CUSTOMER SUPPORT NOTE

# Combinations and Wood-Armer Results

| Note Number: | **CSN/LUSAS/1029** |
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This support note is issued as a guideline only.

LUSAS

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# 1. Introduction

The *Wood-Armer* facility in LUSAS offers an efficient method for determining design moments in the desired reinforcement directions. These moments are calculated using nonlinear functions that incorporate the slab moment field components: Mx, My, and the twisting moment Mxy. This support note explains how LUSAS processes the basic combinations of these results.

# 2. Description

In general, a plate element subjected to Mx (bending moment), My (bending moment), and Mxy (twisting moment) is required to be reinforced in the x and y directions. Wood [1] developed equations that allow the consideration of all three components in slabs with orthogonal reinforcement, while Armer extended the approach to cases with skew reinforcement. A detailed presentation of the Wood-Armer equations can be found in [2].

In a linear elastic analysis, the principle of superposition applies. This means that raw components from individual loadcases can be combined to produce the same outcome as if all loads had been applied simultaneously within a single loadcase. In structural design, load combinations are often used to evaluate the effects on structural members. These combinations consider various loads, each with its own factor, to determine their overall effect. Load factors are applied to components like Mx, My, and Mxy (raw components) to calculate the total effect. However, due to the nonlinear nature of the Wood-Armer equations, the Wood-Armer results from individual loadcases should not be directly combined to determine the overall effect. In other words, the order in which calculations are performed is crucial:

- Correct: Sum the raw components from each loadcase first, then apply the Wood-Armer method to the combined result.
- Incorrect: Applying the Wood-Armer method to each loadcase individually and then summing the results leads to inaccurate and unrealistic outcomes.

This is demonstrated through a simple example based on results from a node in a structure modelled with shell elements.

# 3. Example

A concrete slab is modelled using shell elements and subjected to a uniformly distributed load, self-weight, a patch load, and a point load. The resultants Mx, My, and Mxy at a specific node in the slab are shown in Table 1.

| Stress resultants | | | | |
|---|---|---|---|---|
| **Loadcase** | **Node** | **Mx** | **My** | **Mxy** |
| **UDL** | 90 | -12.29 | 13.52 | 114.75 |
| **SW** | 90 | -7.68 | 8.45 | 71.72 |
| **Patch** | 90 | -2.03 | -7.71 | -1.26 |
| **Point Load** | 90 | -0.85 | 10.38 | 19.32 |
| **Sum of the above** | 90 | -22.85 | 24.64 | 204.53 |

***Table 1 – Stress resultants.***

The slab is orthogonally reinforced, and the Wood-Armer results, calculated using the combined effects from Table 1 in the Wood-Armer equations, are shown in Table 2.

| Wood-Armer results | | | | | |
|---|---|---|---|---|---|
| **Loadcase** | **Node** | **Mx(T)** | **My(T)** | **Mx(B)** | **My(B)** |
| **Combined effects** | 90 | 181.67 | 229.16 | -227.38 | -179.89 |

***Table 2 – Wood-Armer results for combined effects.***

Table 3 presents the results obtained by calculating the Wood-Armer values for each loadcase individually and then summing them. These results differ from those in Table 2 due to the nonlinear nature of the Wood-Armer equations.

| Wood-Armer results | | | | | |
|---|---|---|---|---|---|
| **Loadcase** | **Node** | **Mx(T)** | **My(T)** | **Mx(B)** | **My(B)** |
| **UDL** | 90 | 102.46 | 128.27 | -127.05 | -101.23 |
| **SW** | 90 | 64.04 | 80.17 | -79.40 | -63.27 |
| **Patch** | 90 | 0.0 | 0.0 | -3.29 | -8.98 |
| **Point Load** | 90 | 18.46 | 29.70 | -20.17 | -8.93 |
| **Sum of the above** | 90 | 184.96 | 238.14 | -229.91 | -182.41 |

***Table 3 – Wood-Armer results added together.***

# 4. Summary

### Wood-Armer results and combinations:

1. **Wood-Armer approach:**
   - The Wood-Armer equations are commonly used in the design of reinforced concrete slabs.
   - In LUSAS, the Wood-Armer moments are denoted as Mx(T), Mx(B), My(T), and My(B).
2. **Wood-Armer results and combinations:**
   - Wood-Armer results for load combinations are obtained by applying the combined effects of all loadcases directly in the Wood-Armer equations. LUSAS Basic Combinations follow this logic.
   - However, due to the nonlinear nature of the Wood-Armer equations, these results differ from those obtained by calculating the Wood-Armer moments for each loadcase individually and then summing them.

Please refer to Section 6.2, “Wood-Armer Reinforcement”, in the Theory Manual, Vol 1, for more details. Also, refer to the following pages in our user area for more information:
Index for Wood-Armer & related topics

If you have any doubts or require specific advice for your type of analysis, please contact the LUSAS Technical Support team at support@lusas.com.

# 5. References

[1] Wood, R.H., “The Reinforcement of Slabs in Accordance with a Pre-Determined Field of Moments”, Concrete, V.2, No. 2, 1968, pp. 69-76. (discussion by Armer)

[2] Clark, L.A., “Concrete Bridge Design to BS5400” (Construction Press) Chapter 5 (section entitled “Reinforced Concrete Plates”) and Appendix A.