Design Coefficient for the Wooden Shoring System

Cheer Germ Go¹, Wen-Pei Sung² and Kuen-Suan Chen³

¹Professor, Department of Civil Engineering, National Chung-Hsiang University
Taichung, Taiwan 40227 R.O.C. (go@mail.ce.nchu.edu.tw)
²Lecturer, Department of Landscape Design and Management, National Chin-Yi Institute of Technology
Taichung, Taiwan 41111 R.O.C. (sung809@chinyi.ncit.edu.tw)
³Professor, Department of Industrial Engineering and Management, National Chin-Yi Institute of Technology
Taichung, Taiwan 41111 R.O.C. (kschen@chinyi.ncit.edu.tw)

Abstract
A design coefficient that secures the safety of the wooden shoring system for construction loads is investigated. The effects of different ways of working and variations of material quality are considered in this research. The design coefficient is based on statistics concerning various situations. Random selection and finite difference are both used in the analysis for the buckling load of wooden shoring. The parameters are non-uniformed section, Young's modulus, and arbitrary loading distributions during construction. The design coefficient serves as a reasonable safety factor for wooden shoring design when compared with experimental data.

Keywords: reducing coefficient; wooden shore; non-homogeneous material and sections

1. Introduction
Wooden shores are commonly used in construction engineering for taking construction loads. It is a temporary and convenient supporting system for use during construction work. The quality assurance of the wooden shoring frame guarantees the safety of workers and the completion of construction. The application of wooden shores is usually dependent on the workers’ experience, which lacks in reasonable analysis and design. This fact causes the frequent occurrence of structure failure and results in casualties among workman. It also delays the engineering schedule and increases the construction costs (The Council of Labor Affair of Administration Yuan, Taiwan 1994, El-shahhat, Rosowsky and Chen 1995). Research in this area was usually emphasized on the theoretical model and experimental analysis (Rosowsky and Chen et. al. 1993, Yen and Huang et. al.1995, Peng, Rosowsky and Chen et. al. 1993, Mosallam and Chen 1991, 1992, Peng, Rosowsky and Chen et. al. 1996, Rosowsky and Huang et. al. 1991 and Peng, Pan and Rosowaky et al. 1996). Discussions regarding the behavior of the wooden shoring system during the construction stage are rare despite its popular use in the construction industry (Karshenas and Montes Rivera 1997). In this paper, the statistics method is used to define the design coefficient for the wooden shoring system based on the theoretical model and comparisons with the experimental results. Wood such as Kapur, Apitong, Cunninhhamia, Lanceo Lata, Red Lauan and White Lauan are often used in the construction industry (The Council of Labor Affair of Administration Yuan, Taiwan 1994). These materials all have complicated organisms that are composed of various types and categories of cells. Their mechanical behavior varies with grain, density and moisture. In addition to these characteristics, the difficult conditions of construction sites and unexpected loading types usually lead to an unreliable prediction of the bearing capacity of wooden shores. To prevent failure of the wooden shoring system, the statistical study of load capacity may be a feasible approach for reasonable safety. Herein based on random selections, a design coefficient for wooden shoring system is developed. These results are valid from a practical point of view compared with the experimental data for simple and convenient design.

2. Analysis model
The complexity and irregularity of the wooden shoring system are mainly responsible for structural failure. These random factors have to be taken into account in order to simulate the reality in the wooden shoring system.
Buckling load of a wooden shore

The axial force in a wooden shore with non-homogeneous section is assumed as \( P_{cr} \). The lateral deformation is \( Y(x) \). The associated moment \( M(x) \) is as follows:

\[
M(x) = P_{cr} Y(x).
\]

For a column with varied section and rigidity, the bending moment and the deflection is related by the equation

\[
\frac{d^2 Y(x)}{dx^2} = \frac{M(x)}{E(x)I(x)}.
\]

The left-hand side of the equation (2) may be arranged as finite difference expression as

\[
\frac{1}{\Delta L}[ -1 \quad 2 \quad -1 ] \begin{bmatrix} Y_{i-1} \\ Y_i \\ Y_{i+1} \end{bmatrix} = W_i.
\]

The equivalent elastic load at the right hand side of the equation (2) is the approximate parabolic distribution and expressed as (Ghali and Neville, 1978)

\[
W_i = \frac{P_{cr} \Delta L}{12} \left[ \frac{1}{E_i I_{i-1}} \quad \frac{10}{E_i I_i} \quad \frac{1}{E_i I_{i+1}} \right] \begin{bmatrix} Y_{i-1} \\ Y_i \\ Y_{i+1} \end{bmatrix}.
\]

Equation (5) can be rewritten as follows:

\[
\frac{12}{P_{cr}} \{\gamma\} = [A]^{-1} [B] [C] \{\gamma\}.
\]

The equation (6) is an eigenvalue problem, say

\[
\lambda \{\gamma\} = [H] \{\gamma\}.
\]

Thus the buckling load \( P_{cr} \) is related to the eigenvalue \( \lambda \).

\[
\lambda = \frac{12}{P_{cr}}
\]

Design coefficient of the wooden shoring system

For the wooden shore with a non-homogeneous Young modulus \( E \) and moment inertia \( I \), the related average values are represented by \((\bar{E})\) and \((\bar{I})\) respectively. The maximum possible deviations are \( \Delta E \) for the Young modulus and \( \Delta I \) for moment inertia. For the simulation experimentation using the Monte Carlo Method, the random values are generated using the binary code (Naylor 1966). That is

\[
X_{n+1} = (aX_n) - \text{int}[(aX_n)/M] \times M,
\]

\[
RAN = 2X_{n+1}/M - 1.
\]

Where:

\[
X_n = \text{the remainder of } n\text{th order sampling}
\]

\[
X_{n+1} = \text{the remainder of } (n+1)\text{th order sampling}
\]

\[
a \text{ is randomly selected natural number}
\]

\[
M \text{ is } 2^b - 1 \text{ and } b \text{ is a natural number}
\]

\[
RAN \text{ is the random number between 1 and } -1
\]

The Young modulus \( E_i \) and the moment inertia \( I_i \) at point \( i \) of a wooden shore are individually simulated using the random \((RAN1)\) and \((RAN2)\). They are

\[
E_i = \bar{E} + \Delta E(RAN1),
\]

\[
I_i = \bar{I} + \Delta I(RAN2).
\]

It is noted that the simulated values are created using the following principles:

1. The random variable is a normal distribution mode.
2. The distribution situation is 99.7% of the weight factor plus/minus 100%.
3. The standard deviation is 1/3.

The normal random variable is produced through the uniform distribution random variation on the central limit theorem. Assuming that

\[
RAN_n = X_{n+1}/M
\]

\[
[A] = \frac{1}{\Delta L^2} \begin{bmatrix} 2 & -1 & 0 & \cdots & 0 \\ -1 & 2 & -1 & 0 & \vdots \\ 0 & \ddots & \ddots & \ddots & \vdots \\ 0 & \cdots & 0 & 1 & -1 \\ 0 & \cdots & 0 & 0 & 2 \end{bmatrix}
\]

\[
[B] = \begin{bmatrix} 10 & 1 & 0 & \cdots & 0 \\ 1 & 10 & 1 & 0 & \vdots \\ \vdots & \ddots & \ddots & \ddots & \vdots \\ 0 & \cdots & 0 & 1 & 10 \end{bmatrix}
\]

\[
[C] = \begin{bmatrix} 1 & 0 & \cdots & \cdots & 0 \\ 0 & 1 & 0 & \vdots & \vdots \\ \vdots & 0 & \ddots & \ddots & \vdots \\ 0 & \cdots & 0 & 1 & 0 \end{bmatrix}
\]

\[
\lambda = \frac{12}{P_{cr}}
\]
Let $RAN_n$ be the uniform random variable between 0 and 1. The normal random variable $RAN_n$ is simulated based on the assumption of standard normal distribution (Hillier and Lieberman 1974, Lind, Mason and Marchal 2000). The expression is shown as follows:

$$ RAN_n = \frac{\sigma}{\sqrt{n/12}} \sum_{i=1}^{n} (RAN_i) + (\mu - \frac{n}{2} \frac{\sigma}{\sqrt{n/12}}) \quad (12) $$

Where:
- $n$ is the number of the homogeneous distribution random variables
- $\mu$ is the mean value of the normal distribution.
- $\sigma$ is the standard deviation of the normal distribution.

For a shore, the maximum deviation of buckling load, $\max (\Delta P_c / P_{cr})$, was calculated based on the Young modulus and the moment inertia within the assumed deviation interval. By assuming $R_s$ as the material reduction coefficient, that is

$$ R_s = 1 - \text{Max}(\Delta P_c / P_{cr}) \quad \quad (13) $$

For a shoring system, let $f_i$ be the bearing index for design. Thus, the rate of the weight supported by $i$th wooden shore is $\tau = \overline{f}_i / \overline{w}$, where $\overline{w} = \sum f_i$.

Given the fact that the weight supported by $i$th wooden shore is always varied randomly during construction, the real bearing index may be simulated as normal random variable. That is,

$$ f_i = \overline{f}_i + \Delta f_i (RAN_i) \quad \quad (14) $$

Similarly, the real weight supported by $i$th wooden shore becomes $\tau = f_i / w$, where $w = \sum f_i$.

Therefore, the reducing coefficient for $i$th wooden shore is

$$ R_i = \frac{\overline{\tau}}{\tau_i} \quad \quad (15) $$

For the consideration of safety, the smallest $R_i$, also known as $R_{(min)}$, is of concern in design work. Therefore, the expected design coefficient $R_e$ may be formed by the multiplication of material reduction coefficient $R_s$ and system reduction coefficient $R_{(min)}$.

### 3. Simulated example

Table 1 shows the calculated $\max (\Delta P_c / P_{cr})$ according to the variation ranges of the Young modulus and the second inertia at finite difference nodes of the wooden shore.

| Number of different sections | $\max (\Delta I / I)$ | $\max (\Delta I / I)$ | $\max (\Delta E / E)$ | $\max (\Delta E / E)$ |
|-----------------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| 5                           | 0.027                 | 0.075                 | 0.084                 | 0.088                 |
| 7                           | 0.027                 | 0.056                 | 0.082                 | 0.088                 |
| 9                           | 0.026                 | 0.055                 | 0.080                 | 0.086                 |
| 11                          | 0.024                 | 0.053                 | 0.080                 | 0.086                 |

Fig. 2 is the relationship of the reducing coefficient to the varied ranges of moment inertia. By assuming the design bearing index $\overline{f}_i$ is the same for all the shores, equations (14) and (15) are applied for real system reduction coefficient $R_{(min)}$. Fig. 3 is a plot for the relationship of $R_{(min)}$ and number of shores for taking the construction load. It is noted that ten thousand simulation experiments were conducted in this example.
4. Discussion

The wood, a complicated material, has to be used carefully in construction. The information (The Council of Labor Affairs of Administration Yuan, Taiwan 1994) indicates that more than twenty percent of disasters are due to the collapse of the shoring system.

As shown in figure 1, the buckling load is indifferent to the node number used for finite difference calculations. The max ($\Delta P_v / P_{cr}$) ranges from 0.088 to 0.024.

In figure 2, it shows that the greater the variation of the properties, the less the capacity for load bearing.

Fig. 3 states that the reducing coefficient decreases when the number of wooden shores increases. The reducing coefficient of wood shores is rapidly lowered to 0.67 when the number of wooden shores is increased to ten. The coefficient gradually reduces to 0.6 when the number of wooden shores is increased to sixty. In addition, the coefficient is slowly decreased to 0.56 when the shores are increased to one hundred pieces. The coefficient approaches 0.5 when the number of wooden shores is more than two hundred pieces. Also as shown in Fig. 3, the simulation results agree well with that of the tests done by the Council of Labor Affairs of Administration Yuan, Taiwan R.O.C.

5. Conclusion

Investigations on the bearing capacity of the wooden shore system are performed by simulation using random selection under complicated conditions. Four conclusions are drawn:

1. When the number of shores increases, the reducing coefficient of the structural system will gradually decrease and approach the constant 0.5. Thus, the design safety factor can be defined as 2.0.

2. The design safety factor incorporated with the material effect has to be taken into consideration to formulate the design coefficient when in application.

3. The reducing coefficient is of the 99.7% confidence level.

4. The reducing coefficient is appropriate to serve as the design safety factor for the wooden shoring system.

References

1) The Council of Labor Affairs of Administration Yuan, Taiwan, R.O.C. (1994), Investigation of the wood formwork and shore material and automatic checking techniques.

2) El-Shahhat, A.M., Rosowsky, D.V. and Chen, W. F. (1995), “Accounting for human error during design and construction,” Journal of Architectural Engineering, 1(2), 84-92.

3) Rosowsky, D.V., Chen, W.F., Yen, T. and Huang, Y.L. (1993), “Modeling Concrete Placement Loads During Construction,” Structural Engineering Report, CE-STR-93-31, Purdue University, West Lafayette, In.

4) Yen, T. and Huang, Y. L., Chen, W.F. and Lin, Y.C. (1995), “Design of scaffold systems for concrete building during construction,” Structural Engineering Report, CE-STR-93-31, Purdue University, West Lafayette, In.

5) Peng, J.L., Rosowsky, D.V., Pan, A.D. and Chen, W.F. (1993), “Preliminary Structural Modeling and Development of a Reliability-Based Design Format for High-Clearance Scaffold Systems.” Structural Engineering Report CE-STR-93-2, Purdue University, West Lafayette, In.

6) Mosallam, K.H. and Chen, W.F. (1991), “Determining Shoring Load for Reinforced Concrete Construction,” ACI Structural Journal, 88(3), 340-350.

7) Mosallam, K.H. and Chen, W.F. (1992), “Construction Load Distribution for Laterally Braced Formwork,” ACI Structural Journal, 89(4), 415-424.

8) Peng, J.L., Rosowsky, D.V., Pan, A.D., Chen, W.F. and Yen, T. (1996), “Analysis of concrete placement load effects using influence surface”, ACI Structural Journal, 93(2)

9) Rosowsky, D.V., Huang, Y.L., Chen, W.F. and Yen, T. (1991), “Modeling concrete placement loads during construction”, Struct. Engng. Rev., 6(2), 71-84.

10) Peng, J.L., Pan, A.D., Rosowsky, D.V., Chen, W.F., Yen, T. and Chan, S.L. (1996), “High clearance scaffold systems during construction-I. Structural modeling and models of failure”, Engineering Structures, 18(3), 247-257.
11) Peng, J.L., Pan, A.D., Rosowsky, D.V., Chen, W.F., Yen, T. and Chan, S.L. (1996), “High clearance scaffold systems during construction-II. Structural analysis and development of design guidelines”, Engineering Structures, 18(3), 258-267
12) Karshenas, S. and Montes Rivera, D.A. (1997), “Experimental investigation of performance of wooden formwork shores”, 11(2), Journal of performance of constructed facilities, 58-66.
13) Ghali, A. and Neville A. M. (1978), Structural Analysis, 2nd edition, Chapman and Hall Ltd.
14) Naylor, T.H., et al. (1966), Computer Simulation Techniques, John Wiley and Sons, ch.3.
15) Hillier, F.S. and Lieberman (1974), G.J., Operation Research, 2nd edition, Holdenday, Inc.
16) Lind, D.A., Mason, R.D. and Marchal, W.G (2000), Basic Statistics for Business and Economics, 3rd edition, McGraw-Hill higher Education.