is 1.6 m×2.1 m, and the ledger distance is 1.0 m.

![Scaffolding and formwork design](image)

Figure 1. Scaffolding and formwork design.

The basic material used in the study and their properties are shown in table 2. It is worth mentioning that for H20 beams, both Chinese and British codes considered their bending and shear capacity as 5 kN·m and 11 kN, respectively. Considering different design theory (LRFD and ASD) are adopted, it is not accurate to use the same capacity as it shall unreasonably increase the safety margin of the H20 beam in Chinese codes and cause negative impact to project cost.
Table 2. Material properties.

| Elements                      | Plywood                  | Secondary beam | Main beam    | Cup-lock     |
|-------------------------------|--------------------------|----------------|--------------|--------------|
| Material                      | 18 mm plywood            | 50×150 mm timber | Double H20 beams | φ48*3.2, Q235 |
| Moment of section resistance W | 54000                    | 187500         | 464210       | 4797         |
| (mm³)                         |                          |                |              |              |
| Moment of Inertia I (mm⁴)     | 486000                   | 14062500       | 46421300     | 115857       |
| Modulus of Elasticity E (N/mm²) | 54000                   | 8500           | 8500         | 206000       |
| Bending capacity Chinese codes | 15 N/mm², 15 N/mm², 5 kN·m | 5 kN/mm², 205 N/mm² |
| capacity British codes        | 8.5 N/mm², 8.5 N/mm², 5 kN·m | 5 kN·m, 142 N/mm² |
| Shear capacity Chinese codes  | 1.7 N/mm²                | 11 kN          |
| capacity British codes        | 1.5 N/mm²                | 11 kN          |

The load imposed on the scaffolding system is shown in table 3, both Chinese and British codes used the same dead and live loads to have an accurate study result.

Table 3. Load imposed on the scaffolding.

| Load Category                              | Value          |
|--------------------------------------------|----------------|
| Self-weight of plywood falsework (kN/m²)   | 0.1            |
| Timber                                     | 0.3            |
| H20                                        | 0.5            |
| Scaffolding                                | 0.2            |
| Self-weight of concrete (kN/m³)             | 24             |
| Self-weight of reinforcement (kN/m³)        | 2              |
| Live load (kN/m²)                          | 2.5            |

The design check and comparison results of the formwork and scaffolding system are shown in table 4. By comparing the load reaction and material capacity, it can be concluded that the Chinese codes adopt higher safety level for materials. Hence, in some cases, opposite results may be achieved as some materials are deems safe under British codes and unsafe under Chinese codes.

Table 4. Design checking and comparison.

| Elements       | Design check | Chinese codes | Results | British codes | Results |
|----------------|--------------|---------------|---------|---------------|---------|
| Plywood Loads Comb | Basic $q_s=14.3kN/m$ | $\sigma_s=q_{ps}^2/10W$ | Safe | $\sigma_s=q_{ps}^2/10W$ | Safe |
|                | Nominal      | $q_{ps}=7.9kN/m$ |         | $q_{ps}=10.3kN/m$ |         |
| Capacity check | Safe $\sigma_s=q_{ps}^2/10W$ | $=1.7N/mm^2<8.5N/mm^2$ | Safe  | $v_{ps}=q_{ps}^2/145EI$ | Safe |
| Service check  | Safe $v_{ps}=q_{ps}^2/145EI$ | $=0.2mm<L/270=1.1mm$ | Safe  | $v_{ps}=q_{ps}^2/145EI$ | Safe |
| Basic          | Safe $v_{ps}=q_{ps}^2/145EI$ | $=0.2mm<L/270=1.1mm$ | Safe  | $v_{ps}=q_{ps}^2/145EI$ | Safe |
| Loads Comb     | Safe $v_{ps}=q_{ps}^2/145EI$ | $=0.2mm<L/270=1.1mm$ | Safe  | $v_{ps}=q_{ps}^2/145EI$ | Safe |
| Sec. beam      | Safe $v_{ps}=q_{ps}^2/145EI$ | $=0.2mm<L/270=1.1mm$ | Safe  | $v_{ps}=q_{ps}^2/145EI$ | Safe |

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Elements | Design check | Chinese codes | Results | British codes | Results
--- | --- | --- | --- | --- | ---
Main beam | Loads Comb. | Basic $q_{bc} = 10.6 \text{kN}$ | -- | $q_{bc} = 7.3 \text{kN}$ | --
 | | Nominal $q_{sn} = 5.8 \text{kN}$ | | | |
 | Moment check | $M_{bc} = 7.4 \text{kN} \cdot \text{m} < 10 \text{kN} \cdot \text{m}$ | Safe | $M_{sn} = 5.1 \text{kN} \cdot \text{m} < 10 \text{kN} \cdot \text{m}$ | Safe
 | Shear check | $V_{bc} = 29.8 \text{kN} > 22 \text{kN}$ | Unsafe | $V_{sn} = 15.1 \text{kN} < 22 \text{kN}$ | Safe
 | Service check | $v_{bc} = 0.4 \text{mm} < L/400 = 4\text{mm}$ | Safe | $v_{bn} = 0.5 \text{mm} < L/270 = 5.9\text{mm}$ | Safe
 | Loads Comb. | Basic $N_{bc} = 59.4 \text{kN}$ | -- | $N_{sn} = 40.9 \text{kN}$ | --
 | Effective length | $l_{ec} = k_{l}\{h + 2a\} = 3.0 \text{m}$ | | | |
 | Capacity check | $\sigma_{ec} = \frac{N_{bc}}{1.2\phi A} = 496 \text{N/mm}^2$ | Unsafe | $\sigma_{ec} = \frac{N_{sn}}{\phi A} = 122 \text{N/mm}^2$ | Safe
 | | >205N/mm$^2$ | | <142N/mm$^2$ | |

The development of the national codes must adjust the safety margin based on both the reliability of the design theories and extensive surveys of the materials in the domestic market. Caution should be given when mix using codes from different countries, especially during execution of international projects. It is generally preferable to carry out the design based on the local design codes, even though it may change the input for project cost and safety.

5. Conclusion
A comparison study was carried out for Chinese and British codes for falsework design. A case study was also provided to especially addressing the cup-lock system which are extensively used globally. The following conclusion can be draw from this study:

(1) Chinese firms in construction industry have advantages in falsework managing in international projects as the falsework system is governed by very detailed national laws, regulations, codes and standards, which also facilitate the knowledge transfer and experience accumulation.

(2) Chinese and British standards adopt LRFD and ASD theory for their falsework design, respectively. However, the contemporary trend is to unify the temporary structures and permanent structures design as LRFD theory.

(3) By inducing the concrete slump, initial setting time and the casting rate directly in the equation for calculating the concrete pressure, Chinese codes are more feasible, by comparison, for varieties of concretes, even advanced concretes.

(4) Extreme cautions should be given when mix using different codes to check the wind load, basic wind speed should be properly adjusted over averaging time.

(5) The case study for cup-lock system shows the safety margin of Chinese codes are higher than British codes, opposite assessment results can be achieved if different codes are adopted which should be considered during the project management.

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